Original Research Article

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

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ABSTRACT

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 (I1); Irrigation at 3 days after disappearance of ponded water (I2); Irrigation at 6 days after the disappearance of ponded water (I3) in main plots and four nitrogen doses viz., 0 kg/ha (N0); 80 kg/ha (N1); 100 kg/ha (N2); 120/kg ha (N3) in subplots. Results revealed that with I1 water management practice it is possible to simultaneously increase the yield and decrease the water requirements of irrigated rice significantly. I2 increased the grain yield by about 6% and 16% as compared to I1 and I3, respectively. Continuous submergence resulted in significant yield penalty and considerable wastage of water while as I3 condition created acute moisture deficit in the soil which finally translated into poor crop stand. The benefits of water saving in I1 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 N0 to N3. The yield gain in N1, N2 and N3 was 48%, 60% and 75% as compared to N0.

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

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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 (Boorman 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 indispensable.
(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 study 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 (10.1 mg P/kg soil) and potassium (128 mg K/kg soil). Treatments comprised of three irrigation regimes; flooded conditions (I₁), irrigation at 3 days after disappearance of ponded water (3DAPW) (I₂) and irrigation at 6 days after the disappearance of ponded water (6DAPW) (I₃) in main plots and four nitrogen levels viz., 0 kg/ha (N₀), 80 kg/ha (N₁), 100 kg/ha (N₂) and 120 kg/ha (N₃) in subplots, tested in a split-plot design and replicated thrice. In plots under I₂ and I₃ 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 m² 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 \times yield
Water productivity (kg/ha mm) = Grain yield (kg/ha) \div Water use (m³)

Among the growth parameters; tiller/m², leaf area index, light interception, root dry weight and root volume were measured and among the yield parameters; panicles/m², filled grains per panicle and 1000 grain weight were recorded. Mineral N (NH₄⁺ and NO₃⁻-N) concentration in 2 M KCl extracts was measured by micro-Kjeldahl distillation method (Keeney and Nelson 1982). Photosynthetic rate (Pn; µmol CO₂/ m²/s) and transpiration rate (TR; mmol H₂O/m²/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 I₂ (3DAPW) produced 6% and 12% higher tiller/m² as compared to I₁(flooded condition) and I₃ (6DAPW) respectively. The leaf area index (LAI) of I₂ was at par with I₁ but significantly (11%) higher than I₃, N₁, N₂ and N₃ increased tillering by about 15, 21 and 25%, respectively over N₀. LAI in N₀ was respectively reduced by 21%, 36% and 44% as compared to N₁, N₂ and N₃. I₁ intercepted 85% of PAR whereas I₁ and I₂ intercepted 89% and 91% of the PAR, respectively. Increasing levels of N resulted in significantly higher PAR interception. As N levels were increased from N₀ to N₁, N₂ and N₃, PAR interception was 82, 88, 89 and 92.7%, respectively. Plants grown under I₂ irrigation regime produced highest root dry weight and root volume. Root dry weight was reduced by about 6% and 13% respectively in I₁ and I₃. Root volume was decreased by 6% and 8% respectively in I₁ and I₃ as compared to I₂.

Soil mineral nitrogen

Irrigation regimes had a significant effect on mineral N content (Table 1). Highest NH₄⁺ N content was found under submerged irrigation regime (I₁) followed by I₂ and I₃. The lowest NO₃⁻ N content was observed in I₁ while as I₂ and I₃ were at par with each other. Increasing levels of N resulted in a significant increase in mineral-N. NH₄⁺ N was higher by 4%, 6% and 9%, respectively in N₁, N₂ and N₃ as compared to N₀. The corresponding increase in NO₃⁻ N content was about 48%, 114% and 164%.

Physiological parameters

The rate of photosynthesis was highest in I₂ followed by I₁ and I₃ (Table 1). Photosynthetic rate among N levels was in the order of N₃>N₂=N₁>N₀. The transpiration rate under I₁ was significantly (P≤0.05) higher than I₂ and I₃. I₁ and I₂ registered on par SPAD values but
both higher SPAD values as compared to I₁. Nitrogen being an integral part of chlorophyll had a profound effect on SPAD values. On an average N₁, N₂ and N₃ resulted in an increase in SPAD values by 27.7, 34.0 and 41.0% over N₀. Water productivity was found significantly higher under I₃ (5.85 kg/ha mm) compared with I₂ (5.23 kg/ha mm) and I₁ (3.96 kg/ha mm). Total water (rainfall + irrigation) utilization was highest under I₁ followed by I₂ and I₃. Thus, there was a saving of 20% water under I₂ and 38% under I₃ compared to I₁.

**Yield attributes and yield**

I₂ resulted in about 12% and 5% increase in panicles/m² over I₃ and I₁ respectively (Table 2). Increasing levels of N from N₁, N₂ to N₃ increased panicles/m² by 16, 26 and 30% respectively over N₀. Irrigation level I₃ significantly reduced the number of grains/panicle by 7% while as I₁ and I₂ were at par with each. N₁, N₂ and N₃ significantly increased number of grains by 16.7, 24.0 and 37% respectively over N₀. Irrigation regimes did not affect 1000 grain weight. N₁, N₂ and N₃ 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 I₁ and I₃ was to the tune of 6% and 16%, respectively as compared to I₂. The increase in grain yield in N₁, N₂ and N₃ was of the order of 48, 60 and 75% over N₀. Straw yield in I₂ was 8% and 15% higher than I₁ and I₃ respectively. On an average N₁, N₂ and N₃ resulted in increase of 34, 40 and 54% in straw yield over N₀.

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

|                  | Tillers /m² | LA I | PAR intercepted (%) | SPAD | Root dry weight (g/m) | Root volume (ml/m) | Soil NH₄⁺ N (mg/kg) | Soil NO₃⁻ N (mg/kg) | Photosynthetic rate (Pn) (μ mol/ m²/s) | Transpiration rate (TR) (mmol/m²/s) |
|------------------|-------------|------|---------------------|------|-----------------------|--------------------|-------------------|-------------------|--------------------------------------|--------------------------------------|
| **Irrigation levels** |             |      |                     |      |                       |                    |                   |                   |                                      |                                      |
| I₁               | 383         | 4.32 | 89.4                | 34.7 | 286                   | 1177               | 13.58             | 9.21              | 21.27                  | 7.23                                 |
| I₂               | 406         | 4.37 | 91.8                | 35.6 | 305                   | 1253               | 11.65             | 10.34             | 23.49                  | 6.60                                 |
| I₃               | 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** |             |      |                     |      |                       |                    |                   |                   |                                      |                                      |
| N₀               | 335         | 3.30 | 82.2                | 27.1 | 232                   | 1078               | 7.35              | 5.84              | 20.63                  | 6.42                                 |
| N₁               | 384         | 4.01 | 88.0                | 34.6 | 259                   | 1163               | 10.12             | 8.65              | 22.17                  | 6.66                                 |
| N₂               | 404         | 4.49 | 89.2                | 36.4 | 278                   | 1193               | 11.70             | 12.38             | 21.92                  | 6.89                                 |
| N₃               | 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/m² | Grains/panicle | 1000 grain weight (g) | Grain yield (t/ha) | Straw yield (t/ha) |
|---------------------|-------------|----------------|-----------------------|-------------------|-------------------|
| **Irrigation levels** |             |                |                       |                   |                   |
| I₁                  | 365         | 79.8           | 25.52                 | 6.18              | 7.94              |
| I₂                  | 384         | 80.4           | 25.83                 | 6.50              | 8.58              |
| I₃                  | 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** |             |                |                       |                   |                   |
| N₀                  | 310         | 65.2           | 23.73                 | 4.08              | 5.94              |
| N₁                  | 361         | 76.1           | 25.31                 | 6.04              | 7.90              |
| N₂                  | 391         | 81.3           | 26.15                 | 6.64              | 8.29              |
| N₃                  | 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** |       |         |       |       |
| I₁                  | 111.9 | 50.5    | 28.8  | 132.3 |
| I₂                  | 108.9 | 52.3    | 30.0  | 135.1 |
| I₃                  | 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** |       |         |       |       |
| N₀                  | 69.1  | -       | 19.8  | 95.9  |
| N₁                  | 105.4 | 44.9    | 28.7  | 132.6 |
| N₂                  | 120   | 51.0    | 30.2  | 138.2 |
| N₃                  | 135.1 | 54.6    | 34.8  | 155   |
| SE m±               | 2.10  | -       | 0.58  | 2.88  |
| LSD (5%)            | 5.42  | -       | 1.49  | 7.44  |

813
**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 (mm) | Rain (mm) | Total water use (mm) | Water saving (%) | Water productivity (kg/m²) |
|--------------------|-------------------|----------------|-----------|---------------------|----------------|--------------------------|
|                    | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| I₁                 | 26   | 30   | 1300 | 1500 | 633  | 285  | 1933 | 1785 |       |       | 0.32 | 0.34 |
| I₂                 | 13   | 17   | 650  | 850  | 633  | 285  | 1283 | 1135 | 33.6  | 36.4  | 0.49 | 0.54 |
| I₃                 | 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/m², 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

I₁ and I₂ had at par N uptake but there was decrease of about 9% in I₃ (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 N₁, N₂ and N₃ over N₀, respectively. Similarly P uptake was at par in I₁ and I₂ but decreased significantly in I₃. Data averaged over two years revealed that I₃ 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 N₁, N₂ and N₃, respectively. Likewise K uptake was also significantly affected by irrigation regimes, I₁ and I₂ recorded at par K uptake but the same significantly reduced in I₃. On averaged there was increase of 38, 44 and 61% increase in K uptake at N₁, N₂ and N₃ over N₀, respectively. The N recovery efficiency decreased at I₂ and I₃.

Water use and water productivity

The no of irrigations required in I₂ and I₃ was far lesser than the I₁ 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 I₂ ranged between 33 to 36% where as it ranged between 44 to 56% in I₃ over I₁. Intermittent irrigation in I₂ and I₃ resulted in considerably higher water productivity over I₃.

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 I₂ and I₃ 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/m². The higher light utilization capacity and photosynthetic rate of SRI plants was also reported by Thakur et al., (2011). The improved physiological performance in I₂ (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 I₃ (6DAPW) treatment followed by I₂ (3DAPW) and I₁ (continuous submergence) treatment. Further I₂ and I₃ 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 (Hidayatyi 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 N₃ (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. I₁ and I₂ had at par N, P and K uptake but significantly higher than I₃. Lower grain and straw yield contributed to lower N, P and K uptake in I₃ 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 I₂ and I₃. Higher nitrification rates and lower grain and straw yield in I₂ and I₃ 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 I₃ due to longer drying period and reduced water requirement. However there was a significant reduction in the grain yield in I₃ 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 I₂ i.e irrigation 3 days after the disappearance of ponded water, results in highest grain yield. Although I₃ 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 N₃ i.e 120 kg N/ha.

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