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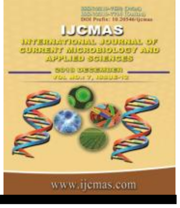

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Moderate Drying and Higher N Increases the Yield and Water Use Efficiency of Rice Established Through System of Rice Intensification (SRI) Method

Ashaq Hussain[1]*, Aabid Hussain Lone[1], M. Anwar Bhat[2], Manzoor A. Ganai[1], Latief Ahmad[3], S. Sheeraz Mehdi[1] and I.A. Jehangir[1]

[1]Mountain Research Centre for Field Crops, [2]Dryland Agriculture Research Station, [3]Division of Agronomy (AFMU Unit), Faculty of Agriculture, Shere Kashmir University of Agricultural Sciences and Technology of Kashmir, Budgam, J&K, India, 190 007

**Corresponding author*

ABSTRACT

Keywords

Nitrogen, Irrigation water saving, Rice, System of rice intensification, Water productivity

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Field experiments were conducted during 2015 & 2016 at Mountain Research Centre for Field Crops, Khudwani, SKUAST-Kashmir, India. Our objective was to measure the impact of alternative water management practices and varying N levels on water productivity, physiology, growth and yield of rice. Treatments comprised of three irrigation regimes; Submerged conditions (I_1); Irrigation at 3 days after disappearance of ponded water (I_2); Irrigation at 6 days after the disappearance of ponded water (I_3) in main plots and four nitrogen doses *viz*., 0 kg/ha (N_0); 80 kg/ha (N_1); 100 kg/ha (N_2); 120/kg ha (N_3) in subplots. Results revealed that with I_2 water management practice it is possible to simultaneously increase the yield and decrease the water requirements of irrigated rice significantly. I_2 increased the grain yield by about 6% and 16% as compared to I_1 and I_3, respectively. Continuous submergence resulted in significant yield penalty and considerable wastage of water while as I_3 condition created acute moisture deficit in the soil which finally translated into poor crop stand. The benefits of water saving in I_3 condition were outweighed by significant decline in physiological performance, growth and yield of rice. The growth and yield of crop increased as the N dose was increased from N_0 to N_3. The yield gain in N_1, N_2 and N_3 was 48%, 60% and 75% as compared to N_0.

Introduction

The food security of Asia largely depends upon the irrigated rice (*Oryza sativa* L.). Flood-irrigated rice consumes more than 45% of total fresh water used (Barker *et al*., 1999). However, owing to immense competition from urban and industrial sectors, the freshwater for irrigation is becoming rapidly scarce (Bouman and Tuong, 2001). It is predicted that by 2025, 15 million ha of Asia's irrigated rice area may experience "physical water scarcity" (Tuong and Bouman 2003). This puts the sustainability of irrigated rice production at a huge risk (Postel, 1997). Hence, adoption of a rice cultivation technology that consumes less water while sustaining or ideally increasing the productivity has become indispensible

(Yang and Zhang 2010). This would provide farmers with the much needed motivation to reduce their irrigation rates.The system of rice intensification (SRI) seems to be a potential approach to increase rice production with reduced water demand, thus improving both water use efficiency and water productivity (Uphoff, 2012). There are reports of increase of 25–50 %, or more in the yields of irrigated rice with SRI practices, while reducing water requirements (Thakur *et al*., 2011). SRI represents a paradigm shift rather than a fixed technology and allows modifications and refinements in its components to best suit the local conditions.

Rice requires high doses of nitrogen for proper growth and development. The steep increase in the N application rates adds to the costs of production and thereby lowers net farm income and also raises environmental concerns over groundwater pollution (Aparicio *et al*., 2008) which eventually undermines the sustainability of rice based cropping systems. This makes it important to evaluate the optimum amounts of N application.

In this study we raised the crop as per the SRI methodology except for the irrigation and N management components.

The present studt objective was to measure the impact of three different irrigation regimes and varying N levels under temperate conditions of Kashmir on water productivity, crop physiology, growth parameters (both above and below ground) and yield components of rice. This could help to determine the scope of reductions in the amount of water required for efficient paddy rice production as compared to flood irrigation practice and possible refinements in the N-fertilizer applications under varied water regimes.

Materials and Methods

The experiment was conducted during *Kharif* (May to September*)* seasons of 2015 and 2016 at Mountain Research Centre for Field Crops Khudwani, SKUAST-Kashmir, India. The centre is located 34° N latitude, 74° E longitude and 1,560 m above the mean sea-level. The amount of rainfall recorded during crop growing seasons of 2015 and 2016 was 644 mm and 242 mm respectively. The experimental field was silty clay loam in texture and neutral in pH (7.1). The soil was low in nitrogen (122 mg N/kg soil) and medium in phosphorus (10.1mg P/kg soil) and potassium (128 mg K/kg soil). Treatments comprised of three irrigation regimes; flooded conditions (I_1), irrigation at 3 days after disappearance of ponded water (3DAPW) (I_2) and irrigation at 6 days after the disappearance of ponded water (6DAPW) (I_3) in main plots and four nitrogen levels *viz*., 0 kg/ha (N_0), 80 kg/ha (N_1), 100 kg/ha (N_2) and 120 kg/ha (N_3) in subplots, tested in a split-plot design and replicated thrice. In plots under I_2 and I_3 the irrigation water of 5 cm was applied to fields to restore flooded condition respectively after three and six days have passed since the disappearance of ponded water. The mean depth of irrigation water in each plot was measured at 4 selected spots after each event of irrigation with measuring rod. Seventeen day old seedlings were transplanted at a spacing of 25 cm× 25 cm. For this purpose bricks at four spots in each plot were fixed into the soil, keeping their upper surface levelled with the soil surface. Drainage was conducted on two occasions during 2015 when heavy rains resulted in pounding. The fertilizers used were urea for N, superphosphate for P and muriate of potash for K. Rotary weeder was used for weed management. At full maturity, rice crop was harvested manually. Grain and straw yields were recorded from a net area of 2 m^2 from the centre of each experimental plot. Grain yield was adjusted to 14% moisture content and straw yield was expressed on oven dry weight basis. Rainfall data recorded at the meteorological observatory of Qazigund, (Distt. Anantnag, J & K) were used for calculation of water use. The other parameters were calculated as given below:

Irrigation water use (mm) = Sum of mean depth of each irrigation
Total water use (mm) = Irrigation water use (mm) + Rain fall (mm)
Nutrient uptake= nutrient concentration × yield
Water productivity (kg/ha mm) = Grain yield (kg/ha) ÷ Water use (m^3)

Among the growth parameters; tiller/m^2, leaf area index, light interception, root dry weight and root volume were measured and among the yield parameters; panicles/m^2, filled grains per panicle and 1000 grain weight were recorded. Mineral N (NH_4^+ and NO_3^--N) concentration in 2 M KCl extracts was measured by micro-Kjeldahl distillation method (Keeney and Nelson 1982). Photosynthetic rate (Pn; µmol CO_2/ m/^{2}/s) and transpiration rate (TR; mmol $H_2O/m^2/s$) were measured in flag leaf at flowering stage using portable photosynthesis system (Model PP Systems, TPS-2).

The data obtained was subjected to analysis of variance using R software (version 3.2.0; Developer: R Core Team, University of Auckland, New Zealand). Significantly different treatment means were separated using Fisher's protected least significant difference (LSD) test (Steel *et al.*, 1997).

Results and Discussion

Growth parameters

All the growth parameters showed significant response to changes made in water management practices (Table 1). Nitrogen levels also significantly affected rice growth parameters. Data pooled over two years revealed that I_2 (3DAPW) produced 6% and 12% higher tiller/m^2 as compared to I_1(flooded condition) and I_3 (6DAPW) respectively. The leaf area index (LAI) of I_2 was at par with I_1 but significantly (11%) higher than I_3. N_1, N_2 and N_3 increased tillering by about 15, 21 and 25%, respectively over N_0. LAI in N_0 was respectively reduced by 21%, 36% and 44% as compared to N_1, N_2 and N_3. I_3 intercepted 85% of PAR whereas I_1 and I_2 intercepted 89% and 91% of the PAR, respectively. Increasing levels of N resulted in significantly higher PAR interception. As N levels were increased from N_0 to N_1, N_2 and N_3, PAR interception was 82, 88, 89 and 92.7%, respectively. Plants grown under I_2 irrigation regime produced highest root dry weight and root volume. Root dry weight was reduced by about 6% and 13% respectively in I_1 and I_3. Root volume was decreased by 6% and 8% respectively in I_1 and I_3 as compared to I_2.

Soil mineral nitrogen

Irrigation regimes had a significant effect on mineral N content (Table 1). Highest NH_4^+ N content was found under submerged irrigation regime (I_1) followed by I_2 and I_3. The lowest NO_3^- N content was observed in I_1 while as I_2 and I_3 were at par with each other. Increasing levels of N resulted in a significant increase in mineral-N. NH_4^+ N was higher by 4%, 6% and 9%, respectively in N_1, N_2 and N_3 as compared to N_0. The corresponding increase in NO_3^- N content was about 48%, 114% and 164%.

Physiological parameters

The rate of photosynthesis was highest in I_2 followed by I_1 and I_3 (Table 1). Photosynthetic rate among N levels was in the order of $N_3>N_2=N_1>N_0$. The transpiration rate under I_1 was significantly ($P\leq0.05$) higher than I_2 and I_3. I_1 and I_2 registered on par SPAD values but both higher SPAD values as compared to I_3. Nitrogen being an integral part of chlorophyll had a profound effect on SPAD values. On an average N_1, N_2 and N_3 resulted in an increase in SPAD values by 27.7, 34.0 and 41.0% over N_0. Water productivity was found significantly higher under I_3 (5.85 kg/ ha mm) compared with I_2 (5.23 kg/ha mm) and I_3 (3.96 kg/ha mm). Total water (rainfall + irrigation) utilization was highest under I_1 followed by I_2 and I_3. Thus, there was a saving of 20% water under I_2 and 38% under I_3 compared to I_1.

Yield attributes and yield

I_2 resulted in about 12% and 5% increase in panicles/m^2 over I_3 and I_1 respectively (Table 2). Increasing levels of N from N_1, N_2 to N_3 increased panicles/m^2 by 16, 26 and 30% respectively over N_0. Irrigation level I_3 significantly reduced the number of grains/panicle by 7% while as I_1 and I_2 were at par with each. N_1, N_2 and N_3 significantly increased number of grains by 16.7, 24.0 and 37 % respectivelyover N_0. Irrigation regimes did not affect 1000 grain weight. N_1, N_2 and N_3 increased 1000 grain weight by about 7, 10 and 14% respectively. Grain and straw yields were also significantly affected by irrigation regimes and nitrogen levels. The reduction in grain yield in I_1 and I_3 was to the tune of 6% and 16%, respectively as compared to I_2. The increase in grain yield in N_1, N_2 and N_3 was of the order of 48, 60 and 75% over N_0. Straw yield in I_2 was 8% and 15% higher than I_1 and I_3 respectively. On an average N_1, N_2 and N_3 resulted in increase of 34, 40 and 54% in straw yield over N_0.

Table.1 Effect of irrigation regimes and nitrogen levels on plant growth and physiological parameters

	Tillers /m^2	**LA I**	**PAR intercepted (%)**	**SPAD**	**Root dry weight (g/m)**	**Root volume (ml/m)**	**Soil NH_4^+ N (mg/ kg)**	**Soil NO_3^- N (mg/kg)**	**Photosynthetic rate (Pn) (μ mol/ m^2/s)**	**Transpiration rate (TR) (mmol/m^2/s)**
Irrigation levels										
I_1	383	4.32	89.4	34.7	286	1177	13.58	9.21	21.27	7.23
I_2	406	4.37	91.8	35.6	305	1253	11.65	10.34	23.49	6.60
I_3	362	3.92	85.3	32.1	270	1157	10.13	10.83	20.82	5.94
SE m±	6.75	0.09	1.64	0.62	4.82	23.65	0.50	0.45	0.72	0.16
LSD (5%)	17.27	0.23	3.64	1.58	12.35	60.54	1.29	1.16	1.85	0.41
Nitrogen levels										
N_0	335	3.30	82.2	27.1	232	1078	7.35	5.84	20.63	6.42
N_1	384	4.01	88.0	34.6	259	1163	10.12	8.65	22.17	6.66
N_2	404	4.49	89.2	36.4	278	1193	11.70	12.38	21.92	6.89
N_3	415	4.74	92.7	38.3	292	1232	13.94	15.46	24.46	7.97
SE m±	7.81	0.12	1.54	0.61	5.64	20.87	0.86	0.76	0.60	0.13
LSD (5%)	20.15	0.31	3.98	1.57	14.55	53.84	2.22	1.95	1.55	0.34

Table.2 Effect of irrigation regimes and nitrogen levels on rice yield

	Panicles/m^2	**Grains/panicle**	**1000 grain weight (g)**	**Grain yield (t/ ha)**	**Straw yield (t/ ha)**
Irrigation levels					
I$_1$	365	79.8	25.52	6.18	7.94
I$_2$	384	80.4	25.83	6.50	8.58
I$_3$	342	74.0	25.31	5.63	7.44
SE m±	6.52	1.43	0.60	0.12	0.11
LSD (5%)	16.63	3.64	NS	0.30	0.27
Nitrogen levels					
N$_0$	310	65.2	23.73	4.08	5.94
N$_1$	361	76.1	25.31	6.04	7.90
N$_2$	391	81.3	26.15	6.64	8.29
N$_3$	404	89.4	27.09	7.26	9.15
SE m±	7.17	1.58	0.50	0.14	0.17
LSD (5%)	18.51	4.07	1.29	0.36	0.43

Table.3 Effect of irrigation regimes and nitrogen levels on N, P and K (kg/ha) uptake and nitrogen recovery efficiency (%) in rice under SRI method

	N	**REN (%)**	**P**	**K**
Irrigation levels				
I$_1$	111.9	50.5	28.8	132.3
I$_2$	108.9	52.3	30.0	135.1
I$_3$	102.2	47.8	26.4	123.8
SE m±	2.16	-	0.59	2.07
LSD (5%)	5.52	-	1.5	5.29
Nitrogen levels				
N$_0$	69.1	-	19.8	95.9
N$_1$	105.4	44.9	28.7	132.6
N$_2$	120	51.0	30.2	138.2
N$_3$	135.1	54.6	34.8	155
SE m±	2.10	-	0.58	2.88
LSD (5%)	5.42	-	1.49	7.44

Fig.1 Relationship of physiological parameters and grain yield of rice as affected by irrigation regimes and nitrogen levels

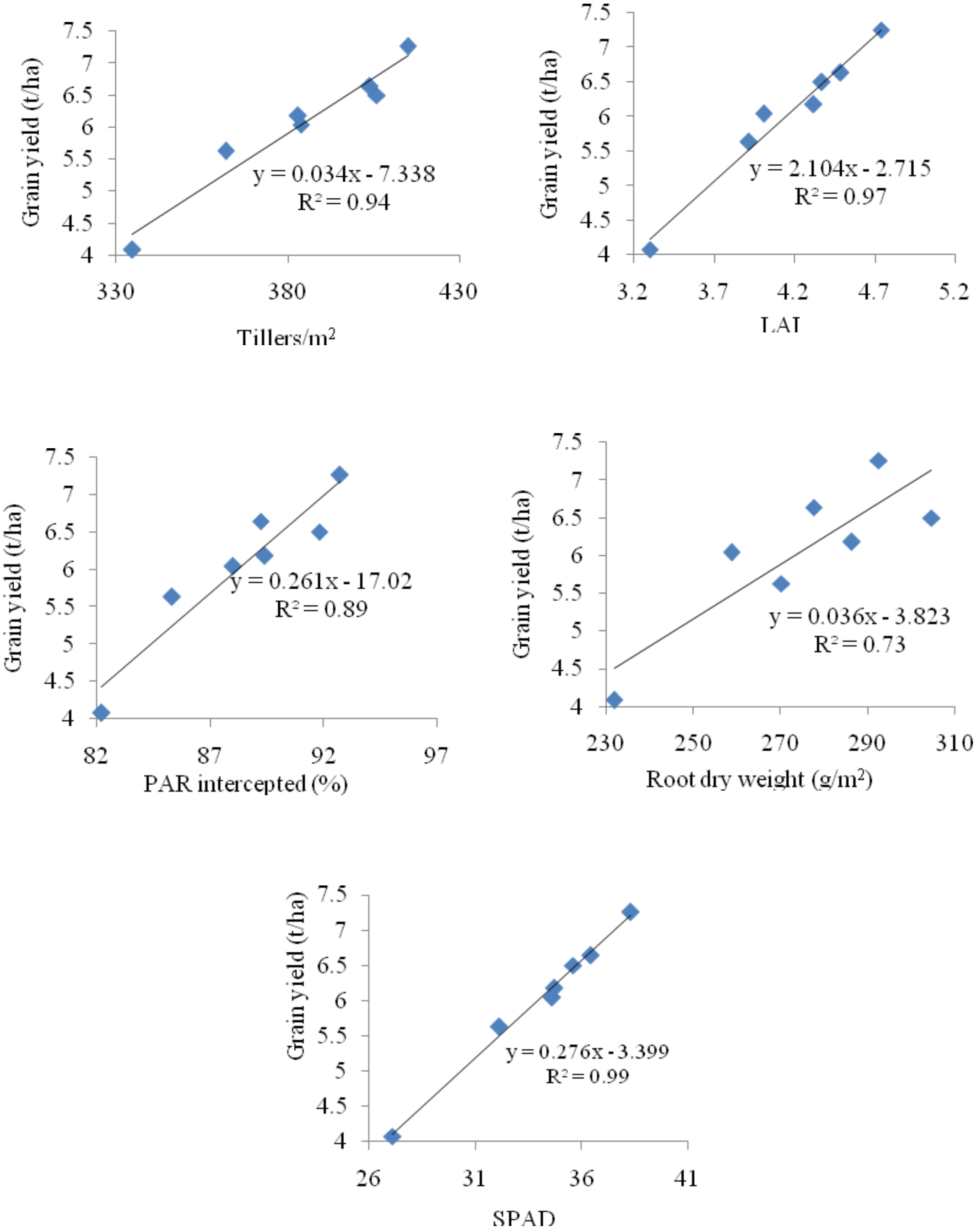

Table.4 Effect of irrigation regimes on water productivity and water saving

Irrigation regimes	No. of irrigations		Irrigation		Rain (mm)		Total water use (mm)		Water saving (%)		Water productivity (kg/m^3)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
I_1	26	30	1300	1500	633	285	1933	1785	-	-	0.32	0.34
I_2	13	17	650	850	633	285	1283	1135	33.6	36.4	0.49	0.54
I_3	9	10	450	500	633	285	1083	785	44.0	56.0	0.53	0.70

Relationship of growth and physiological parameters with grain yield

Coefficients worked out between the growth parameters and yield demonstrated a signification and positive correlation (Fig. 1). The correlation coefficients recorded between the grain yield and tillers/m^2, grain yield and LAI, grain yield and PAR intercepted, grain yield and root dry weight, grain yield and SPAD were 0.94, 0.97, 0.89, 0.73 and 0.99. This indicates that the grain yield is actually dependent on these growth and physiological parameters.

Nutrient uptake and N use efficiency

I_1 and I_2 had at par N uptake but there was decrease of about 9% in I_3 (Table 3). Since N has strong on dry matter accumulation, it significantly affected N, P and K uptake. On an average, N uptake increased by 53, 73 and 99% in N_1, N_2 and N_3 over N_0, respectively. Similarly P uptake was at par in I_1 and I_2 but decreased significantly in I_3. Data averaged over two years revealed that I_3 resulted in about 10% reduction in P uptake. Nitrogen stimulates the growth of both above and below ground plant parts and therefore influenced the uptake and partitioning of other nutrients. The total P uptake increased by 45, 52 and 76% at N_1, N_2 and N_3, respectively. Likewise K uptake was also significantly affected by irrigation regimes, I_1 and I_2 recorded at par K uptake but the same significantly reduced in I_3. On averaged there was increase of 38, 44 and 61% increase in K uptake at N_1, N_2 and N_3 over N_0, respectively. The N recovery efficiency decreased at I_2 and I_3.

Water use and water productivity

The no of irrigations required in I_2 and I_3 was far lesser than the I_1 irrigation regime (Table 4). The no of irrigations and irrigation water applied during 2015 was lower in 2015 than 2016. The rain received during the cropping season in 2015 was 633 and 285 mm in 2016. Total water use in 2016 was lower than 2015 that resulted in higher water saving in 2016. Water saving in I_2 ranged between 33 to 36% where as it ranged between 44 to 56% in I_3 over I_1. Intermittent irrigation in I_2 and I_3 resulted in considerably higher water productivity over I_3.

It was observed a significant influence of different water management practices and N levels on plant growth, physiology, yield, water productivity and soil mineral nitrogen under temperate conditions of Kashmir. However no significant interaction effects between irrigation regimes and nitrogen levels was noticed. Under aerobic environment, nitrogen is transformed to nitrate by the process of nitrification and that is why in I_2 and I_3 higher amounts on nitrate N were observed. The significantly superior performance was observed under 3DAPW treatment as compared to continuous submergence. Plants grown under 6DAPW treatment showed lowest growth. We presume that severe moisture stress under 6DAPW treatment reduced growth parameters and physiological performance which consequently lead to significant decline in grain and straw yield. Further continuous submergence also hampered the normal plant growth to a significant extent. Kima *et al.,* (2014) reported that continuous submergence is not required to produce optimum rice yields if sufficient water is supplied at critical growth stages. Maintenance of soil in moist, non-flooded condition offers an opportunity for rice plant to develop larger root systems (Mishra and Salokhe, 2011). Continuous submergence creates hypoxic conditions and lowers redox potential of soil which adversely affect development and activity of roots (Thakur *et al.,* 2011). The plants grown under such conditions show a higher percentage of decayed roots, more vulnerability to drought stress and attenuated physiological performance (Kar *et al.,* 1974). Due to alternate wetting and drying sufficient oxygen is supplied to the root system. This inhibits soil nitrogen immobilization and accelerates oxidation of soil organic matter which consequently improves the soil fertility to favour rice growth (Bouman, 2007). Nguyen *et al.,* 2009 reported that leaf elongation increases significantly when soil is kept just saturated and not flooded. We attribute higher LAI observed under 3DAPW treatment to higher number of tillers m^{-2} and greater leaf size. Earlier Tadesse *et al.,* (2013) reported that continuous submergence reduces leaf area index, tiller count and crop growth rate. The relatively higher weight and volume of roots observed under 3DAPW treatment can be regarded as a plant adoption strategy to accrue water and nutrient absorption capacity (Kima *et al.,* 2014; Ascha *et al.,* 2005). The greater interception of photosynthetically active radiation (PAR) in 3DAPW treatment could be related to higher leaf area index (LAI) and more number of tillers/m^2. The higher light utilization capacity and photosynthetic rate of SRI plants was also reported by Thakur *et al.,* (2011. The improved physiological performance in I$_2$ (3DAPW) treatment could be due to greater activity and development of root system which increases the transport of cytokinins to leaves via xylem for maintenance of higher photosynthetic rate (San-oh *et al.,* 2004). Yield advantage under 3DAPW practice can be attributed to better plant phenotypes (greater root and shoot growth) and improved physiological performance during the flowering stage of crop growth. This finally translated into significantly higher grain and straw yield. The greater remobilization of carbon reserves from vegetative parts to grains caused due to improved root and shoot growth could also be a reason for higher grain yield (Zhang *et al.,* 2008). The highest water productivity was obtained under I$_3$ (6DAPW) treatment followed by I$_2$ (3DAPW) and I$_1$ (continuous submergence) treatment. Further I$_2$ and I$_3$ resulted in water saving of 20% and 38% respectively. However, significant penalty in terms of plant growth and yield in 6DAPW treatment out-weighs the benefits of its water savings. It is worth mentioning that when the region (Jammu & Kashmir) already has a deficit of 0.6 million tonnes (25.0%) of rice, yield of rice (being the staple food), cannot be sacrificed at the cost of water saving. On the other hand the excessive supply of water under continuous submergence conditions far exceeds the needs of rice plant and goes as wastage (Hidayati *et al.,* 2016). This assumes significance as increasing water crisis due to global climate change scenario threatens the sustainability of irrigated rice production (Postel, 1997).

In the present study we observed the best response in terms of growth, physiology, water productivity and yield at N$_3$ (120 kg) rate of N application. However, plant response was on an increasing trend even at the highest rate (120 kg/ha). A significant effect of irrigation regimes was recorded on N, P and K plant uptake. I_1 and I_2 had at par N, P and K uptake but significantly higher that than I_3. Lower grain and straw yield contributed to lower N, P and K uptake in I_3 level of irrigation. Increased level of N, P and K uptake at higher N level is attributed to higher biomass production at higher N levels. N recovery efficiency decreased slightly in I_2 and I_3. Higher nitrification rates and lower grain and straw yield in I_2 and I_3 resulted in lower N recovery. However, relatively higher N recovery efficiency was recorded at higher N levels. Total water used during 2016 was lower than that of 2015 that resulted in higher water productivity. Highest water productivity was recorded in I_3 due to longer drying period and reduced water requirement. However there was a significant reduction in the grain yield in I_3 and there not economically viable.

In conclusion, this study demonstrates that with a certain water management practice it is possible to concurrently achieve the dual target of increasing rice yield and decreasing the water requirements for irrigated rice. The irrigation regime I_2 *i.e* irrigation 3 days after the disappearance of ponded water, results in highest grain yield. Although I_3 resulted in highest water productivity but the same was achieved at the cost of grain yield. Among the N levels grain yield increased significantly upto N_3 i.e 120 kg N/ha.

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