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Editorial

From the Desk of the Editors

Dear Esteemed ISA Members,

After the New Editorial Board, we have published two Editorials. As you are aware that our overall effort is to improve the "Quality and Relevance of Agronomic Research" which should be reflected in our ISA Journal. Since this is a joint effort, we would like to request all the ISA members and especially to the Editors to communicate their views on the published Editorials and also suggest the areas where we need to improve and how?

In this issue, we would like to share with you the most important Prime Minister's commitment to double the income of the farmers by 2022. Three important ways to increase the farmer's income are: 1) to reduce the cost of cultivation and 2) to increase the productivity and assured high price and 3) facilitate earning extra income through additional activities such as mixed farming, post-harvest, value addition, processing and marketing. Except the price increase, we Agronomists can contribute a lot on this important National issue. We therefore suggest that in our research publications we can focus a little bit more on the Economic analysis of our investigations. Reducing the price of inputs and assured reasonable prices of the produce are not in our hands but we can no more ignore it, as without addressing this issue we can never achieve the PM's Commitment. To address this issue, can we form a small committee which can interact with the Government authorities and suggest some practical and feasible ways to address this most difficult but most important issue completely neglected so far. We can even include the reputed Scientists/Economists from other disciplines in the proposed Group. An attempt to publish the 'Success Stories of Agronomy' is another right move in this direction from ISA.

The Society is striving to find out the ways to improve the job opportunities for Agronomists. We have to keep in mind the fundamental principle that "*Jobs are not created looking to available resource personnel, but we have to change ourselves to be competent and suit to the available opportunities*".

We are also looking to the disparity with regard to publication of research papers in Indian Journal of Agronomy with respect to the crops, region and ICAR institutes and SAUs. Dr. A K Vyas, President of ISA with the help of his colleagues has done an extensive analysis of papers published in ISA Journal during 2013 to 2016 (Four years). We are happy to report that the publications for crops were almost as per importance of crops and cropping systems in the country with 18% publication on rice-wheat based cropping system and additional 7% on rice and 10% on wheat–based cropping system (other than rice-wheat). The only suggestion that we can make is to give little more emphasis on diversification with high value crops (wherever possible) to improve the farmers income. The publications from SAUs and ICAR Institutes are 32% and 67% respectively, almost corresponding to the Agronomists working in the system. Within ICAR Institutes, IARI alone has more than 50% publications, which can be attributed to more than 15 PG students admitted every year who contribute to a larger part of IARI publications. Kerala is one state from where the contribution is less than 1%. Similarly the International publications are also less than 1% and we need to encourage this.

T.C. Jain
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Research Paper

Long-term effects of integrated nutrient management on productivity and soil properties of rice (*Oryza sativa*)–rice cropping system in coastal Odisha

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ABSTRACT

A long-term experiment was initiated in 1983–84 and continued for 31 years on integrated nutrient management (INM) in rice (*Oryza sativa* L.)–rice cropping system at Bhubaneswar, Odisha. The study was conducted on sandy loams under irrigated conditions in a permanently laid out plot in randomized block design with 12 treatments and 4 replications. Application of 50% recommended dose of chemical fertilizers (RDF) coupled with 50% recommended N through green manuring of azolla or through FYM to rainy season (*kharif*) rice followed by supply of 100% RDF through chemical fertilizers to summer rice resulted in higher system yield of 9.07 and 8.75 t/ha/year respectively. This INM treatment was also most sustainable and improved the physico-chemical properties of the soil with respect to bulk density, soil organic carbon, available NPK, microbial biomass carbon and soil nutrient balance. Reduction in RDF by 100, 50 and 25% without supplementing any organic manure reduced system yield by about 52, 23 and 10%, respectively compared to RDF. Reduction in yield due to supplementation of 25 and 50% N through organic sources was to the tune of 10% during initial five years, and the yield gap between RDF and INM practices narrowed down with passage of time. Yield advantage due to supplementation of N through green manuring was noticed after 10 years, whereas that of FYM after 15 years. On the other hand, no yield advantage was observed with supplementation of 25% N through paddy straw even after 31 years. Application of 50% RDF through fertilizers along with 50% recommended N through green manuring of azolla to rainy season (*kharif*) rice followed by supply of RDF through fertilizers to summer rice recorded the highest system gross returns ₹1,11,870 and net returns ₹65,644 with the highest benefit: cost ratio 2.42.

Key words **:** Integrated nutrient management, Long-term experiment, Nutrient balance, Physico-chemical-microbial properties of soil, Rice–rice cropping system, System yield

Rice–rice is the major cropping system in the irrigated areas of Odisha. But productivity of rice in Odisha is one of the lowest in the country, mostly because of inadequate and imbalanced supply of plant nutrients. Fertilizer consumption of the state is as low as 58.7 kg/ha. Poor economic condition of the rice farmers of the state is one of the major causes of low dose of fertilizers. With regard to rice cultivation, farmers of coastal areas were applying only 20 kgN/ha without any P or K, however, application of 2 t FYM/ha was a common practice with the farmers.

Since rice is the staple food crop of the state, it is necessary to increase the productivity of rice–rice system to meet the food requirement of the burgeoning population. Not only the productivity has to be increased but it should be sustainable also over the years. The recommended dose of NPK fertilizers alone does not sustain soil productivity under continuous intensive cropping (Yaduvanshi and Sharma, 2010), whereas inclusion of organic manures improves physical properties, the biological status of soil, soil fertility and crop yields (Yaduvanshi *et al*., 2013). Thus, increasing the productivity and sustainability of rice–rice system through judicious combination of organic and inorganic sources of plant nutrients is important to economise on fertilizer use, besides maintaining productivity and soil health in the long run. A permanent plot experiment on 'integrated nutrient supply system in rice–rice crop sequence' in Odisha was started in 1983-84 under the All India Coordinated Research Project on Integrated Farming Systems at Central Research Station of Orissa University of Agriculture and Technology, Bhubaneswar.

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MATERIALS AND METHODS

A long-term (31-years) field experiment was conducted from 1983–84 to 2013–14 at Central Research Station, Orissa University of Agriculture and Technology, Bhubaneswar (20° 26' N, 85° 81' E, 34 m above mean sea level) under irrigated conditions. The soil at the study site is a sandy loam (sand 68%, silt 15% and clay 17%) and belongs to Typic Epiaquepts having *p*H 5.34, bulk density 1.50 Mg/m^3, organic carbon 0.43%, available N, P and K of 254.2, 20.3 and 210.4 kg/ha respectively. The climate is hot and humid with an average annual rainfall of 1482 mm, received mostly in the monsoon months from July to September. The mean maximum and minimum temperature were 31.5 and 22.3°C respectively. The experiment was conducted in a permanently laid out plot in randomized block design with 12 treatments and 4 replications and the details are given in Table 1.

The organic sources of nutrients used in the experiment such as farm yard manure (FYM), paddy straw and azolla were analysed for nitrogen content and their quantities, required to substitute a specified amount of N (50 and 25%) as per the treatments were calculated. The nutrient contents of the organic manures on air dry weight basis were 0.56% N, 0.28% P and 0.64% K of FYM, 0.45% N, 0.13% P and 1.66% K of paddy straw and 3.56% N, 0.65% P and 1.88% K of azolla. Inorganic N, P and K were given through urea, single super phosphate and muriate of potash. Soil samples were drawn at initial and at the end of each cropping cycle (up to 31st cropping cycle) from a depth of 0–15 cm from each treatment and soil organic carbon (SOC), N, P and K content were analysed using standard procedures (Jackson, 1973). A portion of fresh soil samples were passed through a 2 mm sieve and stored at 4° C for determination of microbial population (Clark, 1965) and soil microbial biomass carbon (MBC) (Anderson and Domsch, 1978). The MBC was estimated from the equation, MBC = 2.64 Ec, where Ec is the difference between organic carbon extracted from the K_2SO_4 extract of fumigated and non-fumigated soils.

In case of organic nutrient management, all manures were applied before final land preparation and thoroughly incorporated in the soil. In case of inorganic nutrient management, full quantity of P and K were applied as basal and N was applied in split doses, 25% as basal, 50% at tillering and rest 25% at panicle initiation stage. The plot size was 10 m × 5 m. The test varieties were 'Savitri', 'Swarna' and 'Pratikshya' for rainy season (*kharif*), and 'Lalat', 'Konark' and 'Naveen' for summer. Standard agronomic management practices were followed to raise the crop.

Grain and straw yields of rice were recorded in each season and system yields were calculated for each cycle. System yield trends were analysed on 5-yearly average basis (1983–88, 1988–93, 1993-98, 1998-03, 2003-08) except for 2008-14 which was on 6-yearly average basis. Average yield for each treatment was also calculated over 31 system cycles at the end of experimentation. The treatment with recommended dose of inorganic nutrients was taken as reference treatment and increase or decrease in system yield was calculated for each treatment on 5-yearly average basis over this treatment for comparison. For economic analysis (cost of cultivation and net returns) costs of inputs and prices of output were used from 2013–14 for all the years. Statistical analyses were done using standard methodology of randomized block design.

RESULTS AND DISCUSSION

Grain and straw yields

Averaged over 31-years, application of 50% recommended dose of fertilizers (RDF) coupled with 50% recommended N (RN) through green manuring of azolla to rainy season (*kharif*) rice followed by supply of RDF through chemical fertilizers to summer rice resulted in higher system yield (Table 1). These grain yields were about 125% higher over no fertilizer control. This treatment combination increased average system yield by 7 and 42% over application of RDF and farmers' practice respectively. Application of 50% RDF through fertilizers coupled with 50% RN through FYM to *kharif* rice followed by supply of RDF through chemical fertilizers to summer rice was the second best treatment combination. Banerjee and Pal (2009) also observed higher system productivity in rice–rice system by reducing 50% RDF and supplementing 50% recommended N through green manuring to *kharif* rice followed by RDF through chemical fertilizers to summer rice in new alluvial soils of West Bengal in a long-term fertility experiment. Long-term application of organic matter might have improved the physico-chemical properties of soil that resulted in increased productivity by increasing availability of plant nutrients (Chaudhary and Thakur, 2007). Further, organic matter also maintained regular supply of macro and micronutrients in soil resulting in higher yields (Sharma and Subehia, 2014).

Application of 50% RDF through fertilizers coupled with 50% recommended N through green manuring or FYM to *kharif* rice followed by supply of RDF through fertilizers to summer rice also recorded significantly higher system straw yield compared to supply of RDF through fertilizers to both the crops (Table 1). However, supplementation of paddy straw as organic manure had no significant beneficial effect on 31-years average system grain or straw yields. Application of 50% RDF coupled with 50% recommended N through paddy straw to *kharif*

Table 1. Effect of integrated nutrient management on system grain and straw yields (t/ha) and economics of rice–rice cropping system over years

Treatment: *Kharif*	Treatment: *Rabi*	Mean 1983–84 to 1987–88		Mean 1988–89 to 1992–93		Mean 1993–94 to 1997–98		Mean 1998–99 to 2002–03		Mean 2003–04 to 2007–08		Mean* 2008–09 to 2013–14		Mean+ 1983–84 to 2013–14		CoC ($\times 10^3$ ₹/ha)	NMR ($\times 10^3$ ₹/ha)	Benefit: cost ratio
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw			
No manure and fertilizers (control)	No manure and fertilizers (control)	3.30	5.10	3.04	5.18	3.01	4.80	3.92	5.19	5.86	8.05	4.86	6.84	4.03	5.84	39.9	10.3	1.26
50% RDF through fertilizers	50% RDF through fertilizers	5.47	7.96	5.04	7.43	4.82	7.06	6.89	9.02	8.83	12.60	7.15	9.32	6.39	8.83	41.4	37.7	1.91
50% RDF through fertilizers	100% RDF through fertilizers	6.53	9.12	6.35	9.00	6.21	8.69	8.22	10.35	10.36	14.25	8.02	9.93	7.63	10.14	42.7	51.3	2.20
75% RDF through fertilizers	75% RDF through fertilizers	6.45	9.03	6.19	8.91	5.84	8.25	8.36	11.09	9.92	14.21	8.00	9.94	7.48	10.14	42.6	49.8	2.17
100% RDF through fertilizers	100% RDF through fertilizers	7.46	10.18	7.50	10.45	7.31	10.14	9.43	12.15	10.82	15.02	8.40	10.68	8.48	11.35	43.8	60.8	2.39
50% RDF through fertilizers + 50% RDN through FYM	100% RDF through fertilizers	7.38	9.54	6.97	9.31	7.15	9.59	10.17	12.84	11.60	16.50	9.14	11.19	8.75	11.42	49.1	58.5	2.19
75% RDF through fertilizers + 25% RDN through FYM	75% RDF through fertilizers	7.09	9.50	6.87	9.37	6.54	8.98	9.67	12.21	10.93	15.50	8.92	11.17	8.36	11.04	45.8	57.2	2.25
50% RDF through fertilizers + 50% RDN through paddy straw	100% RDF through fertilizers	6.86	9.29	6.76	9.35	7.21	9.67	9.80	12.51	11.08	15.93	8.64	10.85	8.40	11.18	48.9	54.6	2.12
75% RDF through fertilizers + 25% RDN through paddy straw	75% RDF through fertilizers	6.73	9.05	6.71	9.28	6.63	9.03	9.42	12.22	10.74	15.94	8.36	10.31	8.11	10.89	45.7	54.4	2.19
50% RDF through fertilizers + 50% RDN as green manuring of *Azolla*	100% RDF through fertilizers	7.43	10.25	7.41	10.46	7.53	10.55	10.26	13.51	12.23	17.46	9.47	11.61	9.07	12.21	46.2	65.6	2.42
75% RDF through fertilizers + 25% RDN as green manuring of *Azolla*	75% RDF through fertilizers	7.13	9.66	7.40	9.77	7.33	10.06	10.09	12.95	11.10	16.03	8.72	10.64	8.63	11.43	45.5	60.9	2.34
Farmers' practice	Farmers' practice	5.64	7.35	4.89	6.79	4.95	6.71	7.34	8.92	8.69	12.44	6.75	9.19	6.39	8.51	42.6	36.2	1.85
SEm±		0.16	0.19	0.12	0.18	0.10	0.17	0.24	0.38	0.38	0.48	0.25	0.33	0.07	012			
CD (P=0.05)		0.46	0.57	0.34	0.51	0.29	0.49	0.71	1.11	1.14	1.43	0.73	0.98	0.21	0.35			

RDF, recommended dose of fertilizers; RDN, rcommended dose of nitrogen; FYM, farm yard manure; CoC, cost of cultivation; NMR, net monetary returns; RDF (N–P–K kg/ha): 80–17.5–33; Farmers' practice: N–P–K @ 20–0–0 kg/ha + 2 t FYM/ha to both *kharif* and summer crops; *Mean of 6 years data; +mean of 31 years data; Sale Price (₹/t): rice grain, 11,000; rice straw, 1000 rice followed by supply of RDF through chemical fertilizers to summer rice reduced average system grain yield marginally compared to application of RDF to both season crops, though the reduction was not significant. This was in conformity with the findings of Singh *et al*. (2006) in rice–wheat cropping system.

Reduction in RDF without supplementing any organic manure significantly reduced the system grain and straw yields compared to application of RDF (Table1). Application of 50% RDF to both *kharif* and summer crops through fertilizers, 50% RDF to *kharif* and RDF to summer crop and 75% RDF to both *kharif* and summer crops reduced average system yield by 25, 10 and 12% compared to RDF. Similar results were also reported in rice–wheat cropping system by Upadhyay and Vishwakarma (2014).

Yield trend analysis

Grain yield trend analysis of data averaged over five years indicates that application of sub-optimal doses of chemical fertilizers reduced system yield throughout the 31-years of experimentation compared to supply of RDF. Reduction in yield due to supplementation of 25 and 50% N through organic sources was to the tune of 10% during initial five years, and the yield gap between RDF and integrated nutrient management practices narrowed down with passage of time. Yield advantage due to supplementation of N through green manuring was noticed from 10th year onwards, whereas that of FYM after 15 years.

The treatments with organic supplementation were more sustainable than those supplied with sub-optimal dose of inorganic fertilizers alone. Organic manure alone or in combination with inorganic fertilizers besides improving the physico-chemical and biological properties of soil, might have prevented leaching and volatilization losses and its slow release pattern might have supplied nutrients in optimal congruence with crop demand improving synthesis and translocation of metabolites to various reproductive structures resulting in improvement in its yield and yield attributes (Kumari *et al*., 2010). The control treatment without application of any manures and fertilizers reduced system yield of rice–rice sequence by 53% compared to RDF, followed by the treatment with 50% RDF to both the seasons with a yield reduction of 25% and farmers' practice with yield reduction of 24%. Similar results were also reported by Upadhyay and Vishwakarma (2014).

Economics

Application of 50% RDF through fertilizers coupled with 50% recommended N through green manuring of azolla to *kharif* rice followed by supply of 100% RDF through fertilizers to summer rice recorded the highest system gross returns ₹1,11,870 and net returns ₹65,644 with highest benefit: cost ratio 2.42 (Table 1). This treatment increased system net returns by 68% over farmers' practice.

Bulk density

The bulk density of the soils at the end of 31-years of rice–rice cropping system ranged from 1.52 (control) to 1.46 Mg/m^3 (INM with 50% N through FYM/*Azolla*). Addition of organic nutrient sources with inorganic fertilizers over the years significantly reduced the bulk density of the soils compared to the soils treated with inorganic fertilizers only. The reduction of bulk density is related to an increase in organic carbon, which results in more pore space and good soil aggregation (Yaduvanshi *et al*., 2013). The marginal decrease in bulk density under RDF over control could be attributed to the increased biomass production with consequent increase in organic matter content of the soils (Selvi *et al*., 2005).

Soil pH

The soil *p*H decreased from the initial level of 5.34 to 5.23 with the application of RDF through inorganic fertilizers (Table 2). Reduction of *p*H by continuous use of fertilizers over the years has also been reported by Sharma and Subehia (2014). The marginal increase in soil *p*H in treatments under integrated nutrient management might be due to moderating effect of FYM, paddy straw or azolla over the years as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelating effect of organic molecules (Prasad *et al*., 2010).

Soil organic carbon (SOC)

Application of organic nutrient sources with inorganic fertilizers over 31-years resulted in a significant increase in SOC contents over the initial status and the increase was to the tune of 89 to 128%. The maximum build-up of SOC was observed in treatment applied with 50% RDF through fertilizers + 50% N as azolla (Table 2). The increase in SOC due to integrated use of inorganic and organics can be attributed to higher contribution of biomass to the soil in the form of better root growth, crop residues and the added organic nutrient sources (Upadhyay and Vishwakarma, 2014).

Available N, P and K

Available N increased in treatments receiving varying combination of FYM, paddy straw and azolla with RDF and the enhancement was from 254.2 kg/ha (initial) to 285.8 to 353.8 kg/ha (Table 3). Increase in available N with organics is attributed to its direct addition through organics which was released on mineralization with time

Table 2. Effect of integrated nutrient management practices in rice–rice cropping system on physico-chemical and microbial properties of soils

Treatment: Kharif	Treatment: Rabi	Bulk density (Mg/m^3)	*p*H	Soil organic carbon (%)	Microbial population (cfu/g): Bacteria (× 10^7)	Fungi (× 10^4)	Actinomycetes (× 10^6)	MBC (µg C/g)
No manure and fertilizers (control)	No manure and fertilizers (control)	1.52	5.40	0.55	19.6	11.7	12.3	101.4
50% RDF through fertilizers	50% RDF through fertilizers	1.51	5.29	0.61	24.7	14.1	15.2	133.6
50% RDF through fertilizers	100% RDF through fertilizers	1.50	5.23	0.64	26.9	15.3	15.9	164.3
75% RDF through fertilizers	75% RDF through fertilizers	1.51	5.25	0.61	24.2	14.0	15.0	131.3
100% RDF through fertilizers	100% RDF through fertilizers	1.50	5.23	0.66	27.5	15.9	16.6	177.4
50% RDF through fertilizers + 50% RDN through FYM	100% RDF through fertilizers	1.46	5.64	0.92	32.3	18.8	19.5	266.7
75% RDF through fertilizers + 25% RDN through FYM	75% RDF through fertilizers	1.48	5.64	0.81	30.7	17.4	18.4	223.3
50% RDF through fertilizers + 50% RDN through paddy straw	100% RDF through fertilizers	1.47	5.50	0.85	31.5	18.2	19.0	241.3
75% RDF through fertilizers + 25% RDN through paddy straw	75% RDF through fertilizers	1.48	5.59	0.83	30.9	17.7	18.7	232.3
50% RDF through fertilizers + 50% RDN as green manuring of *Azolla*	100% RDF through fertilizers	1.46	5.61	0.98	33.3	19.2	20.4	289.3
75% RDF through fertilizers + 25% RDN as green manuring of *Azolla*	75% RDF through fertilizers	1.47	5.54	0.84	31.2	18.0	18.8	237.6
Farmers' practice	Farmers' practice	1.51	5.32	0.64	25.3	14.3	15.7	162.7
SEm±		0.007	0.06	0.023	0.91	0.54	0.56	7.61
CD (P=0.05)		0.02		0.068	2.70	1.60	1.67	22.86
Initial		1.50		0.43	15.8	9.7	10.1	77.3

RDF, recommended dose of fertilizers; RDN, rcommended dose of nitrogen; FYM, farm yard manure; MBC, microbial biomass carbon in soil; cfu, colony forming units; RDF (N–P–K kg/ha): 80–17.5–33; Farmers' practice: N–P–K @ 20–0–0 kg/ha + 2 t FYM/ha to both *kharif* and summer crops

(Sharma and Subehia, 2014). The soils under control and imbalanced nutrient management exhibited a reduction in available N over the initial.

The available P content of the soils varied from 7.4 kg/ha in control to 22.0 kg/ha in treatments receiving 50% RDF + 50% N through azolla in *kharif* followed by RDF in summer through inorganics. Substitution of 25% N through any of the organic sources resulted in significant lower available P content in comparison to their 50% substitution. Application of 50% RDN through FYM and paddy straw supplied an additional 11.65 and 2.75 kg P /ha, respectively over the 50% recommended P (8.75 kg/ha). Enhanced available pool of soil P with the application of inorganic fertilizers in conjunction with organics might be due to the release of organic acids during decomposition which in turn helped in releasing P through solubilizing native P in the soil (Subehia and Sepehya, 2012). The soils under inorganic fertilization over the years exhibited a reduction in available P over the initial status.

Unlike N and P, the available K contents of the soils decreased from the initial status though the reduction was less in soils receiving both inorganic and organic nutrient sources. This might be due to the fact that application of 50% RDN through azolla, FYM and paddy straw supplied additional 5, 31.2 and 131 kg K/ha respectively over the 50% recommended K (16.5 kg/ha). Application of inorganic fertilizers alone or in combination with organic nutrient sources recorded an increase in available K of the soils over control. The depletion of native K pool under inorganic fertilization is due to more crop removal compared to the addition. Higher available K under integrated treatments compared to inorganics might be due to the addition of organic matter that reduced K-fixation and released K due to the interaction of organic matter with clay, besides the direct K addition to the pools of soil (Urkurkar *et al*., 2010).

Microbial population

Growing rice–rice cropping system for 31-years in succession enhanced the microbial densities of the soils (Table 2). The maximum population of bacteria, fungi and actinomycetes was recorded from the soils receiving 50% RDF + 50% N as azolla in *kharif* and RDF in summer.

Table 3. Nutrient balance (kg/ha) as influenced by different nutrient management practices after completion of 31st rice–rice cropping system cycle

Treatment		Nitrogen					Phosphorus					Potassium				
Kharif	*Rabi*	Addition*	Removal*	Final soil status+	Actual gain/loss over initial status+	Balance+	Addition*	Removal*	Final soil status+	Actual gain/loss over initial status+	Balance+	Addition*	Removal*	Final soil status+	Actual gain/loss over initial status+	Balance+
No manure and fertilizers (control)	No manure and fertilizers (control)	0	2,056	190.5	-63.7	-1992.1	0	649	7.4	-12.9	-636.1	0	2,667	72.1	-138.3	-2528.7
50% RDF through fertilizers	50% RDF through fertilizers	2,480	3,280	216.5	-37.7	-762.0	541	966	9.2	-11.1	-413.1	1,029	3,591	92.2	-118.2	-2443.6
50% RDF through fertilizers	100% RDF through fertilizers	3,720	3,867	241.0	-13.2	-133.7	812	1,118	14.8	-5.5	-300.4	1,544	4,044	95.7	-114.7	-2385.5
75% RDF through fertilizers	75% RDF through fertilizers	3,720	3,835	226.5	-27.7	-87.1	812	1,116	14.2	-6.1	-297.8	1,544	4,030	96.5	-113.9	-2372.3
100% RDF through fertilizers	100% RDF through fertilizers	4,960	4,930	254.0	-0.2	30.2	1,083	1,308	14.1	-6.2	-219.0	2,058	4,253	100.8	-109.6	-2085.0
50% RDF through fertilizers + 50% RDN through FYM	100% RDF through fertilizers	4,960	4,650	323.5	69.3	240.7	1,432	1,339	20.0	-0.3	93.0	2,961	4,433	156.0	-54.4	-1418.1
75% RDF through fertilizers + 25% RDN through FYM	75% RDF through fertilizers	4,340	4,260	285.8	31.6	48.4	1,122	1,260	17.0	-3.3	-134.6	2,252	4,184	143.5	-66.9	-1864.6
50% RDF through fertilizers + 50% RDN through paddy straw	100% RDF through fertilizers	4,960	4,690	302.0	47.8	222.2	1,170	1,282	20.2	-0.1	-111.9	6,118	5,065	183.4	-27.0	1080.0
75% RDF through fertilizers + 25% RDN through paddy straw	75% RDF through fertilizers	4,340	4,250	294.0	39.8	50.2	991	1,170	16.9	-3.4	-175.4	3,831	4,463	161.1	-49.3	-582.8
50% RDF through fertilizers + 50% RDN as green manuring of *Azolla*	100% RDF through fertilizers	4,960	4,610	353.8	99.6	250.4	1,038	1,205	22.0	1.7	-168.3	2,199	4,420	168.4	-42.0	-2179.5
75% RDF through fertilizers + 25% RDN as green manuring of *Azolla*	75% RDF through fertilizers	4,340	4,210	312.5	58.3	71.7	925	1172	17.2	-3.1	-243.6	1,871	4,302	151.1	-59.3	-2371.5
Farmers' practice	Farmers' practice	1,934.4	3,237	237.3	-16.9	-1,285.7	347.2	931	11	-9.3	-574.5	793.6	2,904	95.7	-114.7	-1995.7

RDF, recommended dose of fertilizers; RDN, rcommended dose of nitrogen; FYM, farm yard manure; RDF, (N–P–K kg/ha): 80–17.5–33; Farmers' practice: N–P–K @ 20–0–0 kg/ha + 2 t FYM/ha to both *kharif* and summer crops; Initial nutrient status in soil (1983): N, 254.2 kg/ha; P, 20.3 kg/ha; K, 210.4 kg/ha; *Cumulative addition/ removal of 31cropping system cycles; +after completion of 31st rice–rice cropping system cycle

Addition of organic nutrient sources with inorganic fertilizers showed a profound increase in the microbial population in comparison to chemical fertilizers used alone. The FYM, paddy straw or azolla act as a source of nutrients to the microbes and also as a substrate for decomposition and mineralization of nutrients. This creates a favourable condition for the proliferation of microbes in the soil (Bahadur *et al*., 2012).

Microbial biomass carbon (MBC)

Although soil microbial biomass represents only a small portion of overall soil organic matter, it is more dynamic than total soil organic matter and a better indicator of soil health and productive capacity. The MBC of soils varied from 101.4 µg C/g in control to the highest level of 289.3 µg C/g in soils treated with 50% RDF + 50% N through azolla (Table 2). Addition of organics with inorganics for 31 years led to a substantial increase in MBC over application of inorganic fertilizers alone. The supply and availability of additional mineralizable and readily hydrolysable carbon due to organics might be responsible for higher microbial activity and MBC in treatments applied with organics (Sharma and Subehia, 2014).

Nutrient balance

The soils receiving inorganic fertilizers, control and farmers' practice exhibited actual loss of N over initial status (Table 3). On the contrary, the soils applied with both inorganic and organic nutrients registered actual gain of N. The maximum cumulative N uptake of 4930 kg/ha was observed with RDF in both the seasons followed by 50% RDF + 50% N through paddy straw in *kharif* and RDF in summer (4690 kg/ha). All the soils under integrated nutrient management and RDF in both the seasons registered positive N balance.

The highest cumulative P uptake of 1,339 kg/ha was observed in 50% N substitution as FYM (Table 3). The same treatment also registered the positive P balance. The negative P balance observed in all other treatments is due to more uptake of P by crops.

The maximum cumulative uptake was observed in the soils with 50% N substituted as paddy straw (Table 3). The soils of the same treatment also registered positive balance of 1,080 kg K/ha. This might be attributed to higher addition of K through paddy straw. The soils under inorganics exhibited more negative K balance than those under integrated nutrient management, because all organic sources were rich in K content and added more K to the soil without showing much variation in removal. Depletion of soil K reserves leading to negative K balance in soils under INM was also reported by Surekha and Satishkumar (2014).

Application of 50% recommended dose of chemical fertilizers coupled with 50% recommended N through green manuring of azolla or through farm yard manure to *kharif* rice followed by supply of recommended dose of chemical fertilizers to summer rice can be recommended for rice–rice cropping system in coastal Odisha to obtain higher and sustainable yield and maintain soil health.

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Research Paper

Relative performance of rice (*Oryza sativa*)–ratoon production system as influenced by date of sowing and system of cultivation of plant rice genotypes

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ABSTRACT

Field experiments were conducted in coastal Odisha, India during 2009 to 2011 in split split-plot design to investigate whether modified system of rice (*Oryza sativa* L.) intensification (MSRI) mimicking all the production principles of system of rice intensification (SRI), except planting geometry and seedling number that were in accordance to the best management practice (BMP), could improve the performance of plant rice genotypes compared to the latter two different water using systems under varying dates of sowing during the wet season. Attempts were also made to ascertain their relative impacts on the succeeding ratoon crop. Grain yield in plant rice sown by 20 June (early) was significantly the highest followed by 5 and 20 July sowing with 5.73% and 17.14% reduction in yield. MSRI was superior over SRI and BMP with 11.32% and 35.46% increase in yield and Hybrid 'Ajay' yielded higher (9.07%) than HYV 'Tapaswini'. The performance of ratoons followed the similar trend as in plant rice. Early sown hybrid 'Ajay' in MSRI produced significantly the highest and 20 July sown 'Tapaswini' in BMP had the lowest grain yield in plant rice. Superiority of early sown rice, MSRI and hybrid 'Ajay' could be attributed to the synergistic effects of their yield attributes. The root volume of plant rice at 100 DAS had strong correlation with the plant height, straw and grain yield of plant rice as well as the grain yield of subsequent ratoon.

Key words: Correlation, Date of sowing, Genotype, Hybrid, Ratoon, Rice, System of rice intensification

A set of water-saving rice cultivation management practices popularly known as system of rice intensification (SRI) has been introduced from Madagascar to many countries including India. Its changes in management practices include: transplanting of very young seedlings singly in a square pattern, maintaining non-flooded soil rhizosphere up to panicle initiation through alternate wetting and drying, much stress to organic nutrient and plant protection measures and mechanical weeding. The benefits of SRI with the entire set of recommended management practices compared to the continuous flooded traditional farmers' practices in terms of water saving and productivity are well established in rice growing countries including India (Choudhury *et al*., 2007; Sato and Uphoff, 2007; Shekhar *et al*., 2009; Chapagain *et al*., 2011; Krupnik *et al*., 2012; Dass *et al*., 2012; Kumar and Singh, 2013), but research findings on the relative production efficiencies of subsequent ratoon or stubble crop of rice genotypes involving the recommended "Best Management Practices (BMP)", SRI and "Modified SRI (MSRI)" under assured irrigation system during wet season needed careful evaluation. The MSRI is the system of growing rice as in SRI with all similar nursery, nutrient, water, weed and pest management practices but with the plant geometry and seedling numbers/hill like in BMP.

Ratoon crops are usually considered as the bonus to the main crop as lesser external inputs are required for its successful production. Moreover, it can suitably be fitted in to the lag or idle or fallow period between the harvesting of the plant rice and sowing of the succeeding green gram crop in the areas of rice-greengram system of production in India. Similarly, no such work to study the effect of time of sowing of the plant rice on its stubble crop had been done before.

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MATERIALS AND METHODS

The field experiments were conducted during 2009 and 2011 in east and south east coastal plain of Odisha at 25.6 km air distance from the Bay of Bengal at east. The experimental site in particular was located at 86< 22' E, 20< 17' N and 14.0 m above the mean sea-level. The physico-chemical properties of the experimental soil indicated clay loam texture, moderately acidic in soil reaction (*p*H 5.6–5.5), high organic carbon (0.79–0.87) and electrical conductivity (0.96–0.98 dS/m). Available primary plant nutrients analysed were to have medium in N, P_2O_5 (Brays') and K_2O. The climate of the experimental location is characterized as warm and moist, with a hot and humid summer and normal cold winter, which broadly falls in the moist hot group. The range of maximum and minimum temperatures during the experimental cropping years was more or less similar as the long term average. The mean annual rainfall is 1,334 mm and nearly 62.0% of rainfall was being received between June and October (827 mm). The monsoon usually sets in around mid June and recedes by first week of October. July and August are wettest months, while December is the driest one.

The treatments consisted of 3 dates of sowing, viz. 20 June, 5 July and 20 July; 3 systems of cultivation of rice–ratoon, viz. Best management practices (BMP)-ratoon, system of rice intensification (SRI)-ratoon and modified system of rice intensification (MSRI)–ratoon; and 2 medium duration rice genotypes released from National Rice Research Institute, Cuttack, viz. high yielding variety (HYV) 'Tapaswini' (IET 12168) and hybrid 'Ajay' (CRHR-7, IET 18166). The experiment was carried out in a split-split plot design with 18 treatment combinations replicated thrice. The first treatment involving 3 dates of sowing were assigned to the main-plots. The second treatment of 3 systems of cultivation was allotted to 3 sub-plots and the 2 rice genotypes were grown in sub-sub-plots.

For each date of sowing under BMP 3 beds of 5.0 m × 1.0 m were prepared by raising the nursery bed 15.0 cm above the ground level and the beds were separated by channels in-between. In each bed, 15 kg of FYM, 50 g of muriate of potash (MOP) and 100 g of single super phosphate (SSP) were applied at the time of final land preparation. In each bed 0.75 kg of sprouted seeds of 'Tapaswini' and 'Ajay' were sown separately and duly labeled for easy identification. Chemical seed treatment was done with carbendazim powder @ 1.5 g/kg of seeds before soaking with water. After 15 days of sowing, 50 g of urea was applied to each bed.

For each date of sowing under SRI and MSRI cultivation, 3 beds of 2.5m × 1.0m for each genotype were prepared through mixing of one part sand, one part well decomposed FYM and 2 parts of top soil in between 2 parallel bamboos separated at 1.0 m width. In each bed, 50 g of MOP and 100 g of SSP were applied at the time of final bed preparation before sowing. The bed top was leveled and 0.25 kg of sprouted seeds of 'Tapaswini' and 'Ajay' were sown separately and duly labeled for easy identification. The seeds were covered with soil mixture of 1.0cm thickness and irrigated by sprinkling water over it.

Seedlings from the raised nursery beds were uprooted at 25-days old stage for transplanting under BMP. The beds were irrigated before uprooting for smooth lifting of the seedlings. Two seedlings/hills were transplanted in the main field at 25.0cm × 12.5cm spacing in lines.

The main field was puddled and measured quantities of fertilizers were added to the field before final puddling. For transplanting under SRI and MSRI, seedlings from the raised bamboo beds were uprooted at 10 days by scooping the seedlings in bulk at 2cm to 3cm below the nursery bed surface along with the moist mother soil. Due care was taken up to reduce damage to the root system of the seedlings during uprooting. The seedlings were then carried away to the main field by trays without much delay and the transplanting was carried out preferably within half an hour of uprooting. Single seedling/hill in SRI and 2 seedlings/hill in MSRI were then transplanted in the main field at 25.0cm × 25.0cm and 25.0cm × 12.5cm spacing respectively in lines. In SRI, 25.0cm spacing was maintained in both the directions. However, in MSRI, 12.5cm spacing was maintained in east-west direction and 25.0cm spacing was maintained in north-south direction so as to facilitate easy penetration of solar radiation throughout the entire day.

In BMP sub plots, FYM @ 5.0 t/ha along with total phosphorous (P) and one-third of the total recommended dose (100–21.8–41.5 kg/ha of N-P-K) of N and K were applied before final puddling. Rest of the N and K fertilizers were applied in two equal halves i.e. one-third at maximum tillering (40 DAS) and one-third at panicle initiation (PI) stage (70 DAS). In SRI and MSRI, FYM @ 15.0 t/ha along with total P and one-fourth of the total (50–10.9–20.8 kg/ha of N-P-K) N and K fertilizers were applied before final puddling. Rest of the N and K fertilizers were applied in three equal splits i.e. one-fourth each at 25, 40 and 70 DAS. The share of the N fertilizer from chemical source has been reduced to half of the recommended dose keeping in view its availability from the 10.0 t extra FYM applied to the field at the time of final land preparation.

In SRI and MSRI systems of cultivation, 4-weedings at 20, 30, 40 and 50 DAS were carried out by using conoweeder. In SRI, the weeder was operated in criss-cross manner and the weeds were incorporated into the soil. In MSRI, the weeder was run in east-west direction only.

In BMP, 3 hand weedings at 40, 55 and 70 DAS were carried out incorporating the weeds *in- situ*. In BMP, water was allowed to stand in the plots since planting of the seedlings by irrigating at alternate days so as to maintain a layer of 5 to 8 cm depth of water during the entire crop period till 15 days before harvest.

In SRI and MSRI, water was not allowed to stand in the plots and special care was taken to avoid submergence of 10-days old seedlings just after transplanting in the main field. The soil was kept moist above the field capacity by irrigating the sub-sub-plots as per requirement till panicle initiation (PI) stage was attained. These plots were first irrigated 5 days after transplanting to moisten the field without ponding. A second irrigation was given on the evening of 9^{th} day after planting at a ponding depth of 2.0 to 5.0cm and the next morning first weeding was performed by using cono-weeder. Thereafter, alternate wetting and drying method of irrigation was practiced and subsequent irrigation were applied 3 days after disappearance of the ponded water or immediately after the development of hair cracks on the soil surface. However, after PI stage, the plots were allowed to hold standing water of 5.0cm height up to 2 weeks before harvest.

Prophylactic sprays of neem oil @ 5.0 ml/liter of water at 15 days intervals were carried out to avoid any possible damage by insects and diseases. In addition, Trichocards with 1,00,000 viable eggs of *Trichogramma japonicum*/ha were released at 15 days intervals i.e. at 40, 55 and 70 DAS for preventing the infestation by stem borers in all 3 systems of planting. Sex pheromone traps @ 20 traps/ha were installed and lures were regularly changed at 15 days intervals. However, necessary and adequate plant protection measures were adopted depending upon the possibility and incidence of the disease and pest infestation reached at economic threshold limit (ETL).

Immediate after harvesting of plant rice, the nitrogenous fertilizer @ 60.0 kg/ha was applied to the sub-subplots and subsequently irrigated for suppressing the fallen seeds from sprouting and acting as weeds and for promising emergence of ratoon tillers. After retillering, sufficient water was maintained in the field to control weeds. As the maturity in ratoon rice was irregular, the field was drained out at 80% maturity stage and crop was then harvested leaving the residue at 5.0 cm above the ground level.

The data collected were arranged in appropriate tables and analysed statistically by applying analysis of variance technique (AVNOVA) mentioned by Gomez and Gomez (1984). Standard error of means i.e. SEm± were used in all cases. The significance of variance was tested by 'Error mean square' method of Fisher Snedecor's F-test at the probability level of 0.05 for appropriate degrees of freedom (P=0.05). The relationships between yield and yield attributing characters were studied by simple correlation coefficient formula as stated below.

$$r = \frac{\text{Cov (xy)}}{\sqrt{V(x).V(y)}}$$

Where,
Cov (xy) = Covariance xy
V(y) = Variance y
V(x) = Variance x

RESULTS AND DISCUSSION

As elaborated by Stoop *et al.* (2009), any comparison between two systems made up of several different crop management components is subject to compounding effects that will complicate and/or interfere with the subsequent interpretation of the data. In this context, the results obtained in the current studies on SRI are having special significance as the effects of sets of components were evaluated rather than just any one component.

Studies on plant rice

Effect of date of sowing: Early sowing of rice by 20 June had the advantage of recording the highest grain yield of 5.81 t/ha and subsequent fortnightly delay in sowing beyond this time reduced grain yield (Table 1). Rice sown on 20 July lagged behind (4.82 t/ha) in this regard compared to other earlier sowing dates. The root volume at 100 DAS and days to physiological maturity followed the similar trend, whereas, the spikelet sterility was in the reverse direction. Such reduction in growth duration in late sown rice might be due to progressive decrease in soil and air temperature and decline in bright sunshine hours when sown beyond 20 June. Early sown rice received favourable solar radiation levels and temperature regime (Halder *et al*., 2004). Diminishing root configuration in latter dates of sowing could also be due to the reasons ascribed above resulting in reduced crop duration. Yield attributing characters like effective tillers, panicle length and weight, grains/panicle and test weight were in the lowest order in 20 July sown rice compared to other 2 earlier dates.

Effect of system of cultivation: MSRI had the advantage of recording significantly the highest grain yield (6.11 t/ha) in rice followed by SRI (5.49 t/ha) and BMP (4.51 t/ha). Higher productivity in MSRI might be due to the synergistic effect of all the yield attributes, however, BMP lagged behind possibly due to poor production of such components. Wider spacing in SRI resulting in reduced effective tiller/m^2 might have moderated the productivity inspite of its superiority in recording yield contributing components in its panicle.

Root volume/m^2 was significantly more in MSRI compared to both SRI and BMP. The root volume/hill, however was the highest in SRI. Higher volume and deeper roots in the hills of SRI probably be due to favourable soil physic-chemical properties, balanced soil air and moisture, availability of adequate soil volume and greater light interception by open rice canopy. Such result in SRI was the cumulative effects and thus reflected in enhanced root proliferation/hill. However, the present trend of superiority of MSRI in recording higher root morphology/m^2 could be due to crop geometry accommodating more plants/unit area.

BMP, MSRI and SRI were in diminishing order in recording days to physiological maturity. Reduction in phenological duration of rice in SRI and MSRI might be due to favourable growth factors in soil and better light interception by open canopy enhanced growth cycle to complete life earlier. However, rice in BMP having been deprived of such conditions might have toiled hard to complete its growth cycle with delayed growth stages. Little delay in attaining growth stages of rice in MSRI could be attributed to availability of relatively less favourable factors compared to SRI.

Effect of genotypes: Hybrid rice 'Ajay' had the advantage of recording significantly higher grain yield (5.60 t/ha) which could be due to the synergistic effect of good number of yield attributes. Genotype 'Tapaswini' lagged behind in this aspect possibly due to poor performance of such yield contributing characters. Superior genetic character of hybrid 'Ajay' could keep it in frontier line. Longer and heavier panicles and vigorous root configuration in 'Ajay' could be due to its inherent quality and better utilization of nutrients. 'Ajay' was relatively faster in achieving the physiological maturity probably due to its intrinsic genetic character.

The interaction effect of system of cultivation of plant rice at varying dates of sowing (Table 1a) on grain yield indicated significantly superior performance of MSRI under early sowing by 20 June that produced the highest grain yield of 6.46 t/ha but this was at par with the performance of 5 July sown rice by producing grain yield of 6.32 t/ha under same system of cultivation. However, the grain yield of rice under BMP sown by 20 July was not acceptable since producing the lowest i.e. 3.77 t/ha grain yield.

Studies on ratoon rice

Effect of date of sowing: Early sowing of rice by 20 June had the advantage of recording the highest ratoon-grain yield (0.569 t/ha) and subsequent fortnight delay in sowing beyond this time reduced grain yield in their ratoons (Table 2). Such decline in ratoon-grain yield could be due to poor production of yield attributes of ratoon in late sown rice. Ratoon of early sown rice had the benefit of producing heavier grains, more number of panicles/m^2

Table 1. Effect of treatments on agronomic traits of plant rice during *kharif* of 2009 and 2010 (pooled data of 2 years)

Treatment	Root volume at 100 DAS (cm^3/m^2)	At harvest									
		Days to physiological maturity	Plant height (cm)	Panicle			Grains/ panicle	1,000-grain weight (g)	Spikelet sterility (%)	Yield (t/ha)	
				Nos./m^2	Length (cm)	Weight (g)				Straw	Grain
Dates of sowing											
20 June	1166	135.1	121.2	220.4	26.0	4.03	202.7	22.3*	9.67 (3.11)	6.50	5.81
5 July	1040	127.1	118.8	209.3	26.6	3.9	197.8	22.1	12.04 (3.47)	6.34	5.47
20 July	899	119.3	114.1	192.8	23.8	3.7	190.6	21.6	16.73 (4.09)	5.70	4.81
SEm±	9	0.22	1.5	2.9	0.16	0.05	2.29	0.11	0.07	0.077	0.08
CD (P=0.05)	31	0.71	5.1	9.7	0.52	0.15	7.45	0.34	0.23	0.252	0.26
Systems of cultivation											
BMP	850	130.7	113.5	201.3	24.4	3.5	172.2	21.5	16.40 (4.05)	5.69	4.50
SRI	1045	124.8	122.5	193.2	26.5	4.2	217.4	22.5	9.80 (3.13)	5.91	5.48
MSRI	1209	125.9	118.1	228.0	25.5	4.0	201.5	22.0	12.18 (3.49)	6.94	6.10
SEm±	14	0.25	1.4	3.3	0.27	0.05	2.58	0.18	0.07	0.079	0.08
CD (P=0.05)	42	0.74	4.2	9.7	0.78	0.16	7.53	0.54	0.20	0.229	0.23
Genotypes											
'Tapaswini'	946	130.0	107.5	209.7	22.2	3.7	202.6	19.3	11.70 (3.42)	5.85	5.13
'Ajay'	1124	124.3	128.5	205.3	28.7	4.1	191.4	24.7	13.62 (3.69)	6.51	5.60
SEm±	7	0.18	0.9	1.4	0.17	0.03	2.36	0.13	0.05	0.054	0.05
CD (P=0.05)	20	0.50	2.5	4.0	0.48	0.08	6.79	0.37	0.15	0.154	0.14

**Figures in parentheses indicate the square root values and grains/panicle, which might have positive influence on its final grain yield.

Early sowing of plant rice by 20 June had the advantage of recording significantly taller crop of ratoon rice at harvest (62.9cm) and subsequent delay in sowing time of plant rice could produce shorter ratoon crops. Height of ratoons of late sown rice was the shortest (54.2cm). The reason behind such diminishing trend with delay in sowing time of plant rice beyond 20 June could primarily be attributed to reduction in duration of ratoon from cutting to harvesting. Furthermore, decrease in mean atmospheric temperature could have reduced the ratoon height so also the crop duration.

Probably due to less number of tillers/m^2 at harvest of plant rice sown beyond 20 June, the number of panicles/m^2 in its ratoons might have significantly reduced. Other yield attributes like panicle length and weight of ratoon of plant rice sown late were also significantly reduced compared to earlier two dates of sowing. However, spikelet sterility per cent of grains followed the reverse trend. Reduction of growth duration and less nutrient extraction in ratoon crop of 5 and 20 July sown rice could not have effectively and efficiently traslocated assimilates from source to sink and thus would have affected such attributes. This corroborated the findings of Yazdpour *et al*. (2007).

Table 1a. Grain yield (t/ha) of plant rice as affected by dates of sowing and systems of cultivation during rainy season (*kharif*) of 2009 and 2010 (pooled data of 2 years)

Dates of sowing	Systems of cultivation			
	BMP	SRI	MSRI	Mean
20 June	5.26	5.715	6.46	5.81
5 July	4.49	5.613	6.32	5.47
20 July	3.76	5.134	5.54	4.81
Mean	4.50	5.48	6.10	

SEm± for systems of cultivation at same or different dates of sowing	=	0.138
CD (P=0.05) for systems of cultivation at same or different dates of sowing	=	0.403
SEm± for dates of sowing at same or different systems of cultivation	=	0.173
CD (P=0.05) for dates of sowing at same or different systems of cultivation	=	0.525

Table 2. Effect of treatments of plant rice on agronomic traits of its ratoon during 2009–10 and 2010–11 (pooled data of 2 years)

Treatment	At harvest									
	Days to maturity	Crop height (cm)	Panicle Nos./m^2	Panicle Length (cm)	Panicle Weight (g)	Grains/ panicle	1,000 grain weight (g)	Spikelet sterility (%)	Yield (t/ha) Straw	Yield (t/ha) Grain
Dates of sowing										
20 June	58.51	62.94	56.14	16.83	1.36	64.21	20.09	12.11 (3.48)	1.30	0.56
5 July	53.35	57.79	53.71	17.13	1.28	62.58	19.92	13.47 (3.67)	1.21	0.52
20 July	50.02	54.17	48.88	14.99	1.21	60.89	19.31	16.40 (4.05)	1.18	0.50
SEm±	0.10	0.98	0.91	0.30	0.02	0.67	0.12	0.08	0.024	0.006
CD (P=0.05)	0.31	3.20	2.97	0.97	0.08	2.19	0.37	0.26	0.077	0.020
Systems of cultivation										
BMP-ratoon	52.75b	55.79	48.51	15.90	1.19	58.47	19.31	17.56 (4.19)	1.12	0.46
SRI-ratoon	54.77a*	60.51	51.53	16.92	1.37	66.89	20.34	11.36 (3.37)	1.20	0.53
MSRI-ratoon	54.37a	58.61	58.69	16.12	1.29	62.32	19.67	13.25 (3.64)	1.37	0.60
SEm±	0.28	0.79	0.77	0.30	0.03	0.92	0.15	0.09	0.024	0.007
CD (P=0.05)	0.82	2.31	2.26	NS	0.08	2.68	0.44	0.27	0.069	0.021
'Genotypes'										
'Tapaswini'	54.06	52.52	53.50a	15.58	1.21	64.41	17.49	13.18 (3.63)	1.20	0.52
'Ajay'	53.86	64.08	52.32b	17.04	1.36	60.71	22.06	14.75 (3.84)	1.26	0.54
SEm±	0.08	0.59	0.34	0.25	0.02	0.51	0.10	0.06	0.011	0.005
CD (P=0.05)	NS	1.68	0.97	0.70	0.05	1.47	0.27	0.17	0.033	0.015

Figures in parentheses indicate the square root values

Effect of system of cultivation: Grain (0.60 t/ha) and straw yield (1.38 t/ha) of ratoon from MSRI rice were significantly higher than that of ratoon of rice crops from SRI and BMP (Table 2). Ratoon rice yields from BMP were the lowest. Superiority of ratoon rice in MSRI rice could be due to the synergistic effect of all yield attributes. Prolonged growth duration and larger root volume/hill of ratoon of rice in SRI could have effectively and efficiently traslocated assimilates from source to sink and thus would have influenced such attributes as compared to such conditions in ratoon of rice from BMP and MSRI.

Height of ratoon rice crop at harvest in BMP-ratoon was significantly the lowest (55.8 cm) compared to ratoon of rice from SRI and MSRI. The shorter ratoon in BMP-ratoon could be due to its reduced growth duration and also owing to lesser translocation of carbohydrates in individual hills with inferior roots. Taller ratoons in SRI-ratoon and MSRI-ratoon could be due to positive contribution of such characters.

Ratoon from BMP rice matured earlier than that of ratoon from SRI and MSRI, probably because of relatively inferior growth attributes of the ratoon of rice from BMP and thus might have matured earlier.

Effect of genotypes: Ratoon of hybrid 'Ajay' inspite of having fewer grains/panicle and higher per cent of floret sterility could out yield (0.54 t/ha) ratoon of cv. 'Tapaswini' (0.52 t/ha) possibly due to more number of tillers/m^2 and higher test weight. Cumulative effect of taller plants with more number of tillers/m^2 might have reflected in higher straw yield in ratoon of hybrid 'Ajay' (1.26 t/ha). Higher tillering per cent in ratoon of 'Tapaswini' might have increased number of panicles/m^2 compared to 'Ajay'. More number of grains/panicle in ratoon of 'Tapaswini' and higher panicle length and test-weight of grains in ratoon of 'Ajay' might be because of their biological character. Low spikelet sterility per cent (13.2) in ratoon of 'Tapaswini' might have favoured for recording more grains/m^2. Ratoon rice of hybrid 'Ajay' was significantly taller (64.1 cm) than high yielding variety 'Tapaswini' (52.5cm) and number of tillers/m^2 followed the same trend (Table 2). This could be due to inherent capability of genotypes. Larger root volume and higher assimilation of carbohydrates in tillers of 'Ajay' could influence plant height and tillering behavior of its ratoon positively. However, 'Ajay' was little faster in attaining maturity of its ratoon. This might be due to its genetic character.

Correlation studies

In plant rice (table 3), significant positive correlation was observed between plant height and root volume at 100 DAS (r = 0.55). Panicles/m^2 (r = 0.59), length (r = 0.55) and weight (r = 0.64) of panicles and yield of straw (r = 0.75) and grain (r = 0.8) were positively influenced by the root volume of plant rice. Days to physiological maturity had no such alluring statistical effects on such parameters in plant rice. However, the sterility percent in plant rice was significantly but negatively correlated with the root volume (r = -0.54), days to physiological maturity (r=-0.44), grains/ panicle (r=-0.59) and grain yield (r=-0.61).

Days to maturity in ratoon had significant positive influence on its straw (r=0.51) and grain yield (r = 0.55), height (r=0.45), panicles/m^2 and all other panicle characters except sterility where it had significant but negative effect (r=-0.49) (table 4). Ratoon height had significant influence on its panicle weight (r=0.53) and test weight (r =0.71). Moreover, like days required for maturity, ratoon height was also positively and significantly correlated with

Table 3. Correlation coefficients of agronomic traits of plant rice

Treatment	Root volume at 100 DAS	Days to physiological maturity	Plant height	Panicles/m^2	Grains/ panicle	1,000-grain weight	Panicle length	Panicle weight	Spikelet sterility	Straw yield
Days to physiological maturity	0.173									
Plant height	0.545**	-0.128*								
Panicles/m^2	0.593**	0.470**	0.098*							
Grains/panicle	0.355**	0.082	0.146	0.096						
1,000-grain weight	0.525**	-0.194	0.807**	0.081	-0.010					
Panicle length	-0.551**	-0.112	0.742**	0.095	0.056	0.878**				
Panicle weight	0.636**	-0.079	0.580**	0.156**	0.454**	0.648**	0.697**			
Spikelet sterility	-0.544**	-0.441**	-0.194	-0.298*	-0.586**	-0.038	-0.167	-0.446**		
Straw yield	0.752**	0.093	0.451**	0.523**	0.097	0.431**	-0.428**	0.463**	-0.363**	
Grain yield	0.804**	0.110	0.478**	0.510**	0.352*	0.373**	0.409**	0.558**	-0.606**	0.861**

* Means significant at 5% level; ** Means significant at 1% level

Table 4. Correlation coefficients of agronomic traits of ratoon rice

Treatment	Days to maturity	Crop height	Panicles/ m²	Grains/ panicle	1,000-grain weight	Panicle length	Panicle weight	Spikelet sterility	Straw yield
Crop height	0.453**								
Panicles/m²	0.389**	0.080							
Grains/panicle	0.341*	0.087	0.142						
1,000-grain weight	0.180	0.713**	0.117	0.020					
Panicle length	0.383**	0.314*	0.149	0.212	0.447**				
Panicle weight	0.393**	0.530**	0.296*	0.330*	0.557**	0.410**			
Spikelet sterility	-0.485**	-0.214	-0.172	-0.325*	0.028	-0.205	-0.367**		
Straw yield	0.507**	0.325*	0.339**	0.025	0.227	0.253*	0.238	-0.337*	
Grain yield	0.550**	0.361**	0.356**	0.203	0.223	0.201	0.327*	-0.473**	0.893**

* Means significant at 5% level,** Means significant at 1% level

Table 5. Correlation coefficients of agronomic traits of plant and ratoon rice interaction

Treatment		Plant rice					
		Root volume at 100 DAS	At harvest				
			Days to physiological maturity	Plant height	Panicles/ m²	Straw yield	Grain yield
Ratoon rice	Days to maturity	0.553**	0.726**	0.294*	0.500**	0.361**	0.549**
	Crop height	0.606**	0.066	0.794**	0.107	0.459**	0.521**
	Panicles/m²	0.393**	0.192	-0.023	0.498**	0.274**	0.321**
	Straw yield	0.608**	0.126	0.299*	0.543**	0.584**	0.679**
	Grain yield	0.693**	0.131	0.286*	0.502**	0.653**	0.791**

*Means significant at 5% level; **means significant at 1% level

root volume, plant height and yield of straw and grain, except with the days to physiological maturity and panicles/m² in plant rice (table 5). Straw and grain yield of ratoon were significantly and positively correlated with root volume (r = 0.61 and 0.69), plant height (r = 0.3 and 0.29), panicles/ m² (r = 0.54 and 0.5) and yield of straw (r = 0.58 and 0.65) and grain (r = 0.68 and 0.79) in plant rice except days to its physiological maturity.

Based on the study it is concluded that early sowing on 20 June significantly superior over 5 and 20 July sowing with 5.73 and 17.14% reduction in yield. MSRI was superior over SRI and BMP with 11.32 and 35.46% increase in yield. Among the genotypes, Hybrid 'Ajay' was superior to HYV 'Tapaswini' with 9.07 and 11.18% higher grain and straw yield. The performance of ratoons followed the similar trend as in plant rice. Early sown hybrid 'Ajay' in MSRI produced significantly the highest grain yield and 20 July sown 'Tapaswini' in BMP had the lowest in plant rice.

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Research Paper

Diversification of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system and its influence on productivity, profitability and energetics under on-farm situation

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ABSTRACT

A field experiment was conducted at farmers' fields in the district Nainital, Uttarakhand, during 2011–12 and 2012–13, to find out the alternate efficient cropping systems for rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* (L.) emend. Fiori & Paol.) system in western Himalayas. Five cropping systems including the existing rice–wheat were tested at 24 farmers' fields as researcher designed farmer managed trials. The rice equivalent yield of rice–chickpea (*Cicer arietinum* L.)–vegetable cowpea (*Vigna unguiculata* (L.) Walp.) was the highest (23.7 t/ha), followed by rice–wheat–vegetable cowpea (19.3 t/ha), rice–vegetable pea (*Pisum spp.*)–maize for cob (*Zea mays* L.) (17.4 t/ha) and rice–lentil (*Lens esculenta* (L.) Moench)–maize (fodder) (16.2 t/ha) systems. Existing rice–wheat system recorded rice equivalent yield of 11.8 t/ha, which is 50% lesser than rice–chickpea–vegetable cowpea system. The rice–chickpea–vegetable pea cropping system also recorded the highest net returns (₹222.2×10^3/ha) followed by rice–wheat–vegetable cowpea (₹203.6×10^3/ha) and rice–vegetable pea–maize (cob) (₹194.1×10^3/ha) systems. The highest benefit: cost ratio (1.91) was recorded with the rice–chickpea–vegetable cowpea system owing to its lower cost of cultivation and higher returns. Highest energy-use efficiency ratio (5.25) was recorded with the rice–lentil–maize (fodder) system. This system also produced second highest energy input-output efficiency (0.62MJ/ha/day), which is very close to the highest energy input-output efficiency (0.63 MJ/ha/day) of traditional rice–wheat system.

Key words : Diversification, Energetics, Productivity, Rice–wheat cropping system

The rice–wheat is the predominant cropping system of Indo-Gangetic plains of India, covering about 10.5 million ha area and contributing about 38% to the national food basket (Gangwar, 2009). The system is considered as the backbone for food grain security. The productivity of rice and wheat in the country was 2.20 t/ha (during 2011–12) and 2.93 t/ha (during 2010–11) respectively. In Uttarakhand state too, rice–wheat is the predominant cropping system, here rice and wheat crops are being grown on 252.8 and 347.8 thousand hectares, respectively. The average productivity of rice and wheat in Uttarakhand was 2.29 and 2.42 t/ha, respectively during 2013–14 (Government of Uttarakhand, 2014).

The system productivity of traditional rice–wheat cropping system can be increased up to the level of 9.1 to 21.5 t/ha/year depending on the choice of high value crops involved in diversification of rice–wheat system. Continuous cultivation of rice–wheat cropping system during last three decades has resulted in many second-generation problems like decline in water table, emergence of multinutrient deficiencies, formation of hard pan and build up of several weeds in rice and wheat crops, besides that, the stagnation in system productivity and profitability is being experienced in recent years (Ladha *et al.* (2003) and Busari *et al.* (2015)

A need is being felt to diversify and intensify the existing rice–wheat system with remunerative and efficient crops like pulses, oilseeds and vegetables due to multifold problems and stagnation of rice–wheat system productivity. Therefore, present study was undertaken to find out the productivity and economics of various possible cropping

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systems by incorporating pulses and vegetable crops that can replace rice–wheat system.

MATERIALS AND METHODS

The experiment was conducted at farmers' fields to study the influence of diversification of rice–wheat system on productivity, profitability and energetics, during 2011–12 and 2012–13. Twenty four farmers were selected from 6 villages from 2 blocks-Bhimtal and Kotabagh of district Nainital, Uttarakhand. The soil of experiment sites in general was sandy loam. Available nitrogen, phosphorus and potassium varied from 281–345 kg/ha (medium), from 16–18.5 kg/ha (medium), from 196–260 kg/ha (medium), respectively. The organic carbon ranged from 0.76–0.95% (medium to high) with *p*H ranging from 6.6 to 7.6 (neutral) and mean electrical conductivity (EC) of 0.65 to 0.78 dS/m.

Five cropping systems, viz. rice–wheat (control), rice–wheat–vegetable cowpea, rice–chickpea–vegetable cowpea, rice–lentil–maize (fodder) and rice–vegetable pea–maize (cob) were evaluated for productivity, economics and energetics. Initially during the first year of experimentation (2011–12), tomato crop was taken in place of chickpea, but it suffered due to frost, so during the second year tomato crop was replaced by the chickpea crop. 'NPH 567' (hybrid) and 'PRH 10' varieties of rice, 'UP 2572' and 'DBW 17' varieties of wheat, 'Pant Lobia 1' and Pant Lobia 3' varieties of cowpea, 'Him Sona' variety of tomato, 'PG 114' variety of chickpea, 'PL 6' and 'PL 4' varieties of lentil, 'Vasu 555' and 'African Tall' varieties of maize (fodder), 'Arkle' variety of vegetable pea (during both the years) and 'Gaurav' and 'Naveen' varieties of maize (cob) were used in experimentation in all farmers' fields.

As a researcher designed farmer managed experiment, recommended package of practices were followed for all the crops in different cropping systems. The experiment was laid out in randomized block design taking every farmer as a replication. For comparison between different cropping systems, the yields of all the crops in the sequences were converted into rice–equivalent yield. Productivity values in terms of kg/ha/day was calculated by dividing the production of the sequence by 365 days and profitability in terms of ₹/ha/day was obtained by net returns of the sequence divided by total duration of the sequence (Rautararay, 2005). The economics and the rice-equivalent yield were computed using the farm gate prices of 2011–12 and 2012–13.

The energy-use efficiency (EUE), energy-output efficiency (EOE), specific energy, rotational intensity and land use efficiency were obtained by using the following formula:

EUE = Energy output (MJ/ha)/Energy input (MJ/ha); EOE = Energy output (MJ/ha)/Duration of the system (days)

Specific energy=Energy input (MJ/ha)/rice grain equivalent yield (kg/ha)

Rotational intensity (%)=(number of crops grown in a rotation/duration of rotation in year) × 100

Land-use efficiency (%)=Total number of days field remained occupied under different crops in rotation/365) × 100

RESULTS AND DISCUSSION

Productivity

Diversified cropping systems had significantly higher rice equivalent yield than the rice–wheat system (Table 1 and 2). Highest rice equivalent yield (significantly higher than the rest of the systems) (23.7 t/ha) was recorded with rice–chickpea–vegetable cowpea system followed by rice–wheat–vegetable cowpea (19.3 t/ha), rice–vegetable pea–maize (cob) (17.4 t/ha) and rice–lentil–maize (fodder) (16.2 t/ha) systems. Existing pre-dominant rice–wheat system had only 11.8 t/ha as rice equivalent yield. The rice equivalent yield of rice–chickpea–vegetable cowpea, rice–wheat–vegetable cowpea, rice–vegetable pea–maize (cob) and rice–lentil–maize (fodder) cropping systems was higher by 99, 62, 46 and 37% respectively than the exist-

Table 1. Mean crop yields of different crops under different cropping systems

Cropping system	Mean crop yield (t/ha)					
	Rainy season (*kharif*)		Winter season (*rabi*)		Spring/summer (*zaid*)	
	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13
Rice–wheat	8.09	5.65	5.05	5.08	0.00	0.00
Rice–wheat–vegetable cowpea	8.10	5.70	5.05	5.11	5.96	5.84
Rice–chickpea*–vegetable cowpea	8.07	5.70	13.75#	1.94	6.21	5.84
Rice–lentil–maize (fodder)	8.09	5.64	1.65	1.59	26.85	33.02
Rice–vegetable pea–maize (cob)	8.12	5.68	7.70	7.44	4.09	1.96

* during 2011–12 in place of chickpea tomato crop was taken # crop suffered up to some extent at some of the farmers' fields, average figure has been given

ing rice–wheat system. Suitability of vegetable and pulse crops for diversification of rice–wheat system was also reported by many workers (Singh *et al*., 2005; Singh *et al.,* 2008; Kumar *et al.,* 2012; Singh *et al.,* 2012 and Singh and Kumar, 2014)

Rice–wheat system took minimum time (277 days) from sowing to harvesting of all the crops in sequence and followed by rice–vegetable pea–maize (cob) (324 days) and rice–lentil–maize (fodder) (327 days). Rice–wheat–vegetable cowpea system required the highest time period (354 days) and it was closely followed by rice–chickpea–vegetable cowpea (339 days) system. All diversified cropping systems had cropping intensity of 300%, while it was 200% under the traditionl rice–wheat cropping system. Land-use efficiency was recorded the highest with rice–wheat–vegetable cowpea cropping system (96.9%), followed by rice–chickpea–vegetable cowpea (92.8%), which was significantly higher than the rice–lentil–maize for fodder (89.5%), rice–vegetable pea–maize for cob (87.7%) and traditional rice–wheat system (75.8%) (Table 2).

Highest and significantly higher over rest of the treatments system productivity was recorded with rice–chickpea–vegetable cowpea system (64.9 kg/ha/day), followed by rice–wheat–vegetable cowpea (52.9 kg/ha/day), which was significantly higher over rice–vegetable pea–maize (cob) (47.6 kg/ha/day), rice–lentil–maize (fodder) (44.6 kg/ha/day) and traditional rice–wheat system (32.5 kg/ha/day. Significantly higher over rest of the treatments and the highest relative production efficiency was recorded with rice–chickpea–vegetable cowpea system (99.6%), it was followed by rice–wheat–vegetable cowpea system (62.6%), which was superior to rice–vegetable pea–maize (cob) (46.4%) and rice–lentil–maize (fodder) system (37.0 %).

Economics

Rice–wheat system recorded lowest cost of cultivation (₹83.4×10³/ha) and net returns (₹127.4 ×10³/ha). Cost of cultivation and net returns increased with the diversification (Table 3). The highest cost of cultivation was recorded with the rice–chickpea–vegetable cowpea (₹116.0×10³/ha) and it was closely followed by rice–wheat–vegetable cowpea and rice–vegetable pea–maize (cob) cropping systems having cost of cultivation of ₹111.9×10³/ha. Rice–lentil–maize (fodder) system incurred ₹97.5×10³/ha as cost of cultivation. Highest net returns (₹222.2×10³/ha) were recorded in rice–chickpea–vegetable cowpea system and it was followed by rice–wheat–vegetable cowpea (₹203.7×10³/ha), rice–vegetable pea–maize (cob) (₹194.1×10³/ha) and rice–lentil–maize (fodder) (₹143.9×10³/ha). Sharma *et al*. (2007), Singh *et al.* (2012)

Table 2. Rice-equivalent yield and other parameters under different cropping systems (pooled data of 2 years)

Cropping system	Rice equivalent yield (t/ha)	Duration (days)	Rotational intensity (%)	Land-use efficiency (%) (kg/ha/day)	System production efficiency	Relative production efficiency (%)
Rice–wheat	11.8	277	200	75.8	32.5	–
Rice–wheat–vegetable cowpea	19.3	354	300	96.9	52.9	62.6
Rice–chickpea–vegetable cowpea	23.7	339	300	92.8	64.9	99.6
Rice–lentil–maize (fodder)	16.2	327	300	89.5	44.6	37.0
Rice–vegetable pea–maize (cob)	17.4	324	300	88.7	47.6	46.4
SEm±	0.23	–	–	0.86	0.78	0.99
CD (P=0.05)	0.64	–	–	2.42	2.21	2.80

Table 3. Economics under different cropping systems (pooled data of 2 years)

Cropping system	Cost of cultivation (×10³₹/ha)	Net returns (×10³₹/ha)	Benefit: cost ratio	Profitability (₹/ha/day)	Net profit or loss over rice–wheat system (×10³₹/ha)	Relative economic efficiency (%)
Rice–wheat	83.4	127.4	1.53	460	–	–
Rice–wheat–vegetable cowpea	111.9	203.7	1.82	576	76.3	59
Rice–chickpea–vegetable cowpea	116.0*	222.2	1.91	657	94.9	76
Rice–lentil–maize (fodder)	97.5	143.9	1.48	441	16.5	13
Rice–vegetable pea–maize (cob)	111.9	194.1	1.75	600	66.8	53

*during 2011–12 in place of chickpea tomato crop was taken having high cost of cultivation and Singh and Kumar (2014) also reported increased productivity and profitability by inclusion of different vegetables in rice–wheat system.

The highest benefit: cost ratio (1.91) was recorded with rice–chickpea–vegetable cowpea owing to its higher net returns and also system yield (Table 3). This system was followed by rice–wheat–vegetable cowpea (1.82), rice–vegetable pea–maize (cob) (1.75), rice–wheat (1.53) and rice–lentil–maize (fodder) (1.48). Highest system profitability (₹657/ha/day) was again recorded under rice–chickpea–vegetable cowpea, followed by rice–vegetable pea–maize (cob) (₹600/ha/day), rice–wheat–vegetable cowpea (₹576/ha/day) and rice–wheat system (₹460/ha/day). Rice–lentil–maize (fodder) system recorded the lowest system profitability (₹441/ha/day). Higher system profitability may be attributed to better price and lower duration of the crops in sequence. The highest increase in net profit over the traditional rice–wheat cropping system (₹94.9×10^3/ha) was recorded under the rice –chickpea–vegetable cowpea cropping system and it was closely followed by rice–wheat–vegetable cowpea (₹76.3×10^3/ha). The lowest additional returns over traditional rice–wheat system (₹16.5×10^3/ha) was obtained under rice–lentil–maize (fodder) system, while the rice–vegetable pea–maize (cob) system provided ₹66.8×10^3/ha additional returns over the traditional one. The highest relative economic efficiency (76%) was recorded with rice–chickpea–vegetable cowpea system and it was followed by rice–wheat–vegetable cowpea (59%), rice–vegetable pea–maize (cob) (53%) and rice–lentil–maize (fodder) (13%). Other workers have also reported higher economic returns under the diversified rice–wheat systems by vegetables and pulses due to better market price of vegetables and pulses and also due to higher rotational intensity (Singh *et al.,* 2008 and Kumar *et al.,* 2012).

Energetics

Total input energy requirement was lowest (35.0 MJ/ha) in rice–wheat system (Table 4) and it was closely followed by rice–lentil–maize (fodder) system (38.6 MJ/ha). Highest total input energy requirement was recorded with the rice–chickpea–vegetable cowpea (49.2 MJ/ha) followed by rice–vegetable pea–maize (cob) (47.2 MJ/ha) and rice–wheat–vegetable cowpea system (42.6 MJ/ha). Higher energy input requirement might be due to higher requirement of labour and inputs like seed, pesticide and irrigation. Highest total energy output (202.6 MJ/ha) was produced under the rice–lentil–maize (fodder) system and it was significantly higher over rest of the treatments, followed by rice–wheat–vegetable cowpea (187.3 MJ/ha) and rice–vegetable pea–maize (cob) (186.3 MJ/ha) cropping systems and these 2 cropping systems recorded significantly higher output energy over the rice–chickpea–vegetable cowpea (135.7 MJ/ha) and rice–wheat cropping system (175.4 MJ/ha). Highest-energy use efficiency (5.25) was recorded with rice–lentil–maize (fodder) cropping system followed by rice–wheat system (5.01). The energy output efficiency was recorded higher with rice–wheat system (0.63 MJ/ha/day) and it was closely followed by rice–lentil–maize (fodder) system (0.62 MJ/ha/day), which might be due to higher energy-output obtained in these cropping systems. Highest specific energy requirement was recorded with the rice–wheat system (2.97 MJ/kg), followed by rice–vegetable pea–maize for cob (2.71 MJ/kg), rice–lentil–maize for fodder (2.38 MJ/kg), rice–wheat–vegetable cowpea (2.20 MJ/kg) and rice–chickpea–vegetable cowpea (2.07 MJ/kg). Higher specific energy indicates these cropping systems require higher inputs to produce a unit of produce. Kachroo *et al.* (2012) also reported similar findings where inclusion of vegetables resulted in low input use/kg of produce.

Based on two years of experimentation, it can be concluded that the rice–chickpea–vegetable cowpea cropping system can be recommended for diversifying rice–wheat system to increase the productivity and profitability of farmers in the irrigated situations of Kumaon Himalayas. Under the input energy constraint situation, rice–lentil–maize (fodder) system can be recommended as alternate system.

Table 4. Energy values in total inputs, total output, energy-use efficiency and energy-output efficiency (pooled data of 2 years)

Cropping system	Input energy (×10^3MJ/ha)	Output energy (×10^3MJ/ha)	Energy-use efficiency (ratio)	Energy-output efficiency (MJ/ha/day)	Specific energy requirement (MJ/kg)
Rice–wheat	35.0	175.4	5.01	0.63	2.97
Rice–wheat–vegetable cowpea	42.6	187.3	4.40	0.53	2.20
Rice–chickpea–vegetable cowpea	49.2	135.7	2.77	0.40	2.07
Rice–lentil–maize (fodder)	38.6	202.6	5.25	0.62	2.38
Rice–vegetable pea–maize (cob)	47.2	186.3	3.95	0.57	2.71
SEm ±	–	2.70	–	–	–
CD (P=0.05)	–	7.60	–	–	–

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Research Paper

Effect of irrigation and nitrogen management on rice (*Oryza sativa*) under system of rice intensification and its residual effect on lentil (*Lens culinaris*)

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ABSTRACT

A field experiment was conducted to study the effect of irrigation scheduling and nitrogen management on growth, yield, quality and relative economics of hybrid rice (*Oryza sativa* L.) (cv. 'PHB 71') under SRI and their residual effect on lentil (*Lens culinaris* Medik) (cv. 'HUL 57') on sandy-clay loam soil of Varanasi, Uttar Pradesh during rainy (*kharif*) and winter (*rabi*) seasons of 2014–15 and 2015–16. The experiment was laid out in split-plot design assigning 3 irrigation scheduling [irrigation at 2 days after disappearance of ponded water (DADPW), 5 DADPW and 8 DADPW] in the main-plots and 5 nitrogen management practices, [Recommended dose of nitrogen (RDN), RDN + *Sesbania aculeata* Poir as co-culture with rice, 75% RDN + *Sesbania aculeata* Poir as co-culture with rice, RDN + blue green algae (BGA) and 75% RDN+BGA] in the sub-plots, with 3 replications. Results revealed higher growth parameters, yield attributes and grain and straw yields (6.67 and 8.43 t/ha, respectively) under scheduling of irrigation at 2 DADPW as compared to 8 DADPW although it was statistically at par with scheduling of irrigation at 5 days after disappearance of ponded water. The magnitude of increase in grain and straw yield of hybrid rice under SRI by scheduling of irrigation at 2 DADPW over 8 DADPW was 14.0 and 10.3%, respectively on pooled basis. The NPK uptake by the crop and hulling, milling and head rice recovery of rice grain were found to be higher under scheduling of irrigation at 2 DADPW. Among the nitrogen management practices, RDN+BGA produced markedly higher leaf-area index (4.78), dry matter accumulation/hill (67.6 g), effective tillers/m^2 (262), panicle length (31.7 cm), grains/panicle (190), weight/panicle (5.64 g), 1,000-grain weight (24.8 g), grain yield (6.78 t/ha) and straw yield (8.66 t/ha) over other nitrogen management practices. The residual effect of scheduling of irrigation at 5 DADPW applied to rice exhibited higher value of pods/plant, 1,000-grain weight, yield of grain and stover of lentil as well as NPK uptake by the crop. Further, application of RDN (150 kg N /ha) along with BGA (12 kg BGA powder/ha) to rice recorded the highest pods/plant, 1,000-grain weight and grain and stover yield and NPK uptake by succeeding lentil.

Key words : Available NPK, Irrigation scheduling, Nitrogen, Rice, System of rice intensification

Rice is a main dietary component of the Indian population and supplies 31% of total calories required. India will need 112 million tonnes of rice in 2020, which is 7 million tonnes more than the present production as per Agricultural Policy Vision 2020 by Indian Council of Agricultural Research, New Delhi. Further, per capita water availability has declined from 5,000 m^3/annum in 1,950 to around 2,000 m^3 now and is projected to further decline to 1,500 m^3 by 2025 leading to far less water availability for agriculture (www.indiawaterportal.org). The water availability for agricultural use has reached a critical level as the country uses more than 80% of the surface water in this sector alone. Climate change has also brought an alarming situation to agricultural sector particularly of increasing scarcity of water, which threatens irrigated low-land rice production. Moreover, in Uttar Pradesh, rice is mostly cultivated in puddled fields with continuously ponded water and it is also one of the biggest users of world's fresh water resources. With current practices, the rice crop consumes large quantity of irrigation water, ranging between 1,500 and 3,000 mm/ha (Singh *et al.,* 2002). Various water-saving techniques have been developed for rice production systems, such as alternate wetting and drying (Belder *et al*., 2004), saturated soil culture (Tuong *et al*., 2004), direct dry seeding (Tabbal *et al*., 2002) and aerobic rice culture (Kato *et al*., 2009). These water-saving tech-

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nologies are mostly aimed at reducing unproductive losses of water through seepage, percolation, and evaporation, thereby increasing the productivity of total water inputs from rainfall and irrigation. However, very little information is available regarding the minimum volume of water required for enhancing productivity of rice under SRI method in eastern Uttar Pradesh. Further, low use of organic manure by farmers and maximum use of chemical fertilizer leading to the development of nutrient deficiencies are major constraints in realizing higher yield. Nitrogen-management strategies should be aimed at achieving the twin goals of fertilizers economy and sustainability. The negligence to the conservation and use of organic sources for nutrients has not only exhausted soil nutrient reserves but also resulted in an imbalance among the available nutrients leading to problematic soil health (Satyanarayan *et al.,* 2002). Integration of inorganic and organic sources such as green manuring, blue green algae and their efficient management has shown promise in sustaining the productivity and soil health (Karmakar *et al.,* 2011). Alternate wetting and drying and organic manures are important components of SRI. Since location-specific study on irrigation as well as organic nitrogen management in SRI is lacking, a study was undertaken to ascertain the effect of irrigation and nitrogen management on rice under system of rice intensification and its effect on lentil.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2014–15 and 2015–16 at Agricultural Research Farm of Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (25°18' N, 83°03' E, 75.7 m above the mean sea-level) situated in the Northern-Gangetic alluvial plains having characteristics of sub-tropical climate. Soil of the experimental field was sandy-clay loam (typic *Ustochrepts*) with 0.39 and 0.41% organic carbon, 210.1 and 212.0 kg/ha available nitrogen, 24.30 and 26.2 kg/ha available phosphorus and 214.3 and 209.6 kg/ha available potassium during the respective years. The treatments consisted 3 irrigation scheduling in the main-plots (irrigation at 2 DADPW, 5 DADPW and 8 DADPW) and 5 nitrogen-management practices in the sub-plots [Recommended dose of nitrogen (RDN), RDN + *Sesbania aculeata* as co-culture with rice, 75% RDN + *Sesbania aculeata* as co-culture with rice, RDN+BGA and 75% RDN+ BGA] were tested in a split-plot design with 3 replications. Recommended dose of fertilizers was 150, 75 and 75 kg NPK/ha. Nitrogen, phosphorus and potassium were supplied through urea, diammonium phosphate and muriate of potash respectively. Phosphorus and potassium were applied uniformly as basal to all the plots. Half dose of nitrogen was applied as basal and remaining half dose applied in 2-equal splits at tillering and panicle initiation stages respectively as per treatment. Before the transplanting of rice, 50 kg seed/ha of *Sesbania aculeata* was broadcasted manually as per the treatment. Conoweeder as a part of SRI was run manually between rows of rice crop at 20 and 35 days after transplanting irrespective of the treatment to control the weeds as well as to incorporate the green biomass of *Sesbania*. The working principle of conoweeder was uprooting of plants by front wheel and incorporation of uprooted weed into the soil by the rear wheel. The dry algal material was broadcasted at a rate of 12 kg powder/ha as the treatment over the standing water in rice field during both the years. Seedlings of hybrid rice (cv. 'PHB 71') were raised as per the principle of SRI in which the rice seedlings were grown separately on raised beds. Single seedling of 12 days old was transplanted at a spacing of 25 cm × 25 cm on July 1 during 2014 and on July 2 during 2015. The plots were inspected every day in the morning between 7 and 8 AM for disappearance of ponded water i.e. 85±2% soil moisture at plough layer (0–15 cm). The soil moisture was measured through Time-Domain Reflectometer. If the ponded water was not visible at the time of observation then from that day counting for the next irrigation was done, considering that day as zero day. The depth of each irrigation was kept at 5 cm with the help of Parshall flume. Rescheduling of irrigation was done if there was rainfall in between. Irrigation application was stopped 15 days before harvest. All the data pertaining to growth, yield attributes and yield were recorded properly. The total rainfall during both the crop seasons of 2014–15 and 2015–16 was 839.8 and 926.8 mm, respectively. The physical and chemical quality characteristics of kernels were determined for head rice recovery, kernel length, kernel breadth, length/breadth (L/B) ratio and linear kernel elongation ratio using an average of 10 randomly selected kernels (Ghosh *et al.,* 1971). Crop response to the treatments was measured in terms of various quantitative and qualitative indices. The leaf-area index (LAI) was measured by leaves of 5 plants taken from each penultimate rows and leaf area was recorded with a leaf-area meter (Systronics 211). The LAI was worked out as: Leaf-area index = Total leaf-area (cm^2)/Land area (cm^2). To calculate different quality parameters such as hulling and milling (%); 100 g sample of unhusked paddy from each plot was subjected to dehusking in a SATAKE dehusker. The hulling percentage was recorded by weight of brown rice divided by weight of rough rice multiplied by hundred. The milling percentage was calculated by weight of milled rice divided by weight of rough rice and multiplied by hundred. The percentage of the head rice recovery was calculated by weight of whole polished rice divided by weight of rough rice and multiplied by hundred. Protein content in grain was worked out by multiplying the nitrogen content in grain with the factor (6.25). Protein yield was determined by multiplying the protein content in grain with their respective yields. Kernel elongation ratio was obtained by division of length of cooked kernel to length of raw kernel. After harvest of hybrid rice, lentil cv. 'HUL 57' (Malaviya Vishwanath) was sown in the second fortnight of November during both the years at a row spacing of 30 cm with a seed rate of 40 kg/ha. Since the objective of this study was to quantify the residual effect of irrigation scheduling and nitrogen management applied to preceding rice on succeeding lentil, only 50% recommended dose of nitrogen and phosphorus (12.5 kg N and 25 kg P_2O_5/ha) was added to succeeding lentil. Yield attributing characters and productivity of preceding rice as well as succeeding lentil were recorded by standard procedure. Grain and straw/stover samples were dried, processed and analysed for their total nitrogen content by micro-Kjeldahl's, phosphorus by Vanadomolybdo phosphoric acid-yellow colour method and potassium by flame-photometer. Nutrient uptake was estimated by multiplying the content with the oven-dry weight of biological yield. The samples were oven dried at 70°C ± 2°C till constant weight was achieved. All the data obtained from hybrid rice and succeeding lentil crop for consecutive two years were statistically analyzed using the F-test.

RESULTS AND DISCUSSION

Growth and yield attributes of rice

Scheduling of irrigation in rice at 2 days after disappearance of ponded water (DADPW) recorded significantly higher leaf-area index (LAI) (5.02), dry matter accumulation (DMA) (67.6g/hill), effective tillers/m^2 (257), panicle length (31.7 cm) and grains/panicle (187) as compared to 8 DADPW but remained at par with 5 DADPW (Table 1). The magnitude of increase in DMA, effective tillers/m^2 and grains/panicle by 2 DADPW over 8 DADPW was 5.6, 16.3 and 6.9%, respectively. The severe water stress in plots irrigated at 8 DADPW led to less LAI, DMA, number of effective tillers, panicle length, panicle weight and test weight of rice. Water stress at the vegetative stage delayed the heading rate with a decrease of effective tillers/hill. The lowest values of yield attributes at 8 DADPW might be attributed to the fact that plants under this treatment could not get sufficient water to fulfill their evapotranspirational demands. Dass and Chandra (2013) and Sandhu and Mahal (2014) observed that filled spikelets/ panicle, and filled spikelets weight/ panicle of rice signicantly higher under irrigation at 1 DADPW over 5 DADPW and 3 DADPW, respectively. Nitrogen management practices also showed significant effect on all the growth and yield attributing characters of hybrid rice. Application of recommended dose of nitrogen (RDN)+blue green algae (BGA) recorded the highest LAI (4.78), DMA (67.6 g/hill), grains/panicle (190), panicle weight (5.64 g) and 1,000-grain weight (24.8 g). However, application of RDN + *Sesbania aculeata* as co-culture remained statistically at par with 75% RDN + *Sesbania aculeata* as co-culture, while 75% RDN + BGA was found superior to RDN alone. Increase in nitrogen release through either *Sesbania* or BGA for longer time facilitated the plants to remain green for longer period. This contributed to the production of more carbohydrates through enhanced absorption, translocation and assimilation of nutrients by the plants required for various physiological processes for increased photosynthetic products in terms of higher panicle weight and grains/panicle (Fageria and Moreira, 2011). These results are in agreement with the findings of Srivastava *et al.* (2014), who observed that application of 100% RDF (150, 75, 75 kg NPK/ha) increased effective tillers/m^2, grains/panicle, test weight, grain yield and straw yield of rice (cv. 'PHB 71') under SRI over the 50% RDF.

Rice yield

Significant increase in grain yield of rice was recorded when scheduling of irrigation was done at 2 DADPW, but it remained at par with 5 DADPW (Table 1). The grain yield of hybrid rice under scheduling of irrigation at 2 DADPW was 44.0% higher (6.67 t/ha) over scheduling of irrigation at 8 DADPW. The reduction in grain yield with curtailment in the amount of irrigation water applied might be due to the fact that due to less availability of water, the physical and chemical conditions of soil might not have been favourable for proper growth and formation of yield attributes, as it was evident from the data on these attributes. Sandhu and Mahal (2014) observed similar result with rice cv. 'PAU 201'. Nitrogen management practices showed significant effect on grain yield as of rice. Application of RDN along with BGA recorded significantly higher grain yield over rest of the nitrogen management treatment. The grain and straw yields of hybrid rice under application of RDN along with BGA were 13.6 and 14.9% higher than RDN alone. This might be due to incorporation of BGA and more availability of nutrients resulting in higher nutrient uptake with consequent increase in yield attributes. The increase in grain and straw yields might be further ascribed to combined application of RDN along with BGA which enhanced the microbial population in soil, root proliferation and nutrients uptake leading to the better dry matter production (Bahadur *at al.*, 2013). Sharma *et al.* (2015) observed that the substitution of 25% NPK through FYM of the recommended dose along with

Table 1. Effect of irrigation and nitrogen management on growth parameters, yields attributes, yield and relative economics of rice as under SRI (pooled data of 2 years)

Treatment	Growth parameters			Yield attributes				Yield (t/ha)		Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit : cost ratio
	LAI at 90 DAT	Dry-matter accumulation (g/hill) 90 DAT	Effective tillers/m^2	Panicle length (cm)	Grain/ panicle	Panicle weight (g)	1,000-grain weight (g)	Grain	Straw			
Irrigation scheduling												
Irrigation at 2 DADPW	5.02	67.6	257	31.7	187	5.43	24.7	6.67	8.43	110.2	72.2	1.90
Irrigation at 5 DADPW	4.79	65.6	243	30.9	183	5.15	23.9	6.52	7.96	107.2	71.3	1.99
Irrigation at 8 DADPW	4.60	64.0	221	29.5	175	4.83	23.0	5.85	7.64	97.2	62.1	1.77
SEm±	0.07	0.68	4.81	0.30	2.12	0.11	0.24	0.103	0.121	1.6	1.6	0.045
CD (P=0.05)	0.30	2.67	18.9	1.18	8.36	0.43	0.96	0.403	0.473	6.41	6.42	0.18
Nitrogen management												
RDN (150 kg N/ha)	4.52	64.2	221	29.2	178	4.66	23.0	5.97	7.56	98.8	62.9	1.76
RDN + *S. aculeata* as co-culture	4.63	66.4	241	30.6	182	5.20	23.9	6.34	8.04	105.0	67.8	1.83
75% RDN + *S. aculeata* as co-culture	4.87	65.8	238	30.3	180	5.11	23.7	6.30	7.74	103.6	67.1	1.83
RDN + BGA (12 kg/ha)	4.78	67.6	262	31.7	190	5.64	24.8	6.78	8.69	112.3	75.9	2.08
75% RDN + BGA	5.21	64.8	238	30.5	178	5.08	23.8	6.34	8.02	104.7	68.8	1.92
SEm±	0.10	0.78	5.9	0.27	2.55	0.11	0.26	0.124	0.118	1.8	1.8	0.049
CD (P=0.05)	0.29	2.28	17.2	0.78	7.47	0.34	23.0	0.363	0.346	5.36	5.36	0.14

DADPW, Days after disappearances of ponded water

5 kg Zn/ ha and PSB+BGA were better than NPK treatment alone in respect of grain yield.

Nutrient uptake

Different irrigation scheduling exhibited significant effect on nitrogen uptake by rice and the maximum value was observed with 2 DADPW (Table 2). More phosphorus uptake was recorded in plots irrigated at 2 DADPW over 8 DADPW, but it was statistically at par with irrigation schedule in which irrigation was applied at 5 DADPW. The reason for higher nitrogen and phosphorus uptake with more frequent amount of irrigation water might be due to fast mineralization of nitrogen and solubilization of phosphorus by water resulting, their higher availability to plants and hence an increase in nitrogen and phosphorus uptake. Further, among different irrigation schedules, maximum potassium uptake was found in plots irrigated at 2 DADPW. The increase in potassium uptake by rice with increasing amount of irrigation water might have happened due to addition of potassium through underground water used for irrigation. Hazra and Chandra (2014) and Sandhu and Mahal (2014) reported that soil moisture stress signicantly reduced the uptake of phosphorus and potassium.

Application of RDN + BGA recorded significantly higher N, P and K uptake by rice as compared to rest of the nitrogen management practices. The per cent increase in N, P and K uptake with RDN+BGA was in the order of 25.9, 39.4 and 23.5% respectively over application of RDN alone. BGA is directly involved in increasing concentration of nitrogen through their rapid mineralization due to drying and wetting cycles, synthesis of phytohormones, solubilization of minerals like phosphorus and production of siderophores that chelate iron and make it available to the plant root (Mishra *et al*., 2013). Pooniya and Shivay (2011) reported the highest uptake of nitrogen and zinc by Basmati rice through *Sesbania aculeata* as summer green manure crop. Sharma *et al.* (2015) also observed maximum nutrient (N, P, K, S and Zn) uptake of 75.6, 18.4, 120.1, 27.8 kg/ ha and 231.9 g/ ha, respectively by rice when it was supplied with 75% NPK+5 t FYM/ ha+PSB+BGA+Zn (5 kg Zn /ha).

Soil fertility after rice

Scheduling of irrigation at 5 DADPW recorded significantly higher N, P and K and organic carbon content as compared to 2 DADPW, but remained statistically at par with 8 DADPW with respect to available N, P and K in soil (Table 2). The maximum available nitrogen in soil was recorded with the application of RDN either with *Sesbania aculeata* as co-culture or BGA. In case of available phosphorus it was recorded higher under application of RDN along with BGA. The potassium availability was more under RDN+ *Sesbania aculeata* as co-culture and 75% RDN+ *Sesbania aculeata* as co-culture with rice. Yang *et al.* (2004) observed that the total nitrogen in paddy soil was 37–67% higher with the combined use of organic sources and chemical fertilizers against the sole chemical fertilizers treatment. Increment in available phosphorus content of soil with BGA application may also be ascribed to greater mobilization of native soil phosphorus by reducing the capacity of soil mineral to fix phosphorus and increase its availability through release of organic acids. Sharma *et al.* (2015) recorded that the conjunctive use of organic manure and fertilizers along with biofertilizers and micronutrient (Zn) gave the highest availability of N, P, K, S and Zn at post-harvest soil of rice.

Quality parameters

Scheduling of irrigation to rice at 2 DADPW recorded significant improvement in protein content in grains (7.78%), hulling percentage (74.8), milling percentage (70.1) and head rice recovery (58.5%) except kernel length over scheduling of irrigation at 8 DADPW (Table 3). Quality parameters, viz., kernel length and kernel breadth before and after cooking were analysed and found to be statistically at par due to the different irrigation scheduling. Application of RDN along with BGA showed significantly higher protein content (7.77%), hulling (75.61%), milling (68.6%), head rice recovery (58.2%). Yadav *et al*. (2013) also concluded that the application of 75% RDF along with BGA recorded the highest hulling, milling and head rice recovery percentage.

Yield attributes and yield of succeeding lentil

Number of pods/plant and 1,000-grain weight of succeeding lentil were found to be significantly higher when scheduling of irrigation was carried out at 5 DADPW (Table 4). Residual moisture and nutrient availability after harvest of preceding rice was more with scheduling of irrigation at 5 DADPW as compared to rest of the scheduling, which was evident from the enhanced uniform plant stand. Inspite of the residual moisture availability being the highest at 2 DADPW, comparatively low nutrient availability over 5 DADPW for crop growth resulted in less yield contributing characters of lentil. Residual of RDN+BGA had significant effect on pods/plant and 1,000-grain weight of succeeding lentil. Singh *et al.* (2013) and Jat *et al.* (2015) observed that the residual effect of preceding treatment i.e. the application of 50% RDN + 50% N through FYM + *Azospirillum* to rice recorded the highest number of effective tillers, grains/ear, 1,000-grain weight and grain and straw yields of succeeding wheat (cv. 'HUW 234').

Lentil recorded the highest grain yield when it was grown on the residual moisture at 5 DADPW to rice. The grain and stover yields of succeeding lentil grown with scheduling of irrigation at 5 DADPW was 3.0 and 16.6% higher over scheduling of irrigation at 8 DADPW and 2

Table 2. Effect of irrigation and nitrogen management on uptake of NPK by rice, soil available NPK and organic carbon content after harvest of the crop (pooled data of 2 years)

Treatment	Total nutrient uptake (kg/ha) by hybrid rice			Post harvest available nutrient status (kg/ha) of soil after rice			
	Nitrogen	Phosphorus	Potassium	N	P_2O_5	K_2O	Organic carbon (%)
Irrigation scheduling							
Irrigation at 2 DADPW	140	29.90	157	177	19.30	187	0.42
Irrigation at 5 DADPW	131	28.19	144	208	22.99	242	0.45
Irrigation at 8 DADPW	118	24.37	134	202	23.09	219	0.41
SEm±	2.21	0.56	3.0	5.65	0.74	9.05	0.006
CD (P=0.05)	8.71	2.23	11.7	22.20	2.93	35.5	0.026
Nitrogen management							
RDN (150 kg N/ha)	116	22.89	132	179	19.87	183	0.43
RDN + *S. aculeata* as co-culture	130	27.84	146	210	21.90	237	0.43
75% RDN + *S. aculeata* as co-culture	127	26.76	140	192	21.56	226	0.40
RDN + BGA (12 kg/ha)	146	31.90	163	213	23.02	209	0.42
75% RDN + BGA	129	27.95	143	187	22.67	223	0.45
SEm±	2.30	0.54	2.39	6.95	0.51	10.3	0.008
CD (P=0.05)	6.73	1.58	7.0	20.30	1.49	30.3	0.024
Initial value				210.1	24.3	214.3	0.39

DADPW, Days after disappearances of ponded water

Table 3. Effect of irrigation and nitrogen management on quality parameters of rice under SRI (pooled data of 2 years)

Treatment	Protein content in grain (%)	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length before cooking (cm)	Kernel length after cooking (cm)	Kernel breadth before cooking (mm)	Kernel breadth after cooking (mm)	Length elongation ratio	Length breadth ratio before cooking
Irrigation scheduling										
Irrigation at 2 DADPW	7.78	74.8	70.1	58.5	7.48	13.2	2.11	2.25	1.77	1.08
Irrigation at 5 DADPW	7.52	70.8	66.8	57.3	7.62	13.0	1.89	2.21	1.71	1.21
Irrigation at 8 DADPW	7.34	66.7	63.8	52.0	7.45	12.5	1.83	2.18	1.71	1.22
SEm±	0.07	1.40	1.12	0.88	0.06	0.30	0.06	0.03	0.04	0.04
CD (P=0.05)	0.30	5.50	4.42	3.47	NS	NS	NS	NS	NS	NS
Nitrogen management										
RDN (150 kg N/ha)	7.14	64.9	64.0	54.2	7.22	12.2	1.99	2.24	1.70	1.15
RDN + *S. aculeata* as co-culture	7.60	69.5	64.4	56.9	7.55	12.7	1.93	2.27	1.70	1.23
75% RDN + *S. aculeata* as co-culture	7.55	69.6	62.1	55.5	7.41	13.3	1.89	2.14	1.80	1.18
RDN + BGA (12 kg/ha)	7.77	75.6	68.6	58.2	7.77	13.0	1.97	2.12	1.68	1.09
75% RDN + BGA	7.54	70.3	61.3	54.9	7.64	13.3	1.93	2.29	1.77	1.20
SEm±	0.07	1.50	1.09	0.80	0.19	0.32	0.05	0.05	0.05	0.05
CD (P=0.05)	0.23	4.38	3.20	2.35	NS	NS	NS	NS	NS	NS

DADPW, Days after disappearances of ponded water; NS, non-significant

DADPW, respectively. Further, the highest grain and stover yields of succeeding lentil were recorded with the application of RDN along with BGA to rice and the magnitude of increase was 11.7 and 11.6 per cent, respectively over the application of RDN alone. The residual effect of 100% RDN+BGA to preceding rice on succeeding lentil yield might be due to higher organic carbon content as well as more available NPK in the soil after harvest of rice. Similar findings were observed by Tripathi *et al.* (2009) and Singh *et al.* (2013) under succeeding rice and lentil, respectively.

Nutrient uptake by succeeding lentil

Scheduling of irrigation and nitrogen management practices applied to preceding rice had a significant effect on N, P and K uptake by grain and stover of succeeding lentil (Table 4). This might be due to more available potassium and organic carbon found in the soil as compared to initial value. Further, scheduling of irrigation at 5 DADPW exhibited higher uptake of nitrogen, phosphorus and potassium by grain and stover of lentil but remained at par with 8 DADPW. The nutrient left after harvesting of rice under scheduling of irrigation at 2 DADPW was less as compared to scheduling of irrigation at 5 DADPW and 8 DADPW. Application of RDN+BGA to rice also significantly increased the uptake of NPK by succeeding lentil. This might be due to significantly higher post harvest available NPK content in soil after rice harvest under the treatment. Similar results were reported by Singh *et al.* (2013) under rice-lentil system.

Soil fertility after lentil

Scheduling of irrigation and nitrogen management practices applied to rice remained statistically unaffected with respect to available nitrogen, phosphorus and potassium and organic carbon content in soil after harvest of succeeding lentil.

Relative economics

The gross and net returns were higher at 2 DADPW over 8 DADPW but statistically at par with 5 DADPW (Table 1). This higher gross and net returns could be attributed to higher grain and straw production under this treatment. Among nitrogen management practices higher gross returns, net returns and benefit: cost ratio were recorded with application of RDN along with BGA. Srivastava *et al*. (2014) found that the integration of RDF (150, 75, 75 kg NPK/ha) with vermicompost at 30 kg N/ha gave the maximum net returns by hybrid rice under SRI.

The results of the present field investigation revealed

Table 4. Residual effect of irrigation and nitrogen management practices applied to rice on yield attributes, yield, nutrient uptake by succeeding lentil and soil fertility after harvest of lentil (pooled data of 2 years)

Treatment	Yield attributes of succeeding lentil			Yield (t/ha) of succeeding lentil		Nutrient uptake (kg/ha)			Soil nutrient status (kg/ha) at lentil harvest			
	Pods/ plant	Grains/ pod	1,000-grain weight(g)	Grain	Stover	Nitrogen	Phosphorus	Potassium	N	P_2O_5	K_2O	Organic carbon (%)
Irrigation Scheduling												
Irrigation at 2 DADPW	93.3	1.93	23.6	1.14	1.48	59.8	7.37	40.4	189	19.4	204	0.43
Irrigation at 5 DADPW	102.1	1.93	24.3	1.34	1.93	77.0	9.15	50.7	188	20.9	206	0.46
Irrigation at 8 DADPW	91.8	1.94	23.2	1.27	1.83	74.0	8.31	47.5	198	21.8	185	0.42
SEm±	1.58	0.037	0.19	0.024	0.049	1.43	0.10	1.19	10.2	0.62	6.27	0.009
CD (P=0.05)	6.22	NS	0.78	0.094	0.195	4.19	0.40	3.48	NS	NS	NS	NS
Nitrogen management												
RDN (150 kg N/ha)	87.8	1.97	22.8	1.20	1.72	65.4	7.74	43.6	179	19.7	198	0.44
RDN + *S. aculeata* as co-culture	98.7	1.93	23.8	1.26	1.75	69.8	8.34	46.9	193	20.8	198	0.44
75% RDN + *S. aculeate* as co-culture	93.7	1.97	23.7	1.24	1.67	68.1	8.08	44.8	195	20.8	189	0.43
RDN + BGA (12 kg/ha)	105.8	1.86	24.5	1.34	1.92	80.4	9.28	49.6	196	21.5	196	0.42
75% RDN + BGA	92.8	1.94	23.7	1.22	1.68	67.6	7.94	46.0	195	20.6	210	0.46
SEm±	1.84	0.035	0.20	0.022	0.46	0.80	0.13	0.59	4.54	0.39	10.44	0.008
CD (P=0.05)	5.37	NS	0.60	0.065	0.135	3.16	0.39	2.32	NS	NS	NS	NS

DADPW, Days after disappearances of ponded water; NS, non-significant

that application of 5 cm irrigation at 2 days after disappearance of ponded water and recommended dose of nitrogen (150 kg N/ha) along with blue green algae (12 kg powder/ha) increased the growth, yield attributes, yield and quality of hybrid rice (*cv*. 'PHB 71') and was also found to have best residual effect on yield attributes and yield of lentil.

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Research Paper

Influence of long-term organic nutrient management on soil quality and crop productivity in rice (*Oryza sativa*)–potato (*Solanum tuberosum*)–okra (*Abelmoschus esculentus*) cropping system under irrigated condition

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ABSTRACT

A long-term field experiment was conducted during 2006–07 to 2014–15 on organic nutrient management in rice (*Oryza sativa* L.)–potato (*Solanum tuberosum* L.)–okra (*Abelmoschus esculentus* L.) cropping system under irrigated conditions in the coastal alluvial sandy loam soil having *p*H 5.8 and organic carbon 0.62% at Bhubaneswar, Odisha. Eight treatments comprising of five organic, two integrated and one inorganic of nutrient management were tested with three replications in randomized block design. Organic sources of nutrient supply reduced the system yield by 7.6 to 9.7% over the inorganic source in the first year. However, the mean system yield of 'conversion period' (first three cropping system cycles) with organic nutrient management comprising of supply of one-third N each through farm yard manure (FYM), green manuring of *dhaincha* (*Sesbania cannabina*) or vermicompost and neem (*Azadirachta indica*) oilcake + *Azospirillum* or *Azotobacter* + phosphate solubilizing bacteria (PSB) was on par with inorganic approach. The mean system yield from fourth to ninth cropping system cycles ('after conversion period') with organic sources of nutrient supply, i.e. FYM + green manuring or vermicompost + neem oilcake + *Azospirillum* or *Azotobacter* + PSB was significantly higher (11.1%) than that of with inorganic source of nutrient supply *i.e.*, 100% NPK + $ZnSO_4$ @ 25 kg/ha to rice and 100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha to both potato and okra. The organic nutrient management package increased the soil organic carbon and available N, P and K at the end of ninth cropping system cycle over the initial and the build-up was maximum in the soil applied with one third N each through FYM, *dhaincha*/vermicompost and neem oilcake + *Azospirillum*/*Azotobacter* + PSB. The microbial population in terms of colony forming units increased in a higher rate in soils with organic nutrient supply system (bacteria 36.5 to 39.4%, fungi 33.0 to 38.2% and actinomycetes 36.0 to 37.3%) compared to the inorganic source of nutrient supply system (bacteria 5.6%, fungi 10.3% and actinomycetes 12.7%) after ninth cropping system cycle over initial status. The microbial biomass carbon of the soils with organic sources of nutrient supply was enhanced considerably (57.7% to 66.8%) over the initial level (98.7 to 107.4 μg C/g). Application of one-third N each through FYM, green manuring of *dhaincha* and neem oilcake + *Azospirillum* + PSB to rice followed by similar combination of FYM, vermicompost, neem oilcake + *Azotobacter* + PSB to both potato and okra was the best organic nutrient management practice for rice–potato–okra cropping system for improving soil health and productivity. However, this system can be profitable under organic farming only when on-farm generated organic manures are used.

Key words : Cropping system, Microbial biomass carbon, Nutrient uptake, Organic sources of nutrient supply, Soil microbial population, System yield

Rice based cropping systems form an integral part of agriculture in coastal Odisha. Though rice–groundnut is the predominant cropping system under irrigated ecosystem, farmers grow various field crops and short duration vegetables in small patches after rice with limited irrigations. Inclusion of vegetables in the rice-based cropping systems has been suggested for higher productivity and profitability (Kachroo *et al.*, 2014). Rice–potato–okra has been identified as one of the most productive and profitable cropping systems for coastal Odisha under irrigated conditions (OUAT, 2005). Promotion of organic farming is being viewed as farming practice with distinct advan-

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tages of sustainability of crop production. Organic farming also permits the recycling of organic wastes, disposal of which could be difficult and expensive (Manjunatha *et al*., 2012). Though positive role of organic residues, including green manures on soils and crops has been well documented (Rupela *et al*., 2006), information on their use in location specific cropping systems is lacking to understand the role of organic farming on soil health, crop productivity and sustainability. It is a common belief that yields of several crops are reduced during the initial years under organic farming, but many experiments were conducted only for three or four years consecutively and often only with a specific crop; rather than in a well defined high productive cropping system (Rao *et al*., 2014). In view of this an experiment was conducted at Bhubaneswar on rice–potato–okra cropping system with various organic and integrated nutrient management practices consecutively for nine years to find out the impact of various nutrient management practices on system productivity and soil properties.

MATERIALS AND METHODS

A long-term field experiment was conducted from 2006–07 to 2014–15 (nine years) on organic nutrient management in rice–potato–okra system under irrigated condition at Central Research Station, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha situated at 20° 26' N, 85° 81' E, 34 m above mean sea-level having hot humid climate with mean annual rainfall of 1482 mm. The annual mean maximum and minimum temperature were 31.5 and 22.3°C respectively. The soil of the experimental site was sandy loam (68% sand, 15% silt and 17% clay) having *p*H 5.8, organic carbon 0.62%, available N, P and K of 262.2, 19.1 and 170.8 kg/ha, respectively. The experiment was laid out in randomized block design with eight treatments (detailed in Table 1) replicated thrice.

The organic sources of nutrients used in the experiment were farmyard manure (FYM) (N, P, K 0.56, 0.28, 0.64%), vermicompost (N, P, K 1.62, 1.00, 1.54%), neem (*Azadirachta indica*) oilcake (N, P, K 4.48, 0.92, 1.32%)

Table 1. Details of organic nutrient management treatments in rice–potato–okra system

Treatment	Rainy season (rice)	Winter season (potato)	Summer season (okra)
T_1	50% RDF + 50% N as FYM (8 t/ha)	50% RDF + 50% N as FYM (15 t/ha)	50% RDF + 50% N as FYM (8 t/ha)
T_2	Different organic sources equivalent to one-third of recommended N (one-third N as FYM @ 5.5 t/ha, one-third N as green manuring of *dhaincha* (*Sesbania cannabina*), one-third N as neem (*Azadirachta indica*) oilcake)	Different organic sources equivalent to one-third of recommended N (one-third N as FYM @ 10 t/ha, one-third N as vermicompost, one-third N as neem oilcake)	Different organic sources equivalent to one-third of recommended N (one-third N as FYM @ 5.5 t/ha t/ha, one-third N as vermicompost, one-third N as neem oilcake)
T_3	Same as T_2	Same as T_2	T_2 + cowpea (*Vigna sinensis*) as a trap crop (1: 1) in additive series
T_4	T_2 + manual weed control + biopesticides (neem oil and pot manure*)	T_2 + manual weed control + biopesticides (neem oil and pot manure*)	T_2 + manual weed control + biopesticides (neem oil and pot manure*)
T_5	50% N as FYM + *Azospirillum* + RP + PSB (soil application)	50% N as FYM + *Azotobacter* + RP + PSB (soil application)	50% N as FYM + *Azotobacter* + RP + PSB (soil application)
T_6	T_2 + *Azospirillum* + PSB	T_2 + *Azotobacter* + PSB	T_2 + *Azotobacter* + PSB
T_7	100% NPK + 25 kg $ZnSO_4$ /ha	100% NPK + gypsum @ 110 kg + borax @ 10 kg + ammonium molybdate @ 0.8 kg/ha	100% NPK + gypsum @110kg + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha
T_8	T_7 + crop residue recycling**	T_7 + crop residue recycling**	T_7 + crop residue recycling**

RDF, recommended dose of fertilizers; FYM, farmyard manure; RP, rock phosphate; PSB, phosphate solubulizing bacteria; RDF (N-P-K in kg/ha): rice, 80–17.5 –33; potato, 150 –33–82.5; okra, 80 –17.5–33

*Pot manure or *handi khata* as locally called is prepared with karanja (*Pongamia pinnata*) leaves 0.5 kg, bel (*Aegle marmelos*) leaves 0.5 kg, arakha (*Calotropis* sp.) leaves 1 kg, neem (*Azadirachta indica*) leaves 1 kg, jaggery 0.2 kg, cow urine 2 liters and fresh cow dung 1 kg. All the materials and chopped leaves are kept inside an earthen pot and thoroughly mixed. Then the mouth of pot is covered and kept under shade. After a week, another 2 liters of cow urine is poured inside the pot. In 3 weeks, the manure is ready to use in crop fields. The liquid extract is diluted with water and sprayed on the plants; **after harvest the total quantity of crop residue were incorporated in the soil of the respective plots. On an average, rice straw 2.8 t, potato plant residue 3.6 t and okra plant residue 4.1 t/ha were available for recycling. Average nutrient content, rice straw N 0.42, P 0.25, K 1.35%, potato plant residue N 3.29, P 0.21, K 3.29% and okra plant residue N 1.91, P 0.39, K 2.54%

and green manuring of *dhaincha* (*Sesbania cannabina*) (N, P, K 2.82, 0.58%, 1.18%) and biofertilizers such as *Azotobacter*, *Azospirillum* and phosphate-solubilizing bacteria (PSB). In case of organic nutrient management, all manures were applied before final land preparation for transplanting of rice and at planting of potato and okra in furrows. The inorganic sources used were urea, single super phosphate and muriate of potash to supply N, P and K, respectively, zinc sulphate (21% Zn) for zinc, gypsum (21% Ca, 17% S) for calcium and sulphur, borax (10% B) for boron and ammonium molybdate (52% Mo) for molybdenum. In case of inorganic nutrient management, full quantity of P and K were applied as basal in all the crops and N was applied in split doses. In rice, 25% of N was applied as basal, 50% top dressed at tillering and rest 25% was applied at panicle initiation stage. In potato and okra 50% of N was applied as basal and rest N was applied in 2 equal splits at 25 and 45 days after planting. The test varieties for rice, potato and okra were 'Lalat', 'Kufri Jyoti' and 'Utkal Gourav', respectively. Standard agronomic management practices were followed for all crops. Crop yields were recorded at the end of each season and rice equivalent yield (REY) was computed at the end of each cropping cycle. System yield was obtained by adding REY of component crops and prices were used from ninth cycle for all the years. The first three cropping cycles were taken as 'conversion period' and the next six years' yields were taken as 'after conversion period' and the mean yields of 'conversion period' and 'after conversion period' were calculated. Overall mean yield was also calculated taking yields of all the nine years. The treatment with recommended dose of inorganic nutrients (100% NPK + $ZnSO_4$ @ 25 kg/ha to rice and 100% NPK + gypsum @ 110 kg + borax @ 10 kg + ammonium molybdate @ 0.8 kg/ha to both potato and okra) was taken as reference treatment and increase or decrease in system yield was calculated for the 'conversion period', 'after conversion period' and 'overall mean' over this treatment for comparison. Economic efficiency in terms of ₹/ha/day was worked out by net returns of the system divided by 365 days. For economic analysis (cost of cultivation and gross returns) cost of inputs and price of outputs were used from ninth cycle (2014–15) for all the years. Statistical analyses were carried out using standard methodology of randomized block design.

Soil samples were drawn at initial and at the end of each cropping cycle (up to ninth cropping cycle) from a depth of 0–15 cm from each treatment and soil organic carbon (SOC), N, P and K content were analysed using standard procedures (Jackson, 1973). A portion of fresh soil samples were passed through a 2-mm sieve and stored at 4°C for determination of microbial population (Dhingra and Sinclair, 1993) and soil microbial biomass carbon (MBC) (Vance *et al*., 1987). The MBC was estimated from the equation, MBC = 2.64 Ec, where Ec is the difference between organic carbon extracted from the K_2SO_4 extract of fumigated and non-fumigated soils.

RESULTS AND DISCUSSION

Yield

The individual crop yields and system yield in terms of rice-equivalent yield (REY) during the first cropping system cycle were the highest with the recommended dose of fertilizers (RDF) including secondary and micro nutrients (zinc sulphate to rice, gypsum, borax and sodium molybdate to potato and okra), which was closely followed by 50% of the RDF + 50% of N as FYM. The treatment with 50% of N as FYM + *Azospirillum* + RP + PSB recorded the the lowest yield during the first year and the reduction in system yield was 13.5% compared to inorganic sources (Table 2). Organic treatments reduced the system yield by 7.6–9.7%. The lower yield in organic treatment might be related to the continuing phase of transition from conventional to organic agriculture (Surekha and Satishkumar, 2014). After four years of experiments in rice, Rao *et al*., (2014) also concluded that though organic farming had an edge over inorganic farming to sustain the soil health and grain quality, it was less productive as compared to inorganic or integrated nutrient management practices.

Reduction in yields due to replacement of chemical fertilizers with organics decreased during the 'conversion period'. After first three cropping system cycles, the mean system yield with organic treatment FYM + green manuring or vermicompost + neem oil cake + *Azospirillum* or *Azotobacter* + PSB was almost the same as that of inorganic treatment. But application of 50% RDF + 50% of N as FYM increased the mean system yield marginally by 1.7% over the inorganic treatment; however, the other organic treatments without biofertlizers were low yielders than the inorganic treatment.

After conversion period (fourth to ninth cropping system cycles), all the organic nutrient management practices except 50% N as FYM + *Azospirillum* + RP + PSB increased the individual mean crop yields and mean system yields over the inorganic treatment (Table 2). The increase in mean system yield was the highest (9.8%) in the treatment with FYM + green manuring or vermicompost + neem cake + *Azospirillum* or *Azotobacter* + PSB. The trend was also same for the overall mean yield (first to ninth cropping system cycle). Presence of organic matter improved the physico-chemical properties of soil (Table 5) which might have resulted in increased productivity by increasing availability of plant nutrients. Further, organic matter also maintained regular supply of macro and micro-

Table 2. Effect of nutrient management packages on crop yield (t/ha) in rice–potato–okra cropping system

Treatment	Initial yield level (first year)				Mean yield of 'conversion period' (first–third cropping system cycles)				Mean yield of 'after conversion period' (fourth–ninth cropping system cycles)				Overall mean yield (first–ninth cropping system cycles)			
	Kharif	*Rabi*	Summer	REY	*Kharif*	*Rabi*	Summer	REY	*Kharif*	*Rabi*	Summer	REY	*Kharif*	*Rabi*	Summer	REY
T_1	4.30	7.38	4.60	13.78	4.75	8.83	4.66	15.16	4.25	13.48	7.13	20.16	4.41	11.93	6.31	18.49
T_2	3.98	6.62	4.10	12.46	4.82	7.96	4.53	14.57	4.12	13.56	6.82	19.73	4.36	11.70	6.05	18.01
T_3	3.92	6.60	4.20	12.50	4.93	7.65	4.67	14.65	4.31	13.43	6.85	19.87	4.51	11.51	6.12	18.13
T_4	4.00	6.78	4.12	12.60	4.91	8.10	4.47	14.68	4.10	13.53	6.78	19.65	4.37	11.72	6.01	17.99
T_5	3.64	6.49	4.00	11.93	4.60	7.26	4.35	13.74	3.85	12.49	6.54	18.52	4.10	10.75	5.81	16.93
T_6	4.05	7.00	4.10	12.75	4.80	8.72	4.46	14.92	4.53	14.15	7.70	21.47	4.62	12.34	6.62	19.28
T_7	4.28	7.40	4.62	13.80	4.74	8.51	4.61	14.91	3.90	13.26	6.81	19.32	4.18	11.68	6.08	17.85
T_8	4.00	7.25	4.46	13.25	4.67	8.51	4.51	14.72	3.92	13.30	6.78	19.33	4.17	11.71	6.02	17.79
SEm±	0.08	0.14	0.09	0.27	0.04	0.21	0.04	0.18	0.08	0.18	0.11	0.32	0.06	0.18	0.07	0.24
CD (P=0.05)	0.23	0.41	0.26	0.80	0.12	0.62	0.11	0.54	0.22	0.53	0.32	0.94	0.17	0.53	0.21	0.71

REY, rice equivalent yield; *Kharif*, rainy seson; *Rabi*, winter season; Details of treatments is given in Table 1.

nutrients in soil resulting in higher yields (Sharma and Subehia, 2014).

Economics

Application of one-third N each through FYM, green manuring of *dhaincha* and neem oilcake + *Azospirillum* + PSB to rice followed by FYM + vermicompost + neem oilcake + *Azotobacter* + PSB to both potato and okra recorded the highest mean (first to ninth cropping system cycles) gross returns ₹2,65,919/ha (Table 3). However, the highest system net returns ₹1,03,025 with the highest benefit: cost ratio 1.72 and economic efficiency ₹282/ha/day was realized with application of 100% NPK + $ZnSO_4$ @ 25 kg/ha to rice and 100% NPK + gypsum @ 110 kg/ha + borax @ 10 kg/ha + ammonium molybdate @ 0.8 kg/ha to potato and okra. This was due to higher cost of cultivation in case of organic treatment which also include transportation cost of huge quantity of organic manure. Organic treatment incurred ₹42,686/ha more cost than the inorganic treatment, which restricted the net returns/ha. The same trend was also maintained till the ninth cropping system cycle.

Nutrient uptake

The pattern of total nutrient uptake (Table 4) followed almost the same trend as that of the system yield in the first year as well as after conversion period. The maximum uptake of 284.4 kg N, 53.3 kg P and 368.9 kg K/ha was obtained in the inorganic treatment in the first year and 360.4 kg N, 62.6 kg P and 438.3 kg K/ha in the organic treatment involving biofertilizers, when averaged over the nine cropping system cycles. On an average, the organic treatment removed 30.9, 7.3 and 33.4 kg more N, P and K/ha, respectively than the inorganic treatment. The same treatment also recorded the highest increase in system nutrient uptake (32.9, 24.7 and 26.5% higher for N, P and K, respectively) at end of the ninth cropping system cycle over first cropping system cycle. Higher availability of nutrients under organic sources might have improved the physiological and metabolic activities in crops leading to higher biomass production and higher uptake (Shalini Pilai *et al*., 2007).

Soil organic carbon

The initial status of soil organic carbon (SOC) of the experimental site was medium (0.62%). The final status of the soil organic carbon after ninth cropping system cycle was in the range 0.61 to 0.88% (Table 5). The organic carbon contents of soil in all the treatments increased by 19.4% to 41.9% over the initial at the end of ninth cropping system cycle except the treatment applied with 100% RDF through inorganic fertilizers. The treatments with organic nutrient management package registered significant increase in SOC (24.4 to 41.9%) and the build-up was maximum in the soil applied with one-third N each through FYM, green manuring and neem oilcake + *Azospirillum* + PSB to rice followed by similar combination with FYM, vermicompost, neem oilcake + *Azotobacter* + PSB to both potato and okra. Addition of organic nutrient sources might have created environment conducive for formation of humic acid, stimulated the activity of soil microorganisms resulting in an increase in organic carbon contents (Prasad *et al*., 2010). The higher build-up of SOC in the organic sources applied plots may be attributed to slower break down rate (less and constant mineralization rate) and increased above and below ground organic residues due to enhanced crop growth (Moharana *et al*., 2012).

Available N, P and K

The initial status of available N, P and K of the soil were 262.2, 19.1 and 170.8 kg/ha, respectively (Table 5). The increase in available N, P and K in the soils under organic inputs was to the tune of 18.9 to 35.2%, 1.6 to 8.4% and 1.9 to 14.9%, respectively over the initial contents after ninth cropping system cycle. The available N, P and K content in soils under inorganic inputs decreased by 7.6, 22.5 and 17.0%, respectively over the initial contents. Increase in available nitrogen with organics was due to increase in SOC and slow release of N from organics (Yadav *et al*., 2000). The lower nutrient content in soils under inorganic treatment was a result of mining of available N with continuous cropping over a long period of time. Build-up of available P in soils under organics might be due to the release of organic acids during decomposition, which in turn helped in releasing phosphorus through solubilizing action of native phosphorus in the soil (Urkurkar *et al*., 2010).

Soil microbial population

The population of bacteria, fungi and actinomycetes in the soils receiving nutrients from various organic sources

Table 3. Economics of rice–potato–okra cropping system

Treatment	Ninth cropping system cycle					Mean of first to ninth cropping system cycles				
	Gross returns (×10³ ₹/ha)	Total cost (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Economic efficiency (₹/ha/day)	Benefit: cost ratio	Gross returns (×10³ ₹/ha)	Total cost (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Economic efficiency (₹/ha/day)	Benefit: cost ratio
T_1	255.9	155.4	100.5	275	1.65	254.9	155.4	99.5	273	1.64
T_2	244.7	181.9	62.8	172	1.35	248.5	181.9	66.6	183	1.37
T_3	243.2	179.9	63.3	173	1.35	250.3	179.9	70.4	193	1.39
T_4	238.6	184.9	53.7	147	1.29	248.3	184.9	63.4	174	1.34
T_5	227.6	146.0	81.6	223	1.56	233.6	146.0	87.5	240	1.60
T_6	274.3	185.8	88.5	243	1.48	265.9	185.8	80.2	220	1.43
T_7	245.5	143.1	102.4	281	1.72	246.1	143.1	103.0	282	1.72
T_8	232.0	147.6	84.4	231	1.57	245.2	147.6	97.6	267	1.66

Sale Price (₹/t); rice grain, 13500; rice straw, 1000; potato, 800; okra, 15,000; Details of treatments is given in Table 1.

Table 4. System nutrient uptake (kg/ha) under various nutrient management practices in rice–potato–okra cropping system

Treatment	System nutrient uptake by first cropping system cycle			System nutrient uptake by ninth cropping system cycle			Mean system nutrient uptake (first to ninth cropping system cycles)		
	N	P	K	N	P	K	N	P	K
T_1	279.3	51.2	360.4	328.0	56.7	406.7	333.6	55.7	409.3
T_2	253.4	45.1	330.4	318.0	52.8	397.2	319.9	51.4	392.6
T_3	258.7	49.1	337.9	320.8	56.0	398.2	327.8	56.0	401.5
T_4	263.2	49.7	338.3	329.7	57.3	403.1	329.1	55.7	399.3
T_5	245.5	43.5	323.6	297.4	49.9	371.5	307.8	50.0	382.7
T_6	271.3	53.0	350.2	358.6	66.1	443.0	360.4	62.6	438.3
T_7	284.4	53.3	368.9	323.2	56.8	404.0	329.5	55.3	404.9
T_8	273.4	50.0	357.3	326.7	55.6	407.7	322.8	52.8	398.6
SEm±	5.03	1.32	5.96	6.23	2.02	4.88	5.68	1.45	6.13
CD (P=0.05)	15.05	3.91	17.78	18.67	6.05	14.53	16.84	4.31	18.32

Details of treatments is given in Table 1.

increased by 36.5 to 39.4%, 33.0 to 38.2% and 36.0 to 37.3%, respectively after ninth cropping system cycle over the initial status as against the respective increases of 5.6, 10.3 and 12.7% in the soils receiving nutrients through chemical fertilizers (Table 6). Increased organic carbon content of the soil due to application of various organic nutrients over the years served as a source of energy for biological activity, thereby enhancing the density of microbes (Moharana *et al*., 2012). Further, most of the soil microorganisms are chemo-autotrophs, which require organic source of carbon as food and oxidation of organic substances provides energy which might be the reason in improving microbial population in soils applied with organics (Ingle *et al*., 2014).

Microbial biomass carbon

The microbial biomass carbon in the soils under organic nutrient practices was enhanced considerably (57.7 to 66.8%) over the initial (97.6 to 108.6 μg C/g) (Table 6). The soils with inorganic fertilization on the other hand registered the minimum gain (8.7%) in soil microbial biomass carbon over the initial (83.1 μg C/g). The higher MBC in soils receiving organics is related to higher microbial population due to balanced supply of nutrients and carbon (Basak *et al*., 2012). The good quality organic inputs in the soil have a potential to augment soil enzymatic activities and improve the microbial biomass carbon and organic carbon (Nath *et al*., 2012).

Application of one-third N each through farmyard manure, green manuring of *Sesbania cannabina* and neem (*Azadirachta indica*) oilcake + *Azospirillum* + phosphate solubulizing bacteria to rice followed by similar combination of farmyard manure, vermicompost, neem oilcake + *Azotobacter* + phosphate solubulizing bacteria to both potato and okra was found to be the best organic nutrient management practice for rice–potato–okra cropping sys-

Table 5. Changes in soil physico-chemical properties under organic nutrient management practices in rice–potato–okra cropping system (after ninth cropping system cycle)

Treatment	Bulk density (g/cm³)	Water holding capacity (%)	Soil organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
T_1	1.46	44.6	0.74	296.6	20.2	166.6
T_2	1.41	46.3	0.86	328.2	20.6	189.2
T_3	1.40	46.8	0.88	354.6	19.7	182.2
T_4	1.43	45.9	0.83	321.0	19.4	179.4
T_5	1.44	44.8	0.79	311.7	19.7	174.0
T_6	1.40	46.9	0.88	340.4	20.7	196.2
T_7	1.47	43.6	0.61	242.4	14.8	141.8
T_8	1.46	44.9	0.75	288.2	16.8	174.6
Initial	1.48	43.0	0.62	262.2	19.1	172.2

Details of treatments is given in Table 1

Table 6. Changes in microbial attributes under organic nutrient management practices in rice–potato–okra system

Treatment	Initial				After ninth cropping system cycle			
	Microbial population in colony forming units/g dry soil			Microbial biomass carbon in soil (μg C/g)	Microbial population in colony forming units/g dry soil			Microbial biomass carbon in soil (μg C/g)
	Bacteria (×10⁷)	Fungi (×10⁴)	Actinomycetes (×10⁶)		Bacteria (×10⁷)	Fungi (×10⁴)	Actinomycetes (×10⁶)	
T_1	18.4	11.4	10.2	94.3	22.3	13.2	12.6	124.1
T_2	19.7	10.9	11.4	102.4	26.9	14.5	15.5	167.3
T_3	19.2	10.7	11.7	108.6	26.4	14.3	15.8	171.3
T_4	18.7	11.2	10.6	98.7	25.8	15.1	14.5	161.7
T_5	18.1	11.6	10.9	97.6	25.1	15.8	14.8	158.3
T_6	18.8	11.0	11.0	107.4	26.2	15.2	15.1	179.1
T_7	19.8	10.7	10.2	83.1	20.9	11.8	11.5	90.3
T_8	19.6	10.9	10.4	94.6	23.4	12.9	12.5	120.3
SEm±					0.82	0.51	0.61	11.80
CD (P=0.05)					2.41	1.52	1.81	34.36

Details of treatments is given in Table 1 tem for improving soil health and productivity under irrigated condition of coastal zone of Odisha. The same system can be profitable under organic farming only when on-farm generated organic manures are used.

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Research Paper

Influence of cereal–legume combination and sources of nutrients on productivity and profitability under organic production system

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) and winter (*rabi*) seasons of 2012–13 and 2013–14 on sandy loam soil at experimental farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Research Sub-Station, Akrot, District Una, Himachal Pradesh to study the production potential of cereal–legume based cropping system and nutrient sources on productivity under organic conditions. The cropping sequence maize (*Zea mays* L.) + blackgram [*Vigna mungo* (L.) Hepper]–chickpea (*Cicer arietinum* L.) resulted in higher total maize-equivalent yield and benefit: cost ratio. Maize-equivalent yield of this system was statistically at par with maize + blackgram – wheat (*Triticum aestivum* (L.) emend. Fiori & Paol.] + chickpea cropping sequence. Vermicompost (VC) @ 10 t/ha recorded higher maize-equivalent yield of cropping system over VC @ 5 t/ha + liquid manure (LM) vermiwash and was statistically at par with VC @ 5 t/ha + LM + biofertilizers and VC @ 5 t/ha + biofertilizers. Application of VC @ 5 t/ha + LM + biofertilizers recorded the highest benefit: cost ratio (1.44). Higher values of available nitrogen (289.8 kg/ha), phosphorus (23.1 kg/ha) and potassium (176.2 kg/ha) in soil were recorded in VC @ 5 t/ha + LM + biofertilizers than the other nutrient sources.

Key words: Blackgram, Chickpea, Cropping system, Maize, Nutrient sources, Organic, Wheat

Out of 30 major cropping systems identified in India, maize-based cropping system is predominant in rainfed hilly areas, of which maize–wheat is the dominant cropping system. The contribution of this cropping system to total food grain production of the country is considerably large (GoI, 2016). Cropping systems involving legumes and cereals together in the same field for multiple food production has been and is still a popular practice among small scale farmers (Fujita *et al*., 1990). Legumes, with their adaptability to different cropping pattern and their ability to fix nitrogen, may offer opportunities to sustain increased productivity (Jeyabal and Kuppuswamy, 2001). Therefore, productivity is potentially enhanced by the inclusion of a legume in a cropping system (Maingi *et al*., 2001). In addition, legume intercrops are included in cropping systems because they reduce soil erosion and suppress weeds. The success of any cropping system depends upon the appropriate management of resources including balanced use of manures.

Use of organic manures may prove a viable option for sustaining the productivity of legumes and adds life to the soil. The application of appropriate amounts of organic manure is the key for success of organic farming. The role of biofertilizers for enhancing the productivity of soil by fixing atmospheric nitrogen, or by solubilising soil phosphorus, or by stimulating plant growth through synthesis of growth promoting substances has special importance in organic farming. Under organic conditions, application of liquid organic manures is essential to maintain the activity of micro-organisms and other life forms in the soil. A healthy soil can be maintained by continuous incorporation of crop residues, animal dung, urine based manures (FYM, vermicompost etc.), biofertilizers, special liquid manures (viz. vermiwash, compost biosol, matka khad *etc*.) as well as inclusion of legume component in cropping system as intercrop or as green manure. Therefore, an experiment was undertaken to find out the effect of cereal + legume cropping systems and nutrient sources on productivity and economics under organic conditions.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) and winter (*rabi*) seasons of 2012–13 and 2013–14 at ex-

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perimental farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Research Sub-Station, Akrot, District Una, Himachal Pradesh ($30^{o}6'$ to $32^{o}5'$ N, and $75^{o}5'$ to $77^{o}5'$ E, about 425 m above mean sea-level). The soil of the experimental field was sandy loam in texture, having *p*H 6.5, available N 280 kg/ha, available P_2O_5 18.5 kg/ha and available K_2O 170 kg/ha. The experiment was laid out in factorial randomized block design with 3 replications. There were 16 treatments comprising of combinations of 4 nutrient sources, viz. vermicompost (VC) @ 10 t/ha, VC @ 5 t/ha + liquid manure (LM) vermiwash, VC @ 5 t/ha + biofertilizers and VC @ 5 t/ha + LM + biofertilizers with 4 cropping sequences, viz. maize + blackgram–wheat + chickpea, maize + blackgram–chickpea, blackgram–wheat + chickpea and blackgram–chickpea. Maize 'Early composite', wheat 'HPW 155', black gram 'UG 218' and chickpea 'Himachal Chana 1' were sown on 10 and 12 July during first and second year of experimentation with recommended package of practices. For comparison between crop sequences, the yield of all crops was converted into maize-equivalent yield. After harvest, grain yield and straw yield/ha were recorded. Soil samples were collected during both the years after harvesting. The available N content of soil was analysed by Micro-kjeldahl's method, P by Olsen's method and K by flame photometer method. Benefit: cost ratio was worked out by dividing gross returns (₹/ha) with cost of cultivation (₹/ha). Quality parameters of wheat, blackgram and chickpea grown organically and inorganically were recorded by following standard procedure. There was no severe attack of any insect-pests and disease; however general schedule of bioformulations was used to manage insect-pests and diseases (Table 1). The different bioformulations include *Lantana* extract which is a solution containing 4 kg fresh *Lantana* leaves mixed in 12 litres of cow urine in equal amount of water kept for 15 days fermentation. *Tamra lassi* is a solution containing 5 litres fermented butter milk in copper vessel for 15–20 days with proper stirring. *Panchgavya* is prepared by mixing 2 kg fresh cow dung, 3 litres cow urine, 2 litres milk, 2 litres curd and 1 kg desi ghee and fermented for 10–15 days. These bioformulations were sprayed at 15 days interval starting after one month crop. Since data followed the homogeneity test, pooling was done over the seasons and mean data were presented. For calculating the maize-equivalent yield the price of different crops taken were: maize @ ₹10/kg, wheat @ ₹13/kg, blackgram @ ₹60/kg and chickpea @ ₹40/kg.

Table 1. Bioformulations for insect-pests and disease management in rainy (*kharif*) and winter (*rabi*) season

Bioformulations	Quantity	No. of spray
Kharif		
Lantana extract	10%	3
Neem oil	3 ml/lt	2
Tamra lassi	10%	2
Rabi		
Panchgavya	10%	2
Neem oil	3 ml/lt	1
Nucleo polyhedrosis virus (NPV) hali	3 ml/lt	2
Bacillus thuringiensis (Bt)	2.5 g/lt	1
Tamra lassi	10%	2

RESULTS AND DISCUSSION

Productivity

Maize-equivalent yield reflects the total productivity of the cropping systems (Table 2). In maize + blackgram–wheat + chickpea and maize + blackgram–chickpea sequence higher maize-equivalent yield was recorded with application of vermicompost (VC) @ 10 t/ha which was statistically at par with VC @ 5 t/ha + LM + biofertilizers in maize + blackgram–chickpea. It might be due to the fact that vermicompost improved the physical and biological properties of soil including supply of almost all the essential plant nutrients and development of the plant. Application of VC @ 5 t/ha + LM + biofertilizers in maize + black gram – chickpea sequence obtained higher maize-equivalent yield and was statistically at par with VC @ 5 t/ha + biofertilizers and VC @ 10 t/ha. In blackgram–chickpea sequence, application of VC @ 5 t/ha + LM + biofertilizers resulted in significantly higher maize-equivalent yield over other nutrient sources and was statistically at par with VC @ 5 t/ha + LM vermiwash. The crop sequence involving legumes played an important role in restoring the soil fertility in terms of N and other biological parameters due to atmospheric N-fixation through symbiotic process, which in turn improved the yield of succeeding crop compared with that of the cereal crop sequence. Similar findings were also observed by Ramesh and Reddy (2004).

Among the cropping systems, maize-equivalent yield was recorded significantly higher in maize + blackgram–chickpea as compared to the other cropping sequences. However, it was statistically at par with maize + blackgram–wheat + chickpea cropping system. Singh and Sharma (2002) also reported beneficial effect of legumes on the succeeding crops. The improvement in productivity in these crops can be ascribed to fixation of atmospheric nitrogen by legume crops, which might have improved the fertility status of soil. Inclusion of pulses also helped in achieving higher maize-equivalent yield than with sequences having cereal crops (Table 3).

Table 2. Effect of different cropping systems and nutrient sources on yield and maize-equivalent yield (pooled data of 2 years)

Cropping sequences and nutrient sources	Yield (t/ha)				Maize-equivalent yield of cropping system (t/ha)
	Kharif	*Kharif* intercrop	*Rabi*	*Rabi* intercrop	
Maize + blackgram–wheat + chickpea					
F_1, VC @ 10 t/ha	2.91	0.19	1.64	0.87	9.12
F_2, VC @ 5 t/ha + liquid manure (LM) vermiwash	2.59	0.15	1.27	0.61	7.06
F_3, VC @ 5 t/ha + biofertilizers	3.06	0.13	1.11	0.75	7.91
F_4, VC @ 5 t/ha + LM + biofertilizers	2.83	0.14	1.20	0.77	7.92
Maize + blackgram – chickpea					
F_1, VC @ 10 t/ha	3.10	0.15	1.37		9.14
F_2, VC @ 5 t/ha + liquid manure (LM) vermiwash	2.71	0.13	1.05		7.47
F_3, VC @ 5 t/ha + biofertilizers	2.74	0.13	1.05		7.42
F_4, VC @ 5 t/ha + LM + biofertilizers	3.10	0.14	1.24		8.60
Blackgram – wheat + chickpea					
F_1, VC @ 10 t/ha	0.52		1.80	0.57	6.53
F_2, VC @ 5 t/ha + liquid manure (LM) vermiwash	0.51		1.61	0.59	6.35
F_3, VC @ 5 t/ha + Biofertilizers	0.45		1.88	0.67	6.74
F_4, VC @ 5 t/ha + LM + Biofertilizers	0.41		2.07	0.72	6.99
Blackgram–chickpea					
F1, VC @ 10 t/ha	0.45		0.95		5.59
F2, VC @ 5 t/ha + liquid manure (LM) vermiwash	0.48		0.98		5.84
F3, VC @ 5 t/ha + biofertilizers	0.48		0.98		5.82
F4, VC @ 5 t/ha + LM + biofertilizers	0.51		1.09		6.40
SEm±					0.19
CD (P=0.05)					0.56

Economics

The higher net returns and benefit: cost ratio were obtained under maize + blackgram–chickpea followed by maize + blackgram–wheat + chickpea among the different cropping system. Lowest benefit: cost ratio was recorded under blackgram–chickpea cropping sequence. Among the nutrient sources, it is inferred that the highest net returns and benefit: cost ratio were obtained with application of VC @ 5 t/ha + LM + biofertilizers as compared to other nutrient sources (Table 3).

Soil-nutrient status after harvesting

Soil *p*H remained unaffected with cropping sequences and nutrient sources (Table 3). There was significant im-

Table 3. Effect of different cropping systems and nutrient sources on total maize-equivalent yield and economics (pooled data of 2 years)

Treatment	Maize-equivalent yield of cropping system (t/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio	*p*H	Available nutrients (kg/ha)		
					N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Cropping sequences							
C_1, Maize + blackgram – wheat + chickpea	8.00	81.3	1.46	6.7	282.3	18.8	169.4
C_2, Maize + blackgram – chickpea	8.16	83.5	1.77	6.7	283.5	21.6	175.2
C_3, Blackgram – wheat + chickpea	6.65	59.2	1.12	6.6	287.0	22.1	177.4
C_4, Blackgram – chickpea	5.91	44.1	0.99	6.5	290.3	19.7	173.0
SEm±	0.22			0.1	2.9	0.6	1.9
CD (P=0.05)	0.66			NS	8.8	1.8	5.9
Nutrient sources							
F1, VC @ 10 t/ha	7.60	71.4	1.35	6.5	285.2	19.9	172.9
F2, VC @ 5 t/ha + liquid manure (LM) vermiwash	6.68	59.2	1.19	6.6	281.0	18.6	171.7
F3, VC @ 5 t/ha + biofertilizers	6.97	65.7	1.36	6.6	287.1	21.5	174.2
F4, VC @ 5 t/ha + LM + biofertilizers	7.48	71.8	1.44	6.8	289.8	22.2	176.2
SEm±	0.22			0.1	2.9	0.6	1.9
CD (P=0.05)	0.66			NS	8.8	1.8	5.9

Table 4. Quality parameters of organically and inorganically grown wheat, blackgram and chickpea

Quality parameters	Organic	Inorganic	Per cent difference
		Wheat	
Carbohydrates (%)	72.05	72.64	–0.81
Crude protein (%)	11.14	10.25	+8.68
Crude fat (%)	1.78	1.64	+8.54
Crude fiber (%)	1.05	1.25	–16.00
Vitamin C (mg/kg)	4.26	4.52	–5.75
Vitamin A	BDL (MDL 200 µg/100g)	BDL (MDL 200 µg/100g)	–
Vitamin B1	0.44 mg/100g	0.42 mg/100	–4.76
		Blackgram	
Carbohydrates (%)	64.02	67.18	–4.70
Crude protein (%)	18.88	15.65	+20.64
Crude fat (%)	1.90	2.77	–31.41
Crude fiber (%)	7.33	7.57	–3.17
Vitamin C (mg/kg)	4.13	3.24	+27.47
Vitamin A	BDL (MDL 200 µg/100g)	BDL (MDL 200 µg/100g)	-
Vitamin B1	0.09 mg/100g	0.06 mg/100	+50.00
		Chickpea	
Carbohydrates (%)	62.90	66.74	–5.75
Crude protein (%)	22.88	18.85	+21.38
Crude fat (%)	0.68	0.58	+17.24
Crude fiber (%)	3.45	2.58	+33.72
Vitamin C (mg/kg)	10.18	10.80	–5.74
Vitamin A	BDL (MDL 200 µg/100g)	BDL (MDL 200 µg/100g)	–
Vitamin B1	0.12 mg/100g	0.11 mg/100	+9.09

provement in N status in all cropping sequences and maximum value of N was recorded in blackgram–chickpea and was statistically at par with blackgram–wheat + chickpea, maize + blackgram–chickpea and maize + blackgram–wheat + chickpea. Nyoki and Ndakidemi (2016) reported that it might be due to ability of leguminous crop to form symbiotic relationship with rhizobium and fix atmospheric nitrogen. However, available P in soil was observed the highest in blackgram–wheat + chickpea which was statistically at par with maize + blackgram–chickpea. Available K in soil was obtained the highest in blackgram–wheat + chickpea and was statistically at par with maize + black gram–chickpea and black gram – chickpea. Among the nutrient sources, VC @ 5 t/ha + LM + biofertilizers significantly influenced the available NPK in soil over other treatments; however, it was at par with VC @ 5 t/ha + biofertilizers, VC @ 10 t/ha and VC @ 5 t/ha + LM in case of N and K (Table 3). Whereas, in case of P, it was at par with VC @ 5 t/ha + biofertilizers. The increase in available N in soil might be due to the fact that application of vermicompost have reduced the nitrogen losses, improved fertilizer-use efficiency and thus increased the availability of nitrogen. The addition of organic matter in soil might have decreased the phosphate fixation due to the formation of phosphohumic complexes, that easily assimilated by plants, which ultimately increased the available P in soil. The increase in available K in soil might be due to the fact that addition of organic matter in soil have increased the cation exchange capacity, reduced the leaching losses, which ultimately increased the availability of K in soil. Similar results were also reported by Seth *et al*., (2016).

Quality parameters

It is evident from Table 4 that crude protein, crude fat and vitamin B1 contents of organically grown wheat were slightly more in comparison to inorganically grown counterparts with the per cent difference of +8.68, +8.54 and +4.76 respectively. Irrespective of the growing conditions, i.e. organic and inorganic, vitamin A content was below detectable limits (BDL) [minimum detectable limits (MDL) was 200 µg/100 g]. In case of blackgram (Table 4), crude protein, vitamin C and vitamin B1 contents of organically grown blackgram samples were towards higher side in comparison to conventionally grown counterparts with per cent difference of +20.64, +27.47 and +50.00 respectively. On the contrary the values for all the other parameters under study had more values for inorganically grown blackgram samples with per cent difference of –4.70, –31.41 and 3.17 for carbohydrates, crude fat and crude fiber, respectively. Vitamin A content of organically as well as inorganically grown black gram was below detectable limits. In case of chickpea (Table 4), values for crude protein, crude fat, crude fiber and vitamin B1 contents in organically grown chickpea samples were comparatively towards higher side with per cent difference of +21.38, 17.24, +33.72 and +9.09 respectively. Vitamin A content of organically as well as inorganically grown blackgram was below detectable limits.

Based on the results of present study, it was concluded that application of VC @ 10 t/ha in maize + blackgram–chickpea recorded higher system productivity and maintained NPK level of soil in cereal–legume based cropping system in low hill region of Himachal Pradesh.

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Research Paper

Production potential and energy dynamics of efficient cropping systems under diverse nutrient management practices

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ABSTRACT

A field experiment was conducted to evaluate the production potential, their energetics and economics of efficient cropping systems under different nutrient management practices during 2011–12 and 2012–13. The treatments consisted of 3 cropping systems [groundnut (*Arachis hypogaea* L.)–onion (*Allium cepa* L.), groundnut–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] and groundnut–chickpea (*Cicer arietinum* L.)] with 4 nutrient management treatments, viz. recommended dose of fertilizer, fertilizer dose as per soil test, fertilizer dose as per soil test crop response (STCR) equations and control as main-plot treatments, whereas 3 fertilizer levels, viz. RDF, 75% RDF and 50% RDF as sub-plots treatments. Among the cropping systems, groundnut–onion cropping system recorded significantly maximum groundnut equivalent yield (7.82 t/ha), production efficiency (35.1 kg/ha/day) and economic efficiency (₹842.4/ha/day) than rest of the cropping systems. However, groundnut–chickpea (0.82 t/ha) recorded significantly higher protein than groundnut–wheat but at par with groundnut–onion, while carbohydrates (5.41 t/ha) and fats (0.81 t/ha) were registered higher with groundnut–onion cropping system. Application of fertilizer as per STCR equation to preceding groundnut registered significantly higher protein (0.95 t/ha), carbohydrate (4.20 t/ha) and fat (0.88 t/ha) than control treatments. Similarly, groundnut–onion cropping system obtained significantly maximum net monetary returns (₹188.1×10^3/ha) and benefit: cost ratio (2.98), but groundnut–chickpea cropping system registered significantly higher energy output-input ratio (9.54), energy balance/unit input (8.85) and energy intensiveness (2.59 MJ/₹) on pooled mean. At the end of the 2 years cropping cycles, groundnut–onion cropping system found to be most efficient and suitable for obtaining the maximum productivity and monetary returns with application of fertilizer as per STCR equation.

Key words : Cropping systems, Energetics, Economic efficiency, Economics, Nutrient management, Production efficiency

Indian agriculture is now facing many problems like raising or lowering of water table, nutrient imbalance, soil degradation, salinity, resurgence of pests and diseases, environmental pollution and decline in farm profit. The crop diversification may prove to be paramount importance in several farming situations to improve the productivity and profitability without deteriorating soil health for a sustainable agriculture (Jat *et al.,* 2011). It also affects the productivity and soil health (Singh *et al.,* 2010). Cropping systems with suitable legume, fodder, oilseed and vegetable may result in high crop productivity, energetics and economic returns. Groundnut is the premier oilseed crop of India, occupies an area of 6.7 million ha and contributes 7.3 million tonnes towards oilseed production (GoI, 2012). India stands first in area and second in production and fifth in productivity (995 kg/ha). The challenge of producing 58.56% million tonnes of oilseeds to meet the requirement of 1.13 billion Indian populations. A gap of about 33.82 million tonnes of oilseeds needs growth rate of 5.56%/annum in the production (Rathika *et al.,* 2009). Area under oilseeds is not likely to increase in the near future due to delay and uneven occurance of rainfall and increase soil hardness. Groundnut is an unpredictable legume, since its response to nutrient application is always not optimistic, excessive application of nitrogen often resulted in excessive vegetative growth, considering the availability of the major elements in the soil and quantum of losses due to leaching or fixation of the individual elements. The review is aimed to have better understanding of different cropping system with inclusion of legume and different nutrient management treatments like recom-

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mended dose of fertilizer, fertilizer as per soil test and application of fertilizer as per STCR equation (yield target), which can be helpful for increasing the production of rainy season (*kharif*) groundnut and their residual effects on succeeding crops. It also increases the production potential, economics, energetics and sustainability of cropping systems. Therefore, an investigation was undertaken to find out efficient cropping systems and their energetics under different nutrient management.

MATERIALS AND METHODS

A field experiment was conducted during 2011–12 to 2012–13 at Post-graduate Institute, Research Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri (19° 48' N and 74° 32' E and 495 meter above mean sea-level). The average maximum and minimum atmospheric temperatures were 32.4°C and 15.5°C respectively. The average relative humidity was 62% in morning and 42.5% in the evening. Rainfall received during 2011–12 and 2012–13 was 527.8 and 424.0 mm respectively. The soil of the experimental site is sandy clay loam in texture (clay- 44.45%, silt- 33.20% and sand- 21.42%) having *p*H 8.2 and electric conductivity (EC) 0.29 dS/m and organic carbon 0.54% in top of 15 cm soil. Soil was low in available nitrogen (172.1 kg/ha), medium in phosphorus (18.0 kg/ha) and high in available potassium 427.0 kg/ha), moderate in Fe (6.89 µg/g), Mn (9.51 µg/g), Zn (0.62 µg/g) and Cu (3.41 µg/g). The field capacity, bulk density and permanent wilting point of the surface (0–15 cm) soil were 32.2% on volume basis, 1.32 Mg/m^3 and 16.2% respectively.

The experiment was laid out in randomized block design during rainy (*kharif*) season with 9 replications and strip-plot design in winter (*rabi*) season with 3 replications. The treatment tested include 3 cropping systems, viz. groundnut–onion, groundnut–wheat and groundnut–chickpea with 4 nutrient management practices, viz. recommended dose of fertilizer, fertilizer dose as per soil test, fertilizer dose as per STCR equations (2.5 t/ha of yield target) and control as main-plot treatment, whereas 3 fertilizer levels, viz. RDF, 75% RDF and 50% RDF as subplots treatments. The yield target equation was used for rainy season (*kharif*) groundnut as prescribed by Ramamoorthy *et al.,* (1967). Targeted yield equations for FN (kg/ha) = 4.16 T – 0.37 SN; FP_2O_5 (kg/ha) = 4.96 T – 4.36 SP; FK_2O (kg/ha) = 3.14 T – 0.16 SK; Where, FN, FP_2O_5 and FK_2O = Fertilizer in kg/ha; 'T' = Target yield (q/ha), SN = Soil available nitrogen (kg/ha), SP = Soil available phosphorus (kg/ha), SK = Soil available potassium (kg/ha). Groundnut was sown in third week of June and harvested at second week of October. The winter crops, viz. onion, durum wheat and chickpea were sown in second week of November and harvested in third and fourth week of March during both the years. The intercultural operations and plant protection measures were carried out as per the recommendations of respective crops. The economic yield of the component crops was taken into account over the years and then expressed as productivity (t/ha) of different cropping systems. The cost of cultivation was calculated by taking into account the prevailing prices of inputs. To compare different crop systems, the yields of all crops were converted into groundnut equivalents (GEs) on market price basis. Production efficiency in terms of kg/ha/day was worked out by total economic yield in terms of PE in a crop rotation divided by total duration of crops in a system (Tomar and Tiwari, 1990). Economic efficiency in terms of ₹/ha/day was worked out by dividing the net returns of the system by total duration of crops in an agricultural year (Patil *et al.,* 1995). Land utilization index was calculated by dividing total duration of respective crops with 365 days (Tomar and Tiwari, 1990). Net returns were the difference between the gross returns and total cost of cultivation of the component crops. Benefit: cost ratio (Returns/₹ invested) of a system was expressed as net returns/₹ spent. The input and output energies were calculated by energy conversion factors (Table 2) for inputs like labour, fuel, fertilizers, seeds, machineries, pesticides and irrigations etc. used in the respective crop system (Mittal and Dhawan, 1988; Devasenpathy *et al.,* 2009). System net energy returns was calculated by deducting total energy inputs involved in all crops from total energy output from the system. Energy output- input ratio was worked out by energy output divided by energy input. Energy balance per unit input was calculated by system net energy returns divided by total system energy inputs. Energy intensiveness was worked out by dividing energy output by cost of cultivation in-

Table 1. Agronomic practices followed for the different crops and values of energetic/100 g edible portion of the crop.

Crop	Variety	Spacing	NPK (Kg/ha)	Number of irrigations	Protein (%)	Carbohydrate (%)	Fat (%)
Groundnut	'JL 501'	30 cm × 10 cm	25–50–00	3	25.09	26.67	43.71
Onion	'N 2-4-1'	15 cm ×10 cm	100–50–50	5	1.01	11.3	0.7
Wheat	'Trimbak'	22.5 cm line	120–60–40	5	9.51	73.86	1.61
Chickpea	'Digvijay'	30 cm × 10 cm	25–50–00	3	22.39	53.81	1.15

Table 2. Energy conversion factors used in study

Power source	Unit	Equivalent energy (MJ)
Human labour		
Adult man	Man hour	1.96
Adult woman	Woman hour	1.57
Animal labour		
Bullock medium	Pair hour	10.10
Machinery		
Electric motor	kg	64.80
Self propelled machine	kg	68.40
Seed	kg	62.70
Wood	kg	30.80
Chemical fertilizer		
Nitrogen	kg	60.60
P_2O_5	kg	11.10
K_2O	kg	6.70
Chemical	kg	120.00
Farm yard manure (dry)	kg	0.30
Diesel	Litre	56.31
Electricity (1.7630 kw/ h)	Kw/ha	11.93
Seed/output		
Wheat	(dry) kg	14.5
Chickpea	(dry) kg	15.1
Oilseeds	(dry) kg	25.0
Onion	(dry) kg	0.06
Byproducts		
Fodder	(dry) kg	18.0
Straw	(dry) kg	12.5
Stalk	(dry) kg	18.0
Dung	(dry) kg	18.0
Fuel wood		
Hard	(dry) kg	20.70
Soft	(dry) kg	18.90
Kerosene	Litre	41.30

Source, Panesar B.S. and A.B. Bhatnagar, 1994. Energy norms for inputs and outputs of agriculture sector. USG Publication Ludhiana.

curred in crop production. Statistical analysis of the data was carried out by using standard analysis of variance.

RESULTS AND DISCUSSION

Yield of groundnut

The significantly higher dry pod yield (2.36 t/ha) and protein content in rainy season (*kharif*) groundnut was recorded with the application of fertilizer as per the soil test crop response (STCR) equation (40, 50 and 20 kg NPK/ha). The yield target of 2.5 t/ha was achieved by STCR equation with less than 10% variation (–5.8%). The fertilizer dose as per soil test was found second best treatment of 1.93 t/ha (Table 3). Balanced nutrition also increases the chlorophyll content in leaves, which increases the photosynthetic rate and translocation of photosynthetic towards reproductive parts i.e. pods. Similarly, the groundnut being a legume crop having more nitrate reductase activities in root which is beneficial for peg formation and pod development stage (Ghosh *et al.,* 2003). Similar findings were reported by Dudhatra *et al*. (2002) and Varalakshmi *et al*. (2005).

Yield of winter season crops

In onion, application of fertilizer as per STCR equation to preceeding crop rainy season (*kharif*) groundnut registered maximum and significantly higher bulb yield (59.8 t/ha) and it was 9.75% higher than recommended dose of fertilizer. Application of recommended dose of fertilizer (RDF: 100:50:50 kg NPK/ha) to succeeding onion crop preceded by groundnut registered significantly higher bulb yield (48.9 t/ha) and it was 4.46% higher than 75% RDF and 16.65% higher than 50% RDF (Table 3). This might be owing to residual effect of preceding crop maintaining soil organic matter, major and micronutrients, which increases the uptake of these nutrients and accelerating the physiological activities in crop for improving growth attributes. Similarly, it also increased the translocation of photosynthates towards onion bulb, which resulted in increasing the weight of bulb. These results are in conformity with those reported by Reddy and Suresh (2009) and Jat *et al.* (2011).

In wheat, application of fertilizer as per STCR equation to preceding crop groundnut registered significantly maximum grain yield of wheat (4.26 t/ha) and it was 8.28% higher than recommended dose of fertilizer on pooled mean basis (Table 3). Application of RDF (120:60:40 kg NPK/ha) to wheat recorded significantly maximum grain yield (3.64 t/ha) and it was 14.86% higher than reduced level of fertilizer, i.e. 50% RDF but at par with 75% RDF (Table 3). This indicate that growing of wheat crop after *kharif* groundnut saves 25% RDF because of balance nutrition to *kharif* groundnut through STCR equation, which created favourable environment in the root rhizosphere of wheat crop to absorb more nutrients and moisture by improving the nutrient-use efficiency. These results are corroborated with findings of Verma *et al*. (2005), Ramesh *et al*. (2009), Mubarak and Singh (2011) and Hashim *et al.* (2015)

In chickpea, fertilizer management as per STCR equation registered significantly higher grain yield (2.89 t/ha), which was 11.38% higher than recommended dose of fertilizer (Table 3). Application of RDF (25:50:00 kg NPK/ ha) to chickpea crop exhibited significantly maximum growth and grain yield of chickpea and recorded significantly higher grain yield of 2.65 t/ha and at par with 75% RDF (Table 3). This indicates that, 25% of fertilizer dose was saved, when chickpea grown after *kharif* groundnut. These results are in accordance with Rao and Shaktawat (2002), Ramesh *et al*. (2009) and Singh *et al.* (2010).

Groundnut equivalent yield

Among the cropping systems, groundnut–onion cropping system recorded significantly maximum groundnut equivalent yield of 7.82 t/ha and it was 138.89 % higher than groundnut–wheat system and 92.68% higher than groundnut–chickpea system. The nutrient management as per STCR equation proved it's superiority by recording maximum groundnut equivalent yield of 6.69 t/ha and it was 19.25% higher than that of recommended dose of fertilizer (Table 3). Application of RDF to succeeding winter season (*rabi*) crops preceded by *kharif* groundnut registered significantly higher groundnut equivalent yield than 50% RDF and at par with 75% RDF.

Production efficiency

Among the cropping systems, groundnut–onion cropping system registered significantly higher production efficiency of 35.1 kg/ha/day than groundnut–wheat and groundnut–chickpea cropping systems. The nutrient management treatments as per STCR equation registered significantly higher production efficiency of 30.2 kg/ha/day and it was 17.2% higher than recommended dose of fertilizer. Application of RDF to succeeding crop during *rabi* season registered significantly higher production efficiency than 50% RDF and at par with 75% RDF on pooled mean (Table 4).

Economic efficiency

The groundnut–onion cropping system recorded significantly higher economic efficiency of ₹842.4/ha/day than groundnut–wheat and groundnut–chickpea cropping systems. Application of fertilizer as per STCR equation to *kharif* groundnut recorded significantly higher economic efficiency of ₹713.3/ha/day than rest of the nutrient management and control treatment. The economic efficiency of different cropping systems was also influenced by different fertilizer levels to succeeding crops. Application of RDF to succeeding crop during *rabi* season recorded significantly higher economic efficiency than 50% RDF level and at par with 75% RDF (Table 4). This is because of higher yield and biomass production with higher level of fertilizer.

Energetics

Evaluation of different cropping systems through energetics is appreciated these days as it is more stable and meaningful and it indicates the energy yield from the system which does not fluctuates with the market prices since it is based on nutritional value of the system. Unlike, groundnut-equivalent yields, energetics revealed different pattern, where in protein yields were significantly higher in groundnut–chickpea (0.82 t/ha) than groundnut–wheat but at par with groundnut–onion because of higher protein

Table 3. Yield and groundnut equivalent yield, protein, carbohydrates and fat yield as influenced by different treatment (pooled mean of 2 years)

Treatment	Groundnut (t/ha)	Onion (t/ha)	Wheat (t/ha)	Chickpea (t/ha)	Groundnut equivalent yield (t/ha)	Protein (t/ha)	Carbohydrate (t/ha)	Fat (t/ha)
Cropping system								
Groundnut–onion		-	-	-	7.82	0.74	5.41	0.81
Groundnut–wheat		-	-	-	3.27	0.61	2.79	0.55
Groundnut–chickpea		-	-	-	4.06	0.82	1.59	0.55
SEm±		-	-	-	0.06	0.06	0.67	0.13
CD (P=0.05)		-	-	-	0.19	0.17	1.90	N.S.
Nutrient management								
Recommended dose of fertilizer	1.71	54.5	3.94	2.59	5.61	0.78	3.73	0.65
Fertilizer dose as per soil test	1.93	55.7	4.08	2.69	5.93	0.83	3.87	0.73
Fertilizer dose as per STCR eq^n (25 t/ha)	2.36	59.8	4.26	2.89	6.69	0.95	4.20	0.88
Control (No Fertilizers)	0.73	13.5	1.31	1.35	1.97	0.33	1.25	0.29
SEm±	0.05	0.6	0.041	0.05	0.08	0.04	0.78	0.15
CD (P=0.05)	0.14	2.7	0.14	0.20	0.24	0.13	2.20	0.43
Fertilizer level								
RDF		48.9	3.64	2.64	5.24	0.75	3.46	0.62
75% of RDF		46.8	3.48	2.43	5.18	0.74	3.32	0.65
50% of RDF		41.9	3.17	2.07	4.73	0.68	3.01	0.63
SEm±		0.5	0.07	0.04	0.05	0.03	0.67	0.13
CD (P=0.05)		1.8	0.23	0.12	0.14	0.10	NS	N.S.

RDF, Recommended dose of fertilizers

content in groundnut and chickpea grains as compared to other crop study (Table 1, 2 and 3), while carbohydrates (5.41 t/ha) and fats (0.81 t/ha) were registered higher with groundnut–onion cropping system with higher crop yields with respective crops. These results are in conformity with the results of Jain *et al*. (2015).

The groundnut–chickpea cropping system was registered significantly higher energy output-input ratio (9.54), energy balance/unit input (8.85) and energy intensiveness (2.59 MJ/₹). The groundnut–chickpea cropping system was recorded maximum yield with minimum input energy than groundnut–onion and groundnut–wheat cropping system. Application of fertilizer as per STCR equation to preceding *kharif* groundnut recorded significantly higher energy output, system net energy returns and energy intensiveness than rest of all the treatment combinations. The application of recommended dose of fertilizer to succeeding crops registered significantly higher system net energy returns, energy output-input ratio and energy intensiveness than rest of the treatment combinations (Table 5). Both the crops (groundnut and chickpea) fixes atmospheric nitrogen, thereby reduces the input energy required for obtaining higher yield resulting in higher output-input ratio and system net energy returns. Similar results recorded by Devasenapathy *et al.,* (2009) and Honnali and Chittapur, 2014).

Economics

Among the cropping systems, groundnut–onion cropping system obtained significantly higher net monetary returns (₹188.1×10^3/ha) and benefit: cost ratio (2.98) than groundnut–wheat and groundnut–chickpea cropping systems. The groundnut–chickpea cropping system was second in rank with respect to net monetary returns. Application of fertilizer as per STCR equation to *kharif* groundnut obtained significantly maximum net monetary returns (₹158.0×10^3/ha) and benefit: cost ratio (2.90) than rest of the nutrient management treatments. Application of RDF to succeeding crop during *rabi* season obtained significantly higher gross net monetary returns (₹109.8×10^3/ha) and benefit: cost ratio 2.38 than 50% RDF and at par with 75% RDF in respect of gross and net monetary returns and benefit: cost ratio (Table 4).

Thus it can be concluded that, groundnut–onion cropping system found to be most efficient and suitable for achieved maximum productivity and monetary returns with application of fertilizer as per soil test crop response (STCR) equation.

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Table 4. Production efficiency, economic efficiency and economics as influenced by different treatment (pooled mean of 2 years)

Treatment	Production efficiency (kg/ha/day)	Economic efficiency (₹/ha/day)	Cost of cultivation (×10^3 ₹/ha)	Net monetary returns (×10^3 ₹/ha)	Benefit: cost ratio
Cropping system					
Groundnut–onion	35.0	842.4	95.1	188.0	2.98
Groundnut–wheat	15.0	209.3	72.1	46.0	1.64
Groundnut–chickpea	19.2	363.4	69.0	77.2	2.11
SEm±	0.15	5.95	-	1.25	-
CD (P=0.05)	0.45	17.45	-	3.67	-
Nutrient management					
Recommended dose of fertilizer	25.8	552.3	82.2	120.5	2.47
Fertilizer dose as per soil test	27.0	598.1	82.8	131.5	2.59
Fertilizer dose as per STCR eq^n (25 t/ha)	30.2	713.3	83.2	158.0	2.90
Control (No Fertilizers)	9.3	23.24	66.1	4.9	1.07
SEm±	0.18	6.87	-	14.4	-
CD (P=0.05)	0.53	20.15	-	42.4	-
Fertilizer level					
RDF	24.1	499.7	79.5	109.8	2.38
75% of RDF	23.5	492.3	78.7	108.3	2.37
50% of RDF	21.6	423.2	77.8	93.1	2.20
SEm±	0.21	3.76		1.28	
CD (P=0.05)	0.60	10.69		3.85	

Market price: 2011–12, Groundnut 34,500₹/t; Onion 3,600₹/t; Wheat 14,000₹/t; Chickpea 33,000₹/t; 2012–13, Groundnut 37500₹/t; Onion 6000₹/t; Wheat 18,000₹/t; Chickpea 36,000₹/t

Table 5. Energy indices of different cropping systems as influenced by different nutrient managements (pooled mean of 2 years)

Treatment	Input energy (× 10^3 MJ/ha)	Output energy (× 10^3 MJ/ha)	System net energy returns (× 10^3 MJ/ha)	Energy output-input ratio	Energy balance per unit input	Energy intensiveness (MJ/₹)
Cropping system						
Groundnut–onion	23.5	158.4	134.9	6.72	5.72	1.66
Groundnut–wheat	20.9	183.2	162.3	8.74	7.74	2.54
Groundnut–chickpea	18.1	179.2	161.1	9.54	8.85	2.59
SEm±	0.12	1.09	1.09	0.05	0.05	0.03
CD (P=0.05)	0.36	3.21	3.22	0.16	0.16	0.09
Nutrient management						
Recommended dose of fertilizer	21.0	185.1	164.1	8.81	7.81	2.25
Fertilizer dose as per soil test	22.3	202.3	180.0	9.06	8.07	2.44
Fertilizer dose as per STCR eq^n (25 t/ha)	25.7	233.8	208.1	9.09	8.10	2.81
Control (No Fertilizers)	14.5	73.4	58.8	5.03	4.05	1.11
SEm±	0.14	1.26	1.26	0.06	0.06	0.04
CD (P=0.05)	0.42	3.71	3.71	0.18	0.18	0.12
Fertilizer level						
RDF	22.0	186.8	166.0	8.50	7.56	2.35
75% of RDF	20.9	172.3	154.8	8.23	7.40	2.19
50% of RDF	19.8	153.6	137.4	7.74	6.92	1.97
SEm±	0.08	1.09	1.09	0.06	0.06	0.04
CD (P=0.05)	0.22	3.11	3.12	0.17	0.18	0.12

RDF, Recommended dose of fertilizers

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Research Paper

Effect of alkali and canal waters in cyclic and blended mode on potato (*Solanum tuberosum*)–sunflower (*Helianthus annuus*)–sesbania (*Sesbania sesban*) cropping sequence

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ABSTRACT

Response of potato (*Solanum tuberosum* L.)–sunflower (*Helianthus annuus* L.)–sesbania [*Sesbania sesban* (L.) Merr.] cropping sequence to conjunctive use of good quality canal water [EC_{CW} 1.1 dS/m, residual sodium carbonate (RSC) nil, sodium adsorption ratio (SAR) 1.7] and alkali water (EC_{AW} 3.8 dS/m, RSC 15.5 me/L, SAR 11.8) was evaluated for 6 years (2007–2008 to 2012–2013) on a well-drained sandy-loam soil [ECe 2.3 dS/m, *p*H 8.1, exchangeable sodium percentage (ESP) 5.5]. Increase in soil *p*H (8.9–9.1), salinity (3.4–4.7 dS/m) and sodicity (ESP 24.1–39.5) as a consequence of irrigation with alkali water affected the growth and yields of all the crops. When averaged for 6 years, the relative yields ranged between 48 and 78% for potato and 55 and 73% for sunflower in case of cyclic use of alkali water compared to canal water. However, the relative yields ranged 58 to 83% for potato and from 52 to 78% for sunflower when alkali water was used in blended mode. Considerable deterioration in the quality of potato in terms of grade, size and keeping quality, and reduction in oil content of sunflower was observed. The change in soil properties in different modes of water application was in accordance with the proportions of alkali water applied. The analysis on use of canal and alkali waters in similar proportion further indicated that cyclic application of canal water during the initial stages would minimize the adverse effects of alkali water.

Key words : Alkali water, Canal water, Conjunctive use, Cyclic and blending mode, Potato–sunflower–sesbania crop sequence

Degradation of soil with the use of alkali groundwaters constitutes a major threat to irrigated agriculture in semi-arid regions, particularly in South Asia (Qadir and Oster, 2004). In Indo-Gangetic plains, which is the most intensively cultivated area, high incidence of alkali groundwater (30–50%) is found where annual rainfall is between 500 and 700 mm.

Use of alkali water for irrigation to crops leads to increase in soil Sodicity, thus adversely affects physical behaviour of soil in terms of crusting, hard-setting and low infiltration rates. It not only deteriorates the soil quality, but also affects the crop yields and limits the choice of crops that can be grown on such soils. Appropriate selection of crops, improved water-management practices and application of amendment are important in maintaining soil structure/ permeability. Therefore, specialized soil-crop-irrigation management practices, which helps to maintain sodicity levels within permissible limit in crop root zone depth are needed for irrigation with alkali groundwaters for sustainable yield.

Under certain situations, where limited quantity of good quality canal water is available, it should be applied efficiently either in cyclic or blended mode to obtain acceptable crop yield. In case of saline water, germination and seedling establishment stages have been identified as most sensitive for most of the crops. Thus use of good quality water is advocated for pre-sowing and early growth stages before switching to saline water when crops attain higher tolerance. However, with use of alkali waters, where sodication occurs with depletion of Ca^{2+} due to its precipitation as calcite ($CaCO_3$), strategies that would either minimize calcite precipitation or maximize the dissolution of precipitated calcite would be expected to perform better. Usually groundwater aquifers are in equilibrium

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with inherent calcite, thus it seems that blending of groundwaters of higher alkalinity and low calcium with canal waters would result in their under-saturation with respect to calcite. Consequently, in addition to dilution of soil solutions, irrigation with blended water/ better quality canal waters should have a tendency to pick up calcium through dissolution of native calcite. Earlier reports (Minhas *et al*., 2007) indicated that cyclic use of alkali and canal waters decreased sodication of soils and thus helped in sustaining paddy–wheat yields. However, resultant benefits in terms of a decrease in calcite precipitation or its increased dissolution yet to be quantified, where better quality canal and alkali waters are combined for irrigating moderately sensitive crops like potato and sunflower. Therefore, the aim of the study was to evaluate the impact of use of cyclic (annual/crop) and blended mode of alkali water with canal water in potato–sunflower–sesbania cropping sequence on yield, quality and soil health.

MATERIALS AND METHODS

The experiment was conducted at the Research Farm of Raja Balwant Singh College of Agriculture, Bichpuri, Agra, Uttar Pradesh (27^o 2' N and 77^o 9' E). The climate in the region is semi-arid which receives an average annual rainfall of 650 mm, of that about 80% is received during July–September. The soils in the region are generally well-drained (water table 10–12 m below ground level) sandy loam with an electrical conductivity of the saturated paste extract (ECe) of 2.7 dS/m, *p*H of the saturated paste (*p*Hs) of 7.9, exchangeable sodium percentage (ESP) of 5.3, organic matter content of 2.9 g/kg soil and clay content of 14%. The groundwater quality in the region varies, with EC 2–4 dS/m, residual sodium carbonate (RSC) 14–18 me/L and sodium adsorption ratio (SAR) 10–14. The experiment was initiated in 2007 for potato-sunflower-sesbania cropping sequence with potato as the first crop and continued for 6 years (2007–08 to 2012–13). Treatments comprised combinations of irrigation with good quality canal water and alkali water applied alone, in cyclic (annual/ crop-wise) or in blended mode. Nine treatments combinations, comprising (*i*) all irrigation with canal water (CW), (*ii*) all irrigation with alkali water (AW), (*iii*) 1-year canal water (CW) : 2 year alkali water (AW), (*iv*) 2-year alkali water (AW): 1 year canal water (CW), (*v*) 2-year canal water (CW): 1-year alkali water (AW), (*vi*) 1-year alkali water (AW): 2-year canal water (CW) (*vii*) alkali water in potato (AWp) and canal water in sunflower (CWs), (*viii*) mixing 2 parts canal water + 1 part of alkali water (2 CW + 1 AW) (*ix*) mixing 1 part canal water + 2 parts of alkali water (2 AW + 1 CW). One cycle of potato–sunflower–sesbania (GM) crop rotation was 3 years than further cycle of this rotation was next 3 years. The treatments were imposed in a randomized block design with 4 replications. The plot size was 20 m^2 (5 m × 4 m) and to control lateral fluxes of salt and water, each plot was lined with polyethylene sheet down to a depth of 90 cm. Alkali water was synthesized by dissolving the required quantities of sodium bicarbonate in canal water. The equivalent weight of $NaHC_3$ is dissolved in 1L of canal water for our RSC purpose. The analysis of the canal water indicated its quality as 1.1 dS/m, RSC nil and SAR 1.8 whereas the average quality of the synthesized alkali water was EC_{AW} 3.6 dS/m, RSC 15.8 me/L, and SAR 12.4. Potato seed (cv. ‘Kufri Bahar’) was planted in the last week of October and harvested during the last week of February or first week of March. The recommended dose of fertilizer (N P K 100 21 35 kg/ha) was applied to potato crop. After potato, sunflower (‘MSFH 17’) crop was sown in the middle of March and harvested in middle of June. It was fertilized with N : P : K 80 : 16 : 18 kg/ha. Sesbania crop was raised during July–August in the rainy season but no fertilizers or irrigation water was applied. The biomass of the 55 days old sesbania crop was incorporated into the soil. The potato crop sown on beds and the irrigation depth was kept 5 cm; however, sunflower crop was sown in flat field. The irrigation depth was 7 cm but sesbania crop was growing without irrigation in all 6 years experimentation (Table 1). The rainfall received during the potato, sunflower and sesbania seasons averaged 31.1, 39.6 and 362.0 mm respectively (Table 1). The tuber yield was recorded grade-wise, i.e. A grade (> 60 g), B grade (40–60 g) and C grade (< 40 g) in all the treatments. The keeping quality of potato tuber in the form of weight loss (%) was recorded in 3 months potato tuber storage at room temperature.

Sustainability indices (sustainable yield index, SYI) were also calculated. The quantitative assessment of the sustainability of agricultural practices was developed by Singh *et al.* (1990). The SYI was calculated as follows:

$$SYI = \frac{Ym - Sd}{Y_{max}}$$

where, Ym is the mean yield, Sd the standard deviation, Ym ax is the maximum yield obtained under a set of management practices.

Soil samples were collected to a depth of 90 cm at planting and at harvesting of the crops and soil water storage (SWS) was determined using gravimetric method. The quantity of water used (WU) was calculated as difference in soil storage during the season (SWS) plus irrigation (IW) and rainfall (R). The water-use efficiency (WUE, kg/ha-cm) was calculated as the ratio of yield (kg/ha) to WU (cm).

RESULTS AND DISCUSSION

Soil properties

The salt build up in the surface soil layer (0–30 cm), where most of the dense crop roots are confined and has high potential for clay dispersion, surface crusting thus low infiltration rate, was most influenced by the quality of irrigation water. The effect of various modes of irrigation on soil properties, though monitored up to 90 cm in the effective root zone depth, is presented limited to agriculturally important surface soil layer (Fig.1). Continuous irrigation with alkali water (AW) significantly increased the salt built up in soil profile as compared to continuous use of canal water (CW). The average values of *p*H, ECe, SARe and ESP at the harvesting of different crops or sowing of next crops during the sixth year ranged from 7.6 to 9.1, 2.6 to 4.7 dS/m, 3.3 to 21.2 and 9.1 to 39.5, respectively, with higher values being observed at the harvest of sunflower crop.

Soil sodication due to irrigation with alkali waters has been reported in the north-west parts of India (Minhas *et al*., 2007; Chauhan *et al.* 2007). The sodicity build up in soils irrigated with alkali waters in the north-west region has been observed to be the outcome of equilibrium between the processes of precipitation and dissolution of calcite. Precipitation occurs mainly due to concentration of the soil solution due to water uptake during the cropping season, while the monsoon rains induce the release of divalent cations both from exchange sites and dissolution of calcite and other minerals. In these cases, a quasi-equilibrium is established within about 4–5 years of irrigation, depending on the nature of crops grown, soil characteristics and the climate especially rainfall at the site. Due to sodicity-induced reductions in water infiltration, the opportunity for alkali waters to penetrate deeper is farther reduced. The application of alkali waters further increases sodicity in the upper soil layers when concentrated through the loss of water due to evapotranspiration. However, sodicity build up in soil (ESP–2.5 × SAR_{AW}) was greater than the earlier reported values of about 1.2–1.5 × SAR_{AW} for upland double crop rotations like maize/ millet–wheat (Manchanda, 1993). This was in spite of the fact that the content of Ca^{2+} and Mg^{2+} (10.2 me/L) in alkali water used for the irrigation was much higher and the field was regularly incorporated with green manure (sesbania) during the monsoon season. The latter is known to induce bioremediation in soils through dissolution of precipitated calcite in the rhizosphere because of enhanced partial pressure of carbon dioxide and the production of organic acid during its decomposition (Qadir *et al.*, 2002). Moreover, with incorporation of sesbania, the Ca and Mg taken up by the crop during its growth, was being returned to the soil. It is documented that legumes like sesbania rely on N_2-fixation to release protons (H^+) that contribute to a decrease in soil *p*H in calcareous soils and thus dissolve calcite (Qadir and Oster, 2004). These effects were evident, as the ESP in surface soil up to 30 cm averaged between 9.1 and 24.1 at the harvesting of sesbania/ sowing of potato after the cessation of monsoon while it was between 11.1 and 39.5 at the harvesting of sunflower/ sowing of sesbania, thus an average increase in ESP by 2.0 in case of CW alone and 15.4 in case of AW alone (Fig.1). Proportionately higher build up of sodicity in the soils under the present study can be ascribed to the higher quantity of water applied (550 mm – 700 mm) and the proportion of alkali water used for irrigation of potato and sunflower when the soils were in a precipitation phase (October–June). Further, it is interesting to note that the annual rainfall in the region is adequate to sustain the soil ESP (slight reduction in case of CW and slight increase in case of AW despite high inter-seasonal increase) over 6 years of study period (Fig.2). In comparison, wheat was the main winter crop in rotation during the earlier documented studies (Manchanda, 1993) and it required 350–420 mm of irrigation water. The data in the present study corroborate the recent analysis by Minhas and Sharma (2006) that in addition to the ion chemistry of irrigation waters, applied irrigation water, rainfall and evapo-transpiration of the crops

Table 1. Pan evaporation (PE), rainfall (R) and applied irrigation water (IW) to different crops

Crop	Parameters	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	Mean
Potato	PE (mm)	229.0	257.0	285.0	232.0	245.0	266.0	252.0
	R (mm)	25.8	10.3	Nil	87.1	1.3	Nil	31.1
	IW (mm)	250.0	250.0	300.0	300.0	300.0	300.0	283.0
Sunflower	PE (mm)	787.0	775.0	768.0	758.0	769.0	782.0	773.0
	R (mm)	20.2	16.1	61.5	50.0	57.0	32.8	39.6
	IW (mm)	420.0	420.0	420.0	350.0	280.0	280.0	362.0
Sesbania	PE(mm)	223.0	231.0	168.0	211.0	231.0	189.0	208.0
	R (mm)	262.5	367.5	581.6	219.6	212.4	210.8	309.6
	IW (mm)	Nil	Nil	Nil	Nil	Nil	Nil	Nil

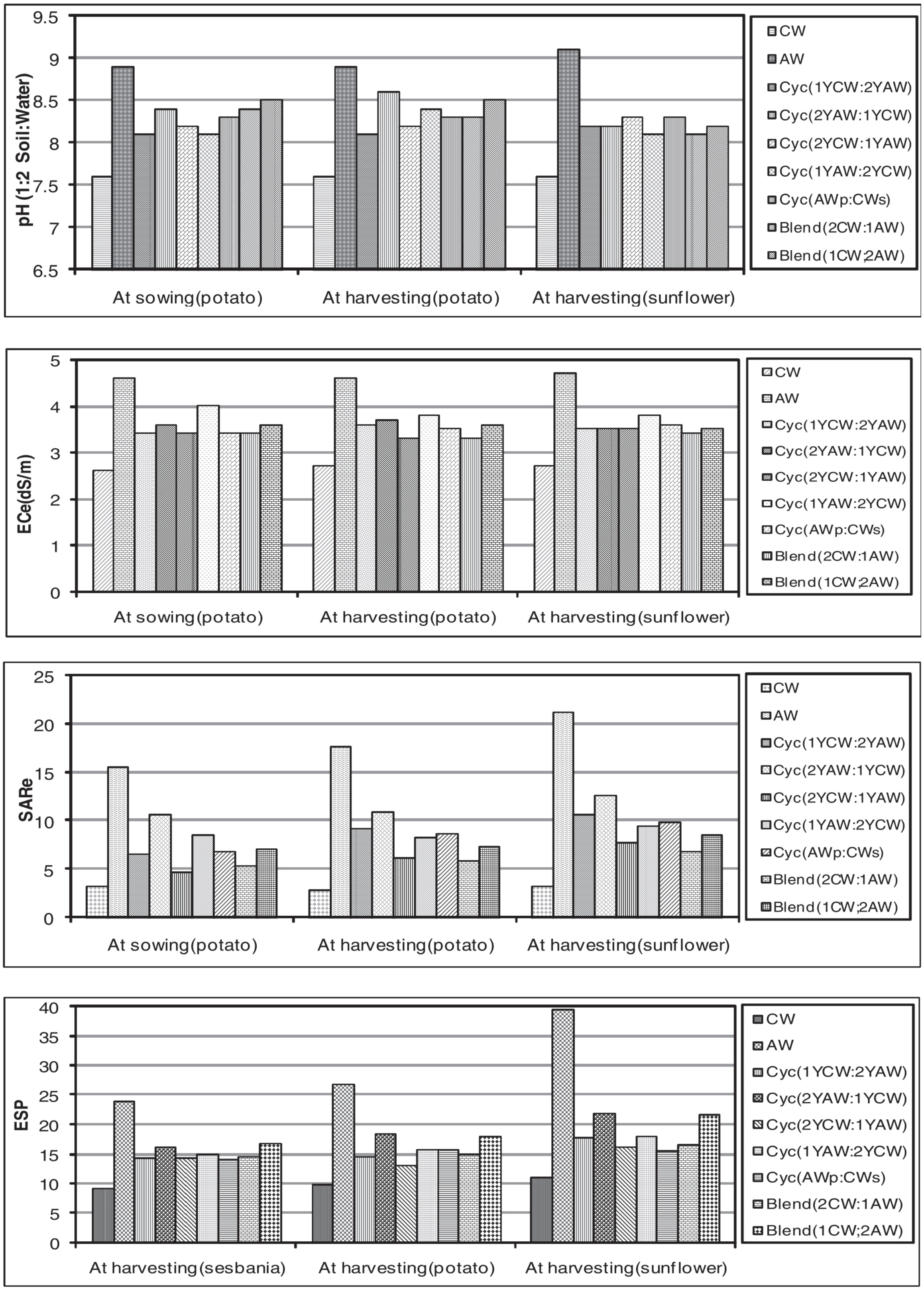

Fig. 1. Effect of use of canal and alkali waters in cyclic (annual) and blended mode on soil Properties (0–30 cm) during 6th year of cropping (SARe, Sodium adsorption ratio; ESP, exchange sodium percentage)

also influence the extent of sodicity buildup in soils irrigated with alkali waters.

The buildup of salinity and sodicity in soils was also related to the proportion of AW used in various modes of irrigation, while little difference was observed between respective use in cyclic and blended modes. The *p*H of the surface soil up to 30 cm ranged between 8.1 and 8.6 though considerable differences in ESP (14.1–22.0) were observed under different modes of combined use of canal and alkali waters during the sixth year (Fig. 1). The average ESP were estimated 17.8, 22.0, 16.3 and 18.0 for 1 YCW 2 YAW, 2 YAW 1 YCW, 2 YCSW: 1 YAW and 1 YAW : 2 YCW cyclic treatments, indicating an enhanced buildup of sodicity with higher proportion of AW used (Fig.1). The increase in ESP was more prevalent when AW was used in initial year(s) and CW was used in subsequent

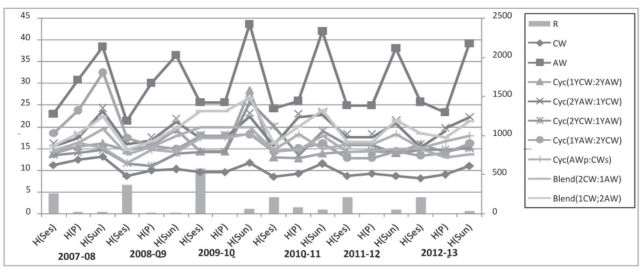

Fig. 2. Effect of different modes of canal and alkali water use on exchangeable sodium percentage (0–30 cm) during study period (2007–08 to 2012–13)

year(s). Further, reduction in ESP after 6 years of study period was observed in treatments when 2YCW was used, whereas, ESP increased marginally when 1YCW was used (Fig. 2). However, the ESP under the crop wise cyclic treatment (AWp : CWs) and blends of canal and alkali waters (2 CW + 1 AW, 1 CW + 2 AW) on sixth year were observed in the range of 15.7–21.8 (Fig. 1). Further, the ESP remained nearly static after 6 years of experiment for AWp : CWs and 2 CW + 1 AW, whereas increased marginally for 1 CW + 2 AW used in blended mode. Among all treatments of combined use of canal and alkali waters, cyclic application of 2 YCW + 1 YAW and blended use of 2 CW : 1 AW were found best in terms of reduction of soil ESP. Minhas *et al.* (2007) also reported similar results with paddy-wheat where keeping the proportion of added AW as the same; the sodicity build up was similar with cyclic use and blending.

Crop

Irrigation with AW alone significantly reduced the average yields over a period of 6 years of potato (85%), sunflower (88%) and sesbania (65%), though the reduction in yields were comparatively lower in the first year (potato 71%, sunflower 74% and sesbania 64%) than subsequent years (Table 2). Both potato and sunflower have been rated as moderately sensitive crops (Maas and Grattan, 1999). Higher relative yield of sesbania than potato and sunflower was observed mainly on account of high

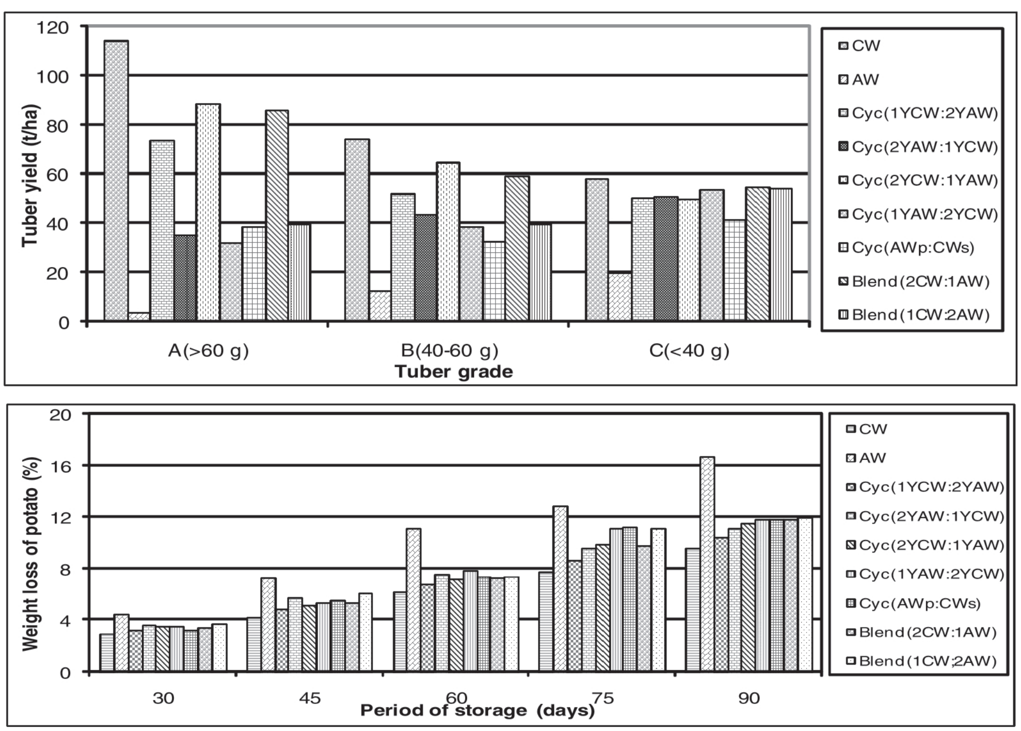

Fig. 3. Effect of different modes of application of canal and alkali water on graded tuber yield (top) and weight loss (bottom) of potato tuber

amount of rainfall received during the crop season. The significant reduction in crop yields can be ascribed to bicarbonate toxicity and build up of alkalinity and sodicity in soils leading to structural deterioration and poor permeability. These factors ultimately result in nutritional imbalances (Qadir and Oster, 2004). The restricted movement of water in soils irrigated with alkali water may also result in the retention of salts in surface layers, which simultaneously induces salinity stresses affecting crop growth (Minhas *et al*., 2003). The salinity during the crop-growth period, though not high (2.9–4.9 dS/m), was above the threshold values reported for the test crops under consideration (Maas and Grattan, 1999).

The yields for each crop improved under various combinations of CW and AW usage compared with AW alone. The crops performed better with yearly water use compared to blending. When averaged over the 6 years, the RY of potato were 66, 54, 78, 60 and 48% under the cyclic 1 YCW : 2 YAW, 2 YAW : 1 YCW, 2 YCW : 1 YAW, 1 YAW : 2 YCW and AWp : CWs treatments respectively, while the relative yield was 83 and 58% for waters blended in the ratio 2 CW + 1 AW and 1 CW + 2 AW re-

Table 2. Effect of modes of irrigation with alkali and canal water on yield of crops

Mode of irrigation	Potato tuber yield (t/ha)								
	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	Mean	RY (%)	SYI
All canal water (CW)	24.5	28.2	25.9	31.2	25.7	36.3	28.6	100	0.83
All alkali water (AW)	7.1	4.3	3.4	2.6	2.3	6.6	4.4	15	0.34
Cyclic (1 YCW : 2 YAW)	23.1	17.9	16.6	23.6	15.9	17.3	19.1	66	0.65
Cyclic (2 YAW : 1 YCW)	18.8	10.8	18.4	13.7	8.4	20.8	15.2	54	0.56
Cyclic (2 YCW : 1 YAW)	19.7	24.1	20.9	24.9	23.4	22.9	22.7	78	0.82
Cyclic (1 YAW : 2 YCW)	9.3	16.8	18.9	13.7	14.1	31.1	17.3	60	0.72
Cyclic (AWp : CWs)	11.4	13.5	15.9	12.7	9.9	19.6	13.8	48	0.73
Blending (2 CW + 1 AW)	21.0	22.4	21.7	23.9	21.3	31.8	23.7	83	0.94
Blending (1 CW+ 2 AW)	13.8	15.3	17.2	16.6	12.8	24.4	16.7	58	0.86
SEm±	0.6	0.7	0.6	0.7	0.8	0.6	-	-	-
CD (P=0.05)	1.8	2.1	1.7	2.1	2.3	1.9	-	-	-
	Sunflower seed yield (t/ha)								
All canal water (CW)	1.29	1.54	1.23	1.48	1.05	1.30	1.32	100	0.73
All alkali water (AW)	0.33	0.17	0.11	0.14	0.11	0.10	0.16	12	0.22
Cyclic (1 YCW : 2 YAW)	1.20	0.65	0.50	11.4	0.61	0.61	0.79	60	0.40
Cyclic (2 YAW : 1 YCW)	0.77	0.71	0.83	0.65	0.58	0.76	0.72	55	0.75
Cyclic (2 YCW : 1 YAW)	0.98	1.37	0.61	1.13	0.95	0.69	0.96	73	0.49
Cyclic (1 YAW : 2 YCW)	0.45	0.96	0.99	0.61	0.68	0.75	0.74	56	0.53
Cyclic (AWp : CWs)	0.82	0.95	0.71	0.79	0.69	0.78	0.79	60	0.73
Blending (2 CW + 1 AW)	1.03	1.32	0.86	1.09	0.94	0.95	1.03	78	0.76
Blending (1 CW + 2 AW)	0.81	0.74	0.65	0.72	0.61	0.63	0.69	52	0.65
SEm±	0.06	0.07	0.07	0.04	0.04	0.03	-	-	-
CD (P=0.05)	0.19	0.23	0.22	0.12	0.13	0.11	-	-	-
	Sesbania biomass yield (t/ha)								
All canal water (CW)	20.1	19.1	19.6	19.9	20.0	20.9	19.9	100	0.93
All alkali water (AW)	7.2	6.8	6.7	6.8	6.9	7.5	7.0	35	0.89
Cyclic (1 YCW : 2 YAW)	19.7	17.9	16.7	17.3	17.6	18.5	18.0	90	0.86
Cyclic (2 YAW : 1 YCW)	18.7	17.0	17.2	17.1	17.3	17.2	17.4	87	0.90
Cyclic (2 YCW : 1 YAW)	17.0	16.8	16.9	16.6	16.7	16.9	16.8	84	0.98
Cyclic (1 YAW : 2 YCW)	12.1	13.0	17.9	12.8	17.8	16.8	15.1	76	0.69
Cyclic (AWp : CWs)	18.2	14.7	17.9	17.5	17.7	18.3	17.4	87	0.88
Blending (2 CW + 1 AW)	18.9	17.4	17.6	17.8	17.9	18.5	18.0	92	0.93
Blending (1 CW + 2 AW)	17.9	16.8	16.4	17.0	17.2	17.6	17.2	86	0.92
SEm±	0.3	0.2	0.2	0.3	0.3	0.4	-	-	-
CD (P=0.05)	1.0	0.7	0.7	1.0	1.1	1.3	-	-	-

RY, Relative yield; SYI, sustainable yield index spectively. Similarly, the relative yield for sunflower were 60, 55, 72, 56 and 60% for cyclic uses of 1 YCW : 2 YAW, 2 YAW : 1 YCW, 2 YCW : 1 YAW, 1 YAW : 2 YCW and AWp : CWs whereas 78 and 52% for blended waters in the ratio 2 CW : 1 AW and 1 CW : 2 AW respectively. The sustainable yield index (SYI) ranged from 0.56–0.94 to 0.40–0.76 for potato and sunflower, respectively, for various yearly modes (Table 2). The values of SYI (0.69–0.92) was higher for sesbania than potato and sunflower. Results of the present study further corroborate that cyclic use of good quality canal and poor quality alkali groundwater performs at par with their use in blended mode in same proportion when good quality canal water is applied initially.

Quality

The system productivity of different crop in potato–sunflower–sesbania cropping sequence given in Table 3. The maximum system yield was observed in all canal (CW) treatment and minimum in all alkali treatment. The other best treatments for system productivity were blending (2 CW + 1 AW) 42.73 t/ha, cyclic (2 YCW : 1 YAW) 40.42 t/ha, and cyclic (1 YCW : 2 YAW) 37.80 t/ha respectively. The rest treatments gave system yield in between for these treatments.

The water use efficiency (WUE) declined with reduced yields and sodicity development under various treatments (Table 3). For different treatments of CW and AW, WUE was found 944–162 kg/ha-cm for potato and 31.4–3.8 kg/ha-cm for sunflower. The highest WUE was estimated for all CW, whereas the lowest for all AW. Among different modes of combined use of alkali and canal waters, WUE was the highest in case of blending of canal and alkali waters in 2 CW : 1 AW for both potato (816 kg/ha-cm) and sunflower (24.8 kg/ha-cm) crops.

Quality of produce

The effect of sodicity build up in the soil profile due to combined use of alkali and canal water under different treatments were evaluated in terms of quality of potato and sunflower. The quality of potato was measured in terms of the tuber grade (A > 60 g, B 40–60 g and C < 40 g) and keeping quality (percentage weight loss in storage) and have been depicted in Fig.2. The quality of sunflower was measured in terms of size of sunflower seed (1,000-seed weight) and its oil content (percentage oil content) as

Table 3. Effect of modes of irrigation on system productivity (Mean data of 2 years)

Treatment	Potato yield (t/ha)	Sunflower yield (t/ha)	Sesbania yield (t/ha)	System yield (t/ha)
All canal water (CW)	28.63	1.32	19.93	49.88
All alkali water (AW)	4.38	0.16	6.98	11.52
Cyclic (1 YCW : 2 YAW)	19.06	0.79	17.95	37.80
Cyclic (2 YAW : 1 YCW)	15.15	0.72	17.42	33.28
Cyclic (2 YCW : 1 YAW)	22.65	0.96	16.81	40.42
Cyclic (1 YAW : 2 YCW)	17.32	0.74	15.07	33.12
Cyclic (AWp : CWs)	13.83	0.79	17.38	32.00
Blending (2 CW + 1 AW)	23.68	1.03	18.02	42.73
Blending (1 CW + 2 AW)	16.68	0.69	17.15	34.52

Table 4. Effect of modes of irrigation on water-use efficiency (WUE) of potato, sunflower and quality produce of sunflower (Mean data of 2 years)

Modes of irrigation	WUE (kg/ha-cm)		Quality of sunflower	
	Potato	Sunflower	1,000-seed weight (g)	Oil content (%)
All canal water (CW)	944	31.4	27.0	42.1
All alkali water (AW)	162	3.8	22.2	37.3
Cyclic (1 YCW : 2 YAW)	650	18.8	24.2	39.9
Cyclic (2 YAW : 1 YCW)	528	17.4	23.8	39.6
Cyclic (2 YCW : 1 YAW)	776	22.9	24.8	39.9
Cyclic (1 YAW : 2 YCW)	605	18.1	25.4	38.9
Cyclic (AWp : CWs)	473	19.4	24.3	39.6
Blending (2 CW + 1 AW)	816	24.8	25.7	40.7
Blending (1 CW + 2 AW)	573	16.8	24.4	39.8
SEm±	-	-	0.6	0.5
CD (P=0.05)	-	-	1.7	1.4

given in Table 3. It was observed that the small-grade potatoes (C grade), increased with the decline in yield under different treatments respectively. Storage quality of potato also deteriorated with AW irrigation (e.g. the potatoes shriveled with two-thirds weight loss (17.8%) on storage for 90 days under AW treatments, whereas the weight loss was just about two-fifths (8.2%) under CW). Similarly, the quality of sunflower produce was also poor with AW due to lower 1,000-seed weight and oil content. Our results confirm findings of Chauhan (2010) and Chauhan *et al.* (2011).

It can be concluded that the combined use of alkali and good quality canal waters can maintain the soil sodium saturation at relatively low levels, depending on the proportion of the 2 types waters. Amongst the various treatment options, the cyclic use should be preferred especially when canal waters are utilized for initial irrigations since it would have both operational and performance advantages over the blending of the water supplies. The use of alkali water should be avoided during the initial stages of crop growth.

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Research Paper

Performance of summer chilli (*Capsicum annum*)–watermelon (*Citrullus lanatus*) crop sequence under different irrigation regimes and fertigation levels under silver black polyethylene mulch

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ABSTRACT

The investigation was carried out in the year 2014 and 2015 at Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra), with summer chilli (*Capsicum annum* L.)–watermelon [*Citrullus lanatus* (Thunb). Mansf.] crop sequence to evaluate the response of irrigation regimes and fertigation levels under black polyethylene mulch. The experiment consisted of 12 treatment combinations with 4 irrigation regimes 70, 80, 90 and 100% of ETc and 3 fertigation levels 75, 100 and 125% of RDF. The treatments were replicated thrice in split-plot design. Control treatment with recommended package of practice and absolute control with recommended package of practice with no fertiliser for chilli and watermelon were grown separately. Black silver polyethylene mulch of 50 micron was used common to all the treatments, except control. Fertigation of N, P_2O_5 and K_2O was done as per growth stages for both the crops by using water soluble fertilizers. The yield contributing characters of chilli and watermelon were higher in irrigation regime of 100% Etc, but at par with irrigation regime of 90% ETc. Fertigation of 125% of RDF recorded higher yield contributing characters of chilli as well as watermelon, but was at par with fertigation of RDF in case of chilli. Irrigation regime of 100% Etc recorded maximum fruit yield of chilli (42.11 t/ha) and watermelon (43.39 t/ha), and it was at par with Irrigation regime of 90% Etc in case of chilli (41.61t/ha) and watermelon (42.12 t/ha). Fertigation of 125% of RDF recorded maximum fruit yield of chilli (42.79 t/ha) and watermelon (46.38 t/ha) and was at par with fertigation RDF in case of chilli yield (40.34 t/ha). In case of irrigation regime, the maximum chilli equivalent yield (57.47 t/ha) and net monetary returns/ha (₹11,37,000) were recorded with 100% Etc, while in case of fertigation level maximum chilli equivalent yield (59.18 t/ha) and net monetary returns (₹11,85,000) were recorded with 125% RDF.

Key words **:** Chilli, Crop sequence, Fertigation, Irrigation regimes, Mulch, Watermelon

Chilli is an important spice cum vegetable crop cultivated extensively in India. In Maharashtra chilli occupies an area of 0.99 lakh ha with 18.10 lakh tonnes of production (GoI, 2015). In recent years, apart from export of dry chilli (2,41,000 tonnes), value added products, viz. chilli powder and oleoresin are exported with the annual total revenue of about ₹1,304.4 crore (Anonymous 2011–12). It occupies 39% of the total volume of spice exports and 24% of the total exports earnings during 2014–15. Watermelon is cultivated in India on 74.6 thousand ha with production of 1809.9 thousand tonnes (GoI, 2015). The hot and dry climate along with irrigation provides excellent condition to obtain high yield and fruit quality of watermelon. Drought is the major inevitable and recurring feature of semi-arid tropics and despite our improved ability to predict their onset, duration and impact, crop scientists are still concerned about it as it remains the single most important factor affecting the yield potential of crops. Optimum use of water is of paramount importance being a scarce resource. Most of the water use in India is for irrigation, amounting to 94% of total withdrawal. With increasing demand of water for industrial and urban uses, the proportion of water use for irrigation will decline to 83% by 2025 AD. This needs an immediate attention towards the judicious application of water. This is possible only by following some scientific water management prac-

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tices. In agriculture, besides water nutrients are most critical inputs and their efficient management is important not only for higher productivity, but also for maintaining environmental quality. Limited supply of water necessitates a shift in the production objectives from attainment of potential yield per unit of land to potential yield per unit of water. Scarce water can be utilized efficiently only through high-tech irrigation system like drip irrigation. Applying the correct amount of water is particularly effective for high value crops like important vegetable as well as commercial crop. Applying plant nutrients along with irrigation water particularly with the drip system (termed as fertigation) is the most efficient way of nutrient application. The rapid development of trickle irrigation and fertigation systems in many parts of the world followed demands to minimize water loss in agriculture, which arose from the shortage of water caused by increasing house hold and industrial demands, and the urge to expand area under irrigation. Therefore, it is necessary to popularize the use of fertigation in vegetables for an efficient use of water and nutrients in eco-friendly manner.

MATERIALS AND METHODS

The experiment was conducted in year 2014 and 2015 at Irrigation Water Management Research Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra, situated between 19°47' and 19°57' N latitude and between 74°19' and 74°32' E and at the altitude of 495 to 555 m above the mean sea-level. The soil used for the experiment was clay and well drained. The soil physical properties viz., field capacity, permanent wilting point and bulk density were 34.4%, 19.4% and 1.32 g/cm^3 respectively. The soil chemical properties, viz. *p*H, EC of soil water suspension (1: 2.5) and organic carbon content were 7.99, 0.42 dS/m and 0.71%, respectively with low in available nitrogen (153.7 kg/ha), high in available phosphorous (20.3 kg/ha) and very high in available potassium (462.9 kg/ha). The average annual rainfall is 520 mm, which is mostly concentrated during monsoon months from June to October from south-west monsoon, which is nearly 80% of the total rainfall. The distribution of rainfall is erratic with 15 to 45 rainy days. The tract is under the rain shadow area lying on eastern sides of Western Ghats, agro-climatically falls under scarcity zone of Maharashtra.

The experiment consists of 12 treatment combinations with 4 irrigation regimes and three fertigation levels. Irrigation regimes consist of 70, 80, 90 and 100% of ETc, while fertigation levels consist of 75, 100 and 125% of RDF. The treatments were replicated three times in split-plot design. Control treatment with recommended package of practices for chilli as well as watermelon was grown separately. Absolute control with recommended package of practice with no fertiliser for chilli as well as watermelon was grown separately. Black silver polyethylene mulch of 50 micron was used common to all the treatments, except control and absolute control. Fertigation of N, P_2O_5 and K_2O was applied in equal quantity as per growth stages in fertigation treatments by using water soluble fertilizers (Table 1).

The transplanting of 15-days old seedlings of chilli hybrid 'sitara' and watermelon hybrid 'sugar queen' was done at spacing of 60 cm × 45 cm on 120 cm wide raised bed covered with black silver polyethylene mulch on March 27, 2014 and February 27, 2015 in case of chilli and on October 10, 2014 and September 15, 2015 in case of watermelon. Same layout along with black polyethylene mulch, which was used for summer chilli crop was utilized for growing watermelon crop by escaping the land preparation for watermelon. For control of weed between the two crops weedicide glyphosate was used. Resting period of one moth is kept in between two crops to avoid residual effect of weedicide.

Crop water productivity is calculated by using following formula

$$\text{Crop water productivity} = \frac{\text{Net income (₹/ha)}}{\text{Total water used (m}^3\text{/ha)}}$$

Equivalent yield of cropping sequence was calculated

Table 1. Scheduling of fertigation as per crop growth stages

Crop	Growth stages	Days	No of splits	Fertilisers in kg/ha		
				N	P	K
Chilli	Growth and branching	60	6	20	10	10.7
	Flowering	30	4	40	20	17.8
	Fruiting	60	6	40	20	21.4
	Total			100	50	50
Watermelon	Growth	15	2	25	12.5	11.5
	Flowering	30	4	50	25	23.1
	Fruiting	15	2	25	12.5	15.4
	Total			100	50	50

by using following formula

Chilli equivalent yield (t/ha)=

$$\text{Green chilli yield (t/ha)} + \frac{\text{Yield of watermelon (t/ha)} \times \text{market rate of watermelon (₹)}}{\text{Market rate of chilli (₹)}}$$

Production efficiency of cropping sequence was calculated by using following formula

$$\text{Production efficiency (kg/ha/day)} = \frac{\text{Green chilli equivalent yield (kg/ha)}}{\text{Total duration of cropping sequence (days)}}$$

RESULTS AND DISCUSSION

Performance of component crops

In case of summer chilli, irrigation regime of 100% ETc produced significantly higher number of fruits/plant (287), fruit weight/plant (1,089g) and green fruits yield (42.11 t/ha) as compared to irrigation regimes of 70% of ETc (Table 2). While, in case of late rainy season (*kharif*) watermelon, irrigation regime of 100% of ETc produced significantly higher number of fruits/vine (1.40), fruit weight/vine (2.34 kg) and fruit yield (43.39 t/ha) as compared to irrigation regimes of 70% of ETc (Table 2). Average fruit length and unit fruit weight in case of summer chilli and unit fruit weight in case of watermelon (Table 2) were not influenced due to the different irrigation regimes. The higher irrigation regime maintained the soil moisture at field capacity throughout the crop period, which enhanced all the growth attributes of the both the crops. More growth attributes resulted in maximum absorbed photosynthetic radiation. This enhanced the rate of photosynthesis and dry-matter accumulation. All these resulted in improve the number of fruits and fruit weight/plant in both the crops owing to efficient translocation of photosynthates towards reproductive parts. All irrigation regimes under study recorded higher number of fruits, fruit weight/plant and fruit yield in case of summer chilli and watermelon as compared to control (recommended practice). Sezen *et al.* (2006) observed decrease in bell paper yield attributes and yield with decrease in the amount of irrigation water applied. Gadissa and Chemeda (2009) recorded maximum values of yield and yield components in case of green paper with higher irrigation level. Similar findings were reported by Hatutale (2010), Choudhary and Bhambri (2012) and Abayomi *et al.* (2012) in case of chilli. While, Kirnak and Dogan (2009) observed the highest yield of watermelon from full irrigated treatment, where as lower ET rates and irrigation amounts in water stress treatments resulted in reductions in all measured

Table 2. Effect of different treatments on yield attributes and yield of green chilli and water melon (mean data of 2 years)

Treatment	Green chilli					Water melon			
	Green fruits/ plant	Green fruits weight/ plant (g)	Unit fruit weight (g)	Average fruit length (cm)	Fruit yield (t/ha)	Fruits/ vine	Fruits weight/ vine(kg)	Unit fruit weight (kg)	Fruit weight (t/ha)
Irrigation regimes									
I_1, 70% ETc	258	919	3.63	9.59	36.41	1.28	2.07	1.62	38.35
I_2, 80% ETc	283	1,049	3.65	9.66	39.86	1.32	2.11	1.60	39.08
I_3, 90% ETc	286	1,076	3.75	9.84	41.61	1.36	2.27	1.67	42.12
I_4, 100% ETc	287	1,089	3.86	9.88	42.11	1.40	2.34	1.67	43.39
SEm±	7.4	37	0.13	0.15	1.20	0.02	0.06	0.02	1.05
CD (P=0.05)	22.7	114	NS	NS	3.70	0.08	0.18	NS	3.24
Fertigation levels									
F_1, 75% RDF	251	925	3.66	9.53	36.86	1.18	1.91	1.62	35.46
F_2, 100% RDF	279	1044	3.78	9.77	40.34	1.36	2.18	1.61	40.36
F_3, 125% RDF	305	1129	3.73	9.92	42.79	1.49	2.50	1.69	46.38
SEm±	11.5	39	0.11	0.10	1.24	0.03	0.05	0.02	1.02
CD (P=0.05)	33.2	112	NS	0.30	3.58	0.09	0.16	0.07	2.93
Interaction									
SEm±	23.1	78.1	0.22	0.21	2.48	0.06	0.11	0.05	2.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm±	20.2	73.7	0.22	0.22	2.36	0.06	0.11	0.04	1.97
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
General mean	278	1,033	3.72	9.74	40.00	1.34	2.20	1.64	40.73
Control (RP)	163	538	3.65	8.59	21.30	0.72	0.99	1.41	18.75
Absolute control (NF)	144	439	3.60	8.17	16.89	0.68	0.78	1.18	14.37

RP, Recommended practice; NF, no fertilizer; RDF, recommended dose of fertilizer; ETc, crop evapotranspiration parameters. The highest yield and most of fruit traits of melon was obtained by Sensoy *et al*. (2007) from the treatment employing the greatest frequency and quantity of irrigation.

The fertigation at 125% of RDF produced significantly higher number of fruits/plant (305.1), fruit weight/plant (11,29.8 g) and average fruit length (9.9 cm) in case of summer chilli as compared to fertigation at 75% of RDF (Table 2). Unit fruit weight in case of summer chilli was not influenced significantly due to the different fertigation levels. In case of watermelon, fertigation at 125% of RDF recorded significantly higher number of fruits/vine (1.49), fruits weight/vine (2.50) and unit fruit weight (1.69 kg) as compared to fertigation at 100% and 75% of RDF (Table 2). This can be explained on the basis that split application of water soluble fertiliser to both the crops saves fertilizer nutrients as it permits applying for fertilizer in small quantity at a time matching with the plants nutrient need. This contributes to an improved availability of moisture, nutrients, and uniform distribution of fertigated nutrients in the crop root zone throughout the growth stages leading to better uptake of nutrients. This might favoured in increasing growth attributes resulted in better chlorophyll development and higher stomatal conductance reflected in higher photosynthetic rate. This further led to more photosynthates, which translocated to the sinks leading to more and heavier fruits subsequently leading to higher yield in both the crops. All fertigation levels under study recorded higher number of fruits, fruit weight/plant and fruit yield in case of summer chilli and watermelon as compared to control (recommended practice). This is in agreement with the findings of Khan *et al.* (2010), who reported significant increase in plant height and branches/plant of chilli at harvest owing to increase in dose of nitrogen fertilizer. Further, Bhuvaneswari *et al.* (2013) recorded more plant height and fruits/plant of chilli at final harvest with higher nitrogen fertilizer dose. Furthermore, the findings of watermelon are collaborated by Feleafel *et al*. (2014), they observed that the application of 125% of recommended NPK resulted in the highest significant mean values for the per cent fruit setting, number fruits/plant, and fruit yield in case of cucumber. Further, Maluki *et al*. (2015) recorded improved growth, yield and quality of watermelon in the coastal region of Kenya with higher dose of nitrogen and phosphorous fertilizers.

Chilli equivalent yield and production efficiency

Irrigation regime of 100% ETc recorded significantly higher chilli equivalent yield (57.47 t/ha) and production efficiency (188.9 kg/ha/day) for summer chilli–water-

Table 3. Effect of different treatments on system productivity water productivity and economics of chilli–watermelon and economics of summer chilli-watermelon sequence (mean data of 2 years)

Treatment	Chilli equivalent yield (t/ha)	Production efficiency (kg/ha/day)	Total water applied (cm-ha)	Water productivity (₹/m³)	Cost of cultivation (× 10³₹/ha)	Net monetary returns (× 10³₹/ha)	Benefit: cost ratio
Irrigation regimes							
I_1, 70% ETc	49.89	163.9	42.6	220.5	494	941	2.74
I_2, 80% ETc	53.63	176.2	47.8	217.5	499	1042	2.89
I_3, 90% ETc	56.51	185.8	53.1	209.8	504	1115	3.02
I_4, 100% ETc	57.47	188.9	58.5	194.5	509	1137	3.05
SEm±	1.35	4.4	–	–	–	38	–
CD (P=0.05)	4.16	13.7	–	–	–	117	–
Fertigation levels							
F_1, 75% RDF	49.33	162.0	50.5	183.2	491	926	2.69
F_2, 100% RDF	54.61	179.5	50.5	210.8	502	1065	2.93
F_3, 125% RDF	59.18	194.5	50.5	234.4	512	1185	3.14
SEm±	1.19	3.9	–	–	–	35	–
CD (P=0.05)	3.43	11.2	–	–	–	100	–
Interaction							
SEm±	2.38	7.8	–	–	–	70	–
CD (P=0.05)	NS	NS	–	–	–	NS	–
SEm ±	2.37	7.8	–	–	–	68	–
CD (P=0.05)	NS	NS	–	–	–	NS	–
General mean	54.37	178.7	50.5	210.6	502	1059	2.92
Control (RP)	27.89	91.5	132.3	32.3	377	428	1.98
Absolute control (NF)	22.04	72.5	132.3	22.5	331	299	1.75

RP, Recommended practice; NF, no fertilizer; RDF, recommended dose of fertilizer; ETc, crop evapotranspiration melon crop sequence as compared to irrigation regime of 70% Etc (Table 3). Yield performance of both the crops was better at liberal irrigation regime resulted in higher chilli equivalent yield and production efficiency. Fertigation at 125% RDF recorded significantly higher chilli equivalent yield (59.18 t/ha) and production efficiency (194.9 kg/ha/day) for summer chilli–watermelon crop sequence as compared to fertigation at 75 and 100 % RDF (Table 3). Both the crops individually reported higher yield at higher fertigation level, which reflected in higher chilli equivalent yield and production efficiency.

Water productivity

Irrigation regimes of 70% ETc produced numerically higher water productivity, while irrigation regimes of 100% ETc resulted numerically low water productivity for summer chilli–watermelon crop sequence (Table 3). In drip irrigation method, irrigation water was applied every day based on crop evapotranspiration in restricted area directly in the vicinity of crop root zone, which minimize the water losses in evaporation and deep percolation. Therefore, the total water requirement was more in surface irrigation than drip irrigation method. However, all the irrigation regimes applied through drip method registered higher water productivity compared to surface irrigation method. Though the total quantity of water applied was more in surface method, the outcome in terms of fruit yield was low because of losses of soil moisture as a deep percolation and evaporation as compared to drip irrigation method. In drip irrigation method, higher fruit yield was obtained with less quantity of water, which resulted in increase in water productivity. The findings are in conformity with Choudhary *et al.* (2012). They reported significantly higher WUE when the chilli crop was exposed to drip irrigation at 0.6 Epan. The highest water-use efficiency in case red hot paper was obtained by Mahajan *et al.* (2007) with drip irrigation at 0.5 Epan as compared to 1.0 Epan with considerable saving of irrigation water compared to check basin method of irrigation. Simsek and Comlekcioglu (2011) reported that WUE in case of melon (*Cucumis melo* L.) increased with decrease in amount of water. Similarly, Fernandes *et al.* (2014) observed the highest water-use efficiency (177.13 kg/ha/mm) in case of watermelon when irrigation was daily and parceled (DPI) compared to more interval irrigation treatments.

Fertigation at 125% RDF recorded numerically higher water productivity, while fertigation at 75% RDF produced numerically low water productivity for summer chilli–watermelon crop sequence (Table 3). This higher water productivity may be due to higher fruit yield in the aforesaid fertigation level with the same quantity of moisture. These results are in accordance with Mahajan *et al.* (2007), who recorded higher water use efficiency in case of chilli with higher level of nitrogen fertilizer. Similarly Ramachandrappa *et al*. (2010) observed higher water-use efficiency when fertigation was applied in the form of MAP and KNO_3 at 125% RDF in case of chilli.

Economics

Irrigation regime of 100% ETc recorded significantly more net monetary returns (₹11,37,000/ha) for summer chilli-watermelon crop sequence as compared to irrigation regime of 70% Etc (₹9,41,000/ha) (Table 3). Numerically higher benefit: cost ratio (3.05) was reported by irrigation regime of 100% ETc. This may be because of higher irrigation regime through drip maintained the soil moisture always at field capacity throughout crop growth period resulting maximum absorption of moisture and nutrients, which favoured important growth and yield attributes, which ultimately resulted in increase on chilli and watermelon fruit yield and gross and net monetary returns. The results are in confirmatory with the findings Choudhary and Bhambri (2012).

The fertigation at 125% RDF recorded significantly higher net monetary returns (₹11,85,000/ha) for summer chilli–watermelon crop sequence than fertigation at 75% RDF (₹9,26,000/ha) and fertigation level of 100% RDF (₹10,65,000/ha) (Table 3). Numerically higher benefit: cost ratio (3.14) was reported by fertigation levels of 125% RDF. In fertigation nutrients are applied in vicinity of the root zone with uniformity and in limited required quantity throughout crop growth period. This increases the nutrient-use efficiency. These results are in line with Brahma *et al*. (2010). Similarly, Ramachandrappa *et al*. (2010) observed that net returns/ha was significantly higher with Urea, SSP, MOP at 125% RDF fertigation (₹69,237/ha) and significantly lower in soil application of Urea, SSP, and MOP at 75% RDF (₹36,015/ha). Brahma *et al*. (2014) noticed higher benefit cost ratio (1:6.86) in case of winter season capsicum with higher fertilizer dose of N and K at Johrat, Assam.

The surface irrigation with recommended dose of fertilizers produced lower chilli equivalent yield and production efficiency in summer chilli–watermelon crop sequence due to lower fruit yield in both the crops, and thereby obtained lower gross and net monetary returns as well as benefit: cost ratio than mean gross, net monetary returns and also benefit: cost ratio of different irrigation regimes and fertigation levels treatments. The results are confirmatory with the findings i.e. net returns and benefit: cost ratio were less with flood irrigation as reported by Choudhary and Bhambri (2012) in case of capsicum (*Capsicum annum* L.).

From pooled analysis of component crops and cropping sequence the irrigation regime of 100% ETc and fertigation at 125% RDF applied in split according to growth stages of component crops, recorded higher yield of individual component crop, system production efficiency, net monetary returns of crop sequence/ha and benefit: cost ratio of crop sequence.

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Research Paper

Contribution of microbial inoculation and zinc-fertilization to growth and yield of rice (*Oryza sativa*) under different cultivation methods in a sub-tropical and semi-arid type climate

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ABSTRACT

A field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during rainy season of 2013–14 and 2014–15 in sandy clay loam soil to verify and validate the contribution of 2 microbial inoculations and zinc (Zn) fertilization on growth, yield and economics of rice (*Oryza sativa* L.). Rice variety 'Pusa Sugandh 5' was grown under 3 methods of cultivation, viz. puddled transplanted rice (PTR), system of rice intensification (SRI) and aerobic rice system (ARS) and 4 nutrient management options, viz. recommended dose of nutrients (RDN) ($N_{120}P_{25.8}$), 75% RDN, 75% RDN + *Anabaena sp.* (CR1) + *Providencia sp.* (PR3) and 75% RDN + *Anabaena- Pseudomonas* (An-Ps) biofilmed formulation with and without Zn (5 kg Zn/ha through $ZnSO_4.7H_2O$). Thus making total eight nutrient management options along with one absolute control ($N_0P_0Zn_0$). Results of 2 year study revealed that, microbial inoculation of An-Ps biofilmed formulation with 75% RDN increased number of tillers/m^2 by 16 and 13 with Zn and by 12 and 10 without Zn in first and second year, respectively. Increase in shoot dry matter due to CR1 + PR3 consortia with 75% RDN was 40.6 and 36.3 g/m^2 with and without Zn in first and 31.4 and 28.6 g/m^2 with and without Zn in second year, respectively. Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing grain yield was 0.29 and 0.30 t/ha with and without Zn and same for CR1 + PR3 consortia was 0.28 and 0.30 t/ha with and without Zn, respectively. Aerobic method saved 6,000 and 9,640 ₹/ha as compared to PTR, while SRI saved 3,440 and 5,800 ₹/ha as compared to PTR in first and second year, respectively. Contribution of microbial inoculation of An-Ps biofilmed formulation in increasing net returns was 7,500 and 7,670 ₹/ha with and without Zn and same for CR1 + PR3 consortia was 7,350 and 7,660 ₹/ha with and without Zn, respectively.

Key words **:** Aerobic rice system, Biological nitrogen fixation, Rice, System of rice intensification, Zinc fertilization

Rice is dietary and protein currency of Indian and world populations as it provide staple food of more than 50% of the world's population and supplies 20 and 31% of total calories required by world and the Indian population, respectively (Zeigler and Barclay, 2008). Any variation in input resources and output from rice paddies has impact on large population. Even in era of diversification of crop and human diet, rice till date play a pivotal place in human dietary intake. As rice grain shaped the cultures, diets and economies of billions of people in the world and in India, its complete replacement was difficult to: i) avoid losses of resources in rice production system like water and nutrient, ii) avoid adverse impact of rice production system on environment like greenhouse gas emission and degrading inherent soil resources and iii) to improve nutrient fact such as Zn in human diet. In such situation diversifying rice cultivation methods from puddled transplanted rice (PTR) to system of rice intensification (SRI) and aerobic rice system (ARS) is one among other possible options. Along with cultivation methods, diversification in nutrient sources also helps producer in several ways if the sources are economically viable and ecologically sustainable. Use of microbial inoculations containing biological nitrogen fixation (BNF) systems and phosphorus solubilising bacteria (PSB) in combination with chemical fertilizer need to

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be objectively assessed in crop production. Along with major nutrients, fertilization of rice crop with Zn has positive impact on rice yield (Shivay *et al*., 2015) and also improves Zn content in rice grain which helps in alleviating Zn deficiency, which rank fifth among the most important health risk factor in developing countries and eleventh globally (Palmgren *et al*., 2008). With this background, the present study was conducted to verify and validate contribution of 3 resource diversification techniques on rice growth and yield, viz. contribution of less water requiring ARS and SRI to rice yield in comparison to PTR, contribution of BNF and PSB to rice yield and contribution of Zn fertilization to rice yield.

MATERIALS AND METHODS

A field experiment was conducted during rainy season for 2 consecutive years (2013–14 and 2014-15) on the Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi located at 28°38' N, 77°10' E, 228.6 m above the mean sea-level. The climate of Delhi is of subtropical and semi-arid type with hot and dry summer and cold winter and falls under the agro-climatic zone 'Trans-Gangetic plains'. The mean annual normal rainfall is 650 mm, with July and August as the wettest months and annual mean pan evaporation of about 850 mm. Weather condition prevailing during both rice growing seasons were different. Total rainfall received in first and second year during rice growing season was 1,349.8 mm and 451.4 mm, which was higher by 699.8 mm in first year and lower by 198.6 mm in second year than mean annual normal rainfall (650 mm). Evaporation losses during first and second rice growing season were 806 mm and 1075.1 mm respectively. This indicates that weather condition was not much favourable for growth and development of rice in second year of experiment. The soil of experimental field was sandy clay loam in texture having *p*H 7.6, organic carbon 0.54% and available N, P, K and DTPA-extractable Zn of 257 kg/ha, 17 kg/ha, 327 kg/ha and 0.85 mg/kg, respectively.

The experiment involving rice variety 'Pusa Sugandh 5' was executed in split-plot design comprised of 3 main-plots as a methods of rice cultivation, viz. Puddled transplanted rice (PTR), System of rice intensification (SRI) and Aerobic rice system (ARS) with 9 nutrient management options as sub-plot treatments. Sub-plot treatments consisted of four treatments, viz. recommended dose of nutrients (RDN) ($N_{120}P_{25.8}$), 75% RDN, 75% RDN + *Anabaena sp.* (CR1) + *Providencia sp.* (PR3) and 75% RDN + *Anabaena-Pseudomonas* (An-Ps) biofilmed formulation with and without Zn, thus making total 8 treatments along with 1 absolute control ($N_0P_0Zn_0$). Potassium (K) was applied uniformly at the rate of 49.8 kg K/ha as basal dose. In case of Zn soil application of 5 kg Zn/ha through Zn sulphate heptahydrate was applied in both rice crops. Sowing of rice in main field for ARS and sowing rice in nursery for transplanting in both PTR and SRI was done on same date. For ARS, direct sowing of seed (seed rate 60 kg/ha) was done with spacing of 20 cm between 2 rows using seed-drill. In SRI, 1 healthy seedling of 14-days old were transplanted/hill at a spacing of 20 cm × 20 cm, whereas in PTR, 2 healthy seeding of 25-days old, were transplanted/hill at a spacing of 20 cm × 15 cm. For application of microbial inoculants, a thick paste of respective culture was made and applied to rice seedling in PTR and SRI method of rice cultivation by dipping roots in paste of respective culture for half an hour before transplanting. In direct seeded rice pre-soaked seeds were treated with thick paste of culture made in carboxyl methyl cellulose. Nitrogen was split applied in all treatments irrespective of dose at sowing, 30 days after sowing (DAS) and 60 DAS in ARS and 5 days after transplanting (DAT), 25 DAT and 55 DAT in both PTR and SRI. In case of P, K and Zn all dose as per treatment details was applied at the time of sowing/transplanting. For weed management hand weeding was done twice (20 and 40 DAT) in PTR and SRI and thrice (15, 30 and 45 DAS) in ARS and use of herbicide was avoided on the ground of adverse impact on inoculated microbial population. Irrigation was given to maintain soil water level at field capacity in ARS and in SRI irrigation was applied to maintain saturated field condition. In PTR, 5 cm depth of water was applied in each irrigation after complete disappearance of water.

Plant tillers were counted from randomly selected one meter square area from each plot at harvest. For measurement of above ground shoot dry matter air dried plant samples were further dried in a hot air oven at $60^{o}\pm2^{o}C$ temperature till constant weight was obtained and expressed in g/m^2. Rice panicle characteristics and yield attributes were measured from a sample of 10 panicles drawn at random from each plot at harvesting. The net plots were harvested and sun-dried in the field and then weighed to record the total biomass yield. Rice grain yield was measured after cleaning and drying. Weighing of the grain was done at 14% moisture content, while straw yield was calculated by subtracting grain yield from the total biomass yield. Zinc (Zn) concentration in rice were determined as per the procedure described by Prasad *et al*. (2006) using Atomic Absorption Spectrophotometer (AAS) and uptake was computed by multiplying Zn concentration with grain and straw yields. Gross and net returns were calculated based on grain and straw yields and their prevailing market prices and benefit: cost ratio was calculated by dividing net returns by cost of cultivation. All the data obtained from the experiment were statistically analysed using the F-test as per the standard statistical procedure (Gomez and Gomez, 1984) and least significant difference (LSD) values ($P = 0.05$) were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Biometric parameters

Effective tillers/m^2 in SRI (346/m^2 and 321/m^2) was statistically superior to PTR in both years even though plant population in SRI was lower than PTR (Table 1). Tillers in PTR were significantly higher than ARS and ARS stand statistically inferior to both PTR and SRI in both years. Significantly lower number of effective tillers/m^2 was reported (Hugar *et al*., 2009) in aerobic method than SRI. Tillers were higher in first year with the highest variation between first and second year in control (59 tillers/m^2), while variation in rest of treatments were 18–22 tillers/m^2. This indicates that adverse impacts of high temperature during establishment and low rainfall on growth of rice were more on control and adequate fertilization of rice able to reduce this impact. Among nutrient management options, the highest tillers/m^2 were recorded in RDN + Zn which were remained on a par with 75% RDN+ An-Ps biofilmed formulation + Zn and 75% RDN + CR1+ PR3 + Zn. These 3 treatments recorded significantly higher tillers/m^2 than same treatments without Zn application, which indicates that Zn fertilization had positive effect on tillers/m^2. The contribution of Zn fertilization was the highest with 75% RDN + CR1 + PR3 + Zn (9.7 and 8.2 tillers/m^2 in first and second year, respectively) and the lowest in RDN + Zn (8.6 and 6.9 tillers/m^2 in first and second year respectively). Increase in tillers/m^2 due to Zn fertilization was also observed by Shivay *et al*. (2015).

Shoot dry matter accumulation also followed similar trend as that of the tillers/m^2 in all 3 cultivation methods and nutrient management options. SRI had significantly higher dry matter than both PTR and ARS. Dry matter in PTR was statistically superior to ARS. Significantly higher dry matter in both mechanical and manual transplanting than direct dry seeded rice was reported in study conducted by Singh *et al*. (2005). Among years, first year recorded higher dry matter than second year. Variation between years was the highest in control (120 g/m^2) and in rest treatments it was 108 to 112 g/m^2. Contribution of microbial inoculation of An-Ps biofilmed formulation to dry-matter production was 41.2 and 32.0 g/m^2 with and without Zn in first and 36.6 and 30.1 g/m^2 with and without Zn in second year and same for CR1 + PR3 consortia was 40.6 and 36.3 g/m^2 with and without Zn in first and 31.4 and 28.6 g/m^2 with and without Zn in second year. Lower contribution during second year in both inoculations indicates that, performance of applied inoculations lower in adverse weather condition prevailing in second year of experiment. Performance of both microbial inoculations was better with Zn fertilization during both years as mentioned-above. A significant enhancement in plant biomass was also recorded (Prasanna *et al*., 2012) in treatments involving combined inoculation with bacterial and cyanobacterial strains in pot experiments.

Yield attributing characters

Panicle length, filled spikelets, weight/panicle, filled spikelets/panicle and spikelet fertility percentage (%) in SRI and PTR was significantly higher than ARS in the both years (Table 1). Higher numbers of panicles/hill and grains/panicle in SRI method was reported in Wahlang *et al*. (2015); while significantly lower spikelets/panicle in ARS compared to PTR was also mentioned Mallareddy and Padmaja (2013). Unfilled grains were significantly lower in both PTR and SRI than ARS. Among nutrient management options, RDN + Zn recorded the highest value for panicle length, filled grains weight/panicle, filled spikelets/panicle and fertility percentage, which remained on a par with 2 treatments, viz. 75% RDN + An-Ps biofilmed formulation + Zn and 75% RDN + CR1 + PR3 + Zn. These three treatments stand statistically superior to all other treatments in yield attributes as discussed above. Unfilled spikelets were significantly lower in above-mentioned 3 treatments than rest of nutrient management options.

Contribution of SRI and PTR to increase filled spikelets weight/panicle was 0.30 g and 0.25 g/panicle in first year and 0.26 g and 0.22 g/panicle in second year as compared to ARS, respectively. The contribution of Zn fertilization to filled spikelets weight/panicle was the highest in RDN + Zn (0.36 g and 0.22 g/panicle in first and second year respectively) and the lowest in 75% RDN + Zn (0.14 g and 0.13 g/panicle in first and second year, respectively). Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing filled spikelets weight/panicle was 0.40 and 0.36 g/panicle with and without Zn in first year and 0.31 and 0.50 g/panicle with and without Zn in second year and same for CR1 + PR3 consortia was 0.35 and 0.33 g/panicle with and without Zn in first year and 0.28 and 0.27 g/panicle with and without Zn in second year. Increase in panicle weight due to application of different combination of PR3 and PR7 (both *Providencia sp.*), CR1, CR2 and CR3 (*Anabaena sp.*) was also recorded by Prasanna *et al.* (2012). Contribution of SRI method to increase the filled spikelets was 1.4 and 1.5 spikelets/panicle than PTR in first and second year respectively and 9.9 and 10 spikelets/panicle than ARS in first and second year respectively.

Table 1. Influence of cultivation methods and nutrient management options on biometric parameters and yield attributes of rice

Treatment	Effective tillers/m²		Shoot dry-matter accumulation at 100 DAS (g/m²)		Panicle length (cm)		Filled spikelets weight/panicle (g)		Filled spikelets/panicle		Unfilled spikelets/panicle		Fertility percentage (%)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Methods of cultivation														
Puddled transplanted rice	342.9	318.0	705.9	593.6	27.4	25.7	2.71	2.48	125.6	115.0	36.1	34.0	77.4	76.8
System of rice intensification	346.0	321.4	711.2	598.2	27.7	25.9	2.76	2.52	127.0	116.5	35.7	33.9	77.9	77.2
Aerobic rice system	334.6	310.3	691.3	581.3	25.7	23.9	2.46	2.26	117.1	106.5	38.6	36.8	74.9	74.0
SEm±	0.69	0.72	1.35	1.18	0.17	0.08	0.030	0.022	0.73	0.59	0.22	0.20	0.19	0.16
CD (P=0.05)	2.69	2.84	5.29	4.62	0.68	0.30	0.118	0.087	2.87	2.31	0.86	0.80	0.75	0.63
Nutrient management options														
Control ($N_0P_0Zn_0$)	282.1	222.3	592.9	472.9	19.8	17.8	1.94	1.62	94.2	81.7	44.3	42.4	67.9	65.7
RDN ($N_{120}P_{25.8}$)	349.5	328.8	718.2	606.5	27.9	26.2	2.64	2.50	128.3	118.4	35.6	33.7	78.2	77.8
RDN + Zn (5 kg Zn/ha)	358.1	335.7	738.0	626.4	29.7	27.8	3.00	2.72	138.6	123.1	32.8	31.1	80.8	79.8
75% RDN ($N_{90}P_{19.35}$)	334.7	316.4	683.1	575.6	25.1	23.1	2.41	2.18	110.1	101.2	39.9	37.7	73.4	72.8
75% RDN + Zn	340.2	321.7	693.8	585.1	26.3	24.9	2.55	2.31	116.8	109.1	38.0	36.2	75.4	75.1
75% RDN + CR1 + PR3	346.3	326.6	714.5	604.3	27.4	25.7	2.69	2.45	124.8	117.9	36.4	34.7	77.4	77.2
75% RDN + CR1 + PR3 + Zn	356.0	334.8	734.4	621.4	29.2	27.4	2.90	2.64	135.0	122.3	33.8	32.1	79.9	79.2
75% RDN + An-Ps biofilmed formulation	347.0	327.1	715.1	605.7	27.6	25.7	2.72	2.68	125.7	118.0	36.5	34.4	77.4	77.4
75% RDN + An-Ps biofilmed formulation + Zn	356.3	335.2	735.0	621.7	29.3	27.5	2.95	2.67	135.5	122.5	33.7	31.8	80.0	79.4
SEm±	1.85	1.68	3.58	3.09	0.32	0.20	0.044	0.041	1.34	1.29	0.44	0.41	0.33	0.35
CD (P=0.05)	5.27	4.79	10.18	8.79	0.90	0.58	0.124	0.116	3.81	3.67	1.24	1.16	0.95	1.01

RDN, recommended dose of nitrogen; 120 kg/ha and phosphorus, 25.8 kg P/ha; Zn, soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

The contribution of Zn fertilization to filled spikelets/panicle was the highest in RDN + Zn (10.3 and 4.7 filled spikelets/panicle in first and second year, respectively) and the lowest in 75% RDN + Zn (6.7 and 7.9 filled spikelets/panicle in first and second year, respectively). This indicates that, optimum dose of N and P is needed to achieve better response of Zn application. Contribution of Zn fertilization to increasing spikelets/panicle was also reported by Shivay *et al.* (2015). Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing filled spikelet was 18.7 and 15.2 numbers of filled spikelets/panicle with and without Zn in first year and 13.4 and 16.8 numbers of filled spikelets/panicle with and without Zn in second year and same for CR1 + PR3 consortia was 18.2 and 14 numbers of filled spikelets/panicle with and without Zn in first year and 13.2 and 16 numbers of filled spikelets/panicle with and without Zn in second year. Contribution of both microbial inculcations was higher in first year than second year which indicates that inculcation did not perform well in second year having low rainfall and higher evaporative demand due to intense high temperature.

Grain, straw and biological yields

Grain, straw and biological yields were the highest in SRI method, which remained on a par with PTR and both these methods stand superior to ARS (Table 2). Statistically identical grain yield in SRI and PTR was reported by Chapagain *et al.* (2011), while in another study Hugar *et al.*, (2009) found that higher grain yield in SRI than ARS. Among nutrient management options, the highest yield was recorded in RDN + Zn, which were statistically identical with 2 treatments, viz. 75% RDN + An-Ps biofilmed formulation + Zn and 75% RDN + CR1 + PR3 + Zn. These 3 treatments were found statistically superior than rest of the treatments in both year. Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing grain yield was 0.29 and 0.30 t/ha with and without Zn in first year and 0.33 and 0.21 t/ha with and without Zn in second year and same for CR1 + PR3 consortia was 0.28 and 0.30 t/ha with and without Zn in first year and 0.33 and 0.19 t/ha with and without Zn in second year. Improvement in yield due to application of CR2, CR1 (both *Anabaena* sp.) and PR10 (*Ochrobacterium* sp.) with two-third nitrogen was also recorded in Prasanna *et al.* (2012). The contribution of Zn fertilization to increasing grain yield was 0.14 and 0.22 t/ha in first and second year, respectively with RDN, while contribution with 75% RDN was 0.17 and 0.08 t/ha in first and second year respectively. Contribution of Zn to increase grain yield with 75% RDN + CR1+ PR3 was 0.15 and 0.22 t/ha and with 75% RDN + An-Ps biofilmed formulation was 0.16 and 0.20 t/ha in first and second year respectively. Increase in grain yield due to Zn fertilization was also reported by Shivay *et al.* (2015).

Economics

Cost of cultivation: Contribution of ARS for saving of cultivation cost was 6,000 and 9,640 ₹/ha in first and second year as compared to PTR, while contribution of SRI to saving of cultivation cost was 3,440 and 5,800 ₹/ha as compared to PTR (Table 2). Lower cost of cultivation in dry direct seeding of rice than transplanted rice was also observed in a study conducted by Singh *et al.* (2005). Contribution of microbial inoculation to saving of cultivation cost was 190 and 200 ₹/ha in first and second year, respectively. Though saving in cultivation cost was less, yield improvement due to microbial inoculation increased gross returns and ultimately reflected in net returns. Application of Zn increase cost of cultivation by 830 ₹/ha in all Zn applied treatment as rate, source and method of application was same in all treatments.

Gross and net returns and benefit: cost ratio:

Gross returns in PTR and SRI were the higher than ARS by 4,160 and 4,170 ₹/ha in first year and 4,540 and 4,540 ₹/ha in second year respectively, which was mainly due to higher yield in both PTR and SRI methods (Table 2). Contribution of Zn fertilization to increase in gross returns with 75% RDN + CR1 + PR3 was 4,100 and 6,090 ₹/ha and with 75% RDN + An-Ps biofilmed formulation was 4,240 and 5,540 ₹/ha in first and second year respectively, which was higher than extra cost of Zn application (830 ₹/ha). Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing gross returns was 7,690 and 7,860 ₹/ha with and without Zn in first year and 9,140 and 5,830 ₹/ha with and without Zn in second year and same for CR1 + PR3 consortia was 7,540 and 7,850 ₹/ha with and without Zn in first and 9,140 and 5,280 ₹/ha with and without

Table 2. Influence of cultivation method and nutrient management options on yield, returns and zinc uptake of rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Gross returns (× 10^3 ₹/ha)		Net returns (× 10^3 ₹/ha)		Benefit: cost ratio		Cost of cultivation (× 10^3 ₹/ha)		Total Zn uptake (g/ha)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Methods of cultivation														
Puddled transplanted rice	4.08	3.95	7.30	7.07	112.5	109.0	66.0	53.0	1.42	0.95	46.51	55.96	474.2	445.9
System of rice intensification	4.10	3.97	7.30	7.08	112.8	109.4	69.8	56.8	1.62	1.08	43.07	52.51	477.2	449.9
Aerobic rice system	3.93	3.80	7.02	6.79	108.3	104.8	67.6	58.5	1.66	1.26	43.43	46.32	429.3	400.3
SEm±	0.016	0.010	0.025	0.017	0.34	0.281	0.34	0.28	0.008	0.005	-	-	3.34	1.64
CD (P=0.05)	0.061	0.040	0.099	0.069	1.33	1.104	1.33	1.10	0.031	0.021	-	-	13.10	6.46
Nutrient management options														
Control ($N_0P_0Zn_0$)	3.28	3.10	6.35	5.96	91.4	86.3	50.5	37.3	1.25	0.77	40.84	48.97	340.4	304.1
RDN ($N_{120}P_{25.8}$)	4.16	4.00	7.34	7.09	114.4	110.1	70.7	58.3	1.62	1.13	43.70	51.87	478.6	449.7
RDN + Zn (5 kg Zn/ha)	4.30	4.22	7.52	7.50	118.1	116.2	73.6	63.5	1.66	1.22	44.53	52.7	511.3	493.3
75% RDN ($N_{90}P_{19.35}$)	3.82	3.76	6.96	6.64	105.5	103.5	62.4	52.2	1.45	1.03	43.09	51.26	417.9	386.6
75% RDN + Zn	3.99	3.84	7.13	6.79	109.9	105.7	66.0	53.6	1.51	1.04	43.92	52.09	443.3	409.3
75% RDN + CR1 + PR3	4.12	3.95	7.29	7.00	113.3	108.8	70.0	57.3	1.62	1.12	43.28	51.46	467.2	438.1
75% RDN + CR1 + PR3 + Zn	4.27	4.17	7.47	7.41	117.4	114.8	73.3	62.6	1.67	1.21	44.11	52.29	502.7	483.2
75% RDN + An-Ps biofilmed formulation	4.12	3.97	7.30	7.03	113.3	109.3	70.1	57.8	1.62	1.13	43.28	51.49	471.2	440.5
75% RDN + An-Ps biofilmed formulation + Zn	4.28	4.17	7.50	7.41	117.6	114.8	73.5	62.6	1.67	1.21	44.11	52.29	509.7	483.7
SEm±	0.031	0.021	0.042	0.037	0.705	0.590	0.70	0.59	0.016	0.011	-	-	4.09	2.71
CD (P=0.05)	0.088	0.061	0.121	0.106	2.004	1.677	2.00	1.67	0.045	0.031	-	-	11.62	7.70

RDN, Recommended dose of nitrogen 120 kg/ha and phosphorus 25.8 kg P/ha; Zn, soil applied 5 kg Zn/ha through zinc sulphate heptahydrate

Zn in second year, respectively.

Net returns were significantly higher in SRI as compared to ARS due to higher yield in SRI, while net returns in ARS were significantly higher than PTR due to lower cost of cultivation in ARS during first year. In second year of study, ARS recorded significantly higher net returns than SRI and both ARS and SRI stand superior to PTR due to lower cost of cultivation in both ARS and SRI. Higher net returns in SRI over PTR were also reported in Jat *et al.* (2015). Among nutrient management options, contribution of Zn fertilization to increase in net returns with 75% RDN + CR1 + PR3 consortia was 3,270 and 5,260 ₹/ha and with 75% RDN + An-Ps biofilmed formulation was 3,410 and 4,710 ₹/ha in first and second year respectively. The benefit: cost ratio in both years was significantly higher in ARS as compared to both SRI and PTR. Among nutrient management options, both Zn fertilization and microbial inoculation contributed significantly to increase in benefit: cost ratio. Contribution of microbial inoculation of An-Ps biofilmed formulation to increasing benefit: cost ratio was 0.16 and 0.17 with and without Zn in first year and 0.17 and 0.10 with and without Zn in second year and same for CR1 + PR3 consortia was 0.16 and 0.17 with and without Zn in first and 0.17 and 0.09 with and without Zn in second year.

Zinc uptake

Total Zn uptake of rice was significantly higher in SRI and PTR than ARS in both years. Total Zn uptake in SRI was 47.9 and 49.6 g/ha higher than ARS, while in PTR it was 44.9 and 45.6 g/ha higher than ARS in first and second year, respectively. The highest uptake of Zn was recorded in RDN + Zn which remained on a par with 75% RDN + An-Ps biofilmed formulation + Zn and 75% RDN + CR1 + PR3 + Zn. These 3 treatments recorded significantly higher uptake than same treatment without Zn application. Increase in Zn uptake due to Zn fertilization was also recorded by Shivay *et al*. (2015). Contribution of Zn fertilization to improving uptake was the highest in 75% RDN + An-Ps biofilmed formulation + Zn (38.5 and 43.2 g/ha in first and second year respectively) and it was the lowest in 75% RDN (25.4 and 22.7 g/ha in first and second year respectively). This indicates the importance of Zn fertilization and importance of optimum fertilization of nitrogen and phosphorus in improving Zn uptake.

From the data presented above and discussion it can be concluded that, Zn fertilization and microbial inculcation contributed significantly to growth and yield of rice. The study verified that contribution of Zn fertilization and microbial inoculation to rice growth and yield was also reflected in gross and net returns of rice in both years. Involvement of An-Ps biofilmed formulation or CR1 + PR3 consortia with 75% RDN found a valid nutrient management option for rice. SRI method gave similar yield and higher net returns and hence can be adopted in place of PTR. Aerobic method even though gave lower yield, net returns was higher than PTR in both years and can be a valid option in low resource condition.

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Research Paper

Evaluation of rice (*Oryza sativa*) cultivars under different crop establishment methods to enhance productivity, profitability and energetics of rice in middle Indo-Gangetic Plains of India

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ABSTRACT

Field investigation was undertaken at the ICAR-Research Complex for Eastern Region, Patna to evaluate the performance of nine promising rice (*Oryza sativa* L.) genotypes ('IR83387-B-B-40-1', 'Shusk Samrat', 'Abhishek', 'IR82870 11', 'Sahbhagi Dhan', 'CR Dhan 40', 'IR84899-B-183-CRA-19-1', 'IR83387-B-B-27-4' and 'IR83376-B-B-24-2') under 2-crop establishment methods i.e. puddle transplanted rice (PTR) and unpuddled transplanted rice (UPTR) during the rainy (*kharif*) seasons of 2013 and 2014. Results showed that PTR produced significantly higher grain yield (4.20 t/ha) than UPTR (3.29 t/ha). Among the rice genotypes, 'IR83387-B-B-27-4' (4.38 t/ha) being on par with 'IR83387-B-B-40-1' (4.20 t/ha) recorded significantly higher grain yield over rest of the genotypes. The maximum net returns (25.9×10^3 ₹/ha) and benefit : cost ratio (1.98) were recorded with PTR. Among the rice genotypes, 'IR83387-B-B-27-4' had significantly the highest net returns (34.8×10^3 ₹/ha) and benefit: cost ratio (2.33). UPTR gave the highest energy efficiency, energy productivity and energy profitability (1.9, 0.06 kg/MJ and 0.9 MJ/ha) than PTR (1.5, 0.05 kg/MJ and 0.50 MJ/ha). Hence, growing of rice genotypes 'IR83387-B-B-27-4' and 'IR83387-B-B-40-1' under PTR condition is better option to obtain the maximum productivity and profitability in this region.

Key words: Crop establishment methods, Economics, Energetics, Rice genotypes, Yield

Rice is the most important staple food crop for more than half of the world's population and provides about 21% of the total calorie intake (Parameswari *et al.*, 2014). In India, rice occupies an area of 43.8 million ha with a production of 105 million tonnes with average productivity of 2.2 tonnes/ha. Demand for rice growing is increasing every year and it is estimated that requirement would be 140 million tonnes by 2025 AD. To sustain the present food self-sufficiency and to meet the future food requirement, India has to increase the rice productivity by 3% per annum. The conventional method of crop establishment in rice is manual transplanting of rice seedlings into puddle soil that requires large amount of water, energy and labour, which are becoming increasing scarce and expensive (Mishra and Singh, 2012). Besides, continuous puddling for rice cultivation over decades has led to deterioration of soil physical properties through structural breakdown of soil aggregates and capillary pores and clay dispersion, thereby restricting germination and rooting of succeeding crops. Alternatively, rice can be transplanted under unpuddled condition (UPTR), in which rice seedlings are transplanted in standing water (5±2 cm) without puddling. This practice saves significant amount of power, fuel, time and water which is a major resource constraint in future. However, this method is subjected to more weed infestation than PTR because weed growth is faster in the absence of puddling (Kumar *et al*., 2016). Energy is one of the most valuable inputs in production agriculture system. Agriculture itself is energy user and energy supplier in the form of bio-energy (Kumar *et al.,* 2015a). Sufficient availability of the right energy and its effective and efficient use are prerequisites for improved agricultural production. Energy analysis, therefore, is necessary for efficient man-

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agement of scarce resources for improved agricultural production. Hence, the evaluation and identification of responsive rice genotypes with respect to crop establishment methods is cost effective and safe approach to sustain the rice productivity, particularly by resources poor farmers of this region (Kumar *et al*., 2016). It is therefore, imperative to identify the suitable crop establishment methods and efficient rice genotypes, which can minimize the consumption of time, fuel energy, money and labour with sustainable productivity of entire rice-cropping in the middle Indo-Gangetic Plains. Farmers of the region mainly grow puddle transplanted rice with traditional genotypes; hence crop yields are low, however, quantum of resources used per unit of production is very high. Rice is a semi-aquatic plant and uses approximately 3000-5000 liters of water to produce 1 kg of rice under puddled condition. Sustaining rice production under decreasing water availability and shrinking land area is becoming major challenge under Indo-Gangetic Plains of India. Therefore, it is imperative to identify the high yielding genotypes of rice, which can withstand better in scarce resources without compromising the yield. Hence, the present investigations were undertaken.

MATERIALS AND METHODS

Field experiments were conducted during the rainy (*kharif*) seasons of 2013 and 2014 at the ICAR Research Complex for Eastern Region, Patna (25º30‘N”, 85º15‘E” and 52 m above mean sea-level). Soil at the experimental site was clay loam in texture (42.1% sand, 35.2% silt and 22.7% clay), low in organic carbon (0.49%) and nitrogen (216 kg N/ha), medium in available phosphorus (22.7 kg P_2O_5/ha) and potassium (215 kg K_2O/ha). The treatments comprised of two crop establishment methods, viz. puddled transplanted rice (PTR) and unpuddled transplanted rice (UPTR) in the main plot and nine rice genotypes including four drought tolerant released varieties, viz. ‘Sahbhagi Dhan’, ‘Sushk Samrat’, ‘CR Dhan 40’, ‘Abhishek’, and five advanced breeding lines. (‘IR84899-B-183-CRA-19-1’, ‘IR83387-B-B-40-1’, ‘IR82870-11’, ‘IR83387-B-B-27-4’ and ‘IR83376-B-B-24-2’) as subplots and replicated thrice in a split-plot design. The details of rice genotypes are described in Table 1. The size of each plot was 25 m^2 (5m×5m). In order to ensure the proper seed germination, seed priming (overnight soaking of seed followed by drying in shades before sowing) was done before nursery raising. Seeds were treated with bavistin fungicide at 2.0 g/kg seed before sowing in the nursery. Nursery for puddled transplanted rice (PTR) and unpuddled transplanted rice (UPTR) was prepared by using a modified mat nursery method using seed rate of 30 kg seed/ha. 21-days old seedlings were transplanted by scooping single seedling. Proper care was taken to transplant the seedlings within half an hour of scooping from the nursery to avoid transplanting shock. Farmyard manure @ 10 t/ha was applied 15 days prior of transplanting to the main field. Recommended dose of fertilizer of 120-60-40-25 kg N-P-K-Zn/ha were applied uniformly in the

Table 1. Characterizations of the rice genotypes used for the trials

Rice genotype	Pedigree	Year of release and place	Grain type	Plant height (cm)	DFF (days)	Maturity duration (days)
‘Sahbhagi dhan’	IR 55419-04*2. Way Rarem (IR 55419-04 (IR 12979-24-1 (Brown)/ UPRLRi5)	2009, CRURRS Hazaribagh	Long bold	100–110	85–90	110–115
‘Shusk samrat’	C 1064-5/Kalari/IR 54	2007, NDUAT, Faizabad	Long slender	95–100	80–85	105–110
‘CR dhan 40’	N 22/RP 20-5	2008, CRURRS Hazaribagh	Short bold	105–115	70–75	100–105
‘Abhishek’	CR 314-5-10 (Open Florat mutant)	2007, CRURRS Hazaribagh	Short bold	95–100	90–95	120–125
‘IR 84899-B-183-CRA-19-1’	IR78877-208-B-1-1 × IRRI 132	Advanced breeding lines	Short bold	110–115	85–90	115–120
‘IR 83387-B-B-40-1’	IR 72022-46-2-3-3-2/ SambhaMahsoori	Advanced breeding lines	Long bold	105–110	85–90	115–120
‘IR 82870-11’	IR 82851-16/IR 82855-9	Advanced breeding lines	Long bold	90–95	90–95	120–125
‘IR 83387-B-B-27-4’	IR72022-46-2-3-3-2 × SambhaMahsuri	Advanced breeding lines	Long bold	90–95	85–90	115–120
‘IR 83376-B-B-24-2’	IR 71700-247-1-1-2/IR 77080-B-34-1–1	Advanced breeding lines	Long slender	100–105	85–90	115–120

CRURRS, Central rainfed upland rice research station; NDUAT, Narendra Dev University of Agriculture and Technology; DFF, days to 50% flowering field through urea, di-ammonium phosphate (DAP), muriate of potash (MOP) and $ZnSO_4$. Half dose of N and full dose of P, K and Zn were applied as basal and remaining half dose of N were applied in 2 equal-splits at maximum tillering and panicle initiation stages. Weeds were controlled through pre-emergence application of butachlor 1.5 kg/ha at 3–4 days after transplanting (DAT) followed by post-emergence application of bispyribac-sodium @ 30 g/ha at 4–6 leaf stage (25–30 DAT) and one hand weeding at 50 DAT. Total rainfall received during cropping season (June-November) was 715.7 and 911.5 mm in 2013 and 2014 respectively (Fig. 1). Mean monthly maximum and minimum temperature varied from 37.3 to 28.4°C and 27.6 to 14.3°C, respectively.

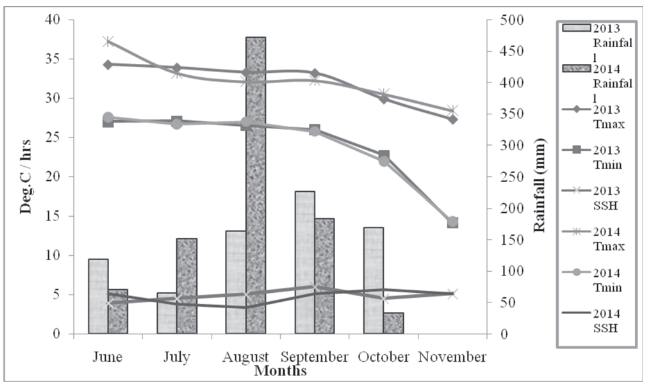

Fig. 1. Weather parameters during the experimentation

All the growth and yield attributes, viz. plant height, number of green leaves, dry matter, panicles/hill, panicle length and grains/panicle were recorded at maturity from randomly selected five hills in each plot following standard procedures. Chlorophyll content was measured at 75 DAT (days after transplanting) as suggested by Hiscox and Israelstam (1979) and expressed as mg/g dry weight. Rate of photosynthesis was measured on fully expanded flag leaves using portable Infrared Gas Analyzer (IRGA LI-6400 Model, LICOR, USA) and expressed as µmol/m²/second. Economics of rice was calculated based on minimum support price (MSP) declared by the Government of India. Net income was calculated as difference between gross income and total cost of cultivation. Benefit: cost ratio was worked out by dividing the gross returns with cost of cultivation. Crop productivity (kg/ha/day) and economic efficiency (₹/ha/day) was calculated as suggested by Kumawat *et al*., (2012). Economic yield of crops was converted into equivalent value of carbohydrate (t/ha) as suggested by Gopalan *et al*. (2004). Energy fluxes of crop were estimated using crop management (machinery operation and amount of input used) and biomass production record. To study the energy input and output of crop and establishment method, a complete inventory of all crop inputs (fertilizers, seeds, plant protection chemicals, fuels, human labour and machinery power) and outputs of both main and by-products was taken into account. Inputs and outputs were converted from physical to energy unit measures through published conversion coefficients (Devasenapathy *et al.,* 2009 and Tuti *et al*., 2012). The field data obtained for 2 years were pooled and statistically analysed using F-test (Gomez and Gomez, 1984). Significant difference between treatments mean were compared with critical differences at 5% levels of probability.

RESULTS AND DISCUSSION

Growth attributes

The data on growth attributes, viz. plant height; green leaves, dry matter production and tillers/m² were markedly influenced with crop establishment methods (Table 2 and Fig. 2). Significantly higher plant height was recorded with UPTR (98.9 cm) as compared to PTR (93.3 cm). The no. of green leaves/meter row was higher with PTR (345) compared to UPTR (309). However, plant height and green leaves/meter row often been described as one of most important factors for weeds competitive ability of crop (Kumar *et al*., 2016). Similarly, PTR recorded significantly higher dry matter production as compared to UPTR at all the stages of crop growth. Maximum dry matter was produced at maturity with PTR (102.6 g/hill) compared to UPTR (94.2 g/hill). The per cent increase of dry matter production of PTR over UPTR was 8.91%. This could be ascribed to vigorous and deeper root system of PTR as compared to UPTR that led to the better crop growth and development (Kumar *et al*., 2015). However, physiological attributes like days to maturity; photosynthesis rate and chlorophyll content were significantly higher with PTR compared to UPTR. Irrespective of the genotypes, UPTR matured early (105 days) as compared to PTR (111 days). This might be owing to less time taken by UPTR to complete its metabolic activities under water stress during their cropping period.

All the growth attributes of rice were markedly influenced by the genotypes (Table 2 and Fig. 2). Among the genotypes, maximum plant height was recorded with 'IR83387-B-B-40-1' (109.4 cm) and minimum with 'Abhishek' (88.4 cm). Number of green leaves/m row at 75 DAT was recorded significantly higher with 'IR82870-11'. Rice genotypes 'IR84899-B-183-CRA-19-1' took significantly less number of days to 50% flowering (80 days) as compared to 'IR83387-B-B-40-1' that took 95 days. Rice genotypes 'IR82870-11' (106 days) and 'Shusk Samrat' (108 days) matured early. Chlorophyll content was significantly higher with 'IR83376-B-B-24-2' (3.96 mg/g), which was statistically similar with 'IR83387-B-B-27-4'

Table 2. Growth and yield attributes of rice genotypes at harvest as influenced by different establishment method (pooled data of 2 years)

Treatment	Plant height (cm)	Green leaves/m row*	Days to 50% flowering	Days to maturity	Tillers/m² (no.) at flowering	Chlorophyll content (mg/g)*	Photosynthetic rate (µmol/m²/S)*	Panicle length (cm)	Grains/ panicle (no.)	Grain filling (%)	1,000-grain weight (g)
Crop establishment method											
PTR	93.3	345	90	111	266	3.62	23.4	24.3	177.3	84.4	23.8
UPTR	98.9	309	91	105	237	3.31	21.7	22.5	169.5	84.1	23.2
SEm±	1.23	8.3	1.2	1.75	7.2	0.28	0.5	0.9	5.7	1.9	0.9
CD (P=0.05)	5.05	29.2	NS	5.1	21.3	0.93	1.4	NS	NS	NS	NS
Genotypes											
'IR 83387-B-B-40-1'	109.4	343	95	114	279	3.65	23.4	25.0	185.9	84.2	23.6
'Sushk Samrat'	88.8	311	89	109	246	3.31	21.2	22.1	178.0	86.5	22.7
'Abhishek'	98.0	338	92	113	280	3.38	22.3	20.9	181.7	86.5	23.2
'IR 82870–11'	90.7	375	86	106	287	3.84	23.4	23.7	176.6	85.8	23.6
'Sahbhagi Dhan'	88.4	306	89	115	243	3.50	23.4	25.5	172.5	81.9	22.6
'CR Dhan 40'	93.7	318	84	111	227	3.46	23.0	26.3	173.4	81.0	20.6
'IR 84899-B-183-CRA-19-1'	90.3	324	80	108	249	2.82	20.0	21.7	180.6	83.2	21.0
'IR 83387-B-B-27-4'	93.4	354	91	115	295	3.92	24.3	26.7	192.7	85.9	25.1
'IR 83376-B-B-24-2'	90.4	275	93	118	223	3.93	22.0	23.3	173.8	80.8	24.8
SEm±	1.03	6.8	1.0	1.37	9.2	0.08	0.5	0.5	4.7	1.5	0.2
CD (P=0.05)	3.07	20.3	3.1	4.1	27.5	0.22	1.2	1.5	14.0	4.4	0.7

*At 75 DAT; PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

(3.92 mg/g) and 'IR82870-11' (3.84 mg/g). Irrespective of crop establishment methods, the highest photosynthetic rate was observed with 'IR83387-B-B-27-4' (24.32 µmol/m²/S), being on a par with 'IR83387-B-B-40-1' and 'Sahbhagi Dhan'. However, the lowest rate of photosynthetic rate was recorded with 'IR84899-B-183-CRA-19-1' followed by 'Shusk Samrat'. This might be due to increase in chlorophyll content vis correlated with an increase in net photosynthetic rate (Ibrahim *et al*., 2011).

Yield attributes and yield

The yield attributes, viz. panicle length, grains/ panicle, grain filling (%) and 1,000-grain weight was markedly influenced with the establishment methods (Table 2). Panicle length was recorded higher with PTR (24.28 cm) compared to UPTR (22.5 cm). Other yield attributes such as Grains/panicle, grain filling (%) and 1,000-grain weight were recorded higher with PTR, but it could not reach the levels of significance. Kumar *et al.* (2016) also reported that higher grain filing (%) with PTR was owing to effective crop management, which reduced the grain sterility. Significantly higher grain yield (3.75 t/ha), straw yield (4.76 t/ha) and biological yield (8.51 t/ha) were recorded with PTR as compared to UPTR (Table 2). The grain yield difference of PTR over UPTR was 16.5%. It was probably due to higher growth and yield attributes caused by better nutrient absorption from the soil, increased rate of metabolic process, rate of light absorption and photosynthetic activity as compared to other establishment method (Kumar *et al*., 2015b). The crop productivity was significantly higher with PTR (33.5 kg/ha/day) compared to UPTR (28 kg/ha/day) (Table 3). This might be due to higher grain yield with PTR as compared to UPTR. Similarly, higher values of carbohydrate equivalent yield were noted with PTR (2.93 t/ha) as compared to UPTR (2.52 t/ha). This might be due to higher yields associated with the PTR.

The yield attributes of rice were significantly influenced by the genotypes (Table 2). Rice genotype 'IR83387-B-B-27-4' (26.7 cm) being at par with 'CR Dhan 40' (26.3 cm) and Sahbhagi Dhan (25.5 cm) produced the longest panicle and 'Abhishek' (20.8 cm) produced the shortest. Grains/panicle was significantly higher with 'IR83387-B-B-27-4' (192.6) followed by 'IR83387-B-B-40-1' (185.8), 'Abhishek' (181.6) and 'IR84899–B–183–CRA–19–1' (180.5), which were at par with each others. The lowest grains/panicle (172.4) was recorded with 'Sahbhagi Dhan'. However, grain filling (%) was significantly

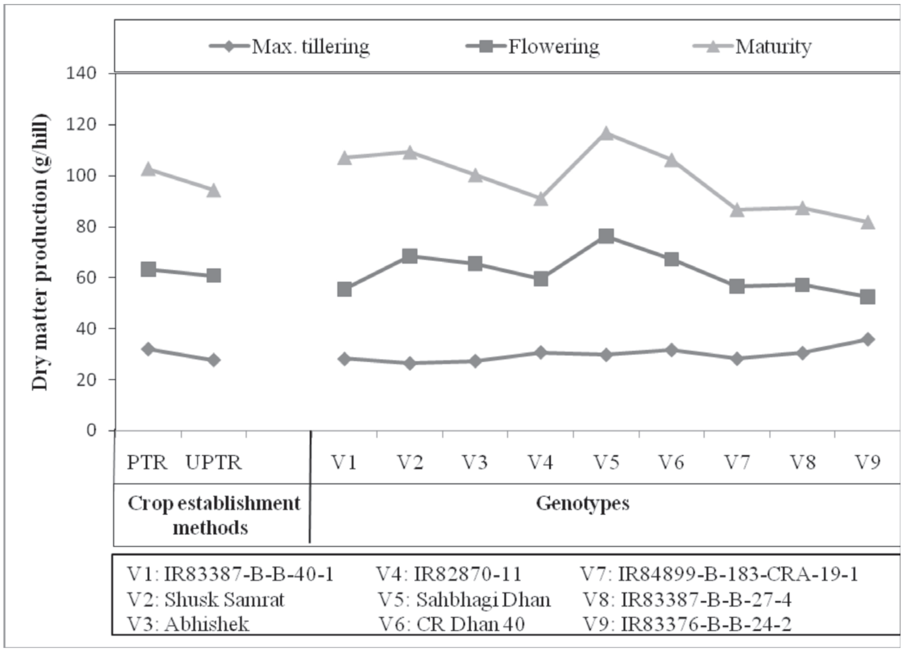

Fig. 2. Dry-matter production of rice genotypes at different stage as influenced by crop establishment method (pooled data of 2 years)

higher with 'Sushk Samrat' (86.5%), but it was noted statistically similar with 'Abhishek' (86.5%), 'IR83387-B-B-27-4' (85.8%) and 'IR82870-11' (85.7%). Grain filling percentage is one of the major yield components and it might be higher due to conversion of source to sink in effectively and insufficient moisture condition and higher weed growth with respective treatment (Kumar *et al.*, 2016). Significantly higher 1,000-grain weight was associated with 'IR83387-B-B-27-4' (25.1 g), but it was noted statistically at par with 'IR83376-B-24-2' (24.8 g). Rice genotype 'IR83387-B-B-27-4' performed significantly better in terms of grain yield (4.38 t/ha), straw yield (5.56 t/ha) and biological yield (9.94 t/ha) compared to rest of the promising genotypes but it was statistically at par with 'IR83387-B-B-40-1' (Table 3). This might be due to the better growth attributes i.e. plant height and leaf-area index, resulted in better suppression of the weeds growth as compared to other genotypes and produced more yield attributes and ultimately higher grain yield. Interaction effect of crop establishment methods and genotypes on grain yield was not significant (Table 4). The crop productivity was significantly higher with 'IR83376-B-B-24-2' (37.8 kg/ha/day) but it was statistically similar with 'IR83387-B-B-40-1' (36.5 kg/ha/day). This might be due to higher yields noted with respective genotypes, which is a genetic charterer. Significantly higher values of the carbohydrate equivalent yield was noted with the rice genotypes 'IR83387-B-B-27-4' (3.42 t/ha).This might be due to the higher yield associated with the respective genotypes.

Economics

Maximum gross returns (52.1×10^3₹/ha), net income (25.9×10^3₹/ha) and benefit: cost ratio (1.98) were recorded with PTR, which was found to be significantly higher than UPTR (44.8×10^3₹/ha, 18.4×10^3₹/ha and 1.73) (Table 3). The PTR had noted 16.4% and 36.6% higher gross and net income over UPTR due to higher grain yield. Among the rice genotypes, 'IR83387-B-B-27-4' had recorded the significantly highest gross returns and net returns (60.9×10^3₹/ha and 34.8×10^3₹/ha) and benefit: cost ratio (2.33). Rice genotype 'IR83376-B-B-24-2' had the lowest gross and net returns and benefit: cost ratio (35.1×10^3₹/ha, 9.4×10^3₹/ha and 1.34) because of its lower yield with the respective genotypes (Table 3). Sale prices of produce for different genotypes were same, thus, difference in net returns was largely due to variation in yield and crop management. The economic efficiency was significantly higher with PTR (₹230.8 ha/day) compared to UPTR (₹167.7 ha/day). This might be owing to higher yield and net returns associated with the respective treatment. Similarly, higher economic efficiency was noted with 'IR83387-B-B-27-4' (₹300.5 ha/day) as compared to rest of the genotypes, but it was statistically similar with 'IR83387-B-B-40-1' (₹281.1 ha/day).

Energetics

Comparison of traction power, time, fuel and time saving, CO_2 emission and consumption of equivalent energy use pattern in different crop establishment methods of rice

Table 3. Yield attributes, yield and economics of rice genotypes as influenced by different establishment method (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Gross returns (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio	Crop productivity (kg/ha/day)	Economic efficiency (₹/ha/day)	Carbohydrate equivalent (t/ha)
Crop establishment method									
PTR	3.75	8.51	44.1	52.1	25.9	1.98	33.5	230.8	2.93
UPTR	3.22	7.31	41.1	44.8	18.9	1.73	28.0	164.7	2.52
SEm±	0.09	0.15	1.8	0.9	0.9	0.05	0.6	8.2	0.05
CD (P=0.05)	0.40	0.90	NS	5.5	5.5	0.21	3.6	49.9	0.31
Genotype									
'IR 83387-B-B-40-1'	4.20	9.53	44.0	58.4	32.3	2.23	36.5	281.1	3.28
'Sushk samrat'	3.29	7.48	42.1	45.8	19.8	1.75	29.8	178.9	2.58
'Abhishek'	3.61	8.19	43.1	50.2	24.1	1.92	31.6	210.9	2.82
'IR 82870-11'	3.27	7.41	44.1	45.4	19.3	1.74	30.4	180.3	2.55
'Sahbhagi dhan'	3.50	7.94	44.0	48.6	22.5	1.86	30.1	194.0	2.73
'CR Dhan 40'	3.12	7.08	44.1	43.3	17.3	1.66	27.6	153.4	2.44
'IR 84899-B-183-CRA-19-1'	3.49	7.92	44.1	48.5	22.4	1.85	31.8	204.5	2.73
'IR 83387-B-B-27-4'	4.38	9.94	44.1	60.9	34.8	2.33	37.8	300.5	3.42
'IR 83376-B-B-24-2'	2.53	5.73	42.1	35.1	9.0	1.34	21.2	76.0	1.97
SEm±	0.07	0.16	0.8	0.9	0.9	0.03	0.6	8.4	0.05
CD (P=0.05)	0.19	0.44	NS	2.7	2.7	0.10	1.7	24.1	0.15

PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

(Table 5) revealed that highest traction power (5), time (15 hr) and fuel consumption (52.5 litres), CO_2 emission (136.5 kg) and consumption of equivalent energy use (2961.9 MJ/ha) were consumed under PTR. However, the lowest traction power (3), time (9 hr), fuel consumption (31.5 litres), CO_2 emission (81.9 kg) and consumption of equivalent energy (1,773.8 MJ/ha) were consumed with UPTR. In respect to fuel, time and CO_2 emission saving, UPTR saves 66.7% as compared to PTR. Similar findings were reported by Bohra and Kumar (2015) in their field investigation.

Table 4. Interaction effect of crop establishment methods and genotypes on grain yield (pooled data of 2 years)

Rice genotype	Grain yield (t/ha)		Mean
	PTR	UPTR	
'IR 83387-B-B-40-1'	4.48	3.92	4.20
'Sushk samrat'	3.56	3.03	3.29
'Abhishek'	3.90	3.32	3.61
'IR 82870-11'	3.53	3.00	3.27
'Sahbhagi Dhan'	3.78	3.21	3.50
'CR Dhan 40'	3.37	2.86	3.12
'IR 84899-B-183-CRA-19-1'	3.77	3.20	3.49
'IR 83387-B-B-27-4'	4.63	4.13	4.38
'IR 83376-B-B-24-2'	2.73	2.32	2.53
Mean	3.75	3.25	3.49
CD (P=0.05)	Establishment (E) =0.40;	Genotypes (G) =0.28	E×G=NS

PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

Comparison of energy use pattern (Table 6) in different crop establishment method revealed that the highest input energy (76.2×10³ MJ/ha) was consumed under PTR compared to UPTR (51.7×10³ MJ/ha). Higher energy consumption under PTR due to more traction operation with the respective treatment (Bohra and Kumar, 2015). However, output energy was significantly higher with PTR (114.6×10³ MJ/ha) compared to UPTR (98.5×10³ MJ/ha). Significantly higher net energy returns (46.8×10³ MJ/ha), energy ratio (1.906) and energy productivity (0.062 kg/MJ) and energy profitability (0.906) were associated with UPTR over PTR. Human energy profitability was recorded the maximum with PTR (46.45) as compared to

Table 5. Traction power, time and fuel consumption and saving, CO_2 emission and consumption of equivalent energy in rice under different crop establishment methods

Crop establishment methods	Tractor operation (number of pass)	Time (hr/ha)	Fuel consumption (litres)	Fuel saving (%)	Time saving (%)	CO_2 emission (kg/ha)	Consumption of equivalent energy (MJ/ha)
PTR	5	15	52.5	–	–	136.5	2,961.9
UPTR	3	9	31.5	66.7	66.7	81.9	1,773.8

Table 6. Energy input-output relationship of genotypes with crop establishment methods

Treatment	Input energy ($\times10^3$ MJ/ha)	Output energy ($\times10^3$ MJ/ha)	Net energy returns ($\times10^3$ MJ/ha)	Energy ratio	Energy productivity (kg/MJ)	Energy profitability (MJ/ha)	Human energy profitability	Energy output efficiency (MJ/ha/day)	Energy intensiveness (MJ/₹/ha)
Crop establishment method									
PTR'	76.2	114.6	38.4	1.50	0.049	0.50	46.45	1023	2.64
UPTR	51.7	98.5	46.8	1.90	0.062	0.90	32.52	857	1.58
SEm±	–	2.1	2.1	0.06	0.002	0.06	1.58	18	–
CD (P=0.05)	–	12.1	12.1	0.20	0.007	0.20	4.54	84	–
Genotype									
'IR 83387-B-B-40-1'	64.0	128.3	64.4	2.05	0.067	1.05	40.28	1117	2.11
'Sushk samrat'	64.0	100.7	36.7	1.60	0.053	0.60	44.13	912	2.11
'Abhishek'	64.0	110.3	46.3	1.76	0.058	0.76	39.94	965	2.11
'IR 82870-11'	64.0	99.8	35.9	1.59	0.052	0.59	42.77	930	2.11
'Sahbhagi dhan'	64.0	106.9	43.0	1.70	0.056	0.70	38.13	919	2.11
'CR Dhan 40'	64.0	95.3	31.4	1.52	0.050	0.52	42.66	845	2.11
'IR 84899-B-183-CRA-19-1'	64.0	106.6	42.7	1.70	0.056	0.70	53.52	971	2.11
'IR 83387-B-B-27-4'	64.0	133. 9	69.9	2.15	0.070	1.15	30.89	1155	2.11
'IR 83376-B-B-24-2'	64.0	77.2	13.3	1.23	0.040	0.23	23.02	647	2.11
SEm±	–	2.0	2.0	0.02	0.001	0.003	0.88	15	–
CD (P=0.05)	–	6.0	6.0	0.09	0.003	0.09	2.28	53	–

PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

UPTR (32.52). Energy output efficiency was significantly higher with PTR (1023 MJ/ha/day) as compared to UPTR (857 MJ/ha/day). Similarly energy effectiveness was higher with PTR (2.647 MJ/₹/ha) over UPTR (1.58 MJ/₹/ha). This might be due to higher energy-use efficiency under particular crop establishment method was mainly attributed to higher energy production with less use of energy (Kumar *et al.,*2017).

With respect to rice genotypes, output energy was recorded significantly higher with 'IR 83387-B-B-27-4' (133.9×10^3 MJ/ha) as compared to rest of the genotypes but it was found statistically at par with 'IR 83387-B-B-40-1' (128.3×10^3 MJ/ha). Similarly, significantly higher net energy returns (69.9×10^3 MJ/ha), energy ratio (2.15) and energy productivity (1.15 kg/MJ) were associated with 'IR 83387-B-B-27-4'. Further, human energy profitability was recorded markedly higher with 'IR84899-B-183-CRA-19-1' (53.52) amongst the tested genotypes. Rice genotype 'IR 84899-B-183-CRA-19-1' (1155 MJ/ha/day) being at par with 'IR 83387-B-B-40-1' (1,117 MJ/ha/day) and produced significantly higher energy-use efficiency over rest of the genotypes. However, higher energy use efficiency of rice genotypes was mainly attributed to higher yields with use of lesser energy.

Hence, the present study suggest that advanced breeding lines 'IR 83387-B-B-27-4' and 'IR 83387-B-B-40-1' having the higher yield potential achieved the more monetary returns when planted with puddle transplanted rice in middle Indo-Gangetic Plains of India.

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Research Paper

Effect of irrigation and methods of weed management on weed dynamics and yield of summer rice (*Oryza sativa*) under system of rice intensification

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ABSTRACT

A field experiment was conducted during the summer season of 2014 and 2015 to study the effect of irrigation and methods of weed management on weed dynamics, yield and nutrient uptake of rice (*Oryza sativa* L.) under system of rice intensification (SRI). Application of 50 mm water on the day before weeding operation was significantly superior to saturation (15 mm) on the day before weeding operation for grain yield (5.5 t/ha) owing to the lowest weed density (172.2/m^2), weed dry weight (76.1 g/m^2), and the highest number of panicles/plant (35.1) and filled grains/panicle (94). Pre-emergence application of pretilachlor @750 g/ha at 3 days after transplanting (DAT) followed by post-emergence application of chlorimuron ethyl + metsulfuron methyl @ 4 g/ha at 20 DAT proved to be most effective in minimizing the density of weeds (139.8/m^2), their dry weight (65.5 g/m^2) and enhancing weed-control efficiency (57.6%), grain yield (5.6 t/ha), N-P-K uptake of 66.1, 20.2, 23.0 kg/ha respectively by grain, net returns (52,714₹/ha) and benefit: cost ratio (3.35).

Key words **:** Chlorimuron + metsulfuron, Pretilachlor, System of rice intensification, Water application method, Weed-control efficiency, Weed density, Weed dry weight, Yield

Rice is not an aquatic plant and does not necessarily require flooding for producing best yields. However, conventional rice cultivation practices around the world involve the continuous flooding and maintain standing water in rice field from transplanting till 15–20 days before maturity (Dass *et al*., 2015). This leads to yield loss as well as huge water losses from rice fields through evaporation, seepage and deep percolation resulting in low water productivity. System of rice intensification (SRI) offers efficient use of limited water and gives higher yield. In SRI, cycles of repeated wetting and drying were found beneficial to rice plant growth through increased nutrient availability leading to higher yield (Hameed *et al.,* 2011 and Sinha and Talati, 2007). The general practice of controlling weeds in SRI is to use Cono or Mandwa weeder. In clay-loam soil, more labour is required for running the weeder in absence of proper moisture in the soil. So it is necessary to standardize the required moisture regime in soil before using the weeder.

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Operating the weeder at 7 or 10 days interval reduces weed problem to a large extent in SRI. The problem of weeding by weeder is that it can not run smoothly after 30 DAT, because of profuse lateral vegetative growth of rice, which creates obstruction in weeder operation (Haden *et al*., 2007). Use of proper post-emergence herbicide can solve this problem by suppressing new flushes of weeds at later stages of growth (Babar and Velayutham, 2012). Any approach that would lessen the amount of water use and control weed without compromising the rice yield would certainly be a welcome strategy. Hence the present field experiment was conducted to study the effect of different depths of water application one day before weeding operation and weed management practices on growth and yield of rice raised under systems of rice intensification.

MATERIALS AND METHODS

A field study was conducted at Regional Research and Technology Transfer Station, Chiplima, Sambalpur, under West Central Table Land Zone Odisha during the summer seasons of 2014 and 2015 to evaluate the effect of irrigation and methods of weed management on weed dynamics, yield and nutrient uptake of rice under system of rice intensification (SRI). The soil of experimental field was clay loam with bulk density 1.50 Mg/m^3, porosity 39.28%, infiltration rate 0.26 cm/hr, water holding capacity 25.6% on weight basis, field capacity 19.7% on weight basis, permanent wilting point 10%, *p*H 5.65 and low in organic carbon content (0.47%) and available N ($KMnO_4$ method), P (Olsen method) and K (NH_4OHC method) content were 242, 9.2 and 155 kg/ha respectively. The experiment was laid out in split-plot design with 3 replications. Main plot treatments consisted of 3 irrigation schedules, viz. I_1, 50 mm water on the day before weeding operation, I_2, 25 mm water on the day before weeding operation and I_3, saturation (15 mm) on the day before weeding operation. The sub-plots received 4 weed management practices , viz. W_1, weeding by Mandwa weeder at an interval of 7 days starting from 10 DAT up to 50 DAT; W_2, application of pre-emergence herbicide pretilachlor @ 750 g/ha at 3 DAT + use of Mandwa weeder at 20 DAT at an interval of 7 days up to 50 DAT; W_3, W_1 + application of a post-emergence herbicide chlorimuron ethyl + metsulfuron methyl @ 4g/ha at 20 DAT; W_4, application of pre-emergence herbicide pretilachlor @ 750 g/ha at 3 DAT followed by post-emergence herbicide chlorimuron ethyl + metsulfuron methyl @ 4 g/ha at 20 DAT. The amount of water applied for puddling was 250 mm for all the treatments. Irrigation was done by alternate wetting and drying method. The water use was quantified for each plot areas with the help of module designed to discharge water @ 3 litres/sec. The total number of irrigation for I_1, I_2 and I_3 were 20, 21 and 23 respectively. For weeding operation as per treatment 6, 5, 5, 2 numbers of irrigations were given to W_1, W_2, W_3 and W_4 respectively over and above the normal schedule. Irrigation treatments were isolated with buffer channels, so that water movement can be effectively controlled and managed. Rice 'MTU 1010' of 125 days duration was grown under SRI. Seeds were soaked for 24 hrs and incubated in moist gunny bags for 2 days. Pre-germinated seeds were broadcast uniformly on nursery beds of 1 m width separated by channels of 30 cm width and 15 cm depth. Soil: farmyard manure mixture (1:1) was spread in a thin layer for covering the seeds. The beds were irrigated daily and thoroughly before lifting the seedlings. The FYM @ 5 t/ha was incorporated 2 weeks before transplanting. Seedlings of 12 days were used for transplanting. Marker was used for square planting with 25 cm × 25 cm spacing. Recommended dose of fertilizer, i.e. 80, 40 and 40 kg/ha N, P_2O_5 and K_2O was applied. All P_2O_5 was applied as basal and N was applied in 3 splits, i.e. 50% as basal, 25% at 45 DAT and 25% at 60 DAT, while K_2O was applied in 2 splits, i.e. 50% as basal and 50% at 60 DAT. The plant protection measures were taken as and when required. Other cultural operations like gap filling and rouging were carried out as per recommendation and weed management was followed as per treatment. Rainfall received during the crop growth period was 30 mm (6 rainy days) in 2014 and 62 mm (9 rainy days) in 2015 respectively during summer season. The average rate of evaporation during crop growing season was 3.5 mm/day. The yield parameters were recorded and the economics was calculated at the prevailing price of inputs and minimum support price of produce. The weeds were counted and the weed dry weight was taken at 60 DAT. The weed-control efficiency (WCE) was calculated from the mean data over 2 years by using formulae.

WCE (%) = (WDc – WDt)/WDc × 100

where, WCE, weed-control efficiency;

WDc, weed dry biomass (g/m^2) in control plot;

WDt, weed dry biomass (g/m^2) in treated plot.

The data were statistically analyzed in split-plot analysis as per Gomez and Gomez (2010).

RESULTS AND DISCUSSION

Weed density and biomass

The major weed flora in the experimental field comprised of grasses, viz. *Echinochloa crusgalli* (L.) P Beav., *Echinochloa colonum* (L.) Link, *Digitaria sanguinalis* (L.) Scop; *Panicum repens* (L.); sedges, viz. *Cyperus difformis* (L.), *Cyperus iria* (L.), *Fimbristylis miliacea* (L.) Vahal and broad-leaved weeds (BLW), viz. *Ludwigia parviflora* (L.), *Ammania baccifera* (L.) Roxb., *Eclipta prostrata* (L.), *Eclipta alba* (L.), *Lippa nodiflora* Nich, *Marsilea quadrifolium* (L.), *Sphenoclea zeylanica* Gaertn., *Commelina benghalensis* (L.). The composition of sedges was found to be the highest followed by grasses and broad leaf weeds.

Use of chemical herbicide with or without mandwa weeder was found superior to only mandwa weeder operated treatment (Table 1). Significantly lower total weed density and biomass were recorded under 50 mm water application on the day before weeding operation (I_1) up to 25.1 and 44.9, 30.1 and 50.1% compared to application of 25 mm water (I_2) and saturation (I_3) respectively. The lower weed population in this treatment was perhaps due to creation of anaerobic conditions that led to formation of hydrogen peroxides. These peroxides have lethal effect on germination of weed seeds. Higher weed population in saturated plot might be due to the optimum conditions for weed seed germination (Haefele *et al*., 2004). Application of pre and post-emergence herbicide (W_4) proved 57.6% more effective in controlling weeds over mandwa weeded plot (W_1). Control of weeds by herbicides during early stage of rice resulted in lower competition for moisture, nutrient and sunlight that influenced the crop to grow better as evidenced in increased yield attributes and yield (Singh *et al*., 2005).

Yield attributes and yield

In the main-plots application of 50 mm water on the day before weeding operation resulted in higher grain yield (5.5 t/ha) being 19 and 12.3% higher over 25 mm water on the day before weeding operation and saturation respectively (Table 2). Increased yield with application of 50 mm water on the day before weeding operation was attributed to higher filled grains/panicle (94) and panicles/ plant (35.1). Increase in yield attributes and yield in this practice of water application might be as a result of better condition for operating weeder in clay-loam soil, causing better aeration and root growth and providing sufficient nutrients for vegetative and reproductive growth.

Pre and post-emergence application of herbicides (W_4) showed significantly higher grain yield (16.7%) compared to mandwa weeded plot (W_1). The higher yield was owing to higher number of panicles/plant (29.8), length of panicle (26 cm) and filled grains/panicle (89.8) over the mandwa weeded treatment. The higher yield might be due to longer weed free period in chemical weed control practices, which reduced partitioning of available resources like moisture and nutrients. Total weed control with application of pre-emergence followed by post-emergence herbicide proved that chemical control of weed is more effective than mechanical and or mechanical and chemical integration in system of rice intensification. Dewangan *et al*. (2011) also recorded higher grain yield with longer weed free period.

Interaction effect of water application methods and weed management on grain yield of rice (Table 3) was found significant. Each weed management practice produced its maximum yield when 50 mm irrigation was given on the day before weeding operation (I_1). Except I_3, all other irrigation treatment produced its maximum yield, when applied with pre- and post-emergence herbicide (W_4).

Water use

The total quantity of irrigation water used was 881, 783 and 693 mm/ha in 50, 25 mm water and saturation on day before weeding operation respectively (Table 2). Irrigation water-use efficiency (IWUE) was found to be the highest (6.19 kg/ha-mm), when 25 mm water was applied on the day before weeding (I_2), however, the highest water saving (187.5 mm/ha) was recorded in the saturated plot (I_3). The highest water saving at saturation could be due to the retention of seepage and deep percolation losses. Because of lower yield recorded in this treatment (I_3) resulted in lower IWUE (6.06) as compared to I_2. Shantappa *et al.* (2014) reported more quantity of water saved (34%) in alternate wetting and drying than continuous submergence without reduction in seepage and percolation losses in rice field. Chemical weed management with application of both pre- and post-emergence herbicides (W_4) saved more water (39

Table 1. Effect of water application methods and weed management on weeds at 60 days after transplanting (DAT) of rice (Mean data of 2 years)

Treatment	Weed density (Nos./m^2)				Weed biomass (g/m^2)				WCE
	Grasses	Sedges	Broad leaved	Total	Grasses	Sedges	Broad leaved	Total	(%)
Water application method (I)									
I_1	21.0	143.6	7.6	172.2	5.7	66.8	3.7	76.1	50.1
I_2	32.0	189.2	8.6	229.8	9.6	89.6	9.5	108.8	30.1
I_3	38.0	255.6	18.4	311.9	16.0	122.8	13.9	152.6	
SEm±	2.0	4.9	0.9	3.5	0.9	2.4	0.5	6.5	
CD (P=0.05)	5.6	14.4	2.7	10.3	2.6	7.2	1.5	19.1	
Weed management practices (W)									
W_1	18.6	281.9	11.5	312.0	8.6	136.0	9.9	154.5	
W_2	21.9	236.5	17.5	275.9	9.0	113.3	9.2	131.4	14.9
W_3	15.0	188.2	17.3	220.5	7.2	89.1	8.7	105.0	32.0
W_4	6.8	122.5	10.5	139.8	4.1	56.3	5.2	65.5	57.6
SEm±	6.0	11.5	2.0	3.6	0.9	5.8	0.4	8.5	
CD (P=0.05)	NS	34.5	5.9	10.6	2.5	17.3	1.1	25.5	

I_1, 50 mm water on the day before weeding operation, I_2, 25 mm water on the day before weeding operation, I_3, Saturation on the day before weeding operation (≈ 15 mm).

W_1, weeding by Mandwa weeder at an interval of 7 days starting from 10 DAT up to 50 DAT; W_2, application of pre-emergence herbicide, pretilachlor @ 750 g/ha at 3 DAT + use of Mandwa weeder at 20 DAT at an interval of 7 days up to 50 DAT; W_3, weeding by Mandwa weeder at 10 DAT + application of a post-emergence herbicide, chlorimuron ethyl + metsulfuron methyl @ 4g/ha at 20 DAT, W_4, application of pre-emergence herbicide pretilachlor @ 750 g/ha at 3 DAT followed by post emergence herbicide chlorimuron ethyl + metsulfuron methyl @ 4 g/ha at 20 DAT; WCE., Weed control efficiency mm/ha) than Mandwa weeded (W_1) plot (15 mm/ha).

Nutrient uptake by rice

Application of 50 mm water on the day before weeding operation (I_1) recorded the highest N, P and K uptake of 64.9, 19.8, 22.6 and 44.4, 2.2 and 124.3 kg/ha of grain and straw respectively, followed by application of 25 mm water (Table 4). Weed management practices exerted positive influence on nutrient uptake. Pre-emergence application of pretilachlor followed by post-emergence application of chlorimuron ethyl + metsulfuron methyl registered highest N-P-K uptake of 66.1, 20.2 and 23.0 kg/ha of grains respectively. This treatment was on par with weeding by Mandwa weeder at 10 DAT + application of a post emergence herbicide (chlorimuron ethyl + metsulfuron methyl) at 20 DAT. Pretilachlor as pre-emergence at 750 g/ha + Mandwa weeding from 10 DAT at 7 days interval recorded N-P-K uptake of 63.7, 19.4 and 22.1 kg/ha, respectively. The lowest N, P and K uptake in grain and straw was found in weeding by Mandwa weeder at an interval of 7 days starting from 10 DAT up to 50 DAT (W_1). This was mainly due to less grain and straw yields observed

Table 2. Effect of water application methods and weed management practices on yield attributes, yield, water use and economics of rice in SRI (mean data of 2 years)

Treatment	Tillers/ plant	Panicles/ plant	Length of panicle (cm)	Filled grains/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	IWU (mm/ha)	IWUE (kg/ha-mm)	Water savings (mm/ha)	Net returns ($\times10^3$ ₹/ha)	Benefit: cost ratio
Water application methods (I)												
I_1	42.2	35.1	21.4	94.0	21.5	5.5	7.4	881	5.82	-	49.0	2.88
I_2	40.3	31.1	22.2	84.0	21.6	5.2	6.8	783.5	6.19	90	44.8	2.72
I_3	38.3	25.4	21.4	82.0	21.4	4.6	5.8	693.5	6.06	187.5	36.3	2.35
SEm±	1.53	2.43	0.92	2.76	0.43	0.21	0.25					
CD (P=0.05)	NS	7.31	NS	8.51	NS	0.58	0.69					
Weed management practices (W)												
W_1	38.7	20.3	19.3	73.7	21.3	4.8	6.2	810.5	4.78	15	36.7	2.21
W_2	52.9	20.1	20.1	79.0	21.7	4.9	6.3	825.5	5.55	-	39.1	2.45
W_3	35.2	25.2	23.5	89.1	22.1	5.4	7.2	825.5	7.25	-	48.0	2.95
W_4	49.7	29.8	26.0	89.8	22.0	5.6	7.5	786.5	8.7	39.0	52.7	3.35
SEm±	1.63	0.61	0.48	3.26	0.51	0.18	0.32					
CD (P=0.05)	4.96	1.89	1.44	9.85	NS	0.57	0.99					

Input price (₹/kg) rice seed, 22; urea, 5.52; di ammonium phosphate, 24.45; muriate of potash, 17.44; chlorimuron +metsulfuron, ₹220/8g, Sale rate of rice grain (₹14,100/t), rice straw (₹800/t) and manual labour (₹127/day); IWU, irrigation water use; IWUE, irrigation water-use efficiency

I_1, 50 mm water on the day before weeding operation, I_2, 25 mm water on the day before weeding operation, I_3, Saturation on the day before weeding operation (≈ 15 mm).

W_1, weeding by Mandwa weeder at an interval of 7 days starting from 10 DAT up to 50 DAT; W_2, application of pre-emergence herbicide, pretilachlor @ 750 g/ha at 3 DAT + use of Mandwa weeder at 20 DAT at an interval of 7 days up to 50 DAT; W_3, weeding by Mandwa weeder at 10 DAT + application of a post-emergence herbicide, chlorimuron ethyl + metsulfuron methyl @ 4g/ha at 20 DAT, W_4, application of pre-emergence herbicide pretilachlor @ 750 g/ha at 3 DAT followed by post emergence herbicide chlorimuron ethyl + metsulfuron methyl @ 4 g/ha at 20 DAT; WCE., Weed control efficiency

Table 3. Interaction effect of water application methods and weed management on grain yield of rice in SRI (mean data of 2 years)

Treatment	Yield (t/ha)			
	W_1(Mandwa weeding	W_2 (W_1 + Pre em. herbicide)	W_3 (W_1 + Post em. herbicide)	W_4 (Pre fb. post- em. herbicide)
I_1	4.6	4.5	5.3	6.2
I_2	4.4	4.4	4.9	5.6
I_3	4.5	4.5	5.2	4.9
			SEm±	CD (P=0.05)
		I in W	1.31	3.90
		W in I	1.02	3.06

Table 4. Effect of water application methods and weed management practices on nitrogen, phosphorus and potassium uptake (kg/ha) by SRI rice (mean data of 2 years)

Treatment	Nitrogen		Phosphorus		Potassium	
	Grain	Straw	Grain	Straw	Grain	Straw
Water application methods (I)						
I_1	64.9	44.4	19.8	2.2	22.6	124.3
I_2	61.3	40.8	18.7	2.0	21.3	114.2
I_3	54.3	34.8	16.6	1.7	18.9	97.4
SEm±	0.68	0.12	0.2	0.01	0.9	2.3
CD (P=0.05)	1.88	0.33	0.55	0.0	2.5	6.4
Weed management practices (W)						
W_1	56.6	37.2	17.3	1.9	19.7	104.2
W_2	57.8	37.8	17.6	1.9	20.1	105.8
W_3	63.7	43.2	19.4	2.2	22.1	121.0
W_4	66.1	37.5	20.2	2.3	23.0	126.0
SEm±	0.78	0.19	0.26	0.01	1.17	2.99
CD (P=0.05)	2.4	0.59	0.81	0.03	3.63	9.27

I_1, 50 mm water on the day before weeding operation, I_2, 25 mm water on the day before weeding operation, I_3, Saturation on the day before weeding operation (≈ 15 mm).

W_1, weeding by Mandwa weeder at an interval of 7 days starting from 10 DAT up to 50 DAT; W_2, application of pre-emergence herbicide, pretilachlor @ 750 g/ha at 3 DAT + use of Mandwa weeder at 20 DAT at an interval of 7 days up to 50 DAT; W_3, weeding by Mandwa weeder at 10 DAT + application of a post-emergence herbicide, chlorimuron ethyl + metsulfuron methyl @ 4g/ha at 20 DAT, W_4, application of pre-emergence herbicide pretilachlor @ 750 g/ha at 3 DAT followed by post emergence herbicide chlorimuron ethyl + metsulfuron methyl @ 4 g/ha at 20 DAT; WCE., Weed control efficiency

under this treatment. Similar results have been reported by Babar and Velayutham (2012).

Economics

Application of 50 mm water on the day before weeding operation (I_1) recorded 8.6 and 25.9% higher net returns than application of 25 mm of water (I_2) and saturation (I_3) respectively (Table 2). It also recorded higher benefit: cost ratio (2.88) over the other two water application method.

Highest net returns (₹52,714/ha) and benefit: cost ratio (3.35) was found with pre and post – emergence application of herbicides (W_4) owing to the highest yield and cultivation cost. One time use of herbicide either as pre- or post-emergence reduced the net returns to 6–23.6% as in case of W_2 and W_3 and the lowest net returns was recorded with W_1 due to ineffective weed control and higher labour cost for weeding. This is in conformity with the finding of Walia *et al*. (2012), who reported that sole application of pre or post-emergence herbicide did not provide effective control of weeds as compared to combination of pre and post-emergence herbicide.

The results of the study showed that application of 50 mm water on the day before weeding (I_1) and pre- emergence herbicide (pretilachlor) at 3 DAT, followed by post-emergence herbicide (chlorimuron ethyl + metsulfuron methyl) at 20 DAT (W_4) recorded the highest yield in rice.

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Research Paper

Residual effects of different soil organic amendments applied to aerobically grown rice (*Oryza sativa*) on succeeding wheat (*Triticum aestivum*) under basmati rice–wheat cropping system

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ABSTRACT

A field experiment was conducted during 2012–14 at Jammu, Jammu and Kashmir, to determine the residual effects of different soil organic amendments, viz. control (recommended fertilizer dose); *in-situ* green manuring of prickly sesban or *dhaincha* (*Sesbania cannabina* Willd.) on N-basis; *in-situ* green manuring of *dhaincha* followed by application of vermicompost on N-basis (1:1); *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1); *in-situ* green manuring of *dhaincha* followed by application of farmyard manure (FYM) on N-basis (1:1); and *in-situ* green manuring of *dhaincha* followed by application of FYM and mulching with *dhaincha* on N-basis (1:1:1) on productivity, nutrient uptake and economics of basmati rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping rotation. Significant residual effects of different soil organic amendments, viz. *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1) and *in-situ* green manuring of *dhaincha* followed by application of FYM and mulching with *dhaincha* on N-basis (1:1:1) were observed on succeeding wheat in comparison to the control and rest of the treatments. With residual effect of *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1); and *in-situ* green manuring of *dhaincha* followed by application of farmyard manure (FYM) on N-basis (1:1); grain yield of succeeding wheat was 15.36% and 14.90%, respectively, higher than the control. The highest N : P : K uptake in wheat grain and straw were recorded with residual effect of *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1) and *in-situ* green manuring of *dhaincha* followed by application of FYM and mulching with *dhaincha* on N-basis (1:1:1); which in turn were significantly superior to the other treatments. The highest net returns of ₹44,092/ha and net returns/rupee invested 2.22 were obtained with residual effect of *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1)

Key words **:** Bread wheat, Economics, Farmyard manure, Green manure crop, Nutrient uptake, Productivity, Residual effects, Vermicompost

In India rice–wheat cropping system covers about 13 million ha, spreading over states of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Himachal Pradesh, Uttarakhand, Madhya Pradesh and Rajasthan. Rice–wheat cropping system accounts for about one-fourth of total foodgrain production of South-East Asia (Abrol *et al.,* 1997) and about 31% of the total foodgrain production of India (Prasad, 2005). This signifies its contribution in meeting food requirements of the country. Though rice–wheat cropping system is considered as the backbone of food self-sufficiency, it is facing a sustainability problem due to practices of modern production system with indiscriminate use of chemical fertilizers and pesticides (Nambiar, 1994; Duxbury and Gupta, 2000; Prasad, 2005). There are concerns like declining factor productivity (Biswas and Sharma, 2008; Patil, 2008; Yadav, 2008), depletion of soil organic carbon and mineral nutrients content (Prakash *et al.,* 2008). However, there is a scope to incorporate the summer green manure crop (*dhaincha*),

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vermicompost and FYM before rice, which acts as a source of nutrients for improved productivity and maintenance of soil fertility. Also, the green manuring before rice improves the nutrient-use efficiency of the applied fertilizer (Singh *et al.,* 1991). Typically; a summer green manure crop is grown for a specific period, and then ploughed under and incorporated into the soil. Green-manure crops being leguminous in nature usually perform multiple functions along with vermicompost and farmyard manure (FYM) that include improvement in nutrient content, organic matter addition in soil and soil protection as well as enhance microbial biomass and enzymatic activity in soil.

Farmyard manure is a product of microbial activity and contains large number of microbial population. Application of farmyard manure can increase the microbial activity in the soil, both by activating the microbial action and by aiding the multiplication of microbial population. Owing to these properties, application of farmyard manure is in perfect tune with biological requirement of soil and helps to build the soil on sustainable basis. Increase organic carbon by application of FYM increases enhances population of bacteria, actinomycetes and fungi (Gaur *et al.,* 1990). Vermicompost is the excreta of earthworm, which are capable of improving soil health and nutrient status. Vermiculture is a process by which all types of biodegradable wastes such as farmwastes, kitchen wastes, market wastes, bio-wastes of agro-based industries, livestock wastes etc. are converted while passing through the worm-gut to nutrient-rich vermicompost. Vermi-worms are used here act as biological agents to consume those wastes and to deposit excreta in the process called vermicompost. It is expected that regular incorporation of green-manure crops, FYM and vermicompost before rice may improve not only physico-chemical properties of soil but also enhance availability of macro and micronutrients in soil and its uptake by succeeding wheat under basmati rice–wheat cropping system. Keeping these in view, the present investigation was taken up to quantify the residual effects of summer greenmanure crop (*dhaincha*), FYM and vermicompost sources on productivity, economics and N: P: K uptake by succeeding wheat crop grown after basmati rice in a basmati rice–wheat cropping system.

MATERIALS AND METHODS

The field experiment was conducted at the research farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India, during the rainy (*kharif*) season (mid-June-mid-November) and winter (*rabi*) season (mid-November-mid-April) of 2012–13 and 2013–14 on a sandy-loam soil. The trials in both the years were conducted with a fixed lay out plan in the same field. The soils had 260.10 kg/ha alkaline permanganate-oxidizable nitrogen (N), 12.24 kg/ha available phosphorus (P), 132.52 kg/ha 1 *N* ammonium acetate-exchangeable potassium (K) and 0.43% organic carbon. The *p*H of soil was 7.27 (1 : 2.5 soil : water ratio) (Prasad *et al.,* 2006) and diethylene triamine penta acetic acid (DTPA)-extractable Zn in soil was 0.67 mg/kg soil. The experiment was conducted in a split-plot design, keeping 4 Basmati cultivars, viz. 'Basmati 370', 'Basmati 564', 'Saanwal Basmati' and 'Ranbir Basmati', as main-plot treatments and 6 sources of different organic amendments, viz. T_1, control (recommended fertilizer dose); T_2, *in-situ* green manuring of *dhaincha* on N-basis; T_3, *in-situ* green manuring of *dhaincha* followed by application of vermicompost on N-basis (1:1); T_4, *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1); T_5, *in-situ* green manuring of *dhaincha* followed by application of FYM on N-basis (1:1); and T_6, *in-situ* green manuring of *dhaincha* followed by application of FYM and mulching with *dhaincha* on N-basis (1:1:1) in subplots and was replicated thrice. After 45 days, the summer green-manuring crop (*dhaincha*) was incorporated into the soil before direct-seeded rice. A seed rate of 60 kg/ha was used for sowing of *dhaincha*. For *in-situ dhaincha,* seed rate was worked out keeping in view the size of the plots of experimental treatments and the seed was sown by broadcasting. Besides, this an additional *ex-situ* crop of *dhaincha* was also grown by using similar quantity of seed 10 days before to the normal sown *in-situ.* This *ex-situ dhaincha*, crop was used to assess nitrogen content to be taken as reference for working out the quantity of *dhaincha* to meet out the different nitrogen requirement as per of the experimental treatments. Organic amendments, viz. FYM with 45% moisture, vermicompost with 50% moisture and fresh biomass of *dhaincha* with 80% moisture, used as sources of nitrogen were analysed for determine their N content (oven-dry weight basis) to decide the total quantity of these organic amendments to be used to supplement 30 kg N/ha. The quantity of FYM, vermicompost and fresh biomass of *dhaincha* to fulfil the recommended dose of nitrogen on their respective N contents was 10.88, 5.00 and 8.30 t/ha were applied 2 weeks before direct-seeded rice each year. Farmyard manure, vermicompost and *dhaincha* had an average composition of 36.6% C, 0.60% N, 1.3% P and 1.5% K and 1.56% N, 1.6% P, 1.8% K and 1.85% N, 1.7% P, 1.4 K respectively. The *ex-situ* raised *dhaincha* crop was cut near the ground surface and 10 kg (8.33 tonnes/ha) of its fresh biomass was spread in the inter-row spaces of each plot of mulching treatments 20 days after sowing. Recommended doses of N: P: K (30:20:10 kg/ha) were applied. Total P, K and half doses of

N were broadcast before sowing and rest was top-dressed at tillering and flowering stages in equal doses. Direct-seeded basmati rice was sown in lines giving row-to-row spacing of 20 cm using a seed rate of 40 kg/ha and bread wheat 'RSP 561' was sown, 22.5 cm apart, in rows using 100 kg seed/ha in the middle of November and harvested in the last week of April in both the years. The fixed lay-out plan of preceding basmati rice was used for bread wheat also for both the years of experimentation. Since the objective of this study was to quantify the residual effects of different soil organic amendments applied to preceding basmati rice on succeeding bread wheat, therefore, a blanket crop of wheat 'RSP 561' was taken with its recommended package of cultivation during winter (*rabi*) in all the treatments using 100:50:25:N:P:K kg/ha to assess the impact of rainy season (*kharif*) treatments on the performance of succeeding wheat in rice–wheat system. Ten spikes were randomly selected from each plot for recording the data on yield attributes. One thousand grains were counted randomly from each subplot, and their weight was recorded at 12% moisture and expressed. Harvesting of the bread wheat was undertaken as soon as it attained the harvest maturity. Economics of durum wheat cultivation was calculated based on the prevailing market prices during the respective crop seasons. The gross and net returns were calculated. Benefit: cost ratio (B:C) was calculated. All the replicated data obtained from the experiments were statistically analysed for pooled analysis using the F-test as per Gomez and Gomez (1984). Critical difference (CD) values at $P = 0.05$ were used to determine the significance of differences between treatment means. Correlation and regression analyses were done by using SPSS 11.5 package of statistical analysis.

RESULTS AND DISCUSSION

Residual effect

Incorporation of soil organic amendments into soil, fixed more atmospheric N biologically in the soil and also added higher amount of organic matter which is good indicator of soil fertility and improved status of available nutrients in the soil (Dwivedi *et al*., 2005). The total amount of N added was the higher in the soil through soil-applied organic amendments (Table 1).

Yield attributes

Yield attributes of succeeding wheat were numerically higher, when it was preceded by 'Ranbir Basmati' and it was followed by wheat preceded by 'Basmati 370', 'Saanwal Basmati' and 'Basmati 564'. Among different soil organic amendments, the wheat crop in the treatment T_4, where the preceding crop of basmati rice was grown by supplementing nutrients through *in-situ* green manuring of *dhaincha* + vermicompost + mulching with *dhaincha* on N-basis (1:1:1) recorded highest yield attributes followed by treatments; T_6, T_3, T_5, T_2, and T_1, RFD during both the cropping seasons of winter 2012–13 and 2013–14 (Table 1).

Table 1. Effect of basmati rice cultivars and soil organic amendments on yield attributes of succeeding crop of wheat and soil pH, organic carbon and available nitrogen (pooled data of 2 years)

Treatment	Soil *p*H	Organic carbon (%)	Available N (Kg/ha)	Plants/m^2	Effective ears/ m^2	Grains/ear	1,000-grain weight(g)
Basmati cultivars							
V_1	7.19	0.52	256	300.3	287.3	41.4	39.2
V_2	7.18	0.53	257	290.5	279.6	39.5	38.6
V_3	7.18	0.52	256	299.3	285.6	40.8	39.1
V_4	7.18	0.52	256	302.5	289.9	41.9	39.3
SEm±	0.18	0.02	6.70	4.89	5.99	3.81	5.27
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
Soil organic amendments							
T_1	7.27	0.42	250	287.1	274.5	40	38.7
T_2	7.18	0.50	268	291.6	280	40.5	38.8
T_3	7.23	0.46	261	297.4	287.5	41.1	39.2
T_4	7.21	0.47	263	304.6	296.4	41.4	39.5
T_5	7.20	0.49	266	294.3	283.7	40.5	38.8
T_6	7.22	0.48	264	303.1	292.4	41.2	39.3
SEm±	0.03	0.01	2.9	5.77	6.79	6.05	7.13
CD (P=0.05)	0.09	0.03	8.9	NS	NS	NS	NS

Initial values of soil *p*H, 7.27; OC, 0.43%, and available; N, 260 kg/ha/details of T_1, T_2, T_3, T_4, T_5, and T_6 are given under materials and methods; V_1, Basmati 370; V_2, Basmati 564; V_3, Saanwal Basmati; V_4, Ranbir Basmati

Yield and harvest index

The grain yield of succeeding wheat after rice recorded significant effect by the application of treatment T_4, *in-situ* green manuring of *dhaincha* + vermicompost + mulching with *dhaincha* on N-basis (1:1:1) during the second year of crop-growing season of winter 2013–14 and straw yield during both the cropping seasons (Table 2). It was followed by treatment T_6, *in-situ* green manuring of *dhaincha* + FYM + mulching with *dhaincha* on N-basis (1:1:1), These treatments in turn were significantly superior to the other treatments. Wheat grain yield was 15.8% higher in *Sesbania*-incorporated plot than summer fallow. Similarly, wheat straw yield was 10% higher in *Sesbania*-incorporated plots than summer fallow. Similar trend was

Table 2. Effect of basmati cultivars and soil organic amendments on productivity and economics of succeeding wheat (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Cost of cultivation(a) (× 10^3₹/ha)	Net returns (×10^3₹/ha)	Benefit: cost ratio
Basmati cultivars						
V_1	4.2	4.7	48.4	19.8	38.9	1.96
V_2	3.9	4.4	47.6	19.8	33.7	1.70
V_3	4.0	4.4	47.3	19.8	38.0	1.91
V_4	4.2	4.7	49.6	19.8	41.8	2.10
SEm±	1.00	2.16	3. 3	-	-	-
CD (P=0.05)	NS	NS	NS	-	-	-
Soil organic amendments						
T_1	3.8	4.0	48.7	19.8	38.1	1.9
T_2	4.0	4.4	49.5	19.8	39.1	1.9
T_3	4.0	4.4	49.6	19.8	39.1	1.9
T_4	4.4	4.9	49.3	19.8	44.0	2.2
T_5	4.0	4.4	48.2	19.8	38.8	1.9
T_6	4.3	4.8	49.1	19.8	42.0	2.1
SEm±	1.1	1.2	1.3	-	-	-
CD (P=0.05)	NS	NS	NS	-	-	-

V_1, 'Basmati 370'; V_2, 'Basmati 564'; V_3, 'Saanwal Basmati' and V_4, 'Ranbir Basmati' were sown in preceding year in rice–wheat system details of T_1, T_2, T_3, T_4, T_5, and T_6 are given under materials and methods

Table 3. Effect of cultivars and soil organic amendments on uptake of N, P and K in wheat (kg/ha) (pooled data for 2 years)

Treatment	Grain			Straw		
	N	P	K	N	P	K
Basmati cultivars						
V_1	40.3	9.1	21.0	33.4	8.5	59.4
V_2	40.1	9.0	20.0	32.0	7.3	59.2
V_3	40.2	9.0	20.0	33.0	8.4	59.3
V_4	41.0	9.5	21.0	34.0	8.7	60.0
SEm±	0.58	0.61	0.34	0.45	0.96	0.99
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Soil organic amendments						
T_1	50.0	10.0	20.0	32.1	8.3	58.0
T_2	49.4	11.1	22.5	33.0	8.9	58.6
T_3	49.5	11.5	23.0	33.0	9.2	58.9
T_4	57.1	13.4	26.3	34.4	11.3	64.3
T_5	49.5	11.5	23.0	33.1	9.0	58.8
T_6	56.0	13.3	26.1	34.1	11.1	64.0
SEm±	1.62	0.20	0.50	0.30	0.67	1.07
CD (P=0.05)	4.87	1.20	1.5	0.90	2.15	3.22

V_1, 'Basmati 370'; V_2, 'Basmati 564'; V_3, 'Saanwal Basmati' and V_4, 'Ranbir Basmati' were sown in preceding year in rice–wheat system details of T_1, T_2, T_3, T_4, T_5, and T_6 are given under materials and methods also recorded for harvest index. This could be attributed to the higher supply of N and other micronutrient cations through the incorporation of legumes into soil (Bisht *et al.,* 2006; Pooniya and Shivay, 2011). The increased availability of Fe and other micronutrients in soil with regular summer green manuring every year before transplanting of rice in rice–wheat system was responsible for higher yields in the green manuring plot compared with the non-green-manuring plot (Nayyar and Chhibba, 2000).

Nutrient uptake

Residuals of organic applied treatments had a significant effect on N, P and K uptake in grain and straw by succeeding wheat. The increase in N,P,K uptake by succeeding wheat with the residuals of T_4 and T_6 treatments was significantly higher than rest of the treatments which led to 25.25, 17.57, 17.43 and 17.33% increase over the treatments T_1, T_2, T_5 and T_3 respectively (Table 3).

Economics

The highest net returns (41.8 × 10^3₹/ha) and benefit: cost ratio (2.10) were recorded by wheat crop which was preceded by 'Ranbir Basmati', whereas the lowest were noticed while preceded by 'Basmati 564'. Amongst the soil organic amendments, the highest net returns (44 × 10^3 ₹/ha) and benefit: cost ratio (2.2) were realized as preceded by treatment *in-situ* green manuring of *dhaincha* followed by application of vermicompost and mulching with *dhaincha* on N-basis (1:1:1).

Based on 2 years study, it can be concluded that the wheat crop preceded by 'Ranbir Basmati' recorded the highest yields and profits, whereas the yield of wheat preceded by basmati was higher with *in-situ* green manuring of *dhaincha* + vermicompost + mulching with *dhaincha* on N-basis (1:1:1).

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Research Paper

Response of maize (*Zea mays*) hybrids to nutrient management practices for enhancing productivity and profitability under sub-humid condition of Southern Rajasthan

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ABSTRACT

A field experiment was conducted during 2 consecutive years of 2013 and 2014 to find out the response of nutrient expert-decision support systems based on the principle of site-specific nutrient management (SSNM) for achieving targeted yield of maize (*Zea mays* L.). This approach estimated high dose of N and K and low dose of P over recommended dose of fertilizer (RDF) to evaluate the response of hybrid under this experiment. Growth parameters, yield, nutrient uptake, harvest index and partial factor productivity of P and K and apparent recovery of N and P and economics were significantly higher with SSNM over RDF and farmer's fertilizer practices (FFP). Yield attributes, harvest index and partial factor productivity of N and apparent recovery of K were found at par with RDF. Among the hybrids, 'CMH-08-292' recorded maximum plant growth parameters, yield attributes, yield and nutrient uptake, which was found statistically at par with 'CMH-08-350'. SSNM gave significantly higher net returns (₹66,350/ha) and benefit: cost ratio (2.60) over RDF and FFP. Among the hybrids, 'CMH-08-292' recorded maximum gross returns (₹84,686/ha), net returns (₹60,120/ha) and benefit: cost ratio (2.41), which was at par with 'CMH-08-350'. The interaction effect revealed that the highest grain yield (7.90 t/ha), net returns (₹84,723/ha), and benefit: cost ratio (3.27) obtained with 'CMH-08-292' under SSNM. Hence, it is concluded that SSNM along with suitable high yielding hybrids are recommended for enhancing yield and profitability of maize under sub-humid condition of Southern Rajasthan and similar ecologies elsewhere.

Key words : Economics, Nutrient harvest index, Nutrient uptake, Partial factor productivity, Yield

Maize is one of the most versatile crop, has the highest genetic yield potential and known as queen of cereals in the world. Maize is considered as the third most important food crop among the cereals in India that contributed to nearly 9% of the national food security (Jat *et al*, 2013). Maize is a stable food, and quality feed, and used as a basic raw material for thousands of industrial products. Currently, it is cultivated over an area 9.23 million ha with 24.2 million tonnes production having an average productivity of 2,560 kg/ha (ICAR-IIMR 2015). Growing market demand for the feed and starch industry and increase in minimum support price from ₹5,400/t in the year 2006–07 to ₹13,100/t in 2013–14 led to make maize as a more profitable crop and encouraged farmers to grow maize to a large extent (DACNET, 2015). However, maize productivity has not increased proportionately and significant yield gaps are evident across the maize growing areas in the country. High yielding maize hybrids, with very high biomass production, extracts higher amounts of mineral nutrients from the soil than other major cereals like rice or wheat. Nutrient requirement of maize varies from field to field due to high variability in soil fertility across farmer's fields and also varies with the yield potential of hybrids. Therefore, single homogenous nutrient recommendations may not be very useful for improving maize yield. To overcome this problem from adoption of the emerging concept of precision agriculture wherein the input variables such as fertilizers are applied in the right amount, at the right place and at the right time (variable rate application) as per the demand of the crop. It helps to improve input-use efficiency, economy, and ensures sustainable use of natural resources, as it minimizes wastage. Nutrient expert is a

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decision support tool based on principles of site-specific nutrient management (SSNM), in which optimum fertilizer management for a crop field is tailored to specific local condition, growth duration of the variety, crop residue management, past fertilizer use and input of nutrients from external sources. It is computer-based decision tool that provides fertilizer recommendations with consideration of yield response and targeted agronomic efficiency in addition to the contribution of nutrients from indigenous sources. It also considers other important parameters of the growing environment, which effect nutrient management recommendations in a particular location. Keeping these in views, a field experiment was undertaken to improve the productivity, nutrient-use efficiency and economics of maize in Southern Rajasthan by altering the fertilizer prescription using SSNM as compared to existing fertilizer recommendation and farmer's fertilizer practice.

MATERIALS AND METHODS

A field experiment was conducted during 2 consecutive years of 2013 and 2014 to find out the response of nutrient expert-decision support system assisted SSNM for achieving targeted yield of maize hybrids under precision agriculture at Agricultural Research Station (MPUAT), Banswara. It is geographically situated at 23° 33' N, 74° 27' E and altitude 220 m above mean sea-level, covered under humid southern plain agro-climatic zone of Rajasthan, which falls under sub-humid climate with dry, hot summer and mild winters. The average annual rainfall is about 862 mm of which more than 80% is generally received during the monsoon season (June–October). The average rainfall received during the crop growing period of experiment from July to October was 784.1 mm. The soil of experimental field was clay loam in texture, slightly alkaline in reaction, low in organic carbon (0.41%) and available nitrogen (218 kg/ha), medium in available phosphorus (26 kg/ha) and high in available potassium (345 kg/ha). The experiment was laid out in a split-plot design (SPD) with fifteen treatment combinations of three nutrient management practices and five hybrids and replicated thrice. The five hybrids taken in the experiment were 'PMH 1', 'PMH 3', 'HQPM 1', 'CMH-08-292' and 'CMH-08-350'. Current nutrient management practices (RDF), site-specific nutrient management (SSNM) practices based on target yield of hybrids and farmer fertilizer practices (FFP) were tested. The nutrient management practices were RDF (120-26.2-33.2 kg N-P-K/ha), SSNM based on target yield of hybrids as 'PMH 1' and 'PMH 3' (140-40:46 kg N: P_2O_5:K_2O/ha) for target yield (6.0 t/ha), 'HQPM 1' (130:37:41 kg N:P_2O_5:K_2O/ha) for target yield (5.0 t/ha) and 'CMH-08-292' and 'CMH-08-350' (160:44:51 kg N:P_2O_5:K_2O/ha) for target yield (7.0 t/ha) and farmer's fertilizer practice (78:23:00 kg N: P_2O_5:K_2O/ha). Nutrient management practices and hybrids were randomized in main-plots and sub-plots, respectively. The planting was done at spacing of 60 cm × 25 cm. A representative soil samples were collected prior to experimentation and after completion of study from 0–30 cm depth using core sampler. The different plant parts, viz. grain and straw were grinded and analyzed for N, P and K at harvest. From each replication 0.5 g grain and stover samples were taken for chemical analysis to determine the N, P and K concentrations. The nutrient uptake was calculated by multiplying dry matter production with corresponding values of their concentrations and expressed in kg/ha. The nutrient harvest indexes, apparent recoveries and partial factor productivity (PFP) of applied nutrients were calculated as follows:

$$\text{Apparent recovery (AR)} = \frac{\text{Nt} - \text{Nf}}{\text{Na}}$$

Where, Nt = Amount of nutrient taken from test treatment plot (kg/ha), Nf = Amount of nutrient taken from the farmer fertilizer practices (kg/ha), Na = Amount of nutrient added (kg/ha)

$$\text{Partial factor productivity (PFP)} = \frac{\text{Economic yield (kg/ha)}}{\text{Nutrient (kg/ha)}}$$

Where, PFP= Partial factor productivity of nutrient (kg grain/kg nutrient applied)

The economic analysis parameters, viz. gross returns, net returns and benefit cost ratio were worked out on the basis of prevailing market prices of inputs and outputs. The data were subjected to analysis of variance technique as per the statistical procedure and the treatment pooled means were compared at 5% level of significance.

RESULTS AND DISCUSSION

Growth parameters

Significantly higher growth characters were recorded in SSNM over RDF and FFP (Table 1). It seems that SSNM based balanced dose provided nutrient as per the crop requirement, hence the better plant height was observed with SSNM. With regards to different hybrids, significantly the highest plant height at harvest was recorded in 'CMH 08-292' over all other hybrids and significantly the lowest plant height was recorded by 'HQPM 1'. The dry-matter accumulation and leaf area index have direct correlation with grain yield of the crop. Leaf area indicates the photosynthetic efficiency, while dry-matter accumulation shows the crop health. Dry-matter accumulation and leaf-area index at 90 days after sowing (DAS) were significantly increased with SSNM, followed by RDF and significantly lowest recorded in the FFP (Table 1). Among different hybrids, 'CMH-08-292' recorded significantly the highest dry matter accumulation and leaf area index at 90 DAS compared to other hybrids and 'HQPM 1' recorded significantly the lowest dry matter accumulation and leaf area index at 90 DAS. It clearly indicated that owing to better leaf-area and higher growth parameters, SSNM proved better than other nutrient applications. Kumar *et al.* (2014) also reported that 'CMH-08-292' recorded the highest dry-matter accumulation/plant compared to other hybrids.

The crop growth rate (CGR) was recorded significantly higher with SSNM over RDF and FFP at all growth stages (Table 1). It might be owing to better availability of nutrients to crop-growth. Among the hybrids, 'CMH-08-292' was recorded significantly higher CGR over other hybrids at all growth stages except 'CMH-08-350' at 60–90 DAS. While significantly lowest CGR obtained by 'HQPM 1' at all growth stages, which show the limitation of hybrids to perform for dry-matter enhancement. It also indicates the difference in the growth potential of maize hybrids used in the experiment.

Yield attributes and yield

All the yield attributes, viz. cobs/plant, grain rows/cob, grains/row, test weight (g) and shelling percentage were influenced significantly by different nutrient management practices (Table 1). Cobs/plant (0.96), grain rows/cob (14.9), grains/row (38.6), test weight (327.6 g) and shelling percentage (85.0%) were the recorded the highest with SSNM, followed by RDF and significantly the lowest recorded in FFP. The highest yield attributes under SSNM practice might be due to higher nutrient availability, which lead to more growth and development compared to other practices. While, cob yield (7.25 t/ha), grain yield (6.56 t/ha) and stover yield (8.61 t/ha) were recorded significantly higher with SSNM over RDF and FFP (Table 2). The highest grain yield in SSNM practice might be due to positive correlation of yield and yield attributes, which were found higher in this treatment. The similar findings were reported by Ameta and Hargilas (2014) and Hargilas (2016).

With regards to hybrids, 'CMH-08-292' recorded significantly higher cobs/plant over 'PMH 1' and 'HQPM 1', however, it remained at par with 'CMH-08-350' and 'PMH 3'. The maximum grain rows/cob recorded in 'CMH-08-292' but it was not found significant with other hybrids. Significantly superior grains/row recorded in 'PMH 3' over rest hybrids. Maximum test weight obtained in 'CMH-08-292' and it found at par with 'CMH-08-350' and significantly superior over rest hybrids. Maximum shelling (83.5%) was observed in 'CMH-08-292', however, it remained at par with 'PMH 1' and 'PMH 3'. Cob, grain and stover yields were recorded maximum in 'CMH-08-292' and found significantly superior over rest hybrids except 'CMH-08-350'. Significantly the lowest yield attributes and grain yield were recorded by 'HQPM 1' (Table 2). Enhancement in growth and yield attributes leads to better photosynthetic partitioning and source–sink relationship, which gave higher yield in such hybrids. The similar findings were reported by Kumar *et al.* (2014).

Table 1. Effect of nutrient management practices and hybrids on growth parameters and yield attributes (mean data of 2 years)

Treatment	Plant height (cm)	Dry matter (g/plant) at 90 DAS	LAI at 90 DAS	CGR (g/plant/day) 0–30 DAS	30–60 DAS	60–90 DAS	Cobs/ plant	Grain rows/cob	Grain/ row	Test weight (g)	Shelling (%)
Nutrient management practice											
RDF	209	289	2.6	1.3	1.7	7.8	0.92	13.9	38.4	315.1	83.3
SSNM	220	329	3.3	1.6	2.1	9.9	0.96	14.9	38.6	327.6	85.0
FFP	201	235	1.9	0.9	1.2	5.6	0.75	13.4	33.7	307.6	74.1
SEm±	1.7	3.0	0.3	0.02	0.01	0.08	0.01	0.5	0.9	9.1	1.7
CD (P=0.05)	4.7	8.4	0.7	0.04	0.04	0.23	0.04	1.3	2.5	25.3	4.7
Hybrid											
'PHM 1'	213	293	2.7	1.3	1.7	7.9	0.81	13.4	34.6	312.6	83.4
'PMH 3'	217	292	2.7	1.3	1.7	8.0	0.91	14.4	41.7	311.5	80.1
'HQPM 1'	174	217	2.0	1.0	1.3	5.9	0.80	14.3	35.6	289.6	79.8
'CMH-08-350'	222	305	2.8	1.4	1.8	8.4	0.92	13.5	35.7	327.5	77.2
'CMH-08-292'	225	316	2.8	1.4	1.8	8.6	0.94	14.8	36.9	342.6	83.5
SEm±	2.9	5.2	0.5	0.03	0.03	0.14	0.04	1.20	1.25	13.5	1.5
CD (P=0.05)	6.0	10.8	1.0	0.06	0.06	0.29	0.08	2.48	2.57	27.8	3.2

RDF, Recommended dose of fertilizers; SSNM, site-specific nutrient management; FFP, farmer's fertilizer practice; LAI, leaf-area index; CGR, crop growth rate; DAS, days after sowing

Nutrient uptake

The data of 2 years indicated that the uptake of NPK by grain and stover and biomass was significantly higher with SSNM over RDF and FFP (Table 2). It clearly shows that application of balanced fertilization based on target yield resulted in significantly higher nitrogen uptake by grain and stover. Among the hybrids, 'CMH-08-292' recorded significantly higher NPK uptake by grain over rest hybrids, however, NPK uptake by stover and biomass of 'CMH-08-292' was obtained at par with 'CMH-08-350'. Better timing and splitting of fertilizer N application and biomass of hybrids were probably the major reasons in higher N uptake, while balanced fertilization lead to enhanced uptake of PK under SSNM and higher uptake by 'CMH-08-292' might be due to higher yield performance. Similar finding was also reported by Kumar *et al.* (2015).

Nutrient harvest index

The harvest index of the nutrient shows, how nutrient partitioning influenced by agronomic management practices and higher index shows more recovery of nutrient in economic yield. The optimum dose of P and K by SSNM has influenced their partitioning in the plant (Table 3). The N harvest index was significantly higher in FFP over RDF and SSNM, whereas phosphorus harvest index was obtained significantly higher in SSNM over RDF and FFP. However, the potassium harvest index was obtained significantly higher in SSNM over RDF, but it remained at par with FFP because lower dose of potassium applied in SSNM compared to RDF and no use of potassium by FFP. Among hybrids, 'HQPM 1' recorded the highest harvest index of N and P, which remained at par with 'CMH-08-292' and 'PMH 3', whereas, the maximum K harvest index recorded in 'PMH 3', which remained at par with 'HQPM 1' and significantly superior over rest hybrids.

Apparent nutrient recovery

Apparent nutrient recovery in maize was significantly influenced by different nutrient management practices and hybrids (Table 3). Apparent recovery of nitrogen and phosphorus recorded significantly higher with SSNM over RDF. Whereas, apparent recovery of potassium in SSNM was recorded at par with RDF, might be owing to high level of K in the soil. The balanced application of nutrient by SSNM obtained significantly higher apparent recovery (%) of nutrient applied, because, all these nutrients are synergistic in nature. Among the hybrids, 'CMH-08-292', resulted in significantly higher apparent recovery (N, P & K) over 'HQPM 1' and 'PMH 1' and it remained at par with 'CMH-08-350' and 'PMH 3'.

Partial factor productivity (PFP)

The maximum PFP of N recorded in SSNM, followed by RDF and it's recorded significantly higher over FFP. The PFP of phosphorus in SSNM was found significantly higher over rest treatments. The highest PFP of K in SSNM, followed by RDF. It clearly shows that balanced nutrient application by SSNM increases partial factor productivity compared to the RDF and FFP. Among the hybrids, maximum partial factor productivity of N (49.4 kg/ha), P (154.8 kg/ha) and K (152.3 kg/ha) recorded with 'CMH-08-292', which recorded significantly higher over rest hybrids. It indicates that 'CMH-08-292' was efficient in the utilization of nutrients and genetic diversity exists

Table 2. Effect of nutrient management practices and hybrids on yield and nutrient uptake (mean data of 2 years)

Treatment	Cob yield (t/ha)	Grain yield (t/ha)	Stover yield (t/ha)	Nutrient uptake by grain (kg/ha)			Nutrient uptake by stover (kg/ha)			Total uptake (kg/ha)		
				N	P	K	N	P	K	N	P	K
Nutrient management practice												
RDF	6.68	5.29	7.93	66.7	16.8	25.8	24.9	11.7	146.8	91.8	30.6	172.6
SSNM	7.25	6.56	8.61	86.3	21.0	35.3	31.1	11.9	158.7	117.4	34.8	185.6
FFP	4.98	3.48	5.55	42.5	10.3	16.9	12.9	6.6	82.1	55.5	17.9	105.4
SEm±	0.12	0.07	0.09	1.01	0.24	0.40	0.36	0.17	2.21	0.68	0.48	3.65
CD (P=0.05)	0.34	0.20	0.24	2.8	0.67	1.12	1.00	0.46	6.13	1.89	1.33	10.14
Hybrid												
'PHM 1'	5.38	4.52	6.96	57.1	14.0	23.0	21.3	10.8	124.1	79.1	25.4	147.9
PMH 3'	6.58	5.21	7.60	64.9	16.3	28.9	22.1	9.0	125.1	86.2	27.4	153.8
'HQPM 1'	5.26	4.24	5.61	55.5	13.9	20.6	18.1	8.3	101.7	73.7	23.4	120.9
'CMH-08-350'	7.09	5.54	8.19	70.4	17.1	28.9	26.4	11.5	147.6	97.2	30.0	174.9
'CMH-08-292'	7.19	6.05	8.46	78.3	18.9	28.7	26.9	10.6	147.7	104.9	32.6	175.4
SEm±	0.30	0.27	0.27	1.74	0.42	0.70	1.26	0.75	6.73	1.18	0.83	6.35
CD (P=0.05)	0.61	0.55	0.55	3.6	0.87	1.44	2.61	1.54	13.89	2.44	1.72	13.11

RDF, Recommended dose of fertilizers; SSNM, site specific nutrient management; FFP, farmer's fertilizer practice for nutrient utilization in maize cultivars.

Economics

The variation in the gross returns, net returns and benefit: cost ratios were recorded due to different nutrient management practices, whereas, cost of cultivation was not varied much with different practices (Table 5). Significantly the highest gross returns (₹91,797/ha), net returns (₹66,350/ha) and benefit: cost ratio (2.60) recorded in SSNM over RDF and FFP. Among the hybrids, 'CMH-08-292', recorded significantly higher gross returns, net returns and benefit: cost ratio, followed by 'CMH-08-292' and significantly superior over rest hybrids. The gross returns, net returns and benefit: cost ratio has direct correlation with economical yield under different nutrient management practices and yield potential of hybrids. Thus, the higher yield resulted into better economics in such treatments.

Table 3. Effect of nutrient management practices and hybrids on nutrient harvest index, apparent recovery, partial factor productivity, and economics of hybrids (mean data of 2 years)

Treatment	Nutrient harvest index			Apparent recovery (%)			Partial factor productivity (kg grain/kg nutrient applied)			Cost of cultivation (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
	N	P	K	N	P	K	N	P	K			
Nutrient management practice												
RDF	73.0	55.2	15.0	30.3	21.2	167.9	44.1	88.1	132.2	25.8	48.3	1.87
SSNM	73.5	60.3	19.1	42.1	41.2	169.9	44.7	159.2	138.9	25.4	66.4	2.60
FFP	76.4	57.6	16.3	-	-	-	40.9	154.6	-	22.0	26.7	1.21
SEm±	0.54	0.62	0.38	1.26	0.82	7.45	0.80	2.76	1.75	0.00	1.03	0.04
CD (P=0.05)	1.49	1.72	1.05	3.50	2.28	20.68	2.22	7.65	4.87		2.86	0.12
Hybrid												
'PHM 1'	72.4	55.1	15.4	33.9	29.3	160.4	38.6	118.5	121.5	25.3	38.9	1.57
'PMH 3'	75.5	59.6	18.6	36.5	31.3	168.3	45.7	140.8	142.5	25.3	48.9	1.96
'HQPM 1'	75.8	59.4	17.2	31.8	29.2	153.1	37.3	114.8	120.7	24.9	35.1	1.42
'CMH-08-350'	72.8	56.5	16.4	38.6	31.6	180.1	45.2	140.9	140.6	25.9	53.0	2.12
'CMH-08-292'	75.1	57.8	16.5	40.2	34.6	182.6	49.4	154.8	152.3	25.9	60.1	2.41
SEm±	0.93	1.12	0.65	2.68	1.74	15.84	1.39	4.79	3.73	0.00	3.75	0.15
CD (P=0.05)	1.92	2.31	1.35	5.53	3.59	32.69	2.87	9.88	7.69	–	7.73	0.31

RDF, Recommended dose of fertilizers; SSNM, site specific nutrient management; FFP, farmer's fertilizer practice

Table 4. Interaction effect of nutrient management practices and hybrids on yield, net returns and benefit: cost ratio (mean data of 2 years)

Nutrient management practice	Hybrid	Grain yield (t/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
RDF	'PHM 1'	4.76	40.8	1.58
	'PMH 3'	5.53	51.6	2.00
	'HQPM 1'	4.56	38.1	1.48
	'CMH-08-350'	5.61	52.8	2.05
	'CMH-08-292'	5.99	58.1	2.26
SSNM	'PHM 1'	5.73	55.0	2.17
	'PMH 3'	6.75	69.3	2.74
	'HQPM 1'	5.23	48.3	1.94
	'CMH-08-350'	7.19	74.8	2.89
	'CMH-08-292'	7.90	84.7	3.27
FFP	'PHM 1'	3.07	20.9	0.95
	'PMH 3'	3.35	24.9	1.13
	'HQPM 1'	2.92	18.9	0.86
	'CMH-08-350'	3.82	31.4	1.42
	'CMH-08-292'	4.26	37.5	1.70
SEm±		0.42	5.81	0.23
CD (P=0.05)		0.96	13.40	0.54

RDF, Recommended dose of fertilizers; SSNM, site specific nutrient management; FFP, farmer's fertilizer practice

Interaction effect of nutrient management practices and hybrids

The interaction effect of nutrient management practices and hybrids was observed on yield, net returns and benefit: cost ratio (Table 6) indicated that maximum grain yield (7.90 t/ha), net returns (₹84,723/ha) and benefit: cost ratio (3.27) recorded with 'CMH-08-292' with SSNM, which found at par with 'CMH-08-350' with SSNM and significantly superior over rest interactions. The lowest value of yield and net returns were recorded under the farmer's fertilizer practice for all hybrids, which might be due to lower/imbalance doses of nutrients under farmer's fertilizer practice in comparison to recommended doses and SSNM. It indicates that every hybrid needs a differential nutrient management strategy for realization of the highest yield and profit.

Based on 2 years study, it can be concluded that target yield based-site-specific nutrient management practice proved to be higher productive, viable and profitable than recommended dose of fertilizers and farmer's fertilizer practices for growing high yielding hybrids in sub-humid condition of Southern Rajasthan and similar agroecoloiges.

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Research Paper

Effect of sowing date and weed management on productivity and economics of rainfed mungbean (*Vigna radiata*)

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season of 2013 and 2014 at Angul, Odisha, to study the effect of sowing date and weed management on crop growth, yield, weed control, economics and nutrient uptake of mungbean [*Vigna radiata* (L.) Wilezek]. The experiment consisted of 3 sowing date and 6 weed management treatments. The pooled results revealed that, the crop sown on June 20, resulted significantly higher plant height, dry matter accumulation, seeds/pod, nodules/plant, seed yield (1.0 t/ha), net returns (₹26,100/ha) and weed control efficiency (68.1%). Application of imazethapyr @ 100 g/ha at 20 days after sowing (DAS) followed by (*fb*) 1 hand-weeding at 40 DAS resulted in significantly higher plant height, dry matter accumulation, dry matter efficiency, pods/plant, seeds/pod, nodules/plant, nodules dry weight, seed yield (1.17 t/ha), harvest index (29.7%), monetary returns (₹872/ha/day) and benefit: cost ratio (2.18). The same treatment also recorded the maximum weed control efficiency (87.9%), which resulted in significant reduction in both weed density (38.0/m^2) and weed dry weight (28.6 g/m^2). In contrast to nutrient uptake by mungbean crop, the decreased nitrogen, phosphorus and potash removal by weeds was recorded upto to 88.5% under weed management treatments.

Key words: Economics, Mungbean, Nutrient uptake, Sowing date, Weed management, Yield

Mungbean is the third most important grain legumes crop after chickpea and pigeonpea grown and consumed in India. It is a good source of protein and minerals. Its protein quality is similar to or better than other grain legumes Mungbean is the major pulse crop of Odisha with a total coverage of 0.86 million ha. The area under mungbean crop in Angul district is 0.03 million ha with a productivity of 0.45 t/ha, which is at par with state average yield (Samant, 2014).

Among the various agronomic practices, sowing time is the most important factor influencing its yield, which differs from region to region and variety to variety. But lack of awareness among farmers about optimum sowing date is one of the reasons of its low productivity. In early sowing of mungbean, a second crop can be grown on the same field in early September for higher income with increasing soil fertility. Any delay in sowing time not only reduces the yield but also creates problem for harvesting of the same. The foremost information on time of sowing therefore needs to be specified. Sowing date is also one of the major non-monetary input affecting growth, yield and its contributing characters. It is considered as important factor which is having the vast potential to explore the maximum yield (Palsaniya *et al*., 2016).

Weed management is the most important agronomic aspect that plays a vital role in exploiting the yield potential of rainy season (*kharif*) mungbean. Weeding and hoeing are common cultural methods for mungbean. Manual weeding at right stage is difficult, time consuming and expensive due to intermittent rainfall during rainy season and scanty labour. Weeds compete with crop plant for water, nutrient, light and space during all the crop growth stages in hot and humid weather. Presence of weeds has been reported to reduce the seed yield of mungbean by 35%. Integration of one herbicide with one hand-weeding provided better growth, yield attributes and consequently higher yield (Raman and Krishnamoorthy, 2005). Therefore, there is an urgent need to move from costly manual-mechanical weed control to an integrated weed control. In the more developed agricultural systems, herbicides have already replaced mechanical weed control. Unavailability of labours at the time of weeding resulting in sever field infestation, which make mechanical weeding ineffective,

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tedious and costly. Under such circumstances, chemical control of weeds may be the viable and cost effective alternative for this crop. Effective herbicide at appropriate rate may prove as an effective weed control method and replace conventional methods of weed control (Chaudhari *et al.,* 2016). Herbicides can be used as an alternative of manual or mechanical weeding. Previously, weed control through herbicides was considered a costly proposition. However in recent times availability of low-dose, high potency, non-residual, broad spectrum herbicides has provided great opportunity to accomplish effective weed control at much lower cost than mechanical methods. Imazethapyr, a post-emergence broad spectrum herbicide, was recommended for use in rainy-season pulses like pigeonpea, urdbean and mungbean (Kumar, *et al.*, 2016). Weed management in mungbean not only increased N, P and K uptake by seed and stover of crop, but also it decreases the total N, P and K uptake by weeds over weedy check (Komal *et al*., 2015). Therefore, the present investigation was undertaken with the objective of finding suitability of sowing date and weed management on growth, yield, weed control, economics and nutrient uptake in rainfed mungbean.

MATERIALS AND METHODS

The experiment was conducted during rainy (*kharif*) season of 2013 and 2014 at Angul, Odisha to study the effect of sowing date and weed management on growth, yield, weed control, economics and nutrient uptake of mungbean. The experiment site is located at the Instructional farm, Krishi Vigyan Kendra (20°49' N, 85°04' E and an altitude of 195 m above mean sea-level). The soil of the experimental field was sandy loam with slightly acidic in reaction (*p*H 5.5), low in organic carbon (0.48%) and available nitrogen (236.4 kg/ha), medium in available phosphorus (14.9 kg/ha) and potassium (172.5 kg/ha). Total rainfall received during the crop season was 956.5 mm. The average relative humidity during the experimental season fluctuated between 75 to 93% in the morning time and 41 to 66% in the evening time. Mean weekly maximum temperature fluctuated between 36.1 and 29.6°C and minimum temperature 22.7 and 27.0°C during the crop growth period.

The experiment was laid out in split-plot design keeping 3 sowing date, viz. June 20, July 5, July 20 in main-plots and 6 weed management practices, viz. imazethapyr 100 g/ha at 20 days after sowing (DAS); mechanical weeding by finger weeder at 20 DAS; imazethapyr 100 g/ha 20 DAS followed by (fb) 1 hand-weeding (HW) at 40 DAS; mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS; hand weeding at 20 DAS fb hoeing at 40 DAS and weedy check in sub-plots during both the years and replicated 3 times.

Mungbean 'OBGG 52' was sown in a plot size of 5 m × 5 m with 20 kg seed/ha at 30 cm apart, as per the sowing-date treatments. Thinning was done 15 DAS to maintain optimum plant population. The recommended dose of fertilizers, i.e. 20, 40 and 40 N, P and K kg/ha was used for all the treatments and pests and diseases control measures were followed as per need of crop. Imazethapyr was applied through knapsack sprayer fitted with a flat-fan nozzle using a spray volume of 500 litres of water per hectare. Mechanical weeding was done by finger weeder as per treatment. Observation on plant growth (plant height, nodules/plant, nodules dry weight/plant, dry matter accumulation and dry matter efficiency), yield attributes (pods/plant and seeds/plant) and yield (seed, stover, harvest index) were recorded following standard procedures. Weed population were counted from 2 places selected randomly by throwing a metallic quadrate of size 0.5 m× 0.5 m at 40 days after sowing in each plot. The weed dry weight was recorded by drying of weeds in hot air oven (65°C for 72 hours). The dry-matter efficiency was calculated as the percent of total dry matter production (seed and stover yields) accumulated in seed per day (Singh and Chaudhary, 2016). The weed control efficiency (WCE) was calculated by using the formula (Kondap and Upadhyay, 1985) on weed dry weight basis.

Economic analysis was done by calculating cost of cultivation, gross returns, net returns and benefit: cost ratio (B:C). Prevailing price of inputs in the market during both the year were used to calculate the economics. The B:C ratio was worked out on the basis of gross returns and cost of cultivation. Monetary returns was calculated by dividing gross return by total crop duration. Available soil nutrients as well as nutrient content and their uptake by crop and weeds were determined by adopting standard procedures (Jackson, 1973). After estimation of NPK concentration in weeds, mungbean seed and stover under different treatments, NPK uptake was calculated by nutrient concentration with respective yields. All the data obtained for 2 years were pooled and statistically analyzed applying the techniques of analysis of variance and the significance of different sources of variations were tested by error mean square of Fisher Snedecor's 'F' test at probability level 0.05 (Cochran and Cox, 1957). Critical difference (CD) values at P=0.05 were used to determine the significance of difference between mean values of different parameters.

RESULTS AND DISCUSSION

Growth parameters

Significant differences were observed due to sowing date and weed management practices on crop-growth parameters (Table 1). The plant height, nodules/plant and dry matter accumulation were significantly higher in June 20 sowing than July 20 sowing, which might be owing to longer period for photosynthesis and growth in early sowing.

Significant differences in plant height, dry matter accumulation, nodules/plant and nodules dry weight/plant were recorded owing to weed management practices. Application of imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS recorded the maximum plant height, dry matter accumulation, nodules/plant and nodules dry weight/plant, which were at par with mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS and was significantly superior to rest of the treatments, which might be due to less crop-weed competition. The increase in nodule number probably due to increase in aeration of rhizosphere in disturbed soil condition. Similar kind of results were reported by Pramanick *et al.* (2013).

Yield attributes

All yield attributes were significantly affected by the sowing date and weed management practices (Table 1). Seeds/pod was found to be significantly higher on June 20 than July 5 and July 20 sowing attributing to better translocation of photosynthates to seed. The reduction in yield attributes in delayed sowing might be due to decrease in cell-division and cell expansion and owing to their genetic variability. Weed management practices showed significant variation in different yield attributes. Imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS resulted maximum pods/plant and seeds/pod, which was at par with mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS and significantly higher than rest of the treatments, which might be owing to its higher plant height and dry matter accumulation. These results are in agreement with the findings of Chaudhari *et al*. (2016).

Weed control

Influence of sowing date on weed control was not perceptible. However, early sowing of mungbean on June 20 recorded (Table 1) the maximum weed-control efficiency with reduction in both weed density and weed dry weight as compared to delayed sowing on July 5 and July 20 (Soomro and Khan, 2003). Among different weed management practices, weed-control efficiency was maximum with imazethapyr 100 g/ha at 20 DAS fb 1 HW at 40 DAS which was followed by mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS and HW at 20 DAS fb hoeing at 40 DAS (Table 1). All the weed control

Table 1. Effect of sowing date and weed management practices on crop growth, yield attributes and weed control of mungbean. (pooled data of 2 years)

Treatment	Plant height at harvest (cm)	Dry-matter accumulation at harvest (g/m^2)	Pods/ plant	Seeds/ pod	Nodules/ plant at post flowering	Nodules dry weight (mg/plant)	Weed density at 40 DAS (No/m^2)	Weed dry weight at 40 DAS (g/m^2)	Weed-control efficiency (%)
Sowing date									
June 20	63.1	275.7	26.4	6.7	12.1	1.90	111.7	75.4	68.1
July 5	61.6	258.4	25.7	6.5	10.6	1.76	119.9	79.7	66.3
July 20	55.2	246.6	24.9	5.8	10.1	1.66	120.3	83.5	64.7
SEm±	1.48	4.31	0.37	0.08	0.11	1.53	5.24	1.77	–
CD (P=0.05)	5.82	16.91	NS	0.33	0.41	NS	NS	NS	–
Weed management practices									
Imazethapyr 100 g/ha at 20 DAS	57.6	259.2	26.4	6.3	11.1	1.72	83.7	66.9	71.7
Mechanical weeding by finger weeder at 20 DAS	62.8	251.0	24.6	6.7	11.4	1.85	87.1	73.2	69.0
Imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS	65.2	295.5	31.2	7.2	12.7	2.26	38.0	28.6	87.9
Mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS	64.8	280.4	28.5	6.9	12.5	2.21	47.7	34.9	85.2
HW at 20 DAS fb hoeing at 40 DAS	55.4	262.1	23.5	5.6	9.5	1.37	52.5	37.1	84.3
Weedy check	54.0	213.3	19.7	5.2	8.3	1.22	394.8	236.3	–
SEm±	2.20	8.66	0.51	0.11	0.21	0.01	3.70	1.66	–
CD (P=0.05)	6.35	25.01	1.48	0.32	0.60	0.02	10.67	4.79	–

FB, followed by; DAS, days after sowing; NS, non-significant; HW, hand weeding treatments significantly reduced both weed density and weed dry weight as compared to weedy check, where maximum weed growth observed during entire crop-growing period. This might be due to effective control of weeds during early stages of crop growth by herbicides and in later stages removal of weeds by HW. These findings are in agreement with Chhodavadia *et al.* (2013).

Yield

Pooled analysis of 2 years data (Table 1) showed significant differences in seed yield, stover yield and harvest index with different sowing date and weed management practices. Maximum seed and stover yields was obtained when sown on June 20, which was statistically at par with July 5 and significantly superior to July 20 sowing due to long vegetation period of the crop and higher yield attributing characters. The harvest index was maximum in July 5 sowing for partitioning of biomass from vegetative to reproductive organ. Similar types of differences among sowing dates were observed by Palsaniya *at el*. (2016). Among the weed management practices, imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS produced significantly higher seed and stover yields and harvest index than other treatments could be owing to better weed control, which ultimately increased the values of yield attributes (Chhodavadia *et al.*, 2013). In addition to this, the least weed density and weed dry weight were also contributed for better seed yield. Higher stover yield was attributed to favourable effect on growth characters by avoiding crop weed competition. This was followed by mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS and weedy check plot recorded the lowest seed and stover yields and harvest index due to higher weed interference.

Economics

Significantly higher gross returns, net returns, monetary returns and benefit: cost ratio were obtained with June 20 sowing which were at par with July 5 and significantly higher than July 20 owing to higher seed yield (Table 2).

Among different weed management practices, application of imazethapyr 100 g/ha at 20 DAS fb 1 HW at 40 DAS recorded the highest gross returns, net returns and monetary returns, which were at par with mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS and significantly higher than rest of the treatments. This was due to higher seed and stover yields of the crop obtained from the above treatments and lower cost of cultivation over rest of the treatments. Maximum benefit: cost ratio among the weed management practices was recorded under mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS. This might be due to lower cost of cultivation with saving of inputs like herbicide and labour. The lowest net returns and benefit: cost ratio among the weed control treatments was obtained under HW at 20

Table 2. Effect of sowing date and weed management practices on yield and economics of mungbean (pooled data of 2 years)

Treatment	Dry-matter efficiency (%/day)	Seed yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Gross returns (×10³₹/ha)	Net returns (× 10³₹/ha)	Monetary return (₹/ha/day)	Benefit: cost ratio
Sowing date								
June 20	0.43	1.00	2.56	28.2	49.0	26.1	753.6	2.18
July 5	0.45	0.99	2.42	28.9	48.0	24.2	738.3	2.04
July 20	0.43	0.91	2.30	28.1	44.5	19.4	684.1	1.75
SEm±	0.01	0.02	0.04	0.31	0.9	0.8	13.6	0.06
CD (P=0.05)	NS	0.07	0.15	NS	3.5	3.1	53.5	0.23
Weed management practices								
Imazethapyr 100 g/ha at 20 DAS	0.44	0.99	2.48	28.6	48.3	24.0	743.4	2.03
Mechanical weeding by finger weeder at 20 DAS	0.44	0.95	2.36	28.7	46.1	23.3	709.6	2.06
Imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS	0.46	1.17	2.76	29.7	56.7	30.3	872.1	2.18
Mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS	0.45	1.03	2.62	29.5	53.2	28.3	817.7	2.19
HW at 20 DAS fb hoeing at 40 DAS	0.44	0.89	2.20	28.8	43.5	18.8	669.2	1.80
Weedy check	0.39	0.71	2.15	25.1	35.1	14.7	540.0	1.70
SEm±	0.01	0.04	0.09	0.46	1.7	1.7	26.3	0.07
CD (P=0.05)	0.02	0.10	0.25	1.33	4.9	4.8	76.0	0.20

Selling price of greengram seed, (₹45,000/t) in 2013–14 and (₹46,000/t) in 2014–15; selling price of stover (₹1,500/t) in 2013–14 and 2014–15; DAS, days after sowing; HW, Hand weeding; FB, followed by

Table 3. Effect of sowing date and weed management practices on nutrient uptake by crop and weeds of mungbean (pooled data of 2 years)

Treatment	Nutrient uptake by seed (kg/ha)			Nutrient uptake by stover (kg/ha)			Nutrient uptake by weed (kg/ha)		
	N	P	K	N	P	K	N	P	K
Sowing date									
June 20	31.0	5.7	14.9	26.4	2.3	30.2	30.0	9.5	22.4
July 5	30.8	5.7	14.8	25.2	2.2	28.9	35.5	13.6	27.2
July 20	29.4	5.4	14.3	24.7	2.2	28.6	43.7	20.6	34.8
SEm±	1.07	0.19	0.43	0.79	0.1	0.53	0.44	0.19	0.39
CD (P=0.05)	NS	NS	NS	NS	NS	NS	1.71	0.74	1.52
Weed management practices									
Imazethapyr 100 g/ha at 20 DAS	28.9	5.3	13.8	24.4	2.1	18.4	22.0	10.7	21.3
Mechanical weeding by finger weeder at 20 DAS	28.5	5.2	13.7	23.9	2.1	18.2	23.3	9.8	22.5
Imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS	38.0	7.0	18.2	30.3	2.6	23.1	9.1	2.9	6.5
Mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS	35.5	6.5	17.1	28.7	2.5	21.8	10.0	6.0	8.7
HW at 20 DAS fb hoeing at 40 DAS	28.7	5.3	14.0	23.9	2.3	18.5	13.1	3.6	13.9
Weedy check	22.8	4.2	11.2	21.2	2.0	16.8	68.1	25.3	39.7
SEm±	1.4	0.25	0.56	1.18	0.1	1.19	0.81	0.33	0.48
CD (P=0.05)	4.1	0.73	1.60	3.40	0.3	3.43	2.33	0.95	1.39

N, Nitrogen; P, phosphorus; K, potassium; DAS, days after sowing; HW, Hand weeding; FB, followed by

DAS fb hoeing at 40 DAS due to higher labour wages (Kumar *et al.,* 2016).

Nutrient uptake by crop and weeds

The N, P and K uptake by both seed and stover of crop was not significantly influenced by sowing date (Table 3). However, early sowing of mungbean on June 20 recorded increased N, P and K uptake by both seed and stover of mungbean with reduced nutrient depletion by weeds as compared to delayed sowing on July 5 and July 20. All weed management practices significantly increased N, P and K uptake by mungbean (seed and stover) over weedy check. The maximum N, P and K uptake by both seed and stover was recorded with imazethapyr 100 g/ha 20 DAS fb 1 HW at 40 DAS, which was statistically at par with mechanical weeding by finger weeder at 20 DAS fb 1 HW at 40 DAS and significantly higher than rest of the treatments owing to less crop weed competition, better crop growth and grain yield.

Maximum nutrient depletion by weed was observed in delayed sowing on July 20. Significant decrease in N, P and K uptake by weeds were recorded due to all weed management practices over weedy check. Application of imazethapyr @ 100 g/ha 20 DAS fb 1 HW at 40 DAS minimized N, P and K removal by weeds to a tune of 86.6, 88.5 and 83.6% respectively over that of weedy-check influencing the weed biomass and weed-control efficiency. Similar reduction in nutrient uptake by weeds under different weed management practices had also reported by Chhodavadia *et al.* (2013) and Yadav *et al.*, (1985).

It can be concluded from the present investigation that June 20 sowing was more suitable for higher productivity and profitability in rainfed mungbean. Imazethapyr @ 100 g/ha at 20 DAS fb 1 hand weeding at 40 DAS proved remunerative and effective in crop growth, weed control, yield and nutrient uptake for timely sown mungbean under rainfed condition.

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Research Paper

Effect of nitrogen and phosphorus management on productivity and profitability of groundnut (*Arachis hypogaea*)

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ABSTRACT

A field experiment was conducted for 3 years at Agricultural Research Station, Shirgaon, Ratnagiri, Maharashtra during rainy season (*kharif*) of 2012–14 to evaluate the effect of different nitrogen and phosphorus ratios on productivity of rainy season (*kharif*) groundnut under Konkan conditions. Eleven combinations of nitrogen-phosphorus ratios were tested in randomized block design with 3 replications. Treatment receiving 0.40 NP ratio (30:75 NP kg/ha) produced significantly higher pod yield of 3.50 t/ha over rest of N:P ratios, but it was at par with 0.42 (25:60 NP kg/ha), 0.33 (25:75 NP kg/ha) and 0.50 (30:60 NP kg/ha) N:P ratios. Kernel yield was also noticed significantly higher under 0.40 NP ratio (2.63 t/ha) over all other N:P ratios except 0.42 NP ratio (2.31 t/ha). The increment in pod and kernel yield due to 0.40 NP ratio over the control was to the tune of 36.7% and 38.7% respectively. However, 0.50 NP ratio (30:60 NP kg/ha) recorded significantly higher haulm yield of 3.94 t/ha over the control. Application of N and P in 0.40 ratio also recorded significantly more number of pods/plant (30.7) and dry pod weight (34.2 g/plant) over all other treatments. Higher net returns of ₹58,826/- and benefit: cost ratio of 1:1.78 were also obtained with 0.40 NP ratio, which was followed by 0.42 NP ratio with net returns of ₹47,638/ha and benefit: cost ratio of 1.66.

Key words: Economics, Groundnut, Nitrogen-phosphorus ratio, Pod yield

Groundnut is a valuable cash crop planted by millions of small farmers because of its economic and nutritional value. Groundnut is rich in digestible protein, minerals and vitamins, so contributes significantly in food security and alleviating poverty in many countries.

Nitrogen and phosphorus are important elements for effective production of groundnut. Plastic response of plant to N and P supply cause up to 50-fold variation in biomass. N:P ratios associated with differences in root allocation, nutrient uptake, biomass turnover and reproductive output. Nitrogen is essential component of many compounds of plant, such as chlorophyll, nucleotides, proteins, alkaloids, enzymes, hormones and vitamins. Phosphorus is essentially required for healthy growth, efficient root system and profuse nodulation, which in turn can affect the N_2-fixation potential. Phosphorus is considered as a limiting factor in plant nutrition due to the deficiency of available soluble phosphate in the soil (Maheswar and Sathiyavani, 2012). Phosphorus is necessary for the proper functioning of the nodules and root growth (Naveen Kumar *et al.* 2015). Positive response of legume crop to fertilizer N indicates that N demand of the crop is not being fully met by nitrogen-fixation.

Intense rainfall in Konkan during rainy (*kharif*) season removed bases and nutrients from soil therefore, quantifying of precise with optimum fertilizer rate is essential to exploit profitability and to minimize the potential environmental impact in Konkan. The systematic and comprehensive research on the different proportions of nitrogen and phosphorus is inadequate or sporadic under such circumstances. Therefore, it is most essential to pay a great attention to the nutrition of groundnut to enhance its productivity. Hence, present investigation was undertaken to study different nitrogen and phosphorus ratios on groundnut productivity during rainy (*kharif*) season.

MATERIALS AND METHODS

Field experiments were conducted at Agricultural Research Station, Shirgaon on lateritic soil of Konkan during 3 consecutive rainy (*kharif*) seasons of 2012–2014. The experiment was conducted in randomized block design

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with 11 combinations of N and P, viz. 0:0 NP kg/ha, 25:75 NP kg/ha (NP ratio: 0.33), 18:46 NP kg/ha (NP ratio: 0.39), 30:75 NP kg/ha (NP ratio: 0.40), 25:60 NP kg/ha (NP ratio: 0.42), 25:50 NP kg/ha (NP ratio: 0.50), 30:60 NP kg/ha (NP ratio: 0.50), 25:45 NP kg/ha (NP ratio: 0.56), 30:45 NP kg/ha (NP ratio: 0.67), 25:30 NP kg/ha (NP ratio: 0.83) and 30:30 NP kg/ha (NP ratio: 1.0). Experimental site was high in organic matter content (1.41%), medium in nitrogen (290.1 kg/ha) and phosphorus (13.1 kg/ha), while high in potassium content (323.3 kg/ha). Groundnut cultivar '*Trombay Konkan Groundnut-Bold'* was sown with spacing of 30cm × 15cm. The plant population was maintained about 2,22,222 plants/ha. All the recommended packages of practices were adopted as per need of crop. The nitrogen to phosphorus ratio was managed through using urea and single super phosphate as a source of N and P, respectively. The total rainfall received during crop growth period in rainy season (*kharif*) 2012 was 3,085 mm with 86 rainy days, rainy season (*kharif*) 2013 was 1949.9 mm with 74 rainy days and 2247.2 mm with 68 rainy days in rainy season (*kharif*) 2014 respectively. At harvest, a random sample of 5 plants were taken from each plot to determine averages of plant height (cm), pods/plant, kernels/pod, dry pod yield/plant, haulm yield/plant (g), 100-seed weight (g), shelling percentage and sound mature kernels. Agronomic yield were determined plot basis and converted into per hectare yield. The economics was calculated based on standard prevailing market prices of inputs.

RESULTS AND DISCUSSION

Growth and yield attributes

Number of pods/plant and pod weight were significantly influenced due to different nitrogen and phosphorus ratios and ranged between 15.7 to 30.7 and 18.4 to 34.2 g/plant, respectively (Table 1). Plant height and branches/plant failed to exhibit any significant effect due to application of different N:P ratios to groundnut. Significantly higher pods/plant and pod weight recorded when nitrogen and phosphorus were applied in the proportion of 30:75 NP kg/ha i.e. 0.40 NP ratio over all other treatments except 0.33 NP ratio (25:75 NP kg/ha) and 0.50 NP ratio (30:60 NP kg/ha) for number of pods/plant and treatment 0.50 NP ratio i.e. 30:60 NP kg/ ha for dry pod weight, which were at par with 0.40 NP ratio. The untreated control treatment i.e. 0:0 NP kg/ha noticed the lowest number of pods/plant (15.7) and dry pod weight (18.4 g/plant) than rest of the treatments. Similar results were also reported by Hemalatha *et al.* (2013) and Shiva Kumar *et al.* (2014), who reported that optimal dose of NP had played significant role in higher uptake of nutrients and yield of crop.

Yield

Application of NP in 0.40 ratio (30:75 NP kg/ha) produced significantly higher pod yield (3.50 t/ha) over rest of NP ratios, except NP ratios of 0.42, 0.33, and 0.50. Likewise, kernel yield was significantly higher under NP ratio of 0.40 (2.63 t/ha), which was on par with 0.42 NP ratio (2.31 t/ha). Moreover, 0.50 NP ratio (30:60 NP kg/ha) produced significantly higher haulm yield of 3.94 t/ha over control, but it was statistically at par with most of the treatments. The increase in pod and kernel yields due to 0.40 NP ratio (3.50 and 2.63 t/ha, respectively) over control i.e. 0.0 NP ratio (2.22 and 1.61 t/ha, respectively) was to the tune of 36.7% and 38.7% respectively. While, the haulm yield in 0.50 NP ratio (30:60 NP kg/ha) treatment was 3.94 t/ha over control (2.75 t/ha), which was to the tune of 30.2%. The highest value of harvest index (0.36) was noticed with 0.40 NP ratio. As the soil was medium in N and P hence, its response was higher when 30 kg N and

Table 1. Growth and yield attributes of groundnut as influenced by different treatments (pooled data of 3 years)

Treatment	Plant height (cm)	Branches/ plant	Pods/ plant	Pod weight (g/plant)	Shelling out turn (%)	Sound mature kernels (%)	100-kernel weight (g)
00:00 NP kg/ha, NP ratio: 0.00	50.3	3.3	15.7	18.4	72.4	84.6	58.9
25:75 NP kg/ha , NP ratio: 0.33	52.1	3.3	28.1	30.1	72.6	85.9	60.5
18:46 NP kg/ha , NP ratio: 0.39	54.7	3.4	23.2	28.9	74.4	83.6	61.0
30:75 NP kg/ha, NP ratio: 0.40	54.9	3.5	30.7	34.2	75.2	86.5	63.8
25:60 NP kg/ha, NP ratio: 0.42	53.3	3.3	25.6	28.8	74.0	87.1	61.1
25:50 NP kg/ha, NP ratio: 0.50	56.3	3.4	23.4	26.9	71.7	85.4	62.6
30:60 NP kg/ha, NP ratio: 0.50	55.4	3.4	27.7	32.7	72.5	85.2	64.9
25:45 NP kg/ha, NP ratio: 0.56	52.8	3.4	21.8	26.3	73.6	85.3	62.8
30:45 NP kg/ha, NP ratio: 0.67	54.2	3.6	23.2	27.0	73.7	86.5	62.9
25:30 NP kg/ha, NP ratio: 0.83	54.9	3.2	18.6	20.3	72.1	85.4	62.9
30:30 NP kg/ha, NP ratio: 1.0	56.5	3.4	19.7	22.5	74.7	85.7	64.8
SEm±	2.9	0.2	1.1	1.3	1.3	0.8	1.7
CD (P=0.05)	NS	NS	3.2	3.7	3.7	2.2	4.8

Table 2. Yield and economics of groundnut as influenced by different treatments (pooled data of 3 years)

Treatment	Dry pod yield (t/ha)	Kernel yield (t/ha)	Haulm yield (t/ha)	Harvest Index	Gross returns (×10^3₹/ha)	Cost of cultivation (×10^3₹/ha)	Net returns (×10^3₹/ha)	Benefit: cost ratio
00:00 NP kg/ha, NP ratio: 0.00	2.22	1.61	2.75	0.32	86.4	62.8	23.6	1.38
25:75 NP kg/ha , NP ratio: 0.33	3.08	2.23	3.59	0.33	116.2	71.7	44.5	1.62
18:46 NP kg/ha , NP ratio: 0.39	2.78	2.06	3.58	0.32	107.2	69.1	38.2	1.55
30:75 NP kg/ha, NP ratio: 0.40	3.50	2.63	3.76	0.36	134.2	75.3	58.8	1.78
25:60 NP kg/ha, NP ratio: 0.42	3.13	2.31	3.67	0.34	120.0	72.4	47.6	1.66
25:50 NP kg/ha, NP ratio: 0.50	2.89	2.07	3.61	0.32	110.3	69.5	40.8	1.59
30:60 NP kg/ha, NP ratio: 0.50	3.07	2.22	3.94	0.32	117.3	71.2	46.1	1.65
25:45 NP kg/ha, NP ratio: 0.56	3.00	2.20	3.55	0.34	115.5	70.5	45.0	1.64
30:45 NP kg/ha, NP ratio: 0.67	2.70	1.99	3.34	0.33	104.3	68.8	35.4	1.51
25:30 NP kg/ha, NP ratio: 0.83	2.73	1.97	3.30	0.33	104.8	68.0	36.8	1.54
30:30 NP kg/ha, NP ratio: 1.0	2.78	2.07	3.41	0.34	106.9	68.5	38.4	1.56
SEm±	0.16	0.13	0.17	–	–	–	0.7	–
CD (P=0.05)	0.44	0.38	0.49	–	–	–	1.9	–

75 kg P/ha was added in soil. Hossain and Hamid (2007) revealed that yield advantage increased from N_{30} and P_{60} kg/ha to N_{30} and P_{75} kg/ha fertilizer application may be due to optimal and higher root growth. These results are in harmony with Bhatol *et al.* (1994), who reported that, crop can grow without or by addition of lower levels of N and P which produced lowest yield. The appropriate elevated levels of N and P, had more nutrient availability to plant and resulted in greater utilization of assimilates into pods and ultimately increased number of pods, 100 seed weight and yield of groundnut.

The shelling out-turn, sound mature kernels (%) and 100-kernel weight were significantly influenced owing to different nitrogen and phosphorus ratios during tenure of experimentation. Application of 0.40 NP ratio noticed higher shelling per cent (75.2%) and sound mature kernels (86.5%), while more 100 kernel weight was recorded with 0.50 NP ratio i.e. 30:60 NP kg/ha (64.9 g).

Economics

The higher net returns of ₹58,826/- and benefit: cost ratio of 1:1.78 was realized under application of 0.40 NP ratio (30:75:00 NPK kg/ha) compared to other treatments ranging from ₹35,424 to ₹47,638/- and control ₹23,610/ha with benefit: cost ratios of 1:1.51 to 1:1.66 and 1:1.38 respectively. Shiva Kumar *et al.* (2014) also reported higher net returns and benefit: cost ratio with increased dose of nitrogen and phosphorus in groundnut.

Application of different proportions of N and P had large scope for obtaining higher yield of groundnut under Konkan situation. The 30:75:00 NPK kg/ha i.e. NP ratio of 0.40 is most suitable for rainy season (*kharif*) groundnut to obtain higher productivity and profitability of crop in Konkan region.

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Research Paper

Productivity, nutrient uptake, energy indices and profitability of soybean (*Glycine max*) as influenced by planting methods, *Bradyrhizobium* and plant growth promoting rhizobacteria

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ABSTRACT

A field experiment was conducted during rainy season (*kharif*) of 2014 and 2015 at Punjab Agricultural University, Ludhiana, Punjab to study the effect of planting methods, viz. Happy seeder sowing, straw chopper + zero tillage sowing and conventional sowing and biofertilizers, viz. *Bradyrhizobium*, plant growth promoting rhizobacteria (PGPR) and *Bradyrhizobium* + PGPR on nutrient uptake, energy indices, productivity and profitability of soybean [*Glycine max* (L.) Merrill). Results showed significantly higher seed yield, gross returns, net returns and benefit: cost ratio with happy seeder sowing as compared to straw chopper + zero tillage sowing and conventional sowing. N, P and K uptake by seed and straw were significantly higher in happy seeder sowing than straw chopper + zero tillage sowing and conventional sowing. Happy seeder sowing recorded the lowest energy input and the highest energy-output, net energy, energy-use efficiency and energy productivity. Seed inoculation with *Bradyrhizobium* and/or PGPR did not influence N, P and K uptake by seed and straw and energy indices significantly. However, combined inoculation of *Bradyrhizobium* and PGPR recorded the highest gross returns, net returns and benefit: cost ratio. Zero tillage with happy seeder sowing was found promising with the highest net returns and energy-use efficiency.

Key words : Biofertilizers, Economics, Energy indices, Happy seeder, Nutrient uptake, Seed yield, Soybean

In Indo-Gangetic Plains of India, rice–wheat cropping system is most important. It produces a lot of crop residues each year. Burning or removal of crop residues causes loss of organic matter and nutrients from soils (Singh *et al*., 2009). Retention of crop residues with zero tillage helps in moisture conservation and reduction of evaporation and soil temperature by modifying the thermal regime (Aulakh *et al*., 2012). Many studies have shown higher nutrient uptake by soybean in zero tillage with or without crop residue (Singer *et al*., 2008; Duseja and Dennis, 2010 and Aulakh *et al*., 2012). Application of crop residues (wheat + soybean) significantly increased the NPK uptake by soybean–wheat system as compared to no residue (Karunakaran and Behera, 2016).

Monetary returns from soybean production was higher in no tillage production system. Sowing of wheat with happy seeder (zero tillage) also saved time and money over the rotavator (reduced tillage) and fuel, time and money over farmer's practice (conventional tillage). Moreover, happy seeder treatment recorded higher net returns than conventional tillage and rotavator (Singh *et al*., 2013). The happy seeder machine cuts and manages the standing stubble and loose straw in front of the furrow openers, retaining it as surface mulch while sowing (Sidhu *et al*., 2007). Application of crop residues as a mulch improved yield and economic returns in soybean (Sekhon *et al*., 2005 and Karunakaran and Behera, 2016). No tillage in soybean recorded higher profitability due to lower cost of production by reducing some mechanized operations (fuel, machinery maintenance and manpower economy) (Santos *et al*., 2015).

Soybean can meet up to 80% of its total nitrogen requirement from biological nitrogen fixation (BNF) (Salvagiotti *et al*., 2008). Biofertilizers help in increasing crop productivity by way of increasing BNF, increasing availability or uptake of nutrients, improving soil fertility and have been proven to be an environmentally sound

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option. Thus, biofertilizers play a crucial role in sustainable crop production.

Plant growth promoting rhizobacteria (PGPR) can play an important role in plant nutrition, plant protection and growth stimulation. They may fix atmospheric nitrogen and supply it to plants; synthesize siderophores which can sequester iron from the soil and provide it to plant cells as a siderophore-iron complex; synthesize phytohormones such as auxins, cytokinins and gibberellins, which may enhance or regulate various stages of plant growth; and solubilize minerals such as phosphorus, making them more readily available for plant growth (Bashan and de-Bashan, 2010).

Many researchers have reported that inoculation of soybean seed with *Bradyrhizobium* enhanced N, P and K uptake by seed in soybean (Fakkar *et al*., 2010 and Rawat *et al*., 2013). Though a lot of information is available on the use of *Bradyrhizobium*, very little information is available on the effects of PGPR in soybean. The information on direct drilling of soybean with happy seeder in wheat crop residues and combined use of biofertilizers (*Bradyrhizobium* and PGPR) in India is still lacking. Moreover, the presence of wheat crop residue may influence the microclimate and consequently affect the performance of biofertilizers. Therefore, this experiment was carried out to study the effect of retention of crop residue with zero tillage and biofertilizers (*Bradyrhizobium* and PGPR) on productivity, nutrient uptake, energy indices and economics of soybean production.

MATERIALS AND METHODS

A study was conducted at Punjab Agricultural University, Ludhiana (30°54' N latitude, 75°48' E longitude with an altitude of 247 metre above mean sea level) during rainy season (*kharif*) of 2014 and 2015. The soil of the experimental site was loamy sand in texture with normal soil reaction (*p*H 7.5) and electrical conductivity (0.27 dS/m), low in organic carbon (0.29%), available nitrogen (131.8 kg/ha), medium in phosphorus (19.6 kg/ha) and potassium (157.4 kg/ha). The total rainfall of 426.3 and 580.5 mm during 2014 and 2015, respectively, was recorded during the soybean growing season against the normal value of 585.4 mm.

The preceding winter wheat crop was sown according to the layout of experiment used for soybean (fixed plots). The wheat crop was harvested with a combine at a stubble height of 30–40 cm to keep the residue within the plot in the treatments of happy seeder sowing and straw chopper + zero tillage sowing, and wheat was manually harvested in conventional sowing treatment. The wheat crop residue was about 9 and 6 t/ha during 2014 and 2015 respectively.

In happy seeder treatment, the sowing of soybean was done after combine harvested wheat in the standing stubbles of wheat after pre-sowing irrigation without any field preparation. In straw chopper + zero tillage sowing treatment, the preceding wheat crop was harvested with a combine harvester and the left over wheat residue was chopped with straw chopper to the size of about 10–20 cm and then the soybean crop was sown without any field preparation with zero-till drill after pre-sowing irrigation. In conventional sowing, a primary tillage operation was done with tractor drawn disc harrow and then pre-sowing irrigation was applied to ensure adequate moisture in the soil profile at the time of sowing. When the field attained proper moisture condition, a fine seedbed was prepared by giving two cultivators each followed by planking and soybean was sown with conventional seed drill.

Experiment was laid out in factorial randomized complete block design (RCBD) replicated 4 times. Soybean 'SL 958' was sown on June 5 during both the years as per treatments at 40 cm rows with happy seeder and at 45 cm rows in zero-till drill and conventional drill using 75 kg seed/ha. Soybean seed was inoculated with two microbial cultures – *Bradyrhizobium* (LSBR 3) and PGPR (*Burkholderia arbosis*) (containing 1×10^8 cells/g of carrier) as per the treatments of biofertilizers before sowing. Seed was spread on a polythene sheet and moistened by sprinkling water. Each culture was added @ 10 g/kg of seed to give a fine coating to the entire lot of seed. The treated seed was dried in the shade and used for sowing.

The recommended dose of nitrogen (39.1 kg/ha) as urea and phosphorus (60 kg P_2O_5/ha) as single superphosphate (SSP) was applied at the time of sowing. The harvesting of soybean was done manually on November 3, 2014 and November 2, 2015 from the net plot area. The harvested crop was kept for sun drying and then the threshing was carried out. Threshing was done with an engine operated thresher. Plant samples were analyzed for of nitrogen, phosphorus and potassium content using standard laboratory procedures. An their uptake was calculated by multiplying the per cent of nutrient content in seed and straw with their respective yields on dry weight basis and expressed in kg/ha.

The energy values for various inputs and outputs were computed as suggested by Singh and Mittal (1992) (Table 1). The total energy input was calculated by adding the energy requirement for human labour, diesel, seed, biofertilizers, herbicides, irrigation and fertilizers used. The energy output was calculated by the energy value of seed yield and straw yield. The energy input and output were expressed as Mega Joule (MJ). The net energy, energy-use efficiency and energy productivity were computed as follows.

Net energy (MJ/ha) = Output energy – input energy

Table 1. Energy equivalents for various sources of energy

Particular	Units	Equivalent energy (MJ)
Inputs		
Human labour	Man-hour	1.96
Seed	kg	14.7
Superior chemicals (Herbicides, insecticides)	kg	120
Diesel	Litre	56.31
Electricity	KWh	11.93
Chemical fertilizers		
N	kg	60.60
P_2O_5	kg	11.10
K_2O	kg	6.70
Biofertilizers	kg	10
Man	Man-hour	1.96
Electricity	KWh	11.93
Submersible pump	HP	68.4
Output		
Seed	kg	14.7
Straw	kg	12.5

$$\text{Energy-use efficiency} = \frac{\text{Energy output}}{\text{Energy input}}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Seed yield}}{\text{Energy input}}$$

The cost of cultivation was worked out on the basis of prevailing market prices of inputs and outputs (Table 2). Gross returns were calculated by multiplying the price of soybean (₹36,000 and ₹38,000/t during 2014 and 2015 respectively) with their seed yield and expressed as ₹/ha. Net returns were calculated by subtracting total cost of production (Table 2) from the gross returns and expressed as ₹/ha. Benefit: cost ratio was calculated by dividing the net returns with total cost of production treatment-wise. The data collected on various aspects of the investigations were statistically analyzed and the comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Productivity and economics

Seed yield was significantly higher in happy seeder

Table 2. Costs (₹/ha) of different operations and price of inputs and outputs (₹/kg)

Treatment	Operation	Mechanical labour (hrs)*	Human labour (hrs)**	2014	2015
Planting methods					
Happy seeder	Sowing	3 hr 20 min	3 hr 20 min × 2	1,484	1,466
				1,484	1,466
Straw chopper	Straw chopper	3 hr 20 min	3 hr 20 min	1,367	1,333
ZT	Sowing	2 hr 30 min	2 hr 30 min × 2	1,113	1,100
				2,480	2,433
CT	Disc 1	2 hr 30 min	2 hr 30 min	1,025	1,000
	Cultivator 2	3 hr 20 min	3 hr 20 min	1,367	1,333
	Planking 2	2 hr 30 min	2 hr 30 min	1,025	1,000
	Sowing	2 hr 30 min	2 hr 30 min × 2	1,113	1,100
				4,530	4,433
Inputs		*Particulars*			
Seed		Soybean		50	50
Biofertilizers		*Bradyrhizobium*		100	100
		PGPR		100	100
Fertilizers		Urea		5.40	5.44
		SSP		8.20	8.20
Herbicides		Stomp 30 EC (pendimethalin)		450/L	450/L
		Parimaze 10 SL (imazethapyr)		1,500/L	1,500/L
Insecticides		Polo 50 WP (difenthiuron)		7,000/L	7,000/L
		Ekalux 25 EC (quinalphos)		480/L	500/L
Irrigations				37	40
Human labour (hrs.)				35	40
Output					
		Seed		36	38

*Mechanical labour @ ₹375 and 360/h during 2014 and 2015 respectively; **Human labour @ ₹35 and 40/h during 2014 and 2015 respectively sowing than straw chopper + zero tillage sowing and conventional sowing (Table 3). Happy seeder sowing registered 14.6 and 17.0% higher seed yield than straw chopper + zero tillage sowing and conventional sowing, respectively. The seed yield of Straw chopper + zero tillage sowing was statistically at par with conventional sowing. Application of crop residues as surface mulch is known to improve soil nutrient status, modify the hydrothermal regimes of the soil surface by reducing the temperature (Aulakh *et al.,* 2012; Kumar *et al.,* 2013 and Prasad *et al.,* 2014), improve the soil physico-chemical and biological environment in the soil through addition of nutrients and enhanced microbial activity (Babujia *et al.,* 2010). Therefore, higher seed yield observed with the retention of crop residues as surface mulch might be due to improvement in soil physical structure, chemical and microbial status and thereby providing favourable environment for establishment, growth and development of the crop. Sekhon *et al.* (2005) also reported that wheat straw mulching increased soybean yield by 4.4 to 68.3% due to lowering of soil temperature and reducing evaporation loss. Inoculation of biofertilizers did not influence the seed yield significantly.

The gross returns, net returns and benefit: cost ratio were significantly influenced by different planting methods. Happy seeder sowing recorded significantly higher gross returns as compared to straw chopper + zero tillage sowing and conventional sowing, which might be due to more seed yield. However, gross returns obtained from straw chopper + zero tillage sowing were statistically at par with conventional sowing, which could be due to similar seed yields in these treatments.

Happy seeder sowing recorded significantly higher net returns as compared to straw chopper + zero tillage sowing and conventional sowing. However, net returns obtained from Straw chopper + zero tillage sowing were statistically at par with conventional sowing but, straw chopper + zero tillage sowing gave numerically higher net returns to the tune of ₹3,827/ha over conventional sowing. This, apart from higher seed yields, might be due to fewer field operations under happy seeder sowing compared to straw chopper + zero tillage sowing and conventional sowing, which resulted in lower fuel and labour cost. Similar results have also been reported in wheat (Singh *et al*., 2013) and soybean (Santos *et al*., 2015).

Significantly higher benefit: cost ratio of 2.59 was recorded in happy seeder sowing as compared to 2.03 in straw chopper + zero tillage sowing and 1.77 in conventional sowing, which might be due to reduction in cost of cultivation incurred on land preparation. Similarly, Karunakaran and Behera (2016) also reported higher benefit: cost ratio in zero tillage than conventional tillage in soybean–wheat system.

Combined inoculation of *Bradyrhizobium* and PGPR recorded the highest gross returns, net returns and benefit: cost ratio (Table 3). However, net returns were non-significantly affected by different biofertilizer treatments. Higher net returns under dual inoculation of biofertilizers have also been reported by Tairo and Ndakidemi (2013) in soybean. Different biofertilizer inoculations treatments did not influence the benefit: cost ratio significantly. However, the benefit: cost ratio was higher in dual inoculation of soybean seed with *Bradyrhizobium* + PGPR than single inoculation of *Bradyrhizobium* or PGPR, which might be due to higher seed yield.

Table 3. Effect of planting methods and biofertilizers on seed yield, economics and energy indices of soybean (pooled data of 2 years)

Treatment	Seed yield (t/ha)	Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹ /ha)	Benefit: cost ratio	Energy input (× 10^3 MJ/ha)	Energy output (× 10^3 MJ/ha)	Net energy	Energy-use efficiency (× 10^3 MJ/ha)	Energy productivity (kg/MJ)
Planting methods									
Happy seeder sowing	2.73	100.61	72.61	2.59	13.9	104.68	90.73	7.51	0.19
Straw chopper + zero tillage sowing	2.38	87.85	58.85	2.03	14.0	91.91	77.81	6.52	0.17
Conventional sowing	2.33	86.07	55.02	1.77	15.0	87.69	72.62	5.82	0.15
SEm±	0.071	2.65	2.65	0.09	–	1.78	1.78	0.12	0.005
CD (P=0.05)	0.144	5.32	5.32	0.18	–	3.57	3.57	0.24	0.01
Biofertilizer									
Bradyrhizobium	2.42	89.24	59.91	2.05	14.3	93.63	79.26	6.54	0.17
PGPR	2.48	91.50	62.17	2.13	14.3	94.28	79.91	6.58	0.17
Bradyrhizobium + PGPR	2.54	93.79	64.41	2.21	14.3	96.37	81.99	6.73	0.18
SEm±	0.071	2.65	2.65	0.09	–	1.78	1.78	0.12	0.005
CD (P=0.05)	NS	NS	NS	NS	–	NS	NS	NS	NS

PGPR, Plant growth promoting rhizobacteria

Nutrient uptake

The nitrogen content in seed was not influenced significantly by different planting methods. However, nitrogen content in straw was significantly higher in happy seeder sowing and straw chopper + zero tillage sowing than conventional sowing (Table 4). The nitrogen uptake by seed was significantly higher in happy seeder sowing (170.1 kg/ha) than straw chopper + zero tillage sowing (148.4 kg/ha) and conventional sowing (144.1 kg/ha). Similarly, the N uptake by straw (46.2 kg/ha) was significantly higher in happy seeder sowing than straw chopper + zero tillage sowing (40.4 kg/ha) and conventional sowing (37.3 kg/ha). Higher nitrogen uptake in seed and straw of soybean in happy seeder sowing may be due to wheat straw mulching, which modified the hydrothermal regime of the soil and resulted in better growth and productivity of the crop (Behera *et al.,* 2007). Furthermore, it may not only be due to higher seed and straw yield but also better growth environment by straw mulching that increased nodulation (Sekhon *et al.,* 2005) and probably more amount of nitrogen fixation (Kitou and Yoshida, 1994) and consequently more availability of nitrogen. Duseja and Dennis (2010) also reported higher nitrogen uptake by the soybean seed in no tillage than conventional tillage. Aulakh *et al.* (2012) reported higher uptake of nitrogen by soybean in crop residue amended treatments of both conventional tillage and conservation agriculture in soybean.

The phosphorus content in seed and straw were similar in different planting methods. Significantly higher phosphorus uptake by seed was recorded in happy seeder sowing (19.9 kg/ha) than straw chopper + zero tillage sowing (17.4 kg/ha) and conventional sowing (16.9 kg/ha) (Table 4). Similarly, phosphorus uptake by straw in happy seeder sowing (12.8 kg/ha) was significantly higher than straw chopper + zero tillage sowing (11.3 kg/ha) and conventional sowing (10.5 kg/ha). This might be due to higher seed and straw yield and production of organic acids as a result of higher microbial activity (Babujia *et al.,* 2010), which solubilized phosphate and resulted in more availability of phosphorus for its uptake by the crop. Seed phosphorus uptake was greater in no tillage compared with mould-board plough and conventional tillage (Singer *et al.,* 2008) in soybean.

The potassium content in seed and straw were not influenced significantly by different planting methods. The happy seeder sowing showed significantly higher K uptake by seed (53.9 kg/ha) as compared to straw chopper + zero tillage sowing (47.1 kg/ha) and conventional sowing (45.7 kg/ha). Similarly, happy seeder sowing showed significantly higher K uptake by straw (43.6 kg/ha) as compared to straw chopper + zero tillage sowing (38.5 kg/ha) and conventional sowing (35.7 kg/ha) (Table 4). Signifi-

Table 4. Effect of planting methods and biofertilizers on nutrient content and their uptake by seed and straw in soybean (pooled data of 2 years)

Treatment	Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)		Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)	
	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw
Planting method												
Happy seeder sowing	6.24	0.90	0.73	0.25	1.97	0.84	170.1	46.2	19.9	12.8	53.9	43.6
Straw chopper + zero tillage sowing	6.24	0.89	0.73	0.25	1.97	0.84	148.4	40.4	17.4	11.3	47.1	38.5
Conventional sowing	6.17	0.87	0.73	0.24	1.95	0.83	144.1	37.3	16.9	10.5	45.7	35.7
SEm±	0.09	0.01	0.004	0.004	0.02	0.01	4.2	0.8	0.5	0.2	1.4	1.1
CD (P=0.05)	NS	0.02	NS	NS	NS	NS	8.5	1.7	1.1	0.5	2.9	2.3
Biofertilizer												
Bradyrhizobium	6.21	0.88	0.73	0.25	1.96	0.84	150.2	41.0	17.6	11.5	47.6	38.9
PGPR	6.22	0.89	0.73	0.25	1.96	0.84	154.1	41.1	18.0	11.4	48.8	38.9
Bradyrhizobium + PGPR	6.23	0.89	0.73	0.25	1.97	0.85	158.3	41.9	18.6	11.7	50.2	40.0
SEm±	0.09	0.01	0.004	0.004	0.02	0.01	4.2	0.8	0.5	0.2	1.4	1.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

cantly higher K uptake by seed in zero tillage has also been reported in soybean by Singer *et al*. (2008).

The nitrogen, phosphorus and potassium content in seed and straw were non-significantly influenced by different biofertilizer treatments (Table 4). Similarly, inoculation of seed with *Bradyrhizobium* and/or PGPR did not affect the nitrogen, phosphorus and potassium uptake by seed and straw significantly which might be due to similar seed and straw yield. However, dual inoculation of seed with *Bradyrhizobium* and PGPR recorded the highest nitrogen, phosphorus and potassium uptake by seed and straw, which might be due to synergistic effect of *Bradyrhizobium* and PGPR on seed yield as a result of production of plant growth hormones like auxins, gibberellins and cytokinins; siderphore production, phosphate solubilization and nitrogen fixation in soybean (Bashan and de-Bashan, 2010). There was no difference in nitrogen, phosphorus and potassium content in seed and straw but higher seed yield in dual inoculation of *Bradyrhizobium* and PGPR resulted in higher uptake.

Energy indices

The energy input was higher in conventional sowing than happy seeder and straw chopper + zero tillage sowing (Table 3). The input energy requirement was less in happy seeder and straw chopper + zero tillage sowings due to no energy expenditure on the seedbed preparation. The energy output was significantly higher in happy seeder sowing than straw chopper + zero tillage and conventional sowings which might be due to high seed yield. The net energy was significantly higher in happy seeder sowing than the other methods, which might be due to less expenditure of input energy and higher seed yield. However, energy input and output were non-significantly influenced by different biofertilizer treatments.

Energy-use efficiency (Table 3) was significantly higher in happy seeder sowing (7.5) and straw chopper + zero tillage sowing (6.5) than conventional sowing (5.8). Higher energy use efficiency in happy seeder and straw chopper + zero tillage sowings might be due to less input energy and high output energy. Karunakaran and Behera (2016) also reported highest energy use efficiency with zero tillage due to less energy used for seed-bed preparation, and slightly higher yield. However, energy use efficiency was not influenced significantly by different biofertilizer treatments.

Energy productivity was recorded significantly higher in happy seeder sowing (0.19) and straw chopper + zero tillage sowing (0.17) than conventional sowing (0.15), which could be due to higher seed yield and less energy input (Table 3). Single or dual inoculation with biofertilizers did not influence the energy productivity significantly, which might be due to higher seed yield.

It may be concluded that happy seeder sowing with higher seed yield, gross returns, net returns, benefit: cost ratio, less energy input, highest energy output, net energy, energy-use efficiency and energy productivity is superior and more promising as compared to straw chopper + zero tillage sowing and conventional sowing soybean production. Although single or dual inoculation of *Bradyrhizobium* and PGPR in soybean recorded almost similar benefits, dual inoculation of *Bradyrhizobium* and PGPR slightly improved the gross returns, net returns and benefit: cost ratio.

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Research Paper

Integrated weed management in chilli (*Capsicum annuum*) grown after rice (*Oryza sativa*) under rice–fallow system

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ABSTRACT

A field experiment was conducted at the Instructional-cum-Research Farm of Assam Agricultural University, Jorhat during 2012 and 2013 to study the effect of weed management practices on growth and yield of chilli (*Capsicum annuum* L.) grown after winter rice (*Oryza sativa* L.). The study revealed that the weed density as well as dry weight were the lowest in all the treatment with metribuzin @ 500g/ha combined with and hand weeding at 30 and 60 or 30, 50 and 60 or 30, 60 and 80 days after planting (DAP) over rest of the treatments. Among the weed management treatments, a higher weed density was observed in the 3 treatments of quizalofop-p-ethyl @ 50 g/ha followed by hand weeding at 45 and 75 or 60 and 80 or 50 and 80 DAP. Plant height, days to 50% flowering, number of primary and secondary branches were recorded the highest in metribuzin treated plots. The fruit yield (fresh and dry) was also found to be higher in the metribuzin treated plots. The available nutrients were found to be lower in the metribuzin treated plots and the treatments with only and hand weeding at different day's interval. The yield loss was 0.29 t/ha under weedy check treatment as compared to the highest yield (3.41 t/ha) obtained from metribuzin 500 g/ha and hand weeding at 30, 50 and 80 DAP. The benefit: cost ratio was found to be the highest (2.60) in metribuzin @ 500 g/ha along with and hand weeding at 30, 50 and 80 DAP. The biochemical attributes like ascorbic acid (62.1 mg/100g) and capsaicin content (60.8 mg/100g) were found to be higher in metribuzin @ 500 g/ha with and hand weeding at 30 and 60 or 30, 50 and 80 days after planting. From this study, it could be inferred that application of metribuzin @ 500g/ha with and hand weeding at 30, 50 and 60 DAP controlled the weeds in chilli effectively and resulted higher fruit yield, quality of chilli and benefit: cost ratio.

Key words: Ascorbic acid, Capsaicin, Chilli, Integrated weed-management, Metribuzin, Quizalofop-p-ethyl,

Chilli is one of the most important vegetable-cum-spice crops valued for its aroma, taste, flavour and pungency. The world production of chilli is about 7 million tonnes, which is cultivated on approximately 1.5 million ha of land. India, the largest producer and exporter of chillies in the world, accounts for 1.1 million tonnes of annual production followed by China (around 0.4 million tonnes), Mexico and Pakistan (around 0.3 million tonnes each). Among the Indian states, Andhra Pradesh stands first in terms of production and area coverage under chilli cultivation. It alone commands for 49% of the chilli production in India, with a production of around 0.27 million tonnes of chillies. Karnataka follows Andhra Pradesh, contributing 14% of the country's production. But chilli growers faces a market problems like low price, heavy commission charges, non-availability of resources and lack of technical knowledge (Dangore *et al.,* 2015). Weed problems and pest and disease infestation also ranked high in chilli cultivation in comparison to other crops. Among all these weed problem is very severe. Weeds emerge fast and grow rapidly competing with the chilli crop severely for growth resources, viz. nutrients, moisture, sunlight and space during entire vegetative and early reproductive stages of the crop. In addition, they also transpire lot of valuable conserved moisture and absorb large quantities of nutrients from the soil depriving the crop. Further, wide space planting provided to the chilli allows fast growth of weed species causing considerable reduction in yield by affecting the plant growth and yield components. Presence of weed reduces the photosynthetic efficiency and their dry matter production and its mobilization to economical parts, which finally reduces the sink capacity of crop resulting in poor fruit yield. The extent of reduction in fruit yield due to weeds has been reported to be in the range of

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60 to 70% depending on the intensity and persistence of weed density in standing crop (Patel *et al.*, 2004). Clean and weed free cultivation is pre-requisite for successful crop production. However, effective weed management practices require large human labour and therefore it is costly as well as time consuming. Hence, integrated weed management by combining chemical control with mechanical weeding is one of the effective and timely operations to reduce crop-weed competition. Herbicides not only control weeds but also offer a great scope of minimizing the cost of weed control irrespective of situation mainly in the states like Assam, where there is a huge floristic diversity and faster weed growth rate due to high rainfall and lesser bright sunshine hours. However, there is no documented evidence of any work or research on chilli as a succeeding crop after winter (*sali*) rice in medium land situation, as well as management of weeds in chilli under such situations but there is a huge scope of utilizing these lands for cultivation of chilli. The cultivation of chilli in the lean period can provide income to the farmers and also it can reduce the infestation by the monophagous pests due to changing cropping system.

MATERIALS AND METHODS

The study was undertaken during winter (*rabi*)-summer season of 2012 and 2013 at Assam Agricultural University, Jorhat, Assam to develop integrated weed management for chilli. The farm is situated at 26º47' N, 94º12' E and altitude of 86.6 m from the mean sea level. The soil of experimental field was sandy clay loam with *p*H 5.4, organic carbon content 8.2 g/kg, 282.4 kg/ha of available nitrogen, 22.8 kg/ha available phosphorus and 178.2 kg/ha available potassium. A local Chilli variety '*kharika jolokia'* of *Capsicum annuum* group was used in the experiment. It is very popular variety among the people of Assam and frequently used for everyday consumption. The 10 treatments, viz., metribuzin @ 500 g/ha + hand weeding (HW) at 30 and 60 days after planting (DAP); metribuzin @ 500 g/ha + HW at 30, 60 and 80 DAP; metribuzin @ 500 g/ha + hand weeding at 30, 50 and 80 DAP, quizalofop-p-ethyl @ 50 g/ha + HW at 45 and 75 DAP, quizalofop-p-ethyl @ 50 g/ha + HW at 60 and 80 DAP; quizalofop-p-ethyl @ 50 g/ha + HW at 50 and 80 DAP; HW at 20, 40, 60 and 80 DAP, and HW at 25, 50 and 75 DAP; HW 30, 60 and 80 DAP and weedy check were tested in randomized block design with 3 replications. Sowing was done in second fortnight of January in both the seasons. Irrigation was provided at an interval of 7–10 days depending upon the rainfall pattern. During land preparation, cowdung was applied @ 2 t/ha and nitrogen, phosphorus and potassium were applied in the form of urea, single super phosphate and muriate of potash, at the rate of 120: 60: 60 kg/ha. The fertilizers were applied in two split doses first at 20 days after planting and second at 40 days after planting. The fertilizers were well mixed with vermicompost at the rate of 3t/ha and applied in ring method 5 cm away from the plant. Observations on weed flora, weed density, dry weight, plant height, number of primary and secondary branches, capsaicin and ascorbic acid content, fresh and dry yield of chilli were recorded. The analysis of soil sample for available N was done by using Kjeldahl method, P by Bray's I method, K by photometric method and organic carbon by Walkley and Black's titration. The capsaicin content of chilli was determined from each treatment by the method described by Quagliotti (1971) and Theymoli *et al.* (1982). Red dried chilli powder of 0.5 g was taken and 10 ml of dry acetone was added to it. Content was centrifuged at 10,000 rpm for 10 min. from clear supernatant 1 ml was taken and evaporated to dryness in hot water bath. Then the residue was dissolved in 5 ml of 0.4% sodium hydroxide solution and 3 ml of 3% phosphomolybdic acid, shaken and allowed to stand for an hour. The solution was filtered into centrifuge tubes and centrifuged at about 5000 rpm for 10 to 15 minutes. The clear blue coloured solution was directly transformed into the cuvette and the absorbance was read at 650 nm. A blank sample was run along with the test samples. A standard graph was prepared using 0–200 ìg capsaicin simultaneously.

The capsaicin content is calculated by using the following formula

$$\text{Capsaicin (\%)} = \frac{\mu\text{g Capsaicin}}{200}$$

The % capsaicin was converted to mg/100g.

The ascorbic acid content was analyzed by using the volumetric method as given by Sadasivam and Theymoli (1987). Green dried powdered chilli of 0.5 g was taken and extracted using 4% oxalic acid and volume was made up to 100 ml and centrifuged. The supernatant was filtered immediately, 5 ml of the supernatant was taken, and 10 ml of 4% oxalic acid was added to it. The solution was titrated using the dye 2,6-dichlorophenol indophenol. Standard was run along with the sample using 1 mg of ascorbic acid.

The amount of ascorbic acid was calculated using the following formula:

$$\text{Amount of ascorbic acid (mg/100g sample)} = \frac{0.5\text{ mg}}{\text{Volume used for standard titration}} \times \frac{\text{Volume used for sample titration}}{15\text{ ml}} \times \frac{100\text{ ml}}{\text{Weight of the sample}} \times 100$$

RESULTS AND DISCUSSION

Weed flora

During the whole crop season, predominant weed species comprised of 2 grass species, 5 broad leaved species and 1 species belonging to sedge (Fig. 1 and Fig. 2). *Oryza sativa*, the cultivated rice species was encountered as one of the major weed species. It was followed by *Cyperus rotundus, Oldenlandia diffusa* and *Polygonum glabrum.* Gare *et al.* (2015) also reported the domination of broad leaved weeds and grasses in transplanted chilli, which includes *Euphorbia hirta, Cynodon dactylon, Cyperus rotundus, Phyllanthus niruri, Amararnthus spinosus, Digera arvensis, Parthenium hysterophorus, Alternanthera triandra.*

Weed density and weed dry weight

The effect of different weed management practices showed that the treatments of metribuzin @ 500 g/ha and hand weeding (HW) at 30, 60 DAP, metribuzin @ 500 g/ha + HW 30, 50, 80 DAP and metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP recorded the lowest weed density throughout the crop season (Table 1). The higher fruit yield of chilli due to lower weed density during its critical growth stages has been reported earlier (Gare *et al.,* 2015). The treatments involving metribuzin @ 500 g/ha as pre-emergence resulted significantly lowest weed dry weight at 20 DAP. However, at 40 and 60 DAP, metribuzin application combined with HW resulted the lowest weed dry weight but these were at par with HW alone at 25, 50, 75 or 30, 60, 80 DAP. This indicated an effective early control of weeds by metribuzin and this effect could be sustained by the subsequent HW. Weed biomass reflects the growth potential of the weeds and is better indicator of its competitive ability with the crop plants (Arvadiya *et al.,* 2012). Weed control-efficiency increased the adoption of weed control measures over the unweeded plot (Gare *et al.,* 2015). This is due to the lower weed population as shown in Table 2.

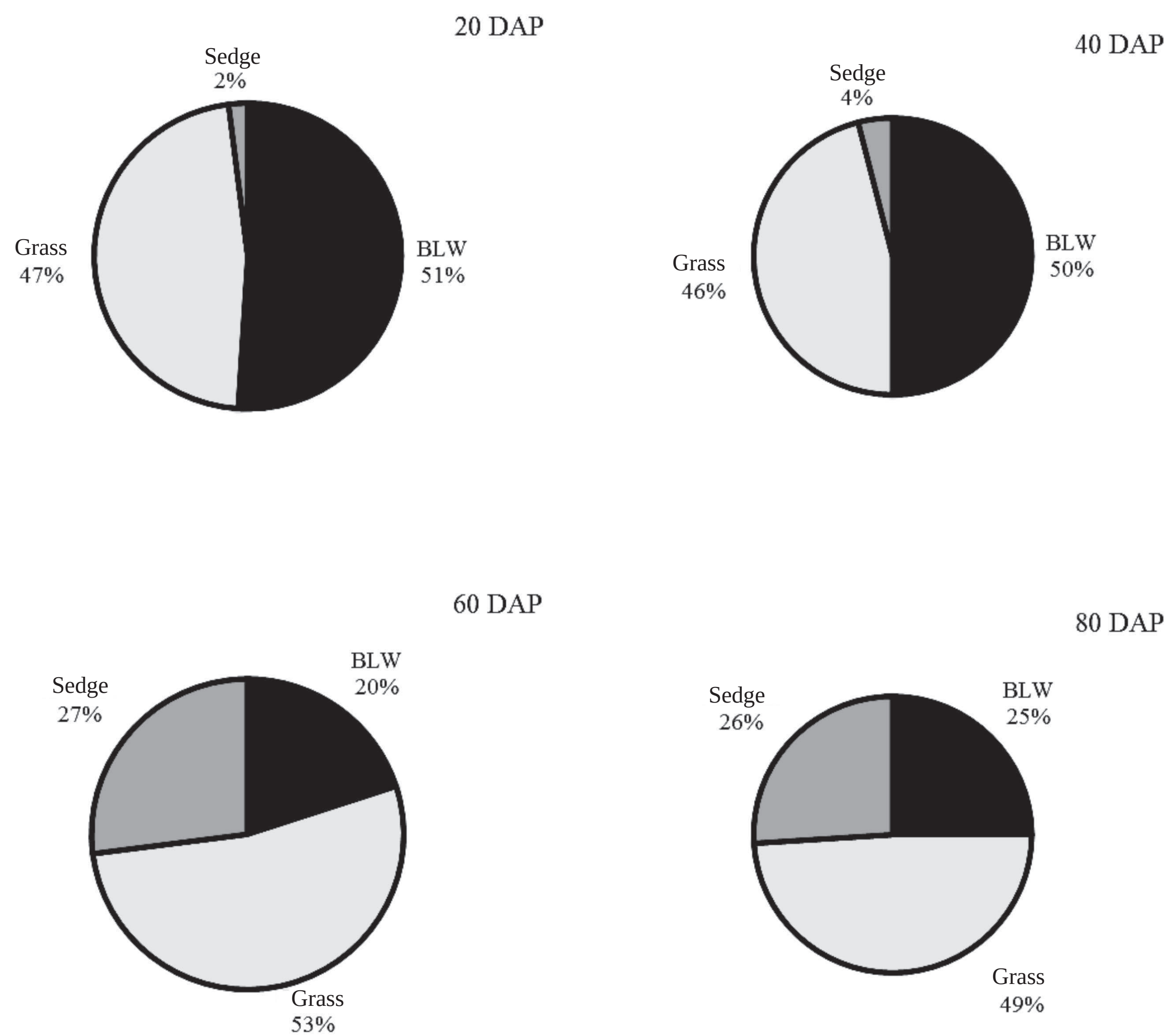

Fig. 1. Percentage of broad-leaved weeds (BLW), grasses, and sedge at 20, 40, 60, 80 DAP recorded in unweeded plot

Table 1. Effect of integrated weed management on weed density and weed dry weight (mean data of 2 years)

Treatment	Weed density (numbers/m^2)*				Weed dry weight (g/m^2)*			
	20 DAP	40 DAP	60 DAP	80 DAP	20 DAP	40 DAP	60 DAP	80 DAP
Metribuzin @ 500 g/ha + HW at 30, 60 DAP	3.9 (14.7)	5.4 (28.7)	5.8 (33.3)	5.1 (25.7)	1.5 (1.7)	3.9 (14.5)	4.6 (20.5)	5.2 (27.0)
Metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP	4.1 (15.79)	5.5 (29.3)	4.6 (21.0)	5.9 (34.0)	1.4 (1.5)	4.0 (15.3)	4.2 (16.9)	5.4 (28.3)
Metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP	4.0 (15.7)	5.4 (28.3)	5.6 (31.3)	5.2 (26.3)	1.4 (1.5)	4.0 (15.5)	4.5 (20.2)	5.1 (26.0)
Quizalofop-p-ethyl @ 50 g/ha + HW at 45, 75 DAP	7.8 (61.0)	9.5 (90.3)	6.9 (47.7)	7.2 (51.0)	3.8 (14.0)	7.8 (61.0)	4.9 (24.0)	5.9 (34.0)
Quizalofop-p-ethyl @ 50 g/ha + HW at 60, 80 DAP	7.6 (57.0)	9.8 (94.7)	7.9 (61.7)	6.1 (36.7)	3.8 (14.0)	7.7 (59.3)	5.8 (33.5)	5.6 (31.3)
Quizalofop-p-ethyl @ 50 g/ha + HW at 50, 80 DAP	7.8 (61.0)	9.6 (92.0)	6.5 (42.0)	7.4 (54.0)	3.7 (13.0)	7.9 (62.3)	4.6 (20.7)	5.8 (32.7)
HW at 20, 40, 60, 80 DAP	7.7 (59.3)	7.0 (48.7)	6.7 (44.0)	5.6 (31.0)	3.9 (14.9)	4.7 (21.3)	4.2 (16.8)	5.2 (26.7)
HW at 25, 50, 75 DAP	7.9 (62.3)	5.9 (34.0)	6.1 (36.7)	5.4 (28.3)	3.8 (14.0)	4.0 (15.7)	4.1 (16.4)	5.9 (34.7)
HW at 30, 60, 80 DAP	7.7 (59.3)	6.2 (38.0)	6.5 (42.0)	5.3 (27.3)	3.7 (13.3)	3.8 (13.7)	4.8 (22.7)	5.3 (27.5)
Unweeded control	7.8 (61.0)	11.6 (133.3)	14.1 (185.7)	14.1(198.7)	3.8 (14.2)	9.4 (88.0)	10.1(102.0)	11.3(126.3)
SEm±	0.36	0.43	0.60	0.36	0.30	0.43	0.28	0.46
CD (P=0.05)	1.08	1.28	1.78	1.07	0.89	1.27	0.83	1.36

*, Square root transformed data, Original data in parentheses; HW, hand weeding; DAP, days after planting

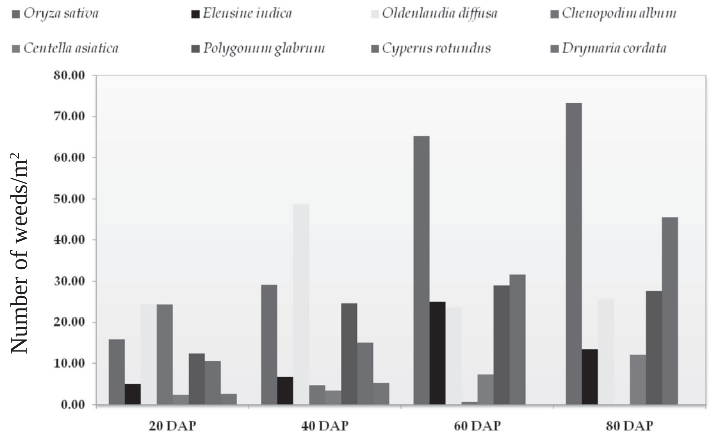

Fig. 2. Dynamics of weed flora in unweeded control in rice-chilli crop situation

Plant height and number of branches

The highest plant height at 30 DAP was recorded in treatment with metribuzin @ 500 g/ha + HW at 30, 60 DAP followed by metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP (Table 2). At 60 DAP, plant height was highest with metribuzin @ 500 g/ha + HW 30, 50, 80 DAP and it was at par with metribuzin @ 500 g/ha + HW 30, 60 DAP, metribuzin @ 500 g/ha + hand weeding at 30, 60, 80 DAP, quizalofop-p-ethyl @ 50 g/ha + hand weeding at 50, 80 DAP, hand weeding at 20, 40, 60, 80 DAP, hand weeding at 25, 50, 75 DAP and hand weeding at 30, 60, 80 DAP. The highest plant height was recorded at harvest in metribuzin @ 500 g/ha + HW 30, 60 DAP which was at par with HW at 20, 40, 60 and 80 DAP. The crop-weed interference is reported up to 39% reduction in plant height and other plant growth variables like stem diameter and internode length (Amador *et al.,* 2007). Integrated weed management practices helps in achieving good plant height and yield (Pal *et. al.,* 2016).

Primary branches per plant was recorded the highest with metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP, which was followed by the treatment with metribuzin @ 500 g/ha + HW at 30, 60 DAP, metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP, HW at 20, 40, 60, 80 DAP and HW at 25, 50, 75 DAP, and HW at 30, 60, 80 DAP; while the number of secondary branches/plant was recorded the highest in metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP and it was at par with metribuzin @ 500 g/ha and hand weeding 30, 60 DAP, metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP and all other treatments involving and hand weeding alone. The difference in the number of branches is found to be one of the factors affected by weed since the growth rate of weed is faster as compared to chilli and weed covers the area and dominates over the main crop.

Fresh and dry weight of fruits

The fresh yield of chilli was the highest in metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP, which was at par with treatment metribuzin @ 500 g/ha + hand weeding at 30, 60, 80 DAP and metribuzin @ 500 g/ha + HW at 30, 60 DAP (Table 3). All these treatments resulted significantly higher yield of fresh fruit as compared to rest of the treatments. Similar trend of result was also observed in respect of dry fruit yield of chilli. Higher content of capsaicin and ascorbic acid in treatments with metribuzin followed by hand weeding confirmed better quality of chilli. Nearly weed free conditions maintained during the early crop growth stages in these above mentioned treatments, might have mainly contributed to better plant growth and yield attributing characters thereby resulting higher yields as compared to weedy check and rest of the treatments. A reduction of 91.6% in fresh fruit and dry fruit yield due to unchecked weed growth in weedy check as compared to the highest yield obtained in metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP was found. The yield reduction in chilli due to uncontrolled weed infestation throughout the crop life cycle was recorded up to 70 to 90 % (Prakash *et al.*, 2003). Moreover, losses due to weed also depends upon the nature of weed species as well as total intensity of weeds (Patel *et al*. 2004). Mandeep and Walia (2012) reported that application of pre-emergence herbicides followed by and hand weeding at 45 days after planting yielded better returns.

Biochemical parameters

Higher content of capsaicin and ascorbic acid with metribuzin followed by mechanical weeding confirmed better quality of chilli. The amount of capsaicin is known to increase under dry and stressful conditions. In the plots where the herbicide metribuzin was applied and weeding was done at regular intervals the capsaicin content was increased (Table 2). It was reported that water deficit affected the phenylpropanoid metabolism and the pungency of pepper fruits (Estrada *et al.*, 1999). The probable reasons would be due to the removal of weeds at regular intervals, which removes the moisture from the soil. Nevertheless, the plants in weedy check are covered or the presence of weeds that helps to retain soil moisture in the soil, which did not let the plant to suffer from water stress condition. Therefore, this has led to lower capsaicin content in the fruits obtained from weedy check.

Available soil N, P, K and organic carbon

Organic carbon content and available content of N, P and K were not significantly affected by the treatments. However, the highest available N and P-content were recorded in unweeded plot. Among the treatments, application of quizalofop @ 50 g/ha + HW at 60, 80 DAP recorded the highest N- content, while treatments involving metribuzin 500g/ha + HW at different stages as well as HW at 25, 50, 75 DAP and HW at 20, 40, 60, 80 DAP. The available P-content was higher in the treatment with quizalofop-p-ethyl @ 50 g/ha + HW at 60, 80 DAP and the lowest in treatment of metribuzin @ 500 g/ha + HW at 30, 60 DAP and hand-weeding at 25, 50, 75 DAP. The available K was found to be the highest due to quizalofop-p-ethyl @ 50 g/ha + HW at 45, 75 DAP and quizalofop-p-ethyl @ 50 g/ha + HW at 60, 80 DAP (Table 3). Treatments involving metribuzin caused decrease in the status

Table 2. Effect of integrated weed management on weed control efficiency, plant height, branches/plant and biochemical parameters of chilli (mean data of 2 years)

Treatment	WCE at 40 DAP	WCE at 80 DAP	Plant height (cm) (at harvest)	Primary branches/ plant	Secondary branches/ plant	Ascorbic acid content (mg/100g)	Capsaicin content (mg/100g)
Metribuzin @ 500 g/ha + HW at 30, 60 DAP	90.6	82.8	122.3	13.3	15.7	62.1	60.4
Metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP	91.2	79.7	112.7	14.4	15.9	62.1	60.8
Metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP	90.9	84.5	110.7	14.1	15.8	60.4	60.0
Quizalofop-p-ethyl @ 50 g/ha + HW at 45, 75 DAP	52.7	85.9	100.9	10.5	12.3	44.0	52.7
Quizalofop-p-ethyl @ 50 g/ha + HW at 60, 80 DAP	58.0	82.4	111.5	9.7	11.4	44.1	52.7
Quizalofop-p-ethyl @ 50 g/ha + HW at 50, 80 DAP	53.6	80.3	109.0	10.2	11.9	44.4	55.2
HW at 20, 40, 60, 80 DAP	76.1	80.1	121.4	12.3	14.4	53.3	59.0
HW at 25, 50, 75 DAP	79.1	86.0	118.9	12.1	14.8	52.9	54.8
HW at 30, 60, 80 DAP	82.1	78.0	109.1	11.9	14.9	59.3	48.5
Unweeded control	0.0	0.0	84.8	8.2	10.4	43.1	40.0
SEm±	-	-	1.35	0.350	0.361	0.40	0.99
CD (P=0.05)	-	-	4.02	1.039	1.072	1.62	1.62

HW, handing weeding; DAP, days after planting; WCE, weed control efficiency

Table 3. Effect of integrated weed management on yield of chilli, net returns, benefit: cost ratio and available nutrient contents (mean data of 2 years)

Treatment	Fresh weight (t/ha)	Dry weight (t/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Metribuzin @ 500 g/ha + HW at 30, 60 DAP	10.34	6.76	68.1	2.41	0.5	298.3	11.6	144.3
Metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP	10.62	6.92	73.9	2.58	0.5	298.7	11.7	147.7
Metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP	6.08	3.98	72.7	2.55	0.5	301.3	11.7	145.7
Quizalofop-p-ethyl @ 50 g/ha + HW at 45, 75 DAP	2.78	1.81	18.7	0.68	0.5	313.7	12.8	154.0
Quizalofop-p-ethyl @ 50 g/ha + HW at 60, 80 DAP	2.41	1.57	14.2	0.52	0.6	315.3	12.5	154.0
Quizalofop-p-ethyl @ 50 g/ha + HW at 50, 80 DAP	2.20	1.43	11.2	0.41	0.6	312.0	12.7	153.3
HW at 20, 40, 60, 80 DAP	8.84	5.74	57.2	2.05	0.5	297.7	11.7	144.7
HW at 25, 50, 75 DAP	8.07	5.24	50.4	1.82	0.6	293.3	11.6	147.7
HW at 30, 60, 80 DAP	7.65	5.05	49.0	1.77	0.6	313.7	12.6	152.0
Unweeded control	0.66	0.43	-18.3	-0.68	0.6	316.7	13.0	151.3
SEm±	6.87	5.38	0.37	0.04	0.03	1.23	0.20	0.45
CD (P=0.05)	17.56	14.71	1.11	0.13	NS	NS	NS	NS

HW, Hand weeding

of available K. It could be inferred that a better plant growth might have caused removal of more amount of nutrients from leaving lesser amount of available N, P and K in soil in the treatments with metribuzin as well as and HW. Rajkumara (2009) reported that unweeded check resulted in significantly higher nitrogen uptake.

Economic evaluation

Cost of cultivation was recoreded the lowest with HW at 25, 50, 75 DAP followed by weeding at 30, 60, 80 DAP excluding weedy check (Table 3). Gross and net returns were recorded the highest in metribuzin @ 500 g/ha + HW at 30, 50, 80 DAP, which was closely followed by metribuzin @ 500 g/ha + HW at 30, 60, 80 DAP. The highest benefit: cost ratio was obtained in these two treatments followed by metribuzin @ 500 g/ha + HW at 30, 60 DAP. Similar results were reported by Biradar (1999) by using herbicide at varied rate or in combination with and HW which gave more profit compared to weedy check.

Based on the study it is concluded that, application of metribuzin along with two to three mechanical weeding was able to give sustained weed control during the whole crop-growing season.

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Research Paper

Integrated weed management practices in turmeric (*Curcuma longa*)

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) season of 2012–13 and 2013–14 at Faizabad, Uttar Pradesh, to study the effect of conventional and integrated weed management [rice (*Oryza sativa* L.) straw mulch and mechanical weeding along with herbicides] practices on the control of weeds and yield of turmeric (*Curcuma longa* L.). The application of metribuzin 700 g/ha as pre-emergence followed by (fb) straw mulch 10 t/ha fb 1 hand-weeding (HW) 75 days after planting (DAP), being at par with pendimethalin 1 kg/ha as pre-emergence fb straw mulch 10 t/ha fb 1 HW 75 DAP and atrazine 750 g/ha as pre-emergence fb straw mulch 10 t/ha fb 1 HW 75 DAP, was found significantly more effective in controlling weeds and improving yield attributes and yield (6.7 t/ha dry rhizome; 272% and 26% increase over weedy check and farmers' practice respectively). The application of metribuzin 700 g/ha as pre-emergence fb straw mulch 10 t/ha fb 1 HW 75 DAP also recorded the maximum net returns (₹392,493/ha) and benefit: cost ratio (3.2). Results showed that integration of mulches and hand weeding with pre-emergence herbicides achieved the maximum yield and returns. However, pre-emergence application of metribuzin 700 g followed by rice straw mulch 10 tonnes/ha along with 1 hand-weeding at 75 days after planting proved most remunerative and economical for growing turmeric crop.

Key words **:** Economics, Herbicide, Mulching, Productivity, Turmeric, Weeding

Turmeric, an ancient and sacred spice of India, is a major rhizomatous spice produced in and exported from India. In India, it is grown over an area of 0.18 million ha, with a production of 0.83 million tonnes and productivity of 4.6 t/ha respectively (Indiastat, 2014). Since turmeric is being grown during the rainy season and is a long-duration crop, a large number of weeds compete with the crop for nutrients, moisture and space causing yield reduction of 35–75% (Krishnamurty and Ayyaswamy, 2000). Being a long-duration crop (more than 280 days), pre-emergence application of herbicides alone does not control weeds throughout the critical crop-weed competition period and hence needs an integration of post-emergence application of herbicide or intercultural operation in combination with pre-emergence herbicide application. Straw mulch is another approach adopted by the farmers that conserves soil moisture and modifies soil temperature for benefit of crop, besides controlling weeds (Mahey *et al*., 1986). Management of the weeds at proper time is one of the major activities related to the crop returns by increasing the crop productivity. Generally, for the control of weeds, farmers do manual weeding, but with increase in wages and scarcity of labourers, manual weed control has become a difficult task. Under such a situation, an alternative method of weed management through integrated system has to be explored. Hence an investigation was carried out to study the effect of conventional and improved integrated weed-management practices on productivity and economics of turmeric crop.

MATERIALS AND METHODS

A field experiment was conducted at Agronomy Research Farm of the Narendra Deva University of Agriculture and Technology, Faizabad (26.32°N and 82.12°E) during the rainy (*kharif*) season of 2012–13 and 2013–14. The soil (reclaimed *usar*) of the experimental field was silt loam in texture with slightly alkaline in reaction (8.3),

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low in organic carbon (0.31%) and available nitrogen (187 kg/ha), medium in phosphorus (16.1 kg/ha) and high in potassium (283 kg/ha). The experimental site falls under sub-tropical zone in the Indo-Gangatic plains. The region enjoys sub-humid climate, receiving a mean annual rainfall of about 1,200 mm; out of which about 80% is received from mid-June to end of September. In the area of experiment normally monsoon begins in the third week of June and lasts up to end of September or the first week of October. The winter months are cold with occasional frost. Period from March to May remains generally hot and dry. Western hot winds start from April and continue up to mid of June. Weekly average minimum and maximum temperatures during the crop season ranged 2.9–29.2 and 14.2–44.3°C during 2012–13 and 5.9–27.1 and 15.7–35.7°C during 2013–14, whereas total rainfall received was 878 and 1,064 mm during 2012–13 and 2013–14 respectively. The relative humidity, evaporation rate and sunshine hours were found to vary from 34.6 to 78.6 and 53.9 to 87.9%, 9.1 to 58.4 and 9.6 to 44.4 mm/day and 1.6 to 8.4 and 0.4 to 8.7 hours during 2012–13 and 2013–14 respectively. Ten treatments [T_1, metribuzin 700 g/ha as pre-em fb 2 hoeings 45 and 75 days after planting (DAP); T_2, Metribuzin 700 g/ha as pre-emergence (pre-em) fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-emergence (post-em) 45 DAP; T_3, metribuzin 700 g/ha as pre-em, fb straw mulch 10 t/ha fb 1 hand-weeding (HW) 75 DAP; T_4, pendimethalin 1 kg/ha as pre-em, fb 2 hoeings 45 and 75 DAP; T_5, pendimethalin 1 kg/ha as pre-em, fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em, 45 DAP; T_6, pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha, fb 1 HW 75 DAP; T_7, atrazine 750 g/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP; T_8, atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP; T_9, farmers' practice (HW 25, 45 and 75 DAP); T_{10}, weedy check] were replicated thrice in a randomized block design with plot size of 5 m × 6 m. All the herbicides were applied as pre-em (3 DAP) with the help of manually operated knapsack sprayer fitted with flat fan nozzle using 500 liters of water/ha. However, a treatment of fenoxaprop and metsulfuron-methyl as tank mixed was executed as superimposed in the treatments of the pendimethalin, metribuzin and atrazine at 45 DAP. Species-wise number of weeds was recorded from 3 places, selected randomly in each plot using a quadrate of 50 cm × 50 cm size. Weeds within the quadrate were identified and counted and weed count expressed as number/m^2. The dry weight of total weed species was recorded from three places in each plot selected randomly. After sun drying, weeds were dried in hot air oven at 70 ± 1°C for 48 hours to obtain a constant weight. Five plants were randomly selected from each plot and the total area of leaves of 5 plants was estimated with the help of electronic leaf area meter, and finally total leaf-area was divided by the number of plants to get the leaf area/plant. Leaf area index was calculated as:

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area}}{\text{Unit land area}}$$

The planting of crop was done on 17 June 2012 and 13 June 2013 in rows, 45 cm apart having plant-to-plant distance of 20 cm. The rhizomes were planted 5–7 cm deep. Four irrigations were provided to maintain adequate soil moisture at all the stages of crop growth during both seasons. Urea, diammonium phosphate and muriate of potash were used to supply 125 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha respectively. The crop was harvested on 18 February 2013 and 24 February 2014 during the first and second seasons respectively. The moisture content in rhizomes at harvesting was around 85%. The data collected on weeds and turmeric crop were statistically analyzed as per analysis of variance procedure (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Weed and weed control efficiency

The dominant weed species in weedy plots at 120 DAP were grassy weeds like jungle rice–*Echinochloa colona* L. (3.3/m^2) and crowsfoot grass, *Eleusine indica* (3.1/m^2), broad-leaved weeds like monarch redstem, *Ammannia baccifera* L. (3.8/m^2), tropical whiteweed, *Ageratum conyzoides* L. (3.2/m^2), yellow sweet clover, *Melilotus indica* (3.1/m^2), tropical spiderwort–*Commelina benghalensis* L. (3.1/m^2) and black nightshade–*Solanum nigrum* (3.6/m^2) and sedges like nutgrass, *Cyperus rotundus* L. (3.7/m^2) and forked fringerush, *Fimbristylis dichotoma* (L.) Vahl. (3.2/m^2). The grassy weeds constituted 27.8, broad-leaf 49.8 and sedges 18.9% of the total weed population under weedy conditions. The application of metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, being at par with pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP and atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, was found significantly more effective in controlling weeds (Table 1). Significant reduction in weed dry-matter accumulation at 120 DAP was observed due to weed-control treatments, viz. metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, farmers' practice, pendimethalin 1 kg/ha as pre-em fb 2 hoeings 45 and 75 DAP, pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, metribuzin 700 g/ha as pre-em fb 2 hoeings 45 and 75 DAP, atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP which were equally effective in reducing weed dry matter and achieving higher weed-control efficiency. Jadhav and Pawar (2014) also reported that application of metrbuzin 700 g/ha fb straw mulch 10 t/ha fb 1 HW proved most effective recording lowest weed dry matter and highest weed control efficiency.

Growth attributes of turmeric

Herbicides superimposed with straw mulch recorded higher rhizome emergence (95.5–96.5%) at 30 DAP (Table 1). It might be owing to the fact that favourable conditions provided by rice straw mulch helped conserve the moisture in the soil and encouraged the better and fast sprouting of rhizomes, as also reported by Hossain (2005). Metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, being at par with pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP and farmers' practice (HW 25, 45 and 75 DAP) [only for plant height], exhibited significantly higher plant height (95.4–102.2 cm) at 180 DAP, LAI (5.1–5.3) at 120 DAP and dry-matter accumulation (289.5–295.0 g/plant) at 180 DAP in turmeric crop. Verma and Sarnaik (2006) observed maximum plant height in turmeric with paddy straw as mulch in combination with herbicides. Higher LAI in turmeric was recorded in weed-free check followed by pendimethalin at 1.5 kg/ha as reported by Channappagoudar *et al*. (2013).

Yield attributes and yield

The yield attributes and yield of turmeric were significantly influenced by the weed-control treatments (Table 2). The application of metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, being at par with pendimethalin 1 kg/ha as pre-em fb straw mulch 10

Table 1. Effect of weed control on weed density, weed dry weight, weed-control efficiency and growth attributes of turmeric (pooled data of 2 years)

Treatment	Weed density (Nos./m^2) 120 DAP					Weed dry weight (g/m^2) 120 DAP	Weed-control efficiency (%)	Rhizome emergence (%) 30 DAP	Height (cm) 180 DAP	LAI 120 DAP	Plant dry weight (g) 180 DAP
	Grasses	Sedges	Broad-leaf weeds	Other weeds	Total						
T_1, Metribuzin 700 g/ha as pre-em fb 2 hoeings 45 and 75 DAP	3.7 (13.2)	3.1 (9.2)	3.9 (14.4)	1.5 (2.1)	6.3 (38.9)	5.9 (33.7)	89.2	90.0	82.0	3.2	206.8
T_2, Metribuzin 700 g/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP	4.6 (21.1)	3.8 (14.0)	6.0 (35.4)	2.1 (4.0)	8.7 (74.5)	21.4 (456.2)	8.7	87.5	50.7	2.3	125.2
T_3, Metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP	2.5 (6.0)	2.2 (4.5)	3.3 (10.6)	1.2 (1.3)	4.8 (22.4)	5.2 (26.2)	93.5	95.5	102.2	5.3	295.0
T_4, Pendimethalin 1 kg/ha as pre-em fb 2 hoeings 45 and 75 DAP	3.6 (12.5)	2.9 (8.3)	3.5 (11.8)	1.5 (2.0)	5.9 (34.6)	5.5 (30.1)	90.6	93.5	85.4	3.4	213.6
T_5, Pendimethalin 1 kg/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP	4.4 (18.7)	3.5 (11.9)	5.7 (31.7)	2.0 (3.6)	8.2 (65.9)	21.0 (437.1)	13.1	91.0	59.8	2.6	129.0
T_6, Pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP	2.6 (6.7)	2.4 (5.4)	3.5 (12.2)	1.3 (1.5)	5.1 (25.8)	5.8 (32.6)	92.2	96.5	97.8	5.1	292.2
T_7, Atrazine 750 g/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP	4.5 (19.6)	3.7 (13.3)	5.8 (33.3)	2.0 (3.8)	8.4 (70.0)	21.2 (448.1)	15.4	89.5	55.5	2.5	124.3
T_8, Atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP	2.8 (7.5)	2.5 (6.0)	3.7 (13.6)	1.4 (1.8)	5.4 (28.9)	6.3 (39.2)	90.3	96.0	95.4	5.1	289.5
T_9, Farmers' practice (HW 25, 45 and 75 DAP)	3.9 (14.5)	3.3 (10.3)	5.0 (24.8)	1.8 (3.2)	7.3 (52.3)	5.3 (27.0)	92.9	89.5	99.9	3.9	216.0
T_{10}, Weedy check	5.9 (33.9)	4.8 (23.0)	7.8 (60.6)	3.1 (9.3)	11.3 (126.8)	22.4 (497.8)	-	89.0	46.9	2.2	119.3
SEm±	0.1	0.1	0.2	0.1	0.3	0.5	-	-	3.2	0.1	8.7
CD (P=0.05)	0.4	0.3	0.5	0.2	0.8	1.6	-	-	9.9	0.4	25.7

t/ha fb 1 HW 75 DAP and atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP, recorded significantly higher number (27.3–29.1) and volume (317.2–344.3 cm^3) of rhizomes/plant, fresh (452.8–474.5 g) and dry weight (93.5–95.6 g) of rhizomes/plant and fresh (31.1–33.9 t/ha) and dry (6.2–6.7 t/ha) yield of rhizomes. Barooah *et al*. (2011) observed that integration of mulching (just after planting of rhizomes and 90 days after planting of rhizomes) with manual (hoeing 40 days after planting and hand-weeding 90 days after planting) and mechanical measures (grubber at 60 days after planting) recorded significantly higher yield in ginger. Metribuzin 700 g/ha fb straw mulch 10 t/ha fb 1 HW, pendimethalin 700 g/ha fb straw mulch 10 t/ha fb 1 HW and atrazine 750 g/ha fb straw mulch 10 t/ha fb 1 HW were the most effective weed-control treatments in turmeric as reported by Kumar *et al*. (2014). The weed-control treatments, metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP and pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP recorded the highest dry rhizome yield and lowest weed index followed by the treatment, atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP which might be due to higher number and weight of rhizomes/plant and better weed-control efficiency. Pre-emergence application of pendimethalin + straw mulch 9 t/ha resulted in higher fresh rhizome yield (29.6 t/ha) and was on par with metribuzin and atrazine both integrated with straw mulch 9 t/ha in turmeric, as also reported by Kaur *et al*. (2008). Sathiyavani and Prabhakaran (2014) also reported that pre-emergence application of metribuzin 700 g/ha *fb* straw mulch 10 t/ha *fb* 1 HW 75 DAP was the most effective for controlling the weeds and enhancing the productivity of turmeric. Ratnam *et al*. (2012) also reported that, integration of pre + post-emergence herbicides supplemented with hand-weeding at 60 and 90 DAP recorded higher fresh rhizome yield in turmeric. However, quality content of turmeric (curcumin and essential oil) was not affected either due to

Table 2. Effect of weed control on yield attributes, rhizome yield, weed index, quality and economics of turmeric (pooled data of 2 years)

Treatment	Rhizomes/plant	Volume of rhizomes (cm^3/plant)	Fresh weight of rhizomes/plant (g)	Dry weight of rhizomes/plant (g)	Fresh yield of rhizomes (t/ha)	Dry yield of rhizomes (t/ha)	Weed index (%)	Curcumin (%)	Essential oil (%)	Gross returns (× 10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	Benefit: cost ratio
T$_1$, Metribuzin 700 g/ha as pre-em fb 2 hoeings 45 and 75 DAP	20.4	258.1	365.0	77.7	23.6	4.8	9.4	7.2	2.2	359.6	245.1	2.17
T$_2$, Metribuzin 700 g/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP	11.7	189.3	227.9	47.3	9.9	2.2	58.5	7.0	2.3	150.9	38.5	0.35
T$_3$, Metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP	29.1	344.3	474.5	95.6	33.9	6.7	–26.4	7.3	2.1	516.6	392.5	3.20
T$_4$, Pendimethalin 1 kg/ha as pre-em fb 2 hoeings 45 and 75 DAP	21.7	273.9	385.3	79.2	24.8	5.1	3.8	7.1	2.1	377.4	263.2	2.32
T$_5$, Pendimethalin 1 kg/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP	13.4	207.7	252.7	52.0	12.7	2.6	50.9	7.0	2.2	192.8	80.6	0.73
T$_6$, Pendimethalin 1 kg/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP	28.1	319.9	463.3	93.5	32.2	6.7	–26.4	7.2	2.2	489.9	366.1	2.99
T$_7$, Atrazine 750 g/ha as pre-em fb fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha as tank mixed and post-em 45 DAP	12.2	195.6	236.4	50.6	11.9	2.4	54.7	6.9	2.2	181.4	69.8	0.64
T$_8$, Atrazine 750 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP	27.3	317.2	452.8	95.0	31.1	6.2	–17.0	7.2	2.2	472.4	349.3	2.88
T$_9$, Farmers' practice (HW 25, 45 and 75 DAP)	22.4	282.5	408.4	83.1	25.8	5.3	-	7.1	2.1	397.1	279.7	2.41
T$_{10}$, Weedy check	11.4	185.3	223.7	44.1	9.8	1.8	66.0	7.0	2.2	146.2	37.4	0.27
SEm±	0.8	11.0	16.5	2.8	1.0	0.2	-	-	-	-	-	-
CD (P=0.05)	2.4	32.7	49.1	8.2	3.0	0.6	-	-	-	-	-	-

Figures in parentheses are original values; DAP, days after planting; *fb*, followed by; HW, hand weeding; LAI, leaf area index conventional or improved weed management practices.

Production economics

The application of metribuzin 700 g/ha as pre-em fb straw mulch 10 t/ha fb 1 HW 75 DAP resulted in higher net returns of ₹392,493/ha and benefit: cost ratio of 3.2 (Table 2). However, moderate net returns ₹279,691/ha) and benefit: cost ratio (2.4) was registered with farmers' practice. Higher economic returns from turmeric with the application of metribuzin 700 g/ha fb straw mulch 10 t/ha fb 1 HW 75 DAP was also reported by Sathiyavani and Prabhakaran (2014).

It was concluded that integration of mulches and hand-weeding with pre-emergence herbicides achieved the maximum yield and returns. However, pre-emergence application of metribuzin 700 g followed by rice straw mulch 10 tonnes/ha along with 1 hand-weeding 75 days after planting in turmeric crop proved superior with respect to productivity and economics.

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Research Communication

Chemical weed management in wheat (*Triticum aestivum*) under semi-arid conditions of Kandahar, Afghanistan

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ABSTRACT

A field experiment was conducted during winter season of 2014–15 at the Research Farm, Tarnak, Afghanistan National Agricultural Science and Technology University (ANASTU), Kandahar, Afghanistan to evaluate the chemical weed control effects on weeds and wheat [*Triticum aestivum* (L.) emend Fiori & Paol.]. The treatments comprised of isoproturon @ 0.75 and 1.00 kg/ha at 35 DAS, sulfosulfuron @ 20 and 25 g/ha at 35 DAS, isoproturon + 2,4-D @ (0.75 + 0.5) kg/ha at 35 DAS (tank-mix treatment), weed-free check and weedy check, laid out in a randomized complete block design with three replications. Sulfosulfuron 25 g/ha at 35 DAS resulted in significant reduction in weed growth (population and dry weight) and caused a considerable increase in weed control efficiency (WCE) and weed control index (WCI) in wheat. This treatment led to a significant improvement in yield attributes and yield of wheat. It also caused a considerable reduction in wheat yield losses due to weeds, and was superior to all other herbicide treatments. Sulfosulfuron 20 g/ha at 35 DAS was the next best treatment. Sulfosulfuron 25 g/ha applied at 35 DAS gave significantly higher gross and net returns, but comparable with sulfosulfuron 20 g/ha. Therefore, sulfosulfuron 25 g/ha applied at 35 DAS may be recommended for effective broad-spectrum weed control in wheat in Kandahar, Afghanistan. However, this report highlights the results of a location-specific study, conducted for one year, which needs to be replicated over times for more refinement/ validation and sound recommendation.

Key words **:** Isoproturon, Sulfosulfuron, Weeds, Wheat, 2, 4-D,

Wheat is a staple food crop in Afghanistan, accounting for about 83% of total cereal consumption. Among various biotic stresses, weeds are considered as one of the most serious problems. The yield losses due to weeds vary between 30-50% based on weed infestation (Pandey and Singh, 1997). In order to achieve higher wheat yields, it is important to control weeds (Khan *et al*., 2003). Among various weed management options, chemical weed management is economic and easy to adopt compared to other methods. Ahmad *et al*. (1993) have observed that herbicides application and hand weeding significantly decreased dry weight of weeds compared to non-treated plots. But, the response of newer low-dose high potency herbicides like sulfosulfuron and tank-mix application for broad-spectrum weed control have not been studied/standardized for wheat crop in Afghanistan. Therefore, this study was planned and undertaken to find out appropriate herbicide and its dose and time of application for effective weed management in wheat in Afghanistan.

The field experiment was conducted during winter season of 2014–15 at the Research Farm, Tarnak, Afghanistan National Agricultural Science and Technology University (ANASTU), Kandahar. The soil was sandy clay loam with *p*H 8.3, electrical conductivity 0.21 dS/m, organic carbon 0.8%, available N 0.06% w/w, available P 12.3 mg/kg, and available K 108.9 mg/kg. There were seven treatments [i.e. isoproturon @ 0.75 and 1.00 kg/ha at 35 days after sowing (DAS), sulfosulfuron @ 20 and 25 g/ha at 35 DAS, isoproturon + 2,4-D @ 0.75 + 0.5 kg/ha at 35 DAS (tank-mix treatment), weed-free check (through manual weeding) and weedy check, laid out in a randomized complete block design with three replications. Wheat cultivar ‘PBW 154’ was sown on 28 December, 2014 using 100 kg

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seed/ha. All the herbicides were applied by a knapsack sprayer fitted with a flat fan nozzle at 35 DAS of wheat with different concentration as per the treatments. The volume rate used was 400 litres of water/ha. The recommended dose of N: P_2O_5: K_2O: 120: 60: 30 kg/ha was applied to wheat crop. The full dose of P and K and one-third dose of N were applied to all the plots across replications as basal at final land preparation/harrowing before seed drilling. Rest of N was applied in equal splits at crown root initiation (CRI) and panicle initiation stages of wheat as top dressing. Species-wise weeds across treatments were collected at 45 DAS and harvest in all the plots using a quadrat of 0.5 m × 0.5 m. Changes in weed flora due to treatments were noted and weed populations were recorded from this area and expressed in no./m^2. Then, weeds were categorized into narrow-leaved, broad-leaved and total (narrow-leaved + broad-leaved) weeds. They were sun-dried for 2 days and kept in an oven at 70±5^{0}C for 48 hrs for dry weight estimation. Dry weight was expressed as g/m^2. Weed control efficiency (WCE) based on weed populations, weed control index (WCI) based on weed dry weights, and weed index (WI; per cent yield loss) were determined as per Das (2008). The economic analysis in terms of gross and net returns, and benefit: cost ratio (returns per Afghani invested) was worked out on the basis of existing rates of inputs and outputs.

The major broad-leaved weeds of the experimental wheat field comprised of *Launaea asplenifolia* (Willd.) Hook. f. (Launaea), *Chenopodium album* L. (Common lambsquarters), *Convolvulus arvensis* L. (Field bind weed), *Fumaria indica* Pugsley (Fumitory), *Alhagi maurorum* L. (Camel thorn), *Polygonum aviculare* L. (Prostrate knotweed), *Carthamus oxyacantha* Bieb. (Wild safflower) and *Melilotus indica* (L.) All. (Yellow sweetclover). Major narrow-leaved weeds were *Avena fatua* L. (Wild oat), *Bromus tectorum* L. (Downybrome), *Cynodon dactylon* (L.) Pers. (Bermuda grass), *Lolium temulentum* L. (Darnel), *Phalaris minor* Retz. (Littleseed canarygrass), *Polypogon monspeliensis* (L.) Desf. (Foxtailgrass), *Setaria viridis* (L.) Beauv. (Green foxtail).

It was observed that grass weeds were pre-dominant than broad-leaved weeds in population and dry weight. The application of sulfosulfuron 25 g/ha resulted in significant reduction in the population of total weeds at 45 DAS and at harvest (Table 1) compared to weedy check. It increased weed controlled efficiency (WCE) by 95.8% and weed control index (WCI) by 93.7% at harvest (Table 1) over weedy check. It also resulted in significant reduction in dry weight of total weeds by 95.1% at 45 DAS and 93.7% at harvest (Table 1) compared to weedy check. Reasons could be that sulfosulfuron is an effective low-dose new herbicide, having broad-spectrum activity against weeds. Besides, the field was dominated by grassy weeds, and sulfosulfuron was more effective against grassy weeds, namely *Avena fatua, Phalaris minor* and so on (Das, 2008). Singh *et al*. (2013) reported similar results. Sulfosulfuron 20 g/ha and isoproturon + 2,4-D (0.75 + 0.5) kg/ha closely followed the sulfosulfuron 25 g/ha in this regard. Nath *et al*. (2015) reported that the application of pendimethalin 1.0 kg/ha as pre-emergence, followed by sulfosulfuron 25 g/ha as post-emergence led to higher weed control efficiency and weed control index in wheat. Shyam *et al*. (2014) observed that sulfosulfuron 33.3 g/ha resulted in significantly lower weed density and biomass and higher weed control efficiency, which was found on par with hand weeding at 30 DAS, but superior to isoproturon and 2,4-D sodium salt.

The application of sulfosulfuron 25 g/ha, being comparable with sulfosulfuron 20 g/ha recorded higher values of all yield attributes, viz. tillers and spikes/m^2, spikelets/spike and grains/spike (Table 1). The collective effects of yield attributes led to higher grain yield of wheat by 24.3% over weedy check (Table 1). Straw and biological yields were increased by 23.1% and 17.8% in this treatment over weedy check. The results are in conformity with Ahmadi and Alam (2013). Das and Kulshrestha (2002) obtained higher wheat grain yields due to sulfosulfuron 25 g/ha without any phototoxic effects on wheat for two years. Grain yield obtained due to sulfosulfuron 25 and 20 g/ha was even higher than that in weed-free check. The application of sulfosulfuron 25 and 20 g/ha increased wheat yield by 8.8% and 3.7% respectively over weed-free check. The negative weed index (WI) reflected their superiority over weed-free check. Indeed, sulfosulfuron 25 g/ha provided almost weed-free situations. Fewer numbers of weeds, which were present in this treatment, could hardly compete with vigorously-growing wheat plants. Due to greater suppression of weeds by sulfosulfuron 25 g/ha, the negative effects of weeds on growth parameters, yield attributes and yields were greatly reduced in wheat. Sulfosulfuron (~sulfonylureas) inhibits acetolactate synthase/acetohydroxyacid synthase (ALS/AHAS) enzyme and is effective against broad-spectrum of weeds, but with more activity against grassy weeds. Probably, higher effects of this herbicide against dominant grassy weeds in this study played a role. Besides, another chemical surfactant had been inherently added with sulfosulfuron, which prevented phytotoxicity and growth inhibition in wheat, which, otherwise, used to be observed upon sulfosulfuron applications. This sulfosulfuron was rather promotive to wheat growth. In weed-free check, hand weeding done at later stages might inflict slight damage to wheat crop. Beside, the post-emergence herbicide like sulfosulfuron may pose slight repellent actions against pests and dis-

Table 1. Yield attributes, weed population, dry weight, weed control efficiency (WCE), weed control index (WCI) and wheat grain, straw and biological yields, harvest index, yield losses and economics across the weed control treatments

Treatment	Tillers/ m^2	Spikes/ m^2	Spikelets/ spike	Grains/ spike	Total weed population (No./m^2)		Total dry weight of weeds (g/m^2)		WCE (%)	WCI (%)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Wheat yield losses (WI) (%)	Net returns ($\times 10^3$ AFN*/ha)	Net benefit: cost
					45 DAS	At harvest	45 DAS	At harvest								
Isoproturon 0.75 kg/ha	307	255.0	17.0	32.7	12.5† ‡ (163.0)	9.5† ‡ (113.3)	5.8† ‡ (33.7)	7.4† ‡ (55.7)	52.2	45.0	3.7	5.5	40.0	10.8	110.7	2.0
Isoproturon 1.00 kg/ha	312	271.7	17.8	38.9	8.3 (70.0)	8.6 (82.7)	5.2 (26.7)	7.3 (53.0)	65.2	47.7	3.9	5.8	40.9	7.0	119.1	2.1
Sulfosulfuron 20 g/ha	354	293.3	18.3	38.9	3.8 (14.3)	3.6 (13.0)	2.0 (3.9)	3.6 (13.7)	94.5	86.5	4.3	6.1	41.9	-3.7	134.5	2.4
Sulfosulfuron 25 g/ha	360	296.7	18.7	39.1	3.2 (11.3)	3.0 (10.0)	1.7 (3.0)	2.6 (6.3)	95.8	93.7	4.6	6.4	43.0	-8.8	144.3	2.6
Isoproturon + 2,4-D (0.75 +0.5) kg/ha	333	278.3	17.7	35.8	7.8 (61.0)	7.8 (64.3)	3.6 (13.1)	6.5 (42.0)	72.9	58.5	4.0	5.4	40.3	3.6	118.1	2.1
Weed-free check	352	291.0	18.9	38.2	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	100.0	100.0	4.2	6.1	40.5	0.0	124.3	1.9
Weedy check	300	255.0	17.0	35.1	13.8 (193.7)	14.5 (237.3)	7.8 (61.1)	9.7 (101.3)	0.0	0.0	3.7	5.2	41.4	12.4	107.6	1.9
SEm±	5.2	13.0	0.5	2.4	0.82 (21.1)	2.2 (58.0)	0.6 (5.8)	1.0 (16.8)	7.8	7.2	0.2	0.2	2.1	4.5	5.59	0.10
CD (P=0.05)	16.1	40.0	1.5	NS	2.5 (65.0)	6.8 (178.6)	1.8 (17.7)	2.9 (51.6)	24.9	23.1	0.6	0.7	NS	13.8	17.2	0.3

†Square-root [$\sqrt{(x+0.5)}$] transformed data, and ‡original data of weed populations and dry weights; *1AFN (Afghani)=0.0147929 USD (i.e. 1 USD = 67.6 AFN)

eases (not studied) at later stages of wheat. Das *et al.* (2010) reported the plant-parasitic nematodes control ability of atrazine in maize crop. Tadesse *et al.* (2010) observed lower infestations of shoot fly (*Atherigona soccata* Rondani) and spotted stem borer (*Chilo partellus* Swinhoe) in atrazine-treated plots than in weed-free plots. In contrast, Shyam *et al.* (2014) reported that weed-free treatment recorded maximum nutrient removal by wheat crop and gave 129.6% higher wheat yield over weedy check, followed by sulfosulfuron 33.3 g/ha).

Weed control/herbicides treatments increased the cost of cultivation slightly over that incurred due to weedy check treatment. Yet, they resulted in higher net returns and net benefit: cost ratio than in weedy check (Table 1). Maximum net returns (144300 AF/ha) and net benefit: cost ratio (2.6) were recorded due to sulfosulfuron 25 g/ha; the minimum net returns (107600 AF/ha) and benefit: cost ratio (1.9) was recorded in weedy check. The reasons for superiority of the sulfosulfuron 25 g/ha application could be better weed control, higher growth and yield attributes of wheat, leading to higher grain and biomass yield. Saquib *et al*. (2012) found that sulfosulfuron 25 g/ha gave significantly higher grain yield (3.71 t/ha) and straw yield (4.79 t/ha). Higher value of benefit: cost ratio (1.91) was also obtained with the application of sulfosulfuron 25 g/ha. Similarly, Shyam *et al.* (2014) observed that the maximum net returns (₹31,475/ha) and benefit: cost ratio (1.8) in wheat cultivation was obtained through sulfosulfuron 33.3 g/ha, which was on par with weed-free check, and the treatment that received weeding at 30 DAS. In contrast, Bharat *et al*. (2012) observed the highest benefit: cost ratio (1.97) with isoproturon + 2,4-D than in sulfosufuron 25 g/ha + 2,4-D 500 g/ha.

Maintaining weed-free situation for whole cropping season using manual labourers is costlier than herbicides and not profitable/economic and time consuming. Therefore, sulfosulfuron 25 g/ha applied at 35 DAS may be recommended for effective broad-spectrum weed control in wheat in Kandahar, Afghanistan. However, integration of herbicides with cultural/ecological options such as furrow-irrigated raised bed planting, zero-tillage with crop/plant residue and adjusting time, method and rate of sowing and spacing may be studied in future for longer, better and efficient weed management in wheat in Kandahar, Afghanistan.

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Research Communication

Planting density and nitrogen management effects on productivity, quality and water-use efficiency of rainfed pearlmillet (*Pennisetum glaucum*) under conservation agriculture

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ABSTRACT

A field experiment was conducted during the rainy season 2015 at New Delhi, to study the effect of planting density and nitrogen-management practices on conservation agriculture-based rainfed pearlmillet [*Pennisetum glaucum* (L.) R. Br. Emend stuntz]. The experiment comprised 3 main-plot treatments, viz. normal distance sowing (D_1), high density sowing followed by (*fb*) alternate row harvesting for fodder at 35 days after sowing (DAS), (D_2) and high density sowing *fb* alternate row harvesting for fodder at 45 DAS (D_3) and 5 subplot treatments, viz. control, 60 kg N/ha as basal, 30 kg N/ha as basal + 30 kg N/ha as side dressing, 75 kg N/ha as basal and 37.5 kg N/ha as basal + 37.5 kg N/ha as side dressing. Maximum production efficiency (56.2 kg/ha-day), system yield (4.49 t/ha), net returns (33.9 × 10^3 ₹/ha) and monetary efficiency (₹424/ha-day) was recorded under D_2. The highest protein yield (285 kg/ha), consumptive use (423.5 mm), water-use efficiency (6.4 kg/ha-mm) and rate of moisture use (5.3 mm/day) were realized from treatment D_1. Among N-management treatments, 75 kg N/ha as basal resulted in the highest system yield (4.69 t/ha), production efficiency (58.6 kg/ha-day), net returns (36.6 × 10^3₹/ha) and monetary efficiency (₹457/ha-day). Protein content in grain (11.4%) and protein yield (298 kg/ha), consumptive use of water (429 mm) and water-use efficiency (7.1 kg/ha-mm) were found highest in 37.5 kg N/ha as basal + 37.5 kg N/ha as side-dressing.

Key words : Conservation agriculture, Nitrogen management, Pearlmillet, Planting density, Water-use efficiency

Pearlmillet is a crucial component to the food security of the rural population in dry areas. In addition, its stover is an important source of fodder, accounting for 40–50% of dry matter intake year round, and the only source of feed during the dry months in majority of arid and semi-arid agro-climatic conditions (Rana and Bana, 2012). Being a crop of marginal environments and arid tropics, it suffers from many abiotic stresses, moisture stress being the most important. Further, profit fetched from the crop is also low due to lesser productivity under soil-moisture scarcity and comparatively higher cost of cultivation. Application of organic mulch effectively reduces evaporative moisture losses with the added advantage of reduced weed growth and improved soil health (Bana *et al.,* 2016). Conservation agriculture (CA) interventions (zero-tillage + mulching) offer a viable alternative for production of this crop as CA practices helps to retain more profile moisture and essential nutrients and reduce cost of cultivation (Choudhary *et al.,* 2016). But, the major obstacles in adoption of CA in dryland ecosystems are less biomass availability for mulching and competing uses of crop residues for livestock component of farming systems of this ecosystem. High density planting followed by alternate row harvesting for fodder at different growth stages may provide a partial solution to the problem of fodder shortage occurring under CA systems. Further, research findings on N-management protocols for pearlmillet are not available under CA. Keeping these in view, the present investigation was carried out to study the effect of planting density and nitrogen management on productivity, quality and water-use efficiency in conservation agriculture-based pearlmillet.

Based on a part of M.Sc. thesis of the first author, submitted to ICAR-Indian Agricultural Research Institute, New Delhi in 2016 (unpublished)

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A field experiment was conducted at the Indian Agricultural Research Institute, New Delhi, during the rainy (*kharif*) season of 2015. The field had an even topography and good drainage system. Soil of the experimental site was sandy loam, poor in organic carbon content (0.44%) as well as available N (146 kg/ha) and medium in available P (15.8 kg/ha) and available K (184 kg/ha), soil was slightly alkaline in reaction with *p*H 7.5. The total rainfall received during crop-growing period was 685 mm. The experiment was conducted in fixed layout of split-plot design, replicated thrice. The field experiment comprised of 3 main plot treatments of planting density, viz. normal distance sowing (45 cm × 10 cm), high density sowing (22.5 cm × 10 cm) followed by (*fb*) alternate row harvesting for fodder at 35 days after sowing (DAS) and high density sowing (22.5 cm × 10 cm) *fb* alternate row harvesting for fodder at 45 DAS and 5 subplot treatments of nitrogen management, viz. control (N_1), 60 kg N/ha as basal [100% recommended dose of nitrogen (RDN); N_2], 30 kg N/ha as basal + 30 kg N/ha as side-dressing (N_3), 75 kg N/ha as basal (125% RDN; N_4), and 37.5 kg N/ha as basal + 37.5 kg N/ha as side-dressing (N_5). Pearlmillet variety 'Pusa Composite 443' was sown by happy seeder following the seed rate of 4 kg seed/ha in normal distance plot and 8 kg seed/ha in high density plots. For basal application urea was drilled in bands 5 cm below the surface during pearlmillet sowing and later, side-dressing of urea was done at 30 DAS as per treatments. The grain-equivalent yield of green fodder and grain-equivalent yield of stover are added in to grain yield to work out system yield. The system yield was divided by duration of crop to work out the production efficiency. Acid and neutral detergent fibre in forage samples were estimated by method described by Van Soest (1963). Consumptive use was calculated as:

$$\text{Consumptive use (mm)} = \Sigma(bj-ej) + \text{effective rainfall}$$

where, bj = total profile moisture content at the beginning of the j^{th} interval; ej = total profile moisture at the end of the j^{th} interval

Water-use efficiency was worked out by dividing grain yield with seasonal crop consumptive use of water. Rate of moisture use was worked out by dividing consumptive use of water by crop duration.

Significantly higher system yield (4.49 t/ha) was observed with high density sowing *fb* alternate row harvesting for fodder at 35 DAS compared to other planting density. This treatment registered 0.1 and 0.53 t/ha improvement in system yield over high density sowing *fb* alternate row harvesting for fodder at 45 DAS and normal distance sowing respectively. The same treatment also recorded the maximum production efficiency (56.2 kg/ha-day). The next best treatment was high density sowing *fb* alternate row harvesting for fodder at 45 DAS (54.8 kg/ha-day), followed by normal distance sowing (49.4 kg/ha-day). System yield and production efficiency enhanced significantly with high density sowing *fb* alternate row harvesting for fodder at 35 and 45 DAS owing to higher grain-equivalent yield of green forage obtained by alternate row harvesting at different growth stages.

Nitrogen-management practices also significantly influenced system yield. The maximum system yield (4.69 t/ha) was noted with 75 kg N/ha as basal (125% RDN); it was found at par with 37.5 kg N/ha as basal + 37.5 kg N/ha as side-dressing (4.68 t/ha). Almost all the nitrogen management treatments significantly affected production efficiency as compared to the control. The maximum production efficiency was recorded with 75 kg N/ha either as basal or under split application (58.5 kg/ha-day). In residue-based zero-till farming systems, slower soil N mineralization and greater immobilization, especially during initial periods of adoption of CA, hinders the crop production. So, application of slightly higher than recommended dose of N (i.e. 60 kg/N) under CA-based system compensates the lesser N availability due to immobilization of N and thus enhance system yield and production efficiency. Availability of nitrogen through mineralization of N at reproductive stage might be responsible for the similar performance of basal application than split application of N.

Grain protein content was non-significantly affected by planting density but marked decline in protein yield was noticed with high density. Pearlmillet planted under normal distance registered significantly higher protein yield (285 kg/ha). This is because of lower grain yield in high density sowing treatments as compared to normal distance sowing. Appreciable increase in protein per cent in pearlmillet grain was observed with an increase in subsequent level of nitrogen. Application of 37.5 kg N/ha as basal + 37.5 kg N/ha as side-dressing resulted in the highest grain protein content (11.4%) as well as protein yield (298 kg/ha). Nitrogen is an important constituent of protein, which always shows a marked promoting influence on protein synthesis by way of promoting synthesis of amino acids, which are constituent building blocks of protein (Bana and Gautum, 2009; Jhadav *et al.,* 2011; Bana *et al.*, 2012). The different treatments of planting density were failed to produce any significant variation on neutral detergent fibre (NDF), acid detergent fibre (ADF) and crude protein (CP) content in green fodder of pearlmillet. Data on NDF and ADF content reveal that increasing level of nitrogen fertilizer shows remarkable decline in NDF and ADF content. The highest NDF and ADF value (70.8 and 42.5% respectively) were noticed in the control. In

Table 1. Effect of planting density and nitrogen management on system yield, production efficiency and quality parameters water-use efficiency and economics of pearlmillet

Treatment	System yield (t/ha)	Production efficiency (kg/ha-day)	Grain quality		Green fodder quality			Consumptive use of water (mm)	Water-use efficiency (kg/ha-mm)	Rate of moisture use (mm/day)	Net returns (× 10³ ₹/ha)	Monetary efficiency (₹/ha-day)
			Protein content (%)	Protein yield (kg/ha)	NDF[a] (%)	ADF[b] (%)	CP[c] (%)					
Planting density												
D_1	3.96	49.5	11.1	285	67.9	41.4	7.7	429.7	7.5	5.4	28.5	356
D_2	4.49	56.2	11.0	258	67.4	41.2	7.5	423.5	6.4	5.3	33.9	424
D_3	4.39	54.8	10.6	226	67.2	41.1	7.3	420.0	5.3	5.2	32.3	404
SEm±	0.04	0.5	0.12	6.17	0.36	0.16	0.13	1.40	0.10	0.02	0.56	6.9
CD(P=0.05)	0.17	2.13	NS	24.3	NS	NS	NS	5.48	0.38	0.07	2.20	27.1
Nitrogen management												
N_1	3.41	42.7	10.3	187	70.8	42.5	6.1	417.0	5.9	5.2	21.3	266
N_2	4.30	53.7	10.7	251	67.8	41.3	8.2	423.8	6.1	5.3	31.8	397
N_3	4.32	53.9	10.8	261	67.3	41.5	7.4	424.2	6.2	5.3	31.7	397
N_4	4.69	58.6	11.3	285	65.8	40.3	8.3	428.0	6.6	5.4	36.6	457
N_5	4.68	58.6	11.4	298	65.9	40.4	7.5	428.9	7.1	5.4	36.3	454
SEm±	0.07	0.86	0.13	4.50	0.51	0.33	0.17	1.25	0.14	0.02	0.87	10.9
CD (P=0.05)	0.20	2.51	0.38	13.1	1.49	0.96	0.49	3.64	0.41	0.05	2.55	31.9

D_1, normal distance; D_2, high density sowing followed by (*fb*) alternate row harvesting for fodder at 35 days after sowing (DAS); and D_3, high density sowing *fb* alternate row harvesting for fodder at 45 DAS; N_1, Control; N_2, 60 kg N/ha as basal; N_3, 30 kg N/ha as basal + 30 kg N/ha as side dressing; N_4, 75 kg N/ha as basal; and N_5, 37.5 kg N/ha as basal + 37.5 kg N/ha as side dressing

[a]Neutral detergent fibre, [b]acid detergent fibre and [c]crude protein

contrary to NDF and ADF value, crude protein content in pearlmillet fodder increased with N levels. The maximum crude protein content (8.3%) in green fodder was recorded in 75 kg N/ha as basal treatment (125% RDN), being at par with 60 kg N/ha as basal (100% RDN).

Normal distance sowing resulted in significantly higher consumptive use of water and water-use efficiency in pearlmillet. Consumptive use (CU) of water increases in exact proportion to the dry weight production. Up to alternate row harvesting stage, CU was more at high density plots attributed to enhanced vegetative growth/unit area. After that, it was higher in normal distance sowing plot due to more dry weight and leaf area/plant. Despite more CU, increased water-use efficiency (WUE) of pearlmillet under normal distance sowing could be ascribed to higher pearlmillet grain yield under this treatment, which is numerator in WUE calculation formula. The utmost CU coupled with rate of moisture use was observed with application of 37.5 kg N/ha as basal + 37.5 kg N/ha as side-dressing to pearlmillet, being at par with 75 kg N/ha as basal (125% RDN). It may be ascribed due to enhanced vegetative growth and an extensive proliferation and deeper root-system that enabled the plant to utilize more moisture from deeper horizons of soil profile. The findings are in close proximity that of Tetarwal and Rana (2006) and Kumar *et al*. (2015). Water-use efficiency was also increased with increasing N levels. It might be owing to the fact that increase in yield was of higher magnitude than the corresponding increase in CU of water, eventually resulted in considerable increase in WUE owing to N levels. The maximum WUE was obtained with 120 kg N/ha under irrigated condition, while for rainfed crop, maximum WUE was achieved with 60 kg N/ha (Singh *et al.,* 2010).

High density sowing *fb* alternate row harvesting for fodder at 35 DAS was found more profitable because of higher net returns and monetary efficiency. Higher profit under this treatment might be owing to more returns from green forage yield as compared to cost involved under this treatment. With increasing doses of N up to the highest level, the net return was increased over the control. Application of 75 kg N/ha as basal (125% RDN) fetched significantly higher net returns and monetary efficiency over all other nitrogen-management treatments and 37.5 kg N/ha as basal + 37.5 kg N/ha as side dressing was at par to it. The increased profitability under this treatments may be ascribed to the comparatively lower cost involved under this treatment.

The effect of CA on soil health may not be visible during initial years of experimentation and only long-term experimentation could provide better insight and more clarity to the present findings. In a short period study, it can be concluded that high density sowing *fb* alternate row harvesting for fodder at 35 DAS is a suitable practice to achieve more forage yield and profits. Hence, it can be a potential panacea to the problem of forage shortage under CA. For getting higher yield with more return under conservation agriculture especially during initial period of CA adoption, pearlmillet should be fertilized with 75 kg/ha either as basal or in split application (37.5 kg N/ha as basal + 37.5 kg N/ha as side dressing).

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Research Communication

Productivity and resource-use efficiency of greengram (*Vigna radiata*) as influenced by sowing methods and phosphorus levels under semi-arid conditions of Afghanistan

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ABSTRACT

A field experiment was conducted during the rainy season of 2015, at the Afghanistan National Agricultural Sciences and Technology University (ANASTU), Kandahar, to study the effect of sowing methods and phosphorus levels on greengram [*Vigna radiata* (L.) R. Wilezek]. The experiment was laid out in a split-plot design with 8 treatment combinations including 2 sowing methods (broadcast and line sowing) in main plots and 4 phosphorus levels (0, 30, 60 and 90 kg P_2O_5/ha) in subplots, replicated thrice. Significantly higher grain yield, biological yield, production efficiency and water-use efficiency were recorded under line sowing over broadcast method. The highest grain yield (1.42 t/ha), biological yield (4.56 t/ha), production efficiency (16.5 kg/ha/day) and water-use efficiency (8.0 kg/ha/mm) were obtained by applying 60 kg P_2O_5/ha. Significantly higher gross returns, net returns, benefit: cost ratio and monetary efficiency were also recorded under line sowing and at 60 kg P_2O_5/ha respectively. Line sowing at 45 cm × 5 cm spacing and 60 kg P_2O_5/ha were found better treatments for higher productivity, profitability and resource-use efficiency of greengram under semi-arid conditions of Afghanistan.

Key words: Greengram, Phosphorus levels, Productivity, Profitability, Resource-use efficiency, Sowing methods

Greengram is the most important crop after wheat, rice and maize in Afghanistan. It is grown both as summer and rainy crop, fitting well into existing cropping systems (Noorzai *et al*., 2017). It plays an important role in the national economy and food security of Afghanistan. However, its yield is quite low in the country due to non-availability of high-yielding varieties and poor agronomic management practices. The efficient nutrient management especially phosphorus and line sowing of greengram may substantially enhance the yield even under traditional varieties and rainfed situations. Greengram is an energy-rich crop; so, phosphorus management plays a major role in enhancing its productivity with healthy root system, which may lead to better nutrient and water acquisition in rainfed conditions besides promoting biological nitrogen fixation (Kumar *et al*., 2016). The line sowing and phosphorus management may also enhance the efficiency of resources like sunlight, nutrients, water and space resulting in improved crop and water productivity, profitability and resource-use efficiency (Choudhary *et al*., 2015). In the country, no systematic work has been done on suitability of sowing methods and optimum dose of phosphorus in green gram. Hence the present investigation was carried out to study the effect of sowing methods and phosphorus levels on productivity, profitability and resource-use efficiency of greengram under semi-arid conditions of Afghanistan.

A field experiment was conducted at the Afghanistan National Agricultural Science and Technology University, Kandahar, Afghanistan (31° 30' N; 65’ 50' E; 1,010 m above sea-level) during the rainy season of 2015 (July to September). Kandahar is situated in southern Afghanistan, where climate is semi-arid to sub-tropical with extreme cold and hot situations. Average normal annual rainfall

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was 190.6 mm. On an average, there were 29 days per year with more than 0.1 mm precipitation. June was the driest month (no rainfall) while January was the wettest month (average rainfall 54 mm). The hottest month was July (mean temperature 31.9°C), whereas January was the coldest month (mean temperature 5.1°C). The average daily temperature variation was 16.7°C. The average monthly relative humidity ranged from 23% (June) to 59% (February).

The field experiment with 8 treatment combinations including 2 sowing methods (broadcast and line-sowing) in main plots and 4 phosphorus levels (0, 30, 60 and 90 kg P_2O_5/ha) in subplots was conducted in a split-plot design, replicated thrice. Experimental soil was sandy-clay loam in texture and almost neutral in reaction (pH 7.2). Using soil-test kit 'LaMotte Garden Guide Soil Test Kit (5679-01)' the soil was characterized as low in available nitrogen, medium in P_2O_5 and high in K_2O//ha. The statistical analysis was done by the standard procedures as suggested by Gomez and Gomez (1984). Critical difference (CD) values at $P = 0.05$ were used to determine the significant differences between treatment means.

Greengram variety 'NM 94' was sown on 1 July 2015 and fertilized with 30 kg N and 30 kg K_2O/ha with varying phosphorus levels (0, 30, 60 and 90 kg P_2O_5 /ha), respectively, using urea, diammonium phosphate and potassium sulphate as basal application. Under line sowing, greengram seed was sown @ 25 kg/ha manually in rows at 45 cm distance at 5 cm depth. The gross plot size was 3.15 m × 4.0 m, whereas the net plot size was 1.8 m × 3.6 m under line-sowing and 2.65 m × 3.5 m under broadcast method. Pendimethalin (30 EC) was applied @ 1.0 kg a.i./ha in 750 litres water/ha as pre-emergence herbicide for weed control. Two hand weedings, first (30–35 days after sowing, DAS) and second (50–55 DAS) were also done. A total of 3 irrigations were given due to long dry spell during the whole crop growth along with 1 pre-sowing irrigation. First irrigation was given at 22 DAS while second and third irrigation at 43 DAS and 70 DAS, respectively.

Due to non-synchronous growth of greengram variety under study, the pods were harvested in 2 pickings (first pod-picking at 80 DAS, second pod-picking at 90 DAS). The pods were harvested and threshed manually. The grains obtained from each net plot were sun-dried for 4–5 days, weighed and converted into grain yield as kg/ha. The grain yield was recorded at 10% moisture content. The straw collected from net plot area was sun-dried properly and weighed as kg/ha. The gross returns were calculated using prevalent market price of the greengram grains (AFN 66.10/kg) and straw (AFN 4.72/kg) in the market using standard procedure. The net returns were then calculated using respective cost of cultivation. The production efficiency (PE) (kg/ha/day) and monetary efficiency (ME) (AFN/ha/day) were computed using the following expression (Kumar *et al.,* 2015):

Production efficiency (PE) = Total economic yield (kg/ha)/Duration of the crop

Monetary efficiency = Total net returns (AFN/ha)/Duration of the crop

The profile water contribution (CS) was not taken into consideration in current study. Thus, the effective rainfall and irrigational water use was considered as the seasonal total water use (Et) in the present study by taking into account the respective crop-growth period by following the procedure:

Water-use efficiency (WUE) = Yield/Et

where, Y is the economic yield (grain yield, kg/ha) and Et refers to total amount of seasonal water used in ha-mm respectively.

Productivity and production efficiency of greengram were significantly affected by different treatments. Significantly higher grain yield, biological yield and production efficiency were recorded under line sowing as compared to broadcast method. Harvest index did not show any significant variation between line sowing and broadcast methods. Among the phosphorus levels, there was a consistent and significant increase in grain and biological yield and production efficiency of greengram up to 60 kg P_2O_5/ha with the highest grain yield, biological yield and production efficiency. Further increase in phosphorus level to 90 kg P_2O_5/ha led to a non-significant decline in grain and biological yield, while production efficiency showed a signicant decline (Table 1). Harvest index was significantly influenced by different phosphorus levels. Yields increased only up to 30 kg P_2O_5/ha (Table 1). Interaction effect of sowing methods and phosphorus levels was found to be non-significant. This variation in grain and biological yield, harvest index and production efficiency due to methods of sowing may be attributed to better crop ecology and efficient use of resources (sunlight, space, water, nutrients and ambient CO_2 concentration) under line sowing over broadcast method (Choudhary and Suri, 2014; Pooniya *et al*., 2015; Noorzai *et al*., 2017). Increase in phosphorus levels right from 0 to 60 kg P_2O_5/ha also led to higher grain and biological yield and production efficiency which may be possible due to maximization of photosynthesis, respiration, energy storage and transfer, cell division and cell elongation with sufficient phosphorus nutrition which led to enhanced yield and production efficiency (Kumar *et al*., 2015; Noorzai *et al.,* 2017). Decrease in grain and biological yield and production efficiency of greengram at 90 kg P_2O_5/ha as compared to 60 kg P_2O_5/ha may be attributed to the role of higher phos-

Table 1. Effect of sowing methods and phosphorus levels on productivity, production efficiency, water-use efficiency and economics of green gram

Treatment	Yield (t/ha)		Harvest index (%)	Production efficiency (kg/ha/day)	Water-use efficiency (kg/ha/mm)	Economics			Monetary efficiency (AFN/ha/ day)
	Grain Yield	Biological yield				Cost of cultivation (× 10^3 AFN/ha)	Net returns (× 10^3 AFN/ha)	Benefit: cost ratio	
Sowing methods									
Broadcast sowing	1.18	3.97	29.6	13.6	6.6	20.5	70.8	3.44	813
Line sowing	1.28	4.23	30.0	14.8	7.1	20.5	78.2	3.81	899
SEm±	0.025	0.043	0.6	0.3	0.1	-	1.63	0.06	18
CD (P=0.05)	0.076	0.130	NS	0.9	0.4	-	4.95	0.19	56
Phosphorus (kg P_2O_5/ha)									
0	0.88	3.39	26.0	10.1	4.9	18.5	51.4	2.77	592
30	1.31	4.14	31.6	15.0	7.3	19.8	80.1	4.03	920
60	1.42	4.56	31.1	16.5	8.0	21.1	88.5	4.17	1,017
90	1.32	4.35	30.4	15.0	7.3	22.4	77.9	3.46	895
SEm±	0.036	0.060	0.8	0.4	0.2	-	2.30	0.08	26
CD (P=0.05)	0.108	0.183	2.4	1.2	0.6	-	7.00	0.24	80

phorus in inducing Fe and Zn deficiency in general which might have adversely affected the growth and development and finally yield attributes and yield of greengram.

During the crop-growth period, 3 irrigations (each of 60 mm) were applied to the crop with no rainfall received during the rainy season of 2015. Thus, the seasonal water use was 180 mm in the greengram crop under different treatments. Sowing methods showed significant differences for water-use efficiency with the highest value under line sowing. Among phosphorus levels, there was again a consistent and significant increase in WUE up to 60 kg P_2O_5/ha with the highest WUE under 60 kg P_2O_5/ha, thereafter, further increase in P application to 90 kg P_2O_5/ha led to a significant decline in WUE (Table 1). This may be due to adverse impact of excess phosphorus application on the growth and development of plant (Bairwa *et al*., 2012). The WUE is dened as the crop yield/unit of crop water use and is the outcome of an entire suite of plant and environmental processes operating over the crop duration. Thus, WUE in greengram both under sowing methods and phosphorus levels followed the same trend as that of grain and biological yield (Table 1). The irrigation water used and precipitation did not differ among different treatments; however, ability of the plants under respective treatments to efficiently utilize the applied water and profile water due to better root-system might have led to significant variation in WUE in greengram in present investigation (Kumar *et al.*, 2016; Noorzai *et al*., 2017).

Gross and net returns, benefit: cost ratio and monetary efficiency were also significantly influenced by different sowing methods and phosphorus levels. Significantly higher gross and net returns, benefit: cost ratio and monetary efficiency were recorded under line sowing over broadcast method (Table 1). Line sowing exhibited crop yield and profitability which may be ascribed to better growth and development of greengram under line sowing as a result of efficient use of resources like sunlight, space, water, nutrients and ambient CO_2 concentration (Choudhary and Suri, 2014; Pooniya *et al*., 2015; Rajpoot *et al.,* 2016a,b; Noorzai *et al*., 2017). Gross and net returns, benefit: cost ratio and monetary-efficiency increased with the successive increase in phosphorus levels up to 60 kg P_2O_5/ha (Table 1). This may be owing to favourable effect of phosphorus application on the growth and development and yield of the crop (Kumar *et al*., 2015, 2016).

It is inferred that line sowing of greengram at 45 cm × 5 cm spacing and phosphorus application @ 60 kg P_2O_5/ha were found better treatments for higher yield, profitability, production efficiency, monetary efficiency and water-use efficiency. Line sowing and 60 kg P_2O_5/ha may be recommended to enhance productivity, profitability and resource-use efficiency of rainy season greengram under semi-arid conditions of Afghanistan.

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Research Communication

Productivity, profitability and quality of soybean (*Glycine max*) as influenced by sowing date and row spacing under mid-hill conditions of Himachal Pradesh

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ABSTRACT

A field experiment was conducted at Palampur, Himachal Pradesh during the rainy (*kharif*) season of 2015 on acidic silty clay loam soil, to find out the optimum sowing date and row spacing for newly developed genotypes of soybean [*Glycine max* (L.) Merr.]. The experiment was laid out in factorial randomized block design with the treatments comprising of 2 genotypes ('HIMSO 1685' and 'Harasoya'), 3 dates of sowing (last week of May, first week and second week of June) and 2 inter-row spacings (45 cm and 60 cm). The new genotype, 'HIMSO 1685', proved superior over 'Harasoya'. Significantly higher number of primary branches/plant, seeds/pod and protein and oil content were recorded in the crop sown during last week of May followed by first week of June. The highest pods/plant (85.4), seed index (208 g), seed yield (2.4 t/ha), straw yield (9.3 t/ha), net returns (₹58,108/ha) and benefit: cost ratio (1.17) were noted in the crop sown during last week of May. Inter-row spacing of 45 cm resulted in the highest seed index (202 g), seed yield (2.1 t/ha), straw yield (8.3 t/ha) and net returns (₹45,281/ha), and benefit: cost ratio (0.91). Sowing of soybean in the last week of May at 45 cm inter-row spacing were found to be the optimum agronomic practices for obtaining higher productivity and profitability, and better quality of 'HIMSO 1685' under mid-hill conditions of Himachal Pradesh.

Key words **:** Genotype, Inter-row spacing, Oil content, Productivity, Profitability, Protein content, Sowing time, Soybean

In India, soybean is cultivated over an area of 10.8 mha having total production of 10.4 mt with an average yield of 959 kg/ha (Anonymous, 2014). Sowing date plays a significant role in determining growth, development and yield of soybean. Crop sown at optimum time increases the yield due to suitable environment at all the growth stages. Optimal sowing dates vary with variety, cropping system, and environmental conditions. Sowing prior to or later than the optimal sowing time can greatly reduce soybean yield and quality, since photoperiodism controls not only the number of days to flowering, but also the amount of time available for vegetative plant growth and development (Berger *et al.,* 2014). Row spacing is considered to be the foremost step to achieve proper and uniform distribution of plants over cultivated area thereby better availability of above and below ground resources towards increasing seed yield and decreasing competition among plants. It influences crop yield through its influence on light interception, rooting pattern, nutrient extraction and moisture extraction pattern etc. In addition to greater light interception and yield, narrow row spacing promotes rapid canopy closure, which can effectively reduce weed seedling growth, compared with wider-row spacing (Board *et al.,* 1996). Considering the above said facts, the present investigation was undertaken to find out the optimum date of sowing and row spacing for obtaining higher productivity and profitability, and better quality of soybean.

The field experiment was conducted during the rainy (*kharif)* season of 2015 at the Research Farm, Department of Agronomy, Forages and Grassland Management, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The soil of the experimental site was silty clay loam with *p*H 5.4, EC 0.224 dS/m, organic carbon 0.54%, available nitrogen 125.4 kg/ha, available phosphorus 14.2 kg/ha and available potassium 159 kg/ha. The weekly maximum and minimum temperature ranged from 13.1°C to 32.4°C and 3.5°C to 21.9°C, re-

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spectively. The mean relative humidity ranged from 52.4% to 94.1% and total of 2569.5 mm rainfall received during the crop season. The mean bright sunshine hours were 1870 during the whole of the crop season. The experiment was laid out in factorial randomized block design comprising of 2 genotypes of soybean ('HIMSO 1685' and 'Harasoya'), 3 dates of sowing (last week of May, first week and second week of June) and 2 row spacings (45 cm and 60 cm). Each treatment was allocated randomly and replicated thrice. Treated seeds with bavistin were applied at the rate of 100 kg/ha. Recommended dose of nitrogen, phosphorus and potassium was applied at the rate of 20 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha, respectively at the time of sowing. Pendimethalin (STOMP 30 EC) was applied at the rate of 1.5 l a.i/ha within 48 hours of sowing for the control of weeds. Other package of practices recommended for the region was also followed.

The new genotype, 'HIMSO 1685', resulted in significantly better yield attributes except seeds/pod, which was better in 'Harasoya' (Table 1). Crop sown during last week of May followed by first week of June produced significantly higher primary branches/plant and seeds/pod than the crop sown during second week of June. The highest number of pods/plant and seed index was recorded in the crop sown during last week of May (Table 1). This might be due to more favourable and sufficient growing period for vegetative and reproductive stages resulting in better yield attributes in early sowing. These results are supported by Yagoub and Hamed (2013) and Asewar *et al.* (2015). Row spacing did not influence primary branches/plant, pods/plant and seeds/pod. Inter-row spacing of 45 cm resulted in the highest seed index.

'HIMSO 1685' resulted in significantly higher seed and straw yields than 'Harasoya'. The highest seed yield was recorded in the crop sown during last week of May (Table 1). This is due to the reason that for these plants there was more time for plant growth in suitable temperature and moisture, so seed yield increasing is rational. With delayed planting the growth period becomes short, while high temperature during flowering decreases the seed yield and yield components. Early sown soybean resulted in higher seed yield (Berger *et al.,* 2014). Inter-row spacing of 45 cm yielded significantly higher seed yield. This might be due to more number of plants in closure row spacing and more light interception. Straw yield also followed the similar trend like seed yield. Harvest index remained unaffected.

The highest oil content was also recorded in 'HIMSO 1685'. Significantly higher oil content was noted in the crop sown during last week of May followed by first week of June (Table 1). This may be due to longer growth period and favourable growth conditions. Protein content was not affected by different genotypes. Significantly higher protein content was noted in the crop sown during last week of May followed by first week of June. This result proves that delayed sowing reduces yield and protein content be-

Table 1. Effect of genotype, date of sowing and row spacing on yield attributes, yield, harvest index, quality, gross returns, net returns and benefit: cost ratio of soybean

Treatment	Yield attributes			Seed index (g)	Yield		Harvest index (%)	Quality		Gross returns (× 10³₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio
	Primary branches/ plant	Pods/ plant	Seeds/ pod		Seed yield (t/ha)	Straw yield (t/ha)		Oil content (%)	Protein content (%)			
Genotype												
'HIMSO 1685'	13.2	84.6	2.54	224	2.1	8.4	19.8	23.3	39.6	75.4	29.4	0.59
'Harasoya'	11.7	52.9	2.78	168	1.7	6.8	20.8	18.3	39.2	93.1	47.9	0.97
SEm±	0.32	3.8	0.06	1.1	0.04	0.3	0.71	0.04	0.20	1.6	1.8	0.04
CD (P =0.05)	0.90	11.3	0.19	3.1	0.12	0.8	NS	0.13	NS	4.7	5.3	0.11
Date of sowing												
Last week of May	13.2	85.4	2.75	208	2.4	9.3	20.6	21.3	39.8	104.4	58.1	1.17
First week of June	13.1	66.9	2.75	200	2.1	7.9	21.3	21.1	39.7	90.3	45.1	0.91
Second week of June	11.1	53.9	2.48	181	1.3	5.7	19.0	20.0	38.8	58.0	12.8	0.26
SEm±	0.38	4.7	0.08	1.30	0.05	0.4	0.87	0.16	0.25	2.0	2.0	0.04
CD (P=0.05)	1.10	13.8	0.23	3.82	0.14	1.0	NS	0.53	0.73	5.8	6.5	0.13
Row spacing												
45 cm	12.5	71.5	2.68	202	2.1	8.3	19.7	20.83	39.5	91.2	45.3	0.91
60 cm	12.4	66.0	2.64	190	1.8	6.9	20.9	20.74	39.3	77.2	32.1	0.65
SEm±	0.32	3.8	0.06	1.1	0.04	0.3	0.71	0.04	0.20	1.6	1.8	0.04
CD (P=0.05)	NS	NS	NS	3.1	0.12	0.8	NS	NS	0.59	4.7	5.3	0.11

cause of lower growth period. In earlier study, Zarger *et al.* (2011) reported that delayed sowing reduced yield and protein content of soybean. Significantly similar oil and protein content was recorded at different inter-row spacings.

The maximum gross returns, net returns and benefit: cost ratio were recorded in 'HIMSO 1685'. The highest gross returns, net returns and benefit: cost ratio was noted in the crop sown during last week of May (Table 1). This might be due to sufficient period for vegetative and reproductive growth of plants, which resulted in higher yield during early sowing. Tomar *et al.* (2014) reported that the early sown soybean crop gave higher gross returns and net returns. The maximum gross returns, net returns and benefit: cost ratio were noted at closure inter-row spacing of 45 cm. The highest gross and net returns and benefit: cost ratio were recorded with closure row spacing (Vyas and Khandwe, 2014).

On the basis of findings, it was concluded that 'HIMSO 1685' proved to be superior over 'Harasoya'. Last week of May and 45 cm inter-row spacing were found to be the best agronomic practices for obtaining higher productivity and profitability and better quality of soybean under mid-hill conditions of Himachal Pradesh.

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Research Communication

Variability in Indian mustard (*Brassica juncea*) genotypes in response to applied phosphorus

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ABSTRACT

A field study was conducted during the winter season (*rabi*) 2012–13 at Ludhiana, Punjab, to identify the phosphorus-efficient genotypes of Indian mustard [*Brassica juncea* (L.) *Czernj. & Cosson*]. Application of 15 kg/ha of P_2O_5 increased the seed yield by 6.8% and stover yield by 8.5% over the control, whereas the increase with 30 kg/ha of P_2O_5 over 15 kg/ha of P_2O_5 was non-significant. The increase in oil content and P uptake at maturity with successive dose of phosphorus was also significant. Among genotypes, 'NRCHB 101' with the highest seed (1.91 t/ha) and stover (7.29 t/ha) yields outyielded all the other tested genotypes by significant margin of 6.7–30.8% for seed yield and 9.0–30.9% for stover yield. Genotype 'NRCDR 2' registered significantly higher oil content (40.2%), while 'NRCHB 101' registered significantly higher total phosphorus uptake at maturity (21.52 kg/ha). Interactions between doses of phosphorus and genotypes for all the parameters were found non-significant.

Key words: Genotypes, Indian mustard, Oil content, Phosphorus uptake, Yield

Indian mustard with a share of about 80% in area and production in the country is the most important *Brassica* species among different rapeseed-mustard crops. Rapeseed–mustard group of crops have relatively high phosphorus(P) requirement. Phosphorus deficiency in crop fields has been observed worldwide (Vance *et al.,* 2003) including India (Muralidharudu *et al*., 2011). Low temperature during the winter season and inadequate moisture under conserved moisture or limited irrigation conditions in the semi-arid region of the country reduce solubilization of fixed forms of P and its uptake by the plants. High P fixation and low P uptake rate make it imperative to evaluate P-efficient germplasm for developing P-efficient cultivars (Fageria *et al.,* 2008) so as to reduce P fertilizer requirements and sustain productivity on low P soils. Genetic improvement of P-nutrition traits in crops is considered to be more economical and sustainable than application of P fertilizers. The aim of the present investigation was to study the variability in Indian mustard genotypes of different genetic background for growth, yield attributes, yields and use efficiency in response to phosphorus application rates so as to identify the P-efficient genotypes.

The field experiment was conducted at the research farm of Oilseeds Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana during the winter (*rabi*) 2012–13. The soil was loamy sand, free from salts (EC 0.10 dS/m), neutral in reaction (*p*H 7.8) with low organic carbon content (0.37%), low in available nitrogen (245 kg/ha), low in Olsen's available phosphorus (11.7 kg/ha) and rich in NH_4OAc-extractable potassium (165 kg/ha) in the 0–15 cm soil depth. Treatments comprising 3 doses of phosphorus (0, 15 and 30 kg P_2O_5/ha) in the mainplots and 14 genotypes of Indian mustard ('RLC 1', 'PBR 210', 'PBR 91', 'RLM 619', 'RL 1359', 'PBR 357', 'ELM 123', 'NRCDR 2', 'NRCHB 101', 'Pusa Bold', 'Varuna', 'MLM 19', 'NPJ 79', and 'PLM 2') in the subplots were replicated thrice. The gross and net plot size were 18.0 m^2 (3.0 m × 6.0 m) and 9.0 m^2 (1.8 m × 5.0 m) respectively. The test genotypes were sown on 5 November 2012 and harvested on 8 April 2013.

Phosphorus as per treatments was applied through single superphosphate at the time of sowing. Nitrogen @ 50 kg/ha as urea and potassium @ 15 kg/ha as muriate of potash were also applied at sowing. Another dose of 50

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kg/ha of N as urea was top-dressed after the first irrigation. The row spacing was kept as 30 cm and plant-to-plant spacing of 12–15 cm was maintained at 3 weeks after sowing. Data were recorded on plant height from 10 random plants, branching and number of siliquae/ plant from 5 random plants at physiological maturity, number of seeds/ siliqua from 25 random selected siliquae/plant, 1,000-seed weight from a representative sample of seeds after threshing. The biomass, seed and stover yields from 6 inner rows were recorded. For dry-matter accumulation, plants were cut at the base in the 0.5 m row length from second outermost row in each plot, were dried first under shade and later in oven at 65 ± 2^{c}C till constant weight. Phosphorus content in seed and stover was determined by Vanado-molybdo-phosphoric yellow colour method. The uptake of phosphorus by seed and stover at harvesting was worked out by multiplying per cent phosphorus content in seed and stover with respective yields.

Application of 15 kg/ha of P_2O_5 resulted in significant increase (9.3%) in DMA over without its application, whereas application of 30 kg/ha of P_2O_5 significantly increased the plant height (2.0%) and DMA (4.9%) over 15 kg/ha of P_2O_5 (Table 1). Number of siliquae/plant, seeds/ siliqua and seed weight are the major yield-forming traits in rapeseed–mustard. Phosphorus application up to 30 kg/ ha of P_2O_5 increased the total number of siliquae/plant by 8.2% and 16.3% over application of 15 kg/ha of P_2O_5 and without its application respectively. Application of 15 kg/ ha of P_2O_5 increased number of seeds/siliqua by 5.7% and 1,000-seed weight by 1.7% over the control, whereas application 30 kg/ha of P_2O_5 increased seeds/siliqua by 4.5% and 1,000-seed weight by 6.7%t over 15 kg/ha of P_2O_5.

Application of 30 kg/ha of P_2O_5 increased the seed yield (1.77 t/ha) by 9.9% and 2.9% and stover yield (6.58 t/ha) by 15.2% and 4.9% over the control and 15 kg/ha of P_2O_5, respectively, whereas application of 15 kg/ha of P_2O_5 significantly increased the seed yield (1.72 t/ha) by 6.8% and stover yield (6.27 t/ha) by 8.5% over the control. Higher seed and stover yields with successive higher doses of phosphorus could be attributed to the improvement in vegetative growth (height and DMA) and yield-forming traits (siliquae/plant, seeds/siliqua and 1,000-seed weight). Similar positive and significant relationships have been reported between seed yield with DMA (Mir *et al.*,

Table 1. Growth, yield attributes, yields, oil content, phosphorus uptake, agronomic efficiency and physiological efficiency of Indian mustard as influenced by doses of phosphorus and genotypes

Treatment	Plant height (cm) at maturity	Dry-matter (t/ha) at maturity	Primary branches	Siliquae/ plant	Seeds/ siliqua	1,000-seed weight (g)	Seed yield (t/ha)	Stover yield (t/ha)	Oil (%)	Total phosphorus uptake (kg/ha)	AE (kg seed/ kg P_2O_5)	PE (kg seed/ kg P uptake)
Phosphorus (kg P_2O_5/ha)												
0	162.9	7.26	4.2	214	10.6	4.61	1.61	5.71	38.9	13.1	-	-
15	165.5	7.93	4.4	230	11.2	4.69	1.72	6.27	39.1	16.9	7.7	80
30	168.8	8.32	4.7	249	11.7	4.92	1.77	6.58	39.3	19.4	5.3	72
SEm±	1.09	0.14	-	5.04	0.04	0.06	0.02	0.12	0.04	0.52	-	-
CD (P=0.05)	2.8	0.38	NS	14	0.1	0.17	0.07	0.34	0.1	1.45	-	-
Genotypes												
'RLC 1'	167.8	7.53	4.0	240	11.1	4.55	1.73	6.08	37.7	18.1	5.0	59
'PBR 210'	166.0	8.23	4.7	221	11.4	4.57	1.77	6.46	39.1	15.9	8.6	76
'PBR 91'	168.3	7.23	4.6	240	11.3	4.84	1.66	5.57	39.7	15.3	9.3	82
'RLM 619'	161.8	7.97	4.0	245	10.7	4.70	1.74	6.23	39.6	17.7	6.6	67
'RL 1359'	160.1	7.88	4.1	217	10.7	4.72	1.74	6.14	39.6	15.9	4.7	60
'PBR 357'	165.6	8.11	4.6	211	10.4	5.56	1.72	6.39	39.1	15.9	7.3	73
'ELM 123'	162.2	7.29	4.4	249	11.1	4.17	1.69	5.59	37.5	15.7	6.2	65
'NRCDR 2'	168.4	7.59	4.7	207	11.0	5.08	1.65	6.04	40.2	16.5	6.2	93
'NRCHB 101'	166.6	9.19	4.8	252	12.8	4.62	1.91	7.29	39.6	21.5	5.3	61
'Pusa Bold'	162.4	7.77	4.4	236	10.4	5.61	1.79	5.99	39.5	17.4	9.4	96
'Varuna'	160.2	7.06	4.7	251	11.6	5.36	1.66	5.68	39.2	15.4	9.3	75
'MLM 19'	168.7	7.59	4.5	221	10.8	4.52	1.53	6.06	38.5	13.9	5.2	95
'NPJ 79'	170.4	7.86	4.0	217	12.3	3.85	1.46	6.40	39.6	14.7	5.0	70
'PLM 2'	171.6	8.40	4.6	233	10.8	4.25	1.71	6.69	39.0	17.1	3.5	95
SEm±	1.85	0.31	0.25	15.5	0.15	0.13	0.05	0.28	0.20	0.56	-	-
CD (P=0.05)	3.70	0.61	0.50	31	0.30	0.27	0.11	0.56	0.40	1.55	-	-

AE, Agronomic efficiency (kg seed/kg P_2O_5); PE, physiological efficiency (kg seed/kg P uptake)

2010), siliquae/plant, seeds/siliqua (Mir *et al.,* 2010) and 1,000-seed weight (Kumar and Yadav, 2007).

The oil content increased consistently and significantly with each increasing dose of phosphorus up to 30 kg/ha of P_2O_5. Apart from direct role of phosphorus in synthesis of phospholipids, higher dose of phosphorus also supplied more amount of sulphur which is involved in oil synthesis, from single superphosphate used as source of P. Application of 30 kg/ha of P_2O_5 resulted in significantly higher (14.2%) total (seed + stover) P uptake than that of 15 kg/ha of P_2O_5 which in turn resulted in significantly higher total P uptake (28.9%) than the control (13.18 kg/ha). Reddy and Sinha (1988) reported significant increase in phosphorus uptake in Indian mustard up to 30 kg/ha of P_2O_5.

Agronomic efficiency (increase in seed yield (kg/ha) per unit of applied phosphorus) and physiological efficiency (increase in seed yield/unit increase in phosphorus uptake with P application in comparison to without application of phosphorus) with application of 15 kg/ha of P_2O_5 were higher than 30 kg/ha of P_2O_5. At lower dose of phosphorus application, its amount available to plants was low and there might have been more competition between plants in comparison to higher dose where due to sufficiency of the nutrient, its utilization decreased.

Genotypes 'PLM 2', 'NPJ 79', 'MLM 19', 'NRCDR 2' and 'PBR 91' attained statistically similar (168.3–171.6 cm) and significantly more plant height than 'RL 1359', 'Pusa Bold', 'RLM 619', 'ELM 123' and 'Varuna' (160.1 cm–162.4 cm). The DMA by 'NRCHB 101' (9.19 t/ha) was significantly higher than all other test genotypes (7.06–7.59 t/ha). Genotype NRCHB 101 also produced the highest (4.8) and significantly more primary branches/plant than 'RLC 1', 'RLM 619', 'RL 1359' and 'NPJ 79'. Genotype 'NRCHB 101' also produced significantly more siliquae/plant (252) than 'PBR 357', 'NRCDR 2', 'RL 1359' and 'NPJ 79'. Genotype 'NRCDR 2' (207) produced significantly lower siliquae/plant than 'RLC 1', 'PBR 91', 'RLM 619', 'ELM 123', 'Varuna' and 'NRCHB 101'. Seeds/siliqua produced by 'NRCHB 101' (12.8) were also significantly higher than rest of the test genotypes. Pusa Bold produced the highest 1,000-seed weight (5.61 g) which was at par with 'PBR 357' (5.56 g) and 'Varuna' (5.36 g) and significantly higher than rest of genotypes, whereas 'NPJ 79' (3.85 g) produced significantly lower 1,000-seed weight than all the test genotypes. Significant variations in cultivars of Indian mustard were reported by Rana and Pachauri (2001) for number of siliquae, number of seeds/siliqua and 1,000-seed weight, by Gurjar and Chauhan (1997) for number of branches/plant and number of seeds/siliqua, and by Singh *et al.* (2002) for 1,000-seed weight.

Genotype 'NRCHB 101' gave the highest seed yield (1.91 t/ha) and stover yield (7.29 t/ha) and significantly outyielded all the other tested genotypes by margin of 6.7%–30.8% for seed yield and 9.0%–30.9% for stover yield. Genotype 'NPJ 79' gave the lowest seed yield (1.46 t/ha) and 'PBR 91' (5.57 t/ha) the lowest stover yield. The highest seed yield given by 'NRCHB 101' may be ascribed to its highest dry-matter, siliquae/plant and seeds/siliqua. Rana and Pachauri, (2001); Kumar and Yadav, (2007) reported similar differences among Indian mustard cultivars for seed and stover yields Interactions between doses of phosphorus and genotypes for different growth and yield attributes, seed and stover yields were non-significant.

Genotype 'NRCDR 2' registered significantly higher oil content (40.2%) than the remaining genotypes. Genotype 'NRCHB 101' exhibited significantly higher total (seed + straw) phosphorus uptake (21.52 kg/ha) than rest of the genotypes. Such an increase in phosphorus uptake in 'NRCHB 101' ranged from 3.4 kg/ha over 'RLC 1' to 7.62 kg/ha over 'MLM 19'. Observed differences in P uptake were mainly due to similar differences in yields of different genotypes. Genotype 'NRCHB 101' also attained highest P content in seed (0.67%) and stover (0.12%). 'Pusa Bold' Indian mustard attained the highest agronomic efficiency (9.4) closely followed by 'Varuna' and 'PBR 91' (9.3) genotypes and, physiological efficiency (96) followed by 'MLM 19' and 'PLM 2' (95). These differences may be due to genotypic differences in P utilization and exudation of organic acids in rhizosphere which facilitate solubilization of fixed forms of P (Zhang *et al.,* 2009).

Thus application of P_2O_5 up to 30 kg/ha significantly increased the DMA at maturity, number of siliquae/plant, seeds/siliqua and 1,000-seed weight. Seed and stover yields though increased up to 30 kg/ha of P_2O_5 but significantly up to 15 kg/ha of P_2O_5. Among the genotypes, 'NRCHB 101' with the highest seed yield (1.91 t/ha), stover (7.29 t/ha) yield and total P uptake (21.52 kg/ha) outyielded all the other tested genotypes by significant margin for seed yield (6.7-30.8%), stover yield (9.0–30.9%) and total P uptake (18.8–46.1%) due to highest dry DMA at maturity, primary branches/plant, number of siliquae/plant and seeds/siliqua. Seed yield given by 'NPJ 79' (1.46 t/ha) was significantly lower than rest of the genotypes except 'MLM 19' (1.53 t/ha). Cultivar 'PBR 91' (5.57 t/ha) produced the lowest stover yield. Genotype 'NRCDR 2' registered significantly higher oil content (40.2%) than the remaining genotypes of Indian mustard.

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Research Communication

Effect of nutrient levels on yield, nutrient uptake and economics of Indian mustard (*Brassica juncea*) in *tarai* region of Uttarakhand

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ABSTRACT

A field experiment was conducted during winter (*rabi*) season 2014–15 at the N.E. Borlaug Crop Research Centre of the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar to study the effect of nutrient levels on yield, nutrient uptake and economics of Indian mustard [*Brassica juncea* (L.) Czernj and Cosson] cultivar 'RGN 73' in *tarai* region of Uttarakhand. Treatment consisted of 3 levels of nitrogen (60, 80 and 100 kg/ha), 2 levels of phosphorus (20 and 40 kg/ha) and 2 levels of potassium (0 and 30 kg/ha), which were evaluated thrice in a randomized block design. The highest seed yield (1.93 t/ha), nutrient (N : P_2O_5 : K) uptake (99 kg N, 42 P_2O_5 and 172 kg K_2O/ha), net returns (37.13 × 10^3 ₹/ha), gross returns (60.45 × 10^3₹/ha) and benefit: cost ratio (1.54) were recorded with application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha followed by 100 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha and 100 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha treatments.

Key words : Economics, Indian mustard, Nutrient management, Nutrient uptake, Yield

The requirement of vegetable oils and fats will be much higher in coming years in view of ever increasing population. India would need 58 million tonnes of oilseeds by 2020 for maintaining minimum edible oil requirement (Mittal, 2008). To produce an additional quantity of oilseeds, the only option is to enhance productivity under the limited land resource condition. Among the oilseed crops, rapeseed and mustard occupy rank next to soybean in acreage and production. The inadequate supply of inputs often leads to limit the yield potential of rapeseed and mustard (DACNET, 2014). Identification of the critical inputs to enhance the mustard production is the need of hour. Apart from improved varieties and irrigation, balanced fertilization is critical for realizing higher seed yield. Indian soils are becoming highly deficient in macronutrients [low nitrogen (N), medium in phosphorus (P) and medium/high in potassium (K) and low in sulphur (S)] and micronutrients due to intensive cultivation and use of high analysis fertilizers. The rapeseed-mustard requires relatively large amount of these nutrients for realization of yield potential, but inadequate supply often leads to low productivity. Under such situation, balanced fertilizers can be exploited to boost the production and also to improve nutrient uptake. However, the use of inadequate amount of nutrients has some limitations. Judicious use of chemical fertilizers facilitates profitable and sustainable production (Singh and Sinsinwar, 2006).

A field experiment was conducted during winter (*rabi*) season of 2014–15 at the N.E. Borlaug Crop Research Centre of the G.B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, situated at 29°N latitude, 79.3°E longitude and at an altitude of 243.24 meters. The soil of experimental field was silty clay loam having *p*H 7.76, electrical conductivity 0.24 dS/m, medium in organic carbon (0.71%) and low in available nitrogen (203 kg/ha), medium in available phosphorus (18 kg/ha) and medium in available potassium (283 kg/ha). The experiment comprised of 12 treatments, viz. T_1, 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha; T_2, 60 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha; T_3, 60 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha; T_4, 60 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha; T_5, 80 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha; T_6, 80 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha; T_7, 80 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha; T_8, 80 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha; T_9, 100 kg N + 20 kg P_2O_5 + 0 kg

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K_2O/ha; T_{10}, 100 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha; T_{11}, 100 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha; and T_{12}, 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha with 3 replications were tested under randomized block design. The fertilizer nutrients were supplied through urea, single superphosphate and muriate of potash. Full dose of phosphorus, potassium and half of nitrogen (as per treatment) were applied at sowing. Remaining half of nitrogen was applied after first irrigation. Mustard cultivar 'RGN-73' was sown in rows 30 cm apart on October 22, with a seed rate of 5 kg/ha. Pre-sowing irrigation was applied for land preparation and germination of seed. Thinning was done 10–15 days after sowing to maintain plant to plant distance of 10 cm.

The crop was harvested in March during crop season. The processed plant samples were analyzed by Micro Kjeldahl method (Jackson, 1973) to determine nitrogen content and wet digestion (di-acid) method (Jackson, 1973) was used for preparation of aliquot to determine P and K content in plant samples. The crop was raised with recommended package of practices.

Data revealed that the yield attributes of Indian mustard were affected significantly due to different fertility levels (Table 1). At harvest stage significantly highest number (8.4) of primary branches was observed under the application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment which was at par with 100 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha treatment but was significantly higher over rest of the fertility levels. However, lowest number (5.1) of primary branches was found in 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatment which was at par with 60 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha, 60 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha, 60 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha and 80 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatments but significantly lower than remaining treatments. Higher number (9.3) of secondary branches was recorded with the application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment, which was at par with 100 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha, 100 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha and 100 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatments. However, the lowest number (6.5) of secondary branches was recorded in 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatment which was at par with 60 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha, 60 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha, 60 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha and 80 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatments but significantly lowest than other treatments. Application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha recorded significantly higher values for number of siliquae/plant (256.6), length of siliqua (4 cm), number of seeds/siliqua (13.8) and 1,000-seed weight (3.9 g) over application of 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha, (Table 1). This may be ascribed to overall improvements in vigour and crop growth. Since all essential plant nutrients, its incorporation in soil promotes rapid vegetative growth and branching, thereby increasing the sink size in terms of flowering, fruiting and seed setting. The improved overall growth and profused branching owing to 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha application coupled with transport of photosynthates towards reproductive structures on the other hand, might have increased the yield attributes (Singh and Pal, 2011). The higher values of yield attributes is the result of higher nutrient availability resulted in better growth and more translocation of photosynthates from source to sink (Tripathi *et al*., 2010).

Data revealed that the seed and stover yields of Indian mustard were affected significantly due to different fertility levels (Table 2). Higher seed yield (1.925 t/ha) was

Table 1. Yield attributes as influenced by different nutrient levels at harvest

Treatment	Primary branches/plant	Secondary branches/plant	Siliquae/ plant	Seeds/ siliqua	Length of siliqua (cm)	1,000-seed weight (g)
$N:P_2O_5:K_2O$ (kg/ha)						
T_1 (60:20:0)	5.1	6.5	205	9.9	2.9	3.1
T_2 (60:20:30)	5.9	6.8	207	10.8	3.2	3.1
T_3 (60:40:0)	6.0	6.8	213	11.2	3.3	3.2
T_4 (60:40:30)	6.0	6.9	214	11.3	3.3	3.3
T_5 (80:20:0)	6.0	7.5	215	11.7	3.3	3.4
T_6 (80:20:30)	6.6	7.7	217	11.7	3.4	3.5
T_7 (80:40:0)	6.6	7.8	229	12.3	3.4	3.6
T_8 (80:40:30)	6.7	8.3	232	12.3	3.5	3.6
T_9 (100:20:0)	7.0	8.4	235	12.4	3.6	3.7
T_{10} (100:20:30)	7.1	8.6	238	13.0	3.7	3.7
T_{11} (100:40:0)	7.6	8.6	241	13.1	3.7	3.7
T_{12} (100:40:30)	8.4	9.3	256	13.8	4.0	3.9
SEm±	0.36	0.45	9.8	0.6	0.1	0.1
CD (P=0.05)	1.07	1.34	28.9	1.8	0.4	0.4

recorded with application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment. The lowest seed yield (1.069 t/ha) was recorded with 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatment. The treatment T_{12} which was at par with T_{10} and T_{11} produced significantly higher seed yield over remaining fertility levels. As seed yield is the resultant outcome of the effect of various growth and yield parameters, its expression was observed with their integrated influence. Balanced supply of essential nutrients to Indian mustard increased their availability, acquisition, mobilization and influx into the plant tissues increased and finally improved growth attributes and yield components and finally the yield. These results are in agreement with the findings of Singh and Sinsinwar (2006). Among the different treatments higher stover yield (7.638 t/ha) was recorded with the application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment which was statistically at par with all the treatments except 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha and 60 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha treatments. However, the lowest stover yield (6.916 t/ha) was recorded under 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatments which was statistically at par with 60 kg N + 20 kg P_2O_5 + 30 kg K_2O/ha, 60 kg N + 40 kg P_2O_5 + 0 kg K_2O/ha, 60 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha and 80 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatments but significantly lower than remaining treatments. The increase in stover yield under adequate nutrient supply might be ascribed, mainly due to balanced nutrition and increased photosynthesis, dry matter accumulation. These results are in conformity with those of Akter *et al.* (2007) and Singh and Pal (2011).

The cost of cultivation was the lowest 21.5×10³₹/ha with application of 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatment, whereas, it was the highest 24.1×10³₹/ha with application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment. Highest net returns (37.1×10³₹/ha) and benefit: cost ratio (1.54) was noted with 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment (Table 2). This was due to higher productivity with this treatment. The lowest net returns (12.9×10³₹/ha) was noted with 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatment and also the lowest benefit: cost ratio (0.60).

Nutrient uptake by crop varied significantly due to different fertility levels (Table 2). The highest nutrient uptake 99 kg N, 42 kg P_2O_5 and 172 kg K_2O/ha, respectively by mustard was noted with the application of 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha treatment that could be ascribed to balanced nutrition to crop that has increased biomass production and nutrients uptake. Similar results were reported by Mandel and Sinha (2002). Nutrient uptake is a numerical product of nutrient content and dry matter accumulation which was significantly low, under 60 kg N + 20 kg P_2O_5 + 0 kg K_2O/ha treatment than other treatments. Higher nutrient uptake might be attributed to more proliferation of root system and higher dry matter accumulation by individual plant which in turn yielded higher in comparison to other treatments. The increase in nutrient uptake was mainly due to better nutrition, which resulted in better growth and yield and ultimately in higher uptake of nutrients. The results confirm the findings of Singh and Singh (2002).

Thus, on the basis of above study it can be concluded that Indian mustard cultivar 'RGN-73' fertilized with 100 kg N + 40 kg P_2O_5 + 30 kg K_2O/ha sustained higher seed, stover and biological yields, nutrient uptake, net returns

Table 2. Seed yield, stover yield, cost of cultivation, net returns, benefit: cost ratio and nutrient uptake as influenced by different nutrients levels

Treatment	Seed yield (t/ha)	Stover yield (t/ha)	Cost of cultivation (× 10³₹/ha)	Net returns (× 10³₹/ha)	Benefit: cost ratio	Nutrient uptake (kg/ha)		
						N	P	K
$N:P_2O_5:K_2O$ (kg/ha)								
T_1 (60:20:0)	1.07	6.92	21.5	13.0	0.60	59.0	28.0	140.5
T_2 (60:20:30)	1.12	7.16	22.4	13.8	0.62	61.9	29.9	147.0
T_3 (60:40:0)	1.17	7.22	22.6	15.0	0.67	64.3	31.7	147.6
T_4 (60:40:30)	1.27	7.30	23.4	17.3	0.74	67.5	32.9	151.8
T_5 (80:20:0)	1.34	7.32	21.9	21.1	0.95	71.5	33.5	152.5
T_6 (80:20:30)	1.38	7.37	22.7	21.6	0.96	74.4	35.2	157.0
T_7 (80:40:0)	1.46	7.47	22.9	24.0	1.05	77.4	36.2	160.1
T_8 (80:40:30)	1.60	7.58	23.7	27.2	1.15	82.6	37.4	162.1
T_9 (100:20:0)	1.63	7.59	22.2	29.9	1.35	84.6	38.1	162.8
T_{10} (100:20:30)	1.74	7.60	23.0	32.3	1.40	90.5	38.7	164.5
T_{11} (100:40:0)	1.80	7.62	23.3	34.0	1.46	93.7	40.3	170.2
T_{12} (100:40:30)	1.92	7.64	24.1	37.1	1.54	99.1	41.8	172.1
SEm±	0.09	0.15	-	-	-	3.6	2.0	6.3
CD (P=0.05)	0.27	0.44	-	-	-	10.8	5.9	18.8

and benefit: cost ratio under *tarai* condition of Uttarakhand.

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Research Communication

Utilization of high residual sodium carbonate water neutralized with chemical amendments for fodder sorghum (*Sorghum bicolor*) production

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ABSTRACT

The effect of high residual sodium carbonate (RSC) irrigation water and its neutralization with gypsum/H_2SO_4 on sorghum [*Sorghum bicolor* (L.) Moench] was evaluated in a micro-plot experiment during rainy (*kharif*) season (May to September 2013) at ICAR-Central Soil Salinity Research Institute, Karnal, Haryana. The experiment was conducted in randomised block design, consisted of 5 treatments of different RSC levels [RSC–nil (control), RSC–5meq/L, RSC–10meq/L, RSC–10meq/L (neutralized 5meq/L with gypsum), RSC–10meq/L (neutralized 5meq/L with H_2SO_4)] with 4 replications. Increase in concentration of RSC in water from RSC 5 to 10 resulted in reduction in growth parameters like plant height, leaf to stem green biomass, leaf area index, but extent of reduction was lesser, while using RSC water reclaimed with gypsum and sulphuric acid. Neutralization of RSC in irrigation water with gypsum proved a safer and economical option to use high RSC groundwater for irrigation of sorghum for profitable fodder production as compared to sulphuric acid.

Key words **:** Fodder sorghum, Gypsum, H_2SO_4, Residual sodium carbonate

The scarcity of good quality irrigation water is one of the major issues around the globe in general and in arid and semi-arid regions in particular. In India, about 50% of the groundwater is either marginal or poor in quality. Of this, 37% has high sodicity, 20% has high salinity and remaining 43% has high salinity as well as sodicity. Ground water surveys have shown that about 41–84% of the well water in different states of the Indo-Gangetic plains is brackish (Minhas and Bajwa, 2001). Ground water with higher RSC are common in central and south western parts of Punjab covering about 25% of the total area of the state (Bajwa *et al.*, 1975).

Gypsum is the most extensively used amendment for the reclamation of sodic soils because of its low cost, general availability, and rich supply of Ca^{2+} followed by leaching, can ameliorate saline-sodic soils (Ghafoor *et al*., 2008; Murtaza *et al*., 2009). However, in addition to gypsum, sulphuric acid is also considered as the most efficient in neutralizing the sodicity and alkalinity of irrigation water (Kumar and Chhabra, 1996; Lotovitskii and Bilai, 2001). Use of such water would not only permit the sustainable and productive use of sodic water for horizontal expansion of irrigated agriculture, but would also reduce associated environment problems (Oster and Grattan, 2002). Reports suggest that the crops grown for grain production are more sensitive to irrigation water quality in comparison to fodder crops. Among fodder crops, the adverse effect of salty water is more on leguminous crops as compared to grassy fodder crops (Yadav *et al.*, 2007). At present, the country faces a net deficit of 36% green fodder, 11% dry crop residues and 44% concentrates (Vision 2050, IGFRI). There is a large gap between requirement and availability of quality fodder and feed at the national level. It is matter of prime concern to bridge this gap. The sorghum is more salt tolerant crop with good fodder yields as compared to maize and Sudan grass. This experiment, therefore, investigated the consequences of application of high RSC irrigation water and after its neutralization with gypsum/H_2SO_4 on fodder sorghum production.

The study was conducted during rainy (*kharif*) (May to September) 2013 in micro-plots at ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India (29°43'N, 76°58'E, 245 m above mean sea level, on soil slightly alkaline in reaction (*p*H 8.3–9.2), low-electrical conductivity (ECe 0.47–1.29), low in available nitrogen (176–230 kg/ha) high in available phosphorus (30–47 kg/ha) and me-

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dium in potassium (234.9–295.3 kg/ha). Climate of experimental site is sub-tropical monsoon type and rainfall is received mainly during July to September. The lowest weekly mean temperature (19.3°C) recorded in 30 April–6 May and highest temperature 44.2°C was recorded in 21–27 May. The total rainfall during the growing period was 649.3 mm and remaining water requirement of the crop was met by irrigation.

Multi-cut forage sorghum hybrid 'Raseela' ('MFSH 4') was used as test crop in the study. The experiment conducted in RBD with 4 replications, consisted of 5 treatments of different RSC levels [RSC–nil (control), RSC–5meq/L, RSC–10meq/L, RSC–10meq/L (neutralized 5meq/L with gypsum), RSC – 10 meq/L (neutralized 5 meq/L with H_2SO_4)]. There were 20 micro-plots of 2 × 2 m^2 size in total. The seeds were sown on May 7, by *pora* method with 8 rows in each micro-plot and the row distance was 25 cm. First cut was taken at 65 DAS and second cut was taken at 50 days after first cut. Leaf area was recorded by portable leaf area meter CI-202. The value obtained by the meter (cm^2) entered in the formula and LAI calculated as below:

$$\text{LAI} = \frac{\text{Average leaf area} \times \text{No. of leaves} \times \text{No. of plants}}{\text{Plot area}}$$

The *p*H, ECe, organic carbon, available nitrogen, phosphorus and potassium were determined using standard method for each parameter following the methods of Page *et al*. (1982). Fodder quality; crude protein, ash content etc. were determined in the fodder samples using standard procedures (AOAC, 2005). Each variable was analysed statistically using (GenStat® 13th Edition, VSN International Ltd., Lawes Agricultural Trust, Rothamsted, UK) statistical software.

The RSC in irrigation water had negative effect on plant height of sorghum and the magnitude of reduction increased with the increase in RSC from control to 5 and to 10meq/L (Table 1). The total reduction in plant height at RSC-10 was 52.4% (1^{st} cut) as compared to control, but the reduction in plant height was lesser when RSC-10 neutralized with gypsum and/or H_2SO_4. This is due to osmotic and specific ion effects together with imbalance plant nutrient supply, especially Ca^{2+} and K^+ due to continuous use of sodic water affect on plant growth (Qadir and Schubert, 2002).

Results depicted in Table 1 showed that the reduction in leaf area index at RSC-10 was 48.1%, but the reduction was mitigated to 20.1% in case of RSC-10 + gypsum as compared to control. The major impact of increasing RSC on decrease in plant growth was due to the specific ion effect, i.e. sodium induced calcium deficiency or sodium toxicity or both. According to Kumar *et al.* (2006) the use of alkali waters having high RSC adversely affected the oat growth. These adverse effects can be moderated through the use of gypsum as amendment.

The data depicted in table 1 showed that the lowest leaf to stem green biomass was recorded for RSC-10 in irrigation water treatment at first cut (0.25) as well as for second cut (0.24). The leaf to stem dry biomass decreased with increase in RSC of irrigation water *i.e* from RSC-5 to10 meq/L. The reduction in leaf to stem dry biomass at RSC-5, RSC-10, RSC-10+gypsum and RSC 10 + H_2SO_4 over the control was 14.2, 23.9, 14.7 and 21.0% at first cut and 14.5, 18.8, 13.2 and 20.0% at the second cut, respectively. There is significant difference in leaf to stem dry biomass between RSC-10 and control and rest treatments were at par with control at both first and second cut. Again, the moderating effects of amendments were observed in case of leaf to stem green and dry biomass and more so in case of use of gypsum. In general, growth of crops decrease with increase in RSC of irrigation water and more so the leafiness thereby leading to decrease in leaf to stem ratio (Singh *et al*., 1994).

The reduction in green fodder yield was less with amendment water (with gypsum and H_2SO_4), which was 40.2% and 44.3% respectively (Table 2). Realization of higher yield with application of gypsum might be due to improved soil physical conditions leading to better aeration, root activity and nutrient absorption (Venkata Rao *et al*., 2014).

Table 1. Effect of different RSC levels in irrigation water with and without amendments on growth parameters of fodder sorghum

Treatment	Plant height	Leaf area index	Leaf to stem green biomass		Leaf to stem dry biomass	
	First cut	First cut	First cut	Second cut	First cut	Second cut
Control	219.4	3.47	0.320	0.288	0.307	0.284
RSC-5	140.7	2.56	0.271	0.257	0.263	0.243
RSC-10	104.5	1.80	0.254	0.241	0.234	0.231
RSC-10 + gypsum	137.4	2.77	0.280	0.263	0.262	0.247
RSC-10 + H_2SO_4	127.8	2.60	0.265	0.252	0.242	0.228
SEm±	19.47	0.18	0.016	0.012	0.016	0.017
CD (P=0.05)	42.4	0.39	0.035	0.026	0.035	0.037

Table 2. Effect of different RSC levels of irrigation water with or without amendments on fodder sorghum yield, quality and economics

Treatment	Total green fodder yield (t/ha)	Total dry fodder yield (t/ha)	Crude protein content (%)	Ash content (%)	Cost of cultivation (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
Control	45.31	7.91	8.94	9.04	24.0	21.3	0.89
RSC-5	25.96 (42.7%)	5.05 (36.21%)	7.47 (16.4%)	9.65 (6.86%)	24.0	2.0	0.08
RSC-10	16.08 (64.5%)	4.14 (47.64%)	4.22 (52.8%)	10.34 (14.44%)	24.0	-7.9	-0.32
RSC-10 + gypsum	27.11 (40.2%)	5.61 (29.12%)	7.41 (17.1%)	9.71 (7.47%)	24.2	2.9	0.12
RSC-10 + H_2SO_4	25.25 (44.3%)	4.99 (36.89%)	7.28 (18.5%)	9.44 (4.48%)	48.3	-23.1	-0.48
SEm±	1.22	0.29	0.20	0.16			
CD (P=0.05)	2.67	0.64	0.44	0.35			

Figures in parenthesis indicate reduction in various parameters as compare to control (except ash content)

The reduction in dry fodder yield in RSC-10 was 47.6%. There was less reduction in dry fodder yield on amendment of RSC water with gypsum and H_2SO_4, which was 29.1% and 36.9% respectively. Yadav *et al.* (2004) reported a linear decline in yield of 5 forage crops: oat (*Avena sativa*), rye grass (*Lolium rigidum*), Indian clover (*Melilotus indica*), Egyptian clover (*Trifolium alexandrinum*) and Persian clover (*Trifolium resupinatum*) with increases in the quantity of salt applied in irrigation water. The reduction in crude protein content in RSC-10 was 52.8%. Lesser reduction in crude protein content was recorded with amended water (gypsum and H_2SO_4) which was 17.1% and 18.5% respectively. The increase in total ash content with RSC-10 irrigation water was 14.4% as compared to control.

The cost of cultivation for treatments of RSC-5 and RSC-10 were same as that of control because of consideration of natural availability of sodic water, but charges of gypsum and H_2SO_4, that were use for neutralization of RSC water, were considered (Table 2). The highest cost of cultivation incurred in case of RSC-10 + H_2SO_4, because the H_2SO_4 is very expensive (₹348/L). Gypsum was economical, though H_2SO_4 can reclaim sodic soils relatively at a faster rate, but at a 5–10 times higher cost as also observed earlier by Ghafoor *et al*., (2001). The highest net returns was obtained (₹21,346/ha) under the control, followed by RSC-10 + gypsum (₹2,889/ha). The highest benefit: cost ratio (0.89) was obtained for the fodder grown in control, followed by RSC-10 + gypsum and the lowest benefit: cost ratio (-0.48) was found for the plots irrigated with RSC-10 + H_2SO_4 water.

Based on the study, a it was concluded that irrigation using increasing levels of RSC in water from 5 to 10 resulted significant reduction in growth parameters and yield of sorghum. This reduction was lesser under irrigation with use of water partially neutralized for RSC amended with gypsum and sulphuric acid.

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