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Nutrient management practices for improved crop and water productivity, grain quality and energy productivity of promising rice cultivars in Eastern Himalayas

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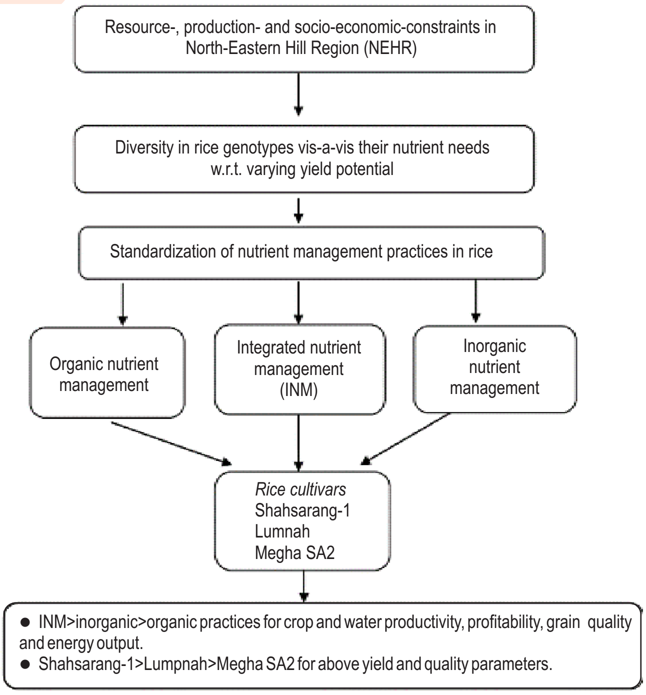
Abstract

Aim: To assess the influence of nutrient management practices on crop and water productivity, grain quality, energy productivity and profitability in promising rice genotypes of Eastern Himalayas.

Methodology: An experiment was conducted at '*Lowland Research Block*' of ICAR–RC–NEHR, Barapani, Meghalaya to assess the influence of different nutrient management practices [Organic nutrient management (through FYM + remaining P through rock phosphate); integrated nutrient management (INM) (50% NPK through fertilizers + 50% N through FYM + remaining P through rock phosphate); inorganic nutrient management (fertilizers); and absolute control] and rice varieties [Shahsarang–1, Lumpnah and Megha semi-aromatic–2] on productivity, quality, energetic and profitability replicated thrice in a split-plot design.

Results: Rice grain yield was significantly higher in INM practice (4.18 t ha^{-1}) followed by inorganic (4.02 t ha^{-1}) and organic practice (3.74 t ha^{-1}). INM practice exhibited highest hulling (68.6%), milling (59.9%), head-rice recovery (53.6%), protein content (7.56%) and protein yield (329 kg ha^{-1}) followed by inorganic, organic practice and control, respectively. However, gross and net returns and B: C ratio were significantly greater in inorganic practice followed by INM practice. Highest TWUE (3.17 kg ha^{-1} mm^{-1}), water productivity (47.6 INR ha^{-1} mm^{-1}), energy output (140342 MJ ha^{-1}) as well as net energy (130813 MJ ha^{-1}) were recorded in INM practice.

Interpretation: INM practice and rice variety 'Shahsarang–1' can be recommended to farmers for enhancing the rice productivity, profitability, resource-use efficiency and soil health in eastern Himalayan region of India.



Key words: Energetics, Grain quality, Integrated nutrient management, Rice varieties, Water-use efficiency

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Introduction

Rice (*Oryza sativa* L.) is a staple food crop of south-east Asia in general and north-eastern states of India in particular with ~3.51 m ha acreage accounting for more than 80% of total cultivated area of the region and 7.8% of total national rice area (Harish *et al.,* 2019). However, rice production in this region is ~5.5 mt production with an average yield of 1.57 t ha^{-1} which is far below the national averages of 2.08 t ha^{-1}, owing to various production constraints and resource vulnerabilities (Yadav *et al.,* 2019). During post-green revolution period, introduction of improved varieties has eventually enhanced the rice yield in this remote region by about 40%. However, there is ample scope for enhancing the rice productivity, profitability and soil health by adopting suitable agronomic practices in the region. Diverse agro-climatic conditions alongwith varying physiographic conditions have led to immense variability among rice cultivars in north-eastern region. North-east India is characterized with high soil acidity/Al^{+3} toxicity, heavy soils, carbon loss, and severe water scarcity during most parts of year though it receives high rainfall (Verma *et al.,* 2017). Organic matter addition is considered as a noble intervention to improve soil physico-chemical and microbiological properties besides enriching soil fertility (Paul *et al.,* 2014). Thus, application of organic manures may improve the soil health for harnessing better rice yield in this region.

In NE India, continuous mono-cropping of rice has posed a serious threat to its sustainability characterized with stagnant crop productivity, declining soil organic carbon (SOC), multi-nutrient deficiencies with poor microbiological activities (Verma *et al.,* 2017). In order to harness better crop yield, it is the genotype of any crop which plays a pivotal role in yield expression under given set of environmental and crop management situations (Choudhary and Suri 2018a; 2018b). So, development and screening of location-specific high yielding varieties (HYVs) w.r.t. to given set of input/production factors like efficient nutrient management etc., is highly important to harness the production potential of rice with better resource-use efficiency and energy output in this far eastern part of the country having diverse agro-climatic variability. With this background, the current study aimed at investigating the effect of different nutrient management practices and promising rice cultivars on productivity, profitability, quality, resource-use efficiency and energy dynamics of rice cultivation in the Eastern Himalayan region of India.

Materials and Methods

Study area, meteorological parameters: The experiment was conducted at the '*Lowland Research Block*' of the Experimental Farm of ICAR–Research Complex for North Eastern Hill Region, Barapani, Meghalaya. Soil of the experimental farm was acidic in nature. Initial chemical and physical properties of soil with their determination methods are presented in Table 1. Climate of experimental site is subtropical type with high rainfall where south-west monsoons contribute a major part of rainfall during rice season. Mean annual normal rainfall ranges between 1750–2450 mm with July and August as the wettest months. Mean weekly meteorological parameters observed during current rice crop season are presented in Fig. 1. A total rainfall of 1646 mm was received during the rice cropping season (Fig. 1).

Experimental details and crop management: The experiment was laid-out in a split-plot design replicated thrice with four main-plot treatments [Organic (through FYM + remaining P through rock phosphate); integrated nutrient management (INM) (50% NPK through fertilizers + 50% N through FYM + remaining P through rock phosphate); inorganic nutrient management (fertilizers); and absolute control] and three sub-plot treatments [3 rice varieties viz. Shahsarang-1, Lumpnah and Megha semi-aromatic-2]. Rice nursery was grown using raised-bed method following recommended practices (Verma *et al.,* 2017). The 30-days old seedlings were transplanted in the puddled field on 19th July, 2016. Seedlings were transplanted in square pattern at spacing of 20×20 cm. In organic main-plot treatments, FYM was applied before field ploughing. In inorganic main-plots treatments, the NPK was applied @ 80:60:40 kg ha^{-1} through urea, single super phosphate and muriate of potash. Urea was applied in 3-splits (50% as basal + 25% at tillering + 25% at panicle initiation).

In INM main-plot treatments, 50% NPK nutrient requirement was fulfilled through recommended dose of fertilizers (RDF) and remaining 50% requirement was fulfilled through FYM. Urea was again applied in 3-splits (50% as basal + 25% each at tillering and panicle initiation). A continuous submergence of 5±2 cm was maintained in plots till grain-filling stage, thereafter it was drained out. Two hand-weeding (20 and 55 DAT) and one cono-weeding (35 DAT) helped in managing weeds. Recommended crop and input management practices were followed for raising the crop as suggested by Rana *et al.* (2014), except nutrient management treatments. At crop maturity, two rows on all the sides of the plot were removed as border and remaining hills were harvested as net plot (18 m^2). Crop harvesting was done on 21st Nov., 2016 manually using sickles.

Root growth analysis and yield estimation: Root parameters (root length, root volume, root dry weight) were collected at 50% flowering stage from randomly selected five hills from sample rows using standard procedures. Yield attributes (Panicles/m^2, panicle length, panicle weight, grains/panicle, unfilled grains/panicle, spikelet fertility percentage, 1000-grains weight) were estimated from 10 selected plants in net plot at maturity using standard procedures. For computing grain and biological yield, the net plots were harvested and the produce was sun-dried for constant weight and then total biomass yield was recorded. After threshing, cleaning and drying; the grain, straw and biological yield were determined on t ha^{-1} basis. The grain yield was recorded at 14% moisture content.

Hulling, milling head-rice recovery: From each plot, 200 g sun-dried paddy (whole grains) samples were drawn and hulled in a mini rice mill and the weight of brown rice was recorded. Hulling percentage was computed by dividing the weights of brown rice by weight of rough rice multiplied by 100. Hulled brown rice was passed through rice whitening machine for 2 minutes to get milled rice. Milling percentage was worked out by dividing the milled rice by brown rice multiplied by 100. For estimating head rice recovery, the milled produce was sieved using appropriate sieves to separate whole kernels from the broken ones. Small proportion of whole kernels which passed along with broken ones was hand-separated. Head rice recovery (%) was calculated by dividing the weight of whole milled rice by weight of rough rice multiplied by 100.

Protein content and protein yield: Crude protein content in rice grains was obtained by multiplying N concentration with a Jones factor 5.95 (Jones, 1941). This factor is based on the nitrogen content (16.8%) of the major rice protein, glutelin (Jones, 1941). Protein yield in rice grains was worked out using standard methods (Rana *et al.,* 2014).

Water productivity: Total rainfall received during the crop season was 1646.3 mm (Fig. 1), while no irrigation was applied to the crop. Thus, effective rainfall worked-out to be 1317 mm using standard procedures (Rana *et al.,* 2014), was the total water-use (1317 mm). Total water-use efficiency (kg ha^{-1} mm^{-1}) and economic water productivity (INR ha^{-1} mm^{-1}) were computed using standard methodology (Adeboye *et al.,* 2015). Market price of rice grains was INR 1500 q^{-1}.

Energy dynamics: For assessing energy dynamics and energy-use efficiency of rice crop, each input used in rice production and the respective output, were converted into the form of energy using energy equivalents (Table 2). The energy efficiencies were estimated using standard methods (ISA, 2016).

Soil microbiological analysis: Dehydrogenase enzyme activity of soil samples of experimental plots was estimated by the method of Casida *et al.* (1964). Soil microbial biomass carbon (SMBC) in soil samples was estimated following the method of Vance *et al.* (1987). Alkaline phosphatase activity in soil was assayed by the method developed by Tabatabai and Bremner (1969).

Statistical analyse: Data related to each parameter were analyzed as per the procedure of analysis of variance (ANOVA) and significance of split-plot design tested by F-test (Gomez and Gomez, 2010). Standard error of means (SEm±) and least significant difference (LSD) at 5% level of significance were worked out for each parameter.

Results and Discussion

The perusal of data revealed that root parameters like root volume and root dry weight were found highest under INM practice followed by inorganic, organic practice and control, respectively (Fig. 2). However, root length was recorded highest in inorganic practice followed by INM and organic practice. Here, better nutrient supply under inorganic and INM treatments led to greater root volume and root dry weight (Suri and Choudhary, 2013; Omran *et al.,* 2020). Rice varieties showed a non-significant effect on root length. Amongst varieties, significantly highest root volume and root dry weight were found in Shahsarang-1 (45.3 cc; 13.69 g) both over Lumpnah and Megha SA2 which may be attributed to its genetic characteristics (Verma *et al.,* 2017).

Plant population in each plot was kept same *i.e.* 2,50,000 plants ha-1 so as to evaluate the experimental outcome in current study. The number of panicles m^{-2} and panicle length were found to be highest in INM practice (Table 3), however, panicle weigh was found similar both under organic and INM practices. Number of grains per panicle was highest for INM practice whereas inorganic and organic practices remaining at par with each other showed intermediate magnitude. Number of unfilled grains per panicle was found highest for control and lowest for INM practice. Spikelet fertility was again highest under INM practice (91.4%). Test weight followed the trend of INM>organic>inorganic>control treatment. INM practice exhibited significantly higher grain (4.18 t ha^{-1}), straw (6.38 t ha^{-1}) and biological yield (10.54 t ha^{-1}) followed by inorganic, organic and control treatment, respectively (Table 4). Grain yield enhancement under INM practice was found to the tune of 56.5% over control. Harvest index followed the trend of

Table 1: Initial physical and chemical properties of experimental soil

Parameters	Content	Methods used
Physical characteristics		
Soil texture	Sandy-clay loam	(Hydrometer method; Bouyoucos, 1962)
Soil bulk density (0–15 cm layer) (g cm^{-3})	1.05	(Rana *et al.,* 2014)
Chemical characteristics		
Soil organic carbon (%)	2.45	(Walkley and Black, 1934)
Alkaline permanganate oxidizable N	236.0	(Subbiah and Asija, 1956)
Available phosphorus (P_2O_5 kg ha^{-1})	6.3	(Olsen's method; Olsen *et al.,* 1954)
Available potassium (K_2O kg ha^{-1})	293.4	(Flame photometer method; Hanway and Heidel, 1952)
pH (1:2.5 soil: water)	4.8	(Elico pH meter; Piper, 1950)
Biological characteristics		
MBC (µg microbial biomass carbon g^{-1} soil)	142.4	(Vance *et al.,* 1987)
Dehydrogenase activity (µg TPF g^{-1} soil day^{-1})	11.4	(Casida *et al.,* 1964)
Alkaline phosphatase (µg PNP g^{-1} soil hr^{-1})	20.2	(Tabatabai and Bremner, 1969)

Table 2: Energy equivalent used for input and output of rice production (Source: Rana *et al.*, 2014; ISA, 2016)

A. Inputs	**Energy equivalents**
1. Human labour	1.95 MJ man hr^{-1}
2. Machinery	158.3 MJ hr^{-1}
3. Diesel fuel	56.31 MJ l^{-1}
4. Chemical fertilizers/organic manures/biofertilizers:	
Nitrogen (N)	60.6 MJ kg^{-1}
Phosphorus (P_2O_5)	11.1 MJ kg^{-1}
Potassium (K_2O)	6.7 MJ kg^{-1}
Farmyard manure (FYM)	0.3 MJ kg^{-1}
5. Chemicals:	
Herbicides	238.0 MJ kg^{-1}
Fungicides/Pesticides	1.95 MJ kg^{-1}
6. Water for irrigation	1.02 MJ m^{-3}
7. Seed (rice)	14.57 MJ kg^{-1}
B .Outputs	
1. Main product	14.57 MJ kg^{-1}
2. By-product	12.5 MJ kg^{-1}

Table 3: Effect of nutrient management practices and rice varieties on yield attributes of rice

Treatments	Panicles (m^{-2})	Panicle length (cm)	Panicle weight (g)	Grains $panicle^{-1}$	Unfilled grains $panicle^{-1}$	Spikelet fertility (%)	1000-grain weight (g)
Nutrient management practices							
Organic	191.3	25.2	4.1	139.0	15.0	90.2	26.05
INM	199.5	26.8	4.1	146.9	13.8	91.4	26.25
Inorganic	193.9	26.2	4.0	141.2	17.7	88.9	26.04
Control	135.9	18.9	3.1	106.9	27.8	79.3	25.77
CD (*P*=0.05)	1.5	0.8	0.03	3.6	1.2	0.6	0.27
Rice varieties							
Shahsarang–1	185.7	24.3	3.8	138.7	16.8	88.9	23.68
Lumpnah	180.2	23.8	3.7	131.6	18.4	87.3	25.21
Megha SA2	174.5	24.8	3.9	130.1	20.5	86.1	29.20
SEm ±	0.9	0.4	0.01	0.81	0.23	0.17	0.06
CD (*P*=0.05)	2.7	NS	0.04	2.4	0.7	0.5	0.17

Table 4: Effect of nutrient management practices and rice varieties on crop productivity and harvest index of rice

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Nutrient management practices				
Organic	3.74	6.05	9.79	38.15
INM	4.18	6.36	10.54	39.58
Inorganic	4.02	6.29	10.31	38.93
Control	2.26	3.90	6.16	36.52
SEm ±	0.06	0.05	0.07	0.53
CD (*P*=0.05)	0.21	0.18	0.24	1.83
Rice varieties				
Shahsarang–1	3.86	5.73	9.59	39.98
Lumpnah	3.60	5.66	9.26	38.63
Megha SA2	3.19	5.56	8.75	36.27
SEm ±	0.05	0.02	0.06	0.35
CD (*P*=0.05)	0.15	0.06	0.18	1.03

Table 5: Effect of nutrient management practices and rice varieties on protein content, protein yield, hulling, milling and head-rice recovery of rice

Treatments	Protein content (%)	Protein yield (kg ha^{-1})	Hulling (%)	Milling (%)	Head-rice recovery (%)
Nutrient management practices					
Organic	7.38	276.9	67.83	58.34	51.02
INM	7.86	329.0	68.58	59.96	53.55
Inorganic	7.59	305.8	68.01	59.04	52.62
Control	6.85	154.7	64.38	56.23	48.67
SEm ±	0.14	7.95	0.136	0.14	0.18
CD (*P*=0.05)	0.49	27.5	0.47	0.50	0.63
Rice varieties					
Shahsarang–1	7.62	297.4	67.85	58.88	52.15
Lumpnah	7.46	271.2	67.32	58.54	52.27
Megha SA2	7.18	231.1	66.43	57.77	49.99
SEm ±	0.13	6.44	0.22	0.15	0.14
CD (*P*=0.05)	NS	19.29	0.66	0.45	0.43

Table 6: Effect of nutrient management practices and rice varieties on cost of cultivation, gross and net returns, and B: C ratio of rice

Treatments	Cost of cultivation (INR ha^{-1})	Gross returns (INR ha^{-1})	Net returns (INR ha^{-1})	B: C ratio
Nutrient management practices				
Organic	34,680	68,210	33,530	1.97
INM	29,205	75,382	46,177	2.58
Inorganic	21,741	72,882	51,141	3.35
Control	17,269	41,657	24,388	2.41
SEm ±	-	904	904	0.04
CD (*P*=0.05)	-	3,128	3,128	0.14
Rice varieties				
Shahsarang–1	25,724	69,315	43,591	2.77
Lumpnah	25,724	65,371	39,647	2.60
Megha SA2	25,724	58,913	33,189	2.36
SEm ±	-	758	758	0.04
CD (*P*=0.05)	-	2,272	2,272	0.11

Table 7: Effect of nutrient management practices and rice varieties on energy dynamics of rice crop

Treatments	Energy input (MJ ha^{-1})	Energy output (MJ ha^{-1})	Energy-use efficiency	Net energy (MJ ha^{-1})	Specific energy (MJ kg^{-1})	Energy productivity (kg MJ^{-1})
Nutrient management practices						
Organic	10071	130091	12.92	120021	1.031	0.972
INM	9529	140342	14.73	130813	0.906	1.106
Inorganic	8948	137210	15.33	12863	0.868	1.152
Control	3119	81707	26.20	78588	0.508	1.976
SEm ±	-	950	0.29	949	0.005	0.022
CD (*P*=0.05)	-	3286	1.01	3286	0.020	0.075
Rice varieties						
Shahsarang–1	7917	127819	18.13	119902	0.794	1.361
Lumpnah	7917	123243	17.37	115326	0.822	1.307
Megha SA2	7917	115954	16.38	108035	0.869	1.236
SEm ±	-	862	0.20	862	0.005	0.015
CD (*P*=0.05)	-	2583	0.61	2583	0.016	0.044

Table 8: Effect of nutrient management practices and rice varieties on soil microbiological properties of soil after the harvest of rice crop

Treatments	Soil microbial biomass carbon (µg g^{-1} soil)	Alkaline phosphatase enzyme activity (µg p-NP g^{-1} soil 24 hr^{-1})	Dehydrogenase enzyme activity (µg TPF g^{-1} soil hr^{-1})
Nutrient management practices			
Organic	140.9	223.7	10.92
INM	161.7	224.5	11.92
Inorganic	154.6	220.1	10.66
Control	129.6	214.3	8.25
SEm ±	3.5	2.1	0.37
CD (*P*=0.05)	11.9	7.2	1.30
Rice varieties			
Shahsarang–1	147.3	222.1	11.02
Lumpnah	142.5	220.2	10.05
Megha SA2	150.2	219.7	10.23
SEm ±	1.9	1.3	0.46
CD (*P*=0.05)	5.6	NS	NS

INM> inorganic>organic>control treatment. Higher magnitude of shoot and root growth parameters under INM practice may be attributed to good early vigorous plant growth under INM practice with better leaf area index and photosynthesis which resulted in superior yield attributes and rice yield (Varatharajan *et al.,* 2019a, 2019b; Omran *et al.,* 2020). Further, better performance of rice varieties under INM practice may probably be accrued to good crop establishment and better anchorage of roots (Dass *et al.,* 2016). That's' why the highest grain, straw and biological yield were observed in INM practice. Among varieties, Shahsarang-1 recorded maximum panicles m^{-2}, grains $panicle^{-1}$ and spikelet fertility followed by Lumpnah and Megha SA2 (Table 3). Both panicle length and panicle weight were highest in Megha SA2, followed by Shahsarang-1 and Lumpnah, respectively. Highest test weight and number of unfilled grains per panicle were found in Megha SA2 followed by Lumpnah and Shahsarang-1. Overall,

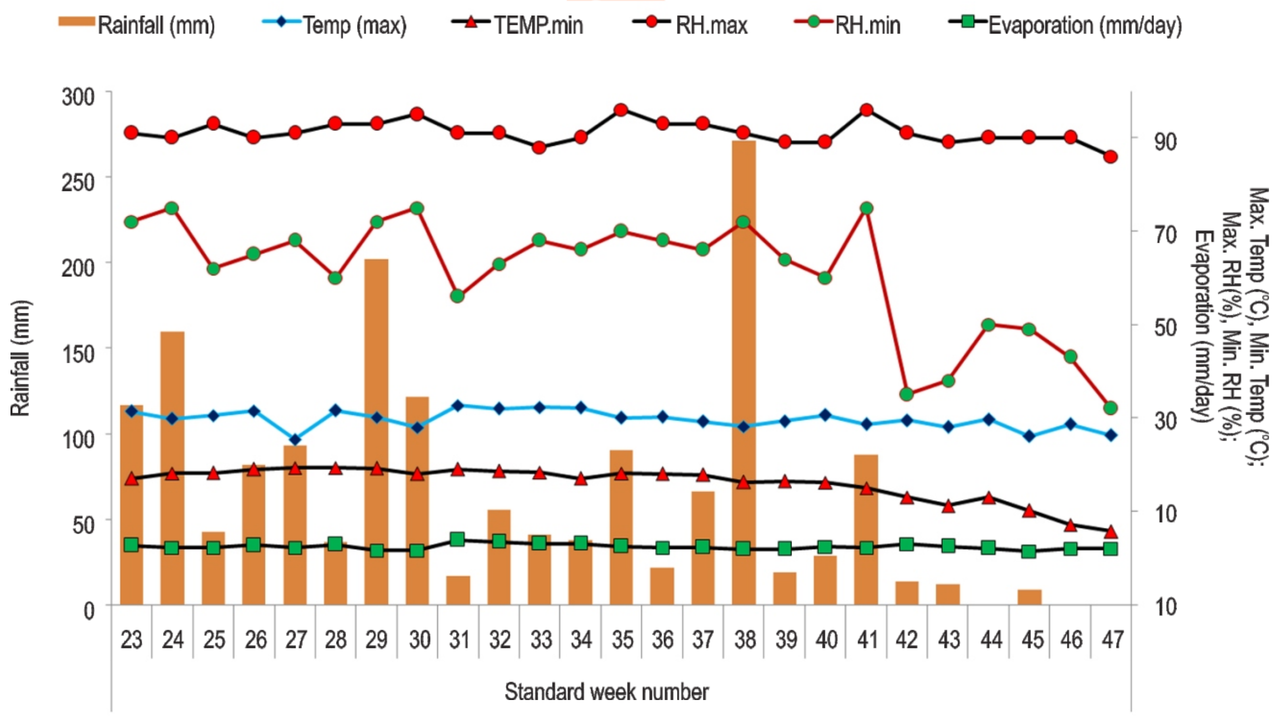

Fig. 1: Mean weekly meteorological parameters during the crop growth period (Kharif 2016).

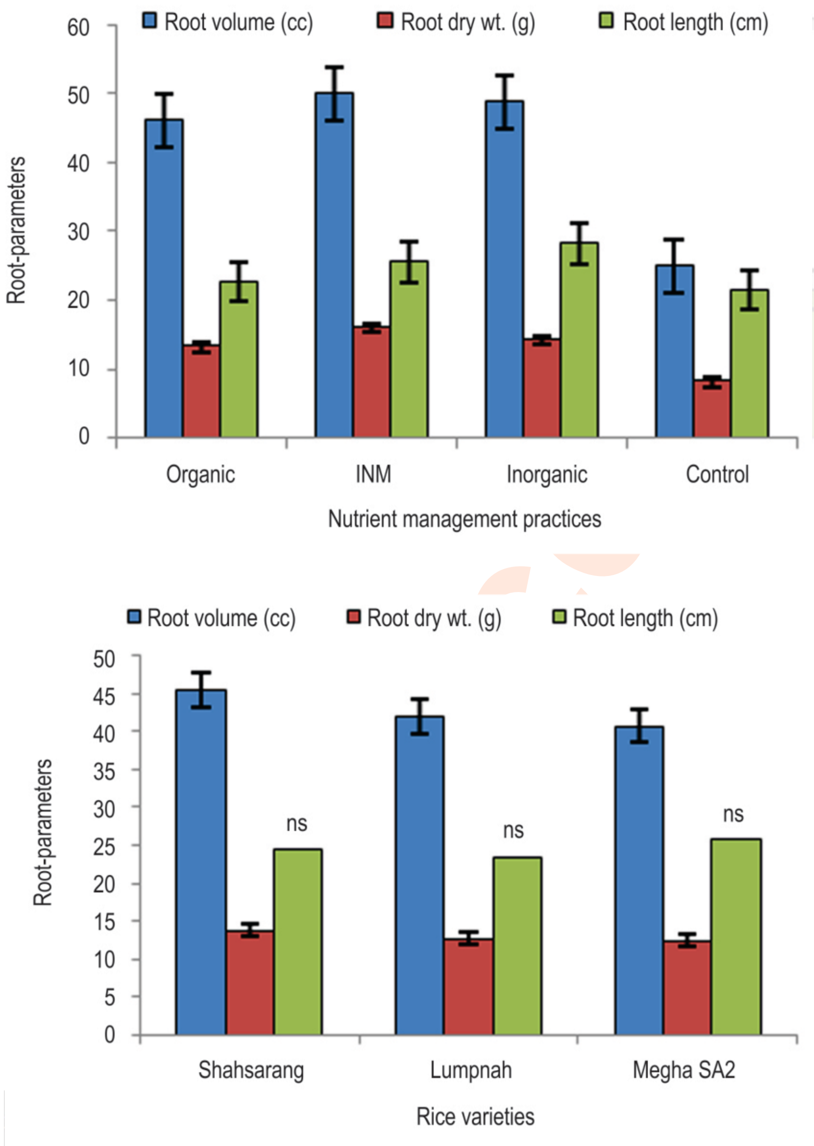

Fig. 2: Effect of nutrient management practices and rice varieties on root parameters of rice at maximum flowering stage.

Shahsarang-1 exhibited significantly higher grain (3.86 t ha^{-1}), straw (5.73 t ha^{-1}) and biological yield (9.59 t ha^{-1}) followed by Lampnah and Megha SA2 (Table 4). Harvest index followed the trend of Shahsarang-1>Lampnah>Megha SA2. Since, these varieties had differential production potential (Diwakar, 2012), which might have led to differential response to applied nutrients/nutrient management practice leading to variation in yield attributes, yield and harvest index (Choudhary and Suri, 2014).

INM practice exhibited highest hulling, milling, head-rice recovery, protein content and protein yield followed by inorganic and organic practices, respectively all of which were statistically superior over control (Table 5). Among varieties, hulling, milling and protein yield were highest in Shahsarang-1 followed by Lumpnah and Megha SA2. But, head-rice recovery was highest in Lumpnah followed by Shahsarang-1 and Megha SA2. Significantly higher protein content and protein yield were observed in INM practice with least values in control. This may be attributed to improved soil physico-chemical and microbiological properties, nutrient availability and soil rhizospheric conditions which collectively helped in harnessing higher rice productivity with better quality (Choudhary and Suri, 2009; Paul *et al.,* 2016; Singh *et al.,* 2020a). Among varieties, hulling and milling were highest under Shahsarang-1 followed by Lumpnah and Megha SA2; whereas, highest head-rice recovery was observed under Lumpnah followed by Shahsarang-1 and Megha SA2, respectively which may be accrued to the specific varietal characteristics (Pooniya *et al.,* 2019). The results indicated that

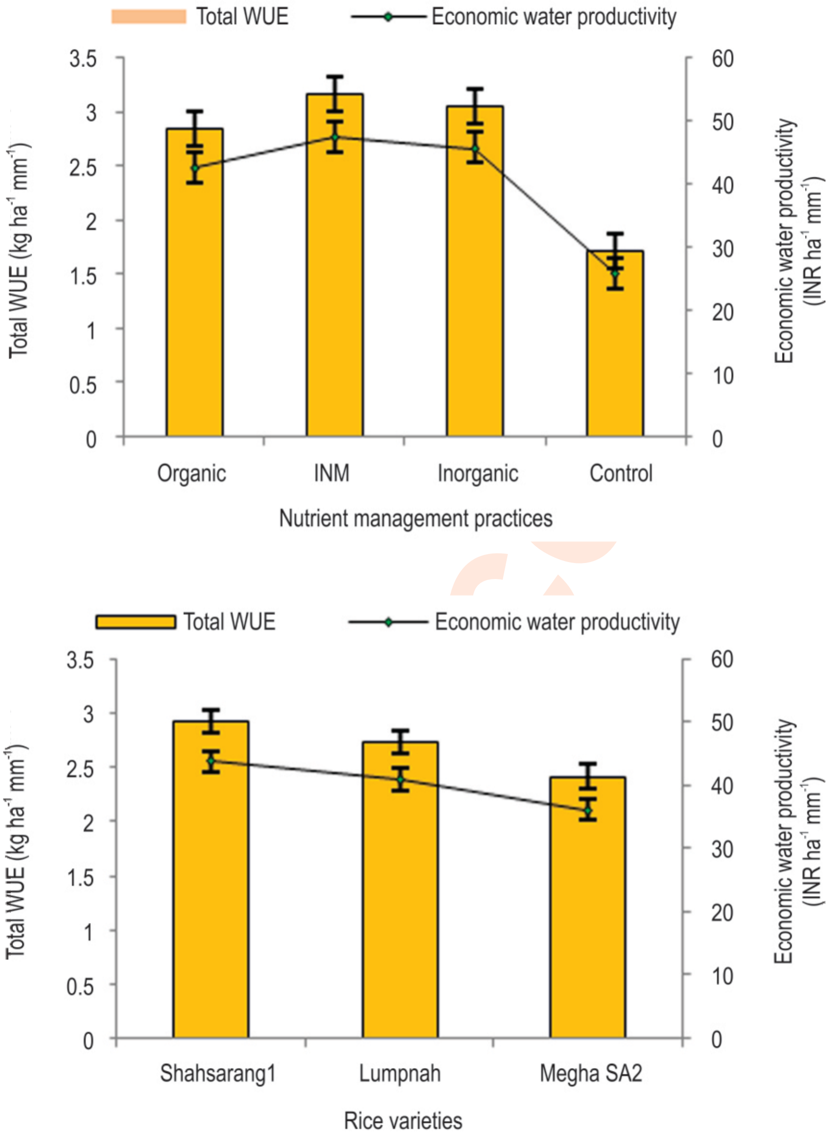

Fig. 3: Effect of nutrient management practices and rice varieties on total water use efficiency and economic water productivity of rice.

INM practice exhibited highest total water-use efficiency (TWUE) (3.17 kg ha^{-1} mm^{-1}) and economic water productivity (EWP) (47.6 INR ha^{-1} mm^{-1}) followed by inorganic, organic practice and control, respectively (Fig. 3). In general, TWUE and EWP followed the similar trend as that of rice grain yield with significantly higher values under INM practice. Among varieties, TWUE and EWP again followed the similar trend as that of their grain yield i.e. Shahsarang-1>Lampnah>Megha Sa2.

As, total water-use (TWU) was constant (1317 mm) under different nutrient management practices. Hence, higher crop productivity under INM practice again enhanced the water productivity in current study (Dass *et al.,* 2016). It indicates that integration of 50% RDF alongwith FYM in rice may prove as best fertilization schedule to realize highest rice productivity and WUE in eastern Himalayas. Cost of cultivation (INR ha^{-1}) ranged between INR 17,269–34,680 ha^{-1} under different nutrient management practices due to varying inputs and crop management practices (Table 6). Significantly higher gross returns were observed in INM practice (INR 75,382 ha^{-1}) which was followed by inorganic, organic practice and control treatment (Table 6). However, higher net returns (INR 51,141 ha^{-1}) and B: C ratio (3.35) were observed in inorganic practice which was followed by INM, organic practice and control, respectively. Since, gross returns are the sum of the product of respective grain and straw yields under different treatments and their respective prices (Rana *et al.,* 2014). Thus, gross returns followed the similar trend as that of grain and straw yield. Under inorganic practice, higher net returns and B: C ratio may be accrued to comparatively higher grain and straw yield but with lower cost of cultivation compared to INM and organic practices (Choudhary *et al.,* 2007). Among varieties, Shahsarang-1 gave significantly higher gross and net returns and B: C ratio followed by Lampnah and Megha SA2; following the similar trend as that of grain and straw yield. Hence, current economics trend can be attributed to varietal make-up and differential production potential (Diwakar, 2012).

The energy input ranged between 3,119–10,071 MJ ha^{-1} among different nutrient management practices and followed the trend of organic>INM>inorganic>control treatment (Table 7). INM practice had highest energy output (1,40,342 MJ ha^{-1}) as well as highest net energy (1,30,813 MJ ha^{-1}), followed by inorganic and organic practices, respectively. The control treatment had highest energy-use efficiency (15.33) and energy productivity (1.976 kg MJ^{-1}) followed by inorganic, INM and organic practice. Organic practice had highest specific energy (1.031 MJ ha^{-1}) followed by INM and inorganic practice. Variation in energy input among nutrient management practices may be attributed to varying inputs and crop management practices like tillage, fertilizer application, water, weet, pest and disease management, etc. Likewise, higher energy consumption under organic practice was due to higher energy equivalents of FYM applied (Varatharajan *et al.,* 2019a). On the other hand, higher energy output and net energy under INM over the organic practice may be attributed to higher respective grain and straw yield. Organic practice exhibited highest specific energy due to better energy input/product output ratio (Varatharajan *et al.,* 2019a). TWUE and EWP again followed the similar trend as that of their grain yield i.e. Shahsarang-1>Lampnah>Megha SA2. which may be accrued to the specific varietal characteristics (Diwakar, 2012).

Soil microbial biomass carbon (SMBC) was significantly higher under INM practice (161.7 µg g^{1} soil) followed by organic and inorganic practice and control, respectively. Among rice varieties, highest SMBC was reported for Megha SA2 (150.2 µg g^{1} soil) followed by Shahsarang–1 and Lumpnah (Table 8). Dehydrogenase activity (DHA) was significantly higher under INM practice (11.92 µg TPF g^{-1} soil hr^{-1}) followed by inorganic, organic practice and control. Alkaline phosphatase activity (APA) was significantly higher under INM practice followed by organic, inorganic practice and control, respectively. Among varieties, highest DHA was reported for Shahsarang–1 followed by Megha SA2 and Lumpnah while highest APA was reported for Shahsarang–1 followed by Lumpnah and Megha SA2 (Table 8). Paul *et al.* (2014) reported that FYM alongwith inorganic NPK greatly improves the crop productivity and bio-fertility of soil with substantial influence on SMBC, DHA and APA enzyme activity. Hence, higher organic matter additions under INM and organic nutrient management practices might have acted as appropriate triggering force for improved soil biological activities (Choudhary and Rahi, 2018; Yadav *et al.,* 2019; Singh *et al.,* 2020b). Overall, it is concluded that INM practice and rice variety 'Shahsarang–1' can be recommended for enhancing the rice productivity, profitability, grain quality, resource-use efficiency and soil biology in eastern Himalayan region of India.

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Add-on Information

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