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Effect of irrigation methods, moisture regimes and integrated nitrogen management on growth, yield and quality of potato (*Solanum tuberosum* L.)

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Abstract
A field experiment was conducted in split-plot design during the (*rabi*) 2015-16 at Agronomy Research Farm, ANDUAT, Kumarganj, Ayodhya (U.P.) to evaluate the response of potato to irrigation methods, moisture regimes and nitrogen management. The growth characters *viz*. plant height, number of haulms, number of leaves at 60 DAP and fresh weight of haulms (dehaulming stage) were significantly superior under regular furrow irrigation method, 1.0 IW/CPE and 75% dose of urea through N+25% dose of N through FYM over their counterparts. In case of nitrogen management all the growth characters were recorded highest under nitrogen management treatment 75% dose of urea through N + 25% dose of N through FYM, which was statistically superior over rest of nitrogen management treatments. Yield attributes *viz*., Number of superior grade tubers (>75g)/hill, weight of superior grade tubers (>75g) kg/plot and tuber yield (q/ha) were found highest under regular furrow method of irrigation (M_1) and moisture regime, 1.0 IW/CPE (I_2) over 0.8 IW/CPE (I_1) and 1.2 IW/CPE (I_3). Number of all grade of tubers was found to be significant due to effect of moisture regimes. In nitrogen management all the yield attributes were recorded significantly higher under nitrogen management treatment (N_2), which was statistically superior over rest of the nitrogen management treatments. Quality parameters *viz*., dry matter (%) and starch content in tuber (%) was found highest under regular furrow method of irrigation (M_1) and moisture regime, 1.0 IW/CPE (I_2) and nitrogen management treatment (N_2). The highest Net return (Rs/ha) and B:C ratio was recorded with regular furrow method (M_1) in combination with I_2 (1.0 IW/CPE ratio) and N_2 nitrogen management practice (75% dose of N through Urea+25% N through FYM) followed by M_1I_2 N_2 and $M_2I_2N_2$ respectively.

Keywords: B:C ratio, FYM, irrigation methods, moisture regimes, nitrogen management, water use efficiency

Introduction
Production of potato (*Solanum tuberosum* L.) takes a very important place in world agriculture, with a production potential of about 370 million ton harvested and 17 million ha area (Anonymous, 2018-19) [1, 2]. Potato is a water-stress-sensitive crop. Potato plants are more productive and produce higher quality tubers when watered precisely using soil water tension (SWT) than if they are under- or over irrigated (Ati *et al*., 2012) [3]. India is the second largest producer of potato with the production of 51.3 mt from an area of 2.16 mha (Anonymous, 2018-19) [1, 2].

Nitrogen is the most limiting nutrient in potato production and has a great influence on crop growth, tuber yield and quality. A mature crop of potato yielding 25-30 tonnes tuber/ha consumes about 120-140 kg N/ha. However, excess of N delays tuber initiation and onset of linear phase of tuber growth, ultimately resulting in lower yield. The Indian soils are generally deficient in organic matter, thus unable to release N at the rate required to maintain adequate supply to the growing plant. Therefore, application of nitrogen in form of fertilizers and manures becomes indispensable to meet the needs of the crop (Trehan *et al*., 2008) [18]. The application of organic manures particularly FYM or compost is recommended for potato crop and it helps in improving the physical conditions of soils, such as texture and its water holding capacity.

FYM also supplies macro and micro nutrients and maintains healthy positive nutrient balance besides being a source of organic matter, and further it emphasizes the need for integrated and balanced nutrient management in potato (Sharif *et al*., 2014) [14]. Water is another important input for potato production and its management problem varies from methods of irrigation. Optimum soil moisture need to be maintained in root zone to meet crop requirement for higher yield. Normally in potato furrow irrigation method is adopted for its growth and tuber formation. Normally in potato furrow irrigation method is adopted for its growth and tuber formation. In every furrow irrigation, the water is advanced both laterally and downwards as it moves along the irrigated furrow and eventually the lateral wetted fronts from the adjacent furrow meets. But when irrigation water is deficient, water has to be saved without much reduction in yield. The practice of alternate furrow irrigation results in application of water to one side of each crop row. The entire soil surface may still be thoroughly wetted after irrigation due to lateral movement and applied water is reduced by 25 to 35 per cent compared to every furrow irrigated method with a slight (2-16%) reduction in crop yield. Thus, one of the best methods of deficit irrigation is alternate furrow method of irrigation. Each plant is irrigated by infiltration from one side of furrow in this method. This method promotes irrigation efficiency and prevents losses of water (Stone *et al.* 1993) [16]. The yield, quality and disease resistance is greatly influenced by timing and frequency of irrigation applied (Murtani and Guz, 1989) [6]. Further, the crop due to its high turnover has high nutrient requirement particularly of nitrogen. Irrigation regime is also crucial in determining plant ability to take up the nitrogen available in the soil, since a well-watered crop is more capable to take benefit of the applied fertilizer. Adequate and timely supply of irrigation and optimum dose of nutrients to crop contribute maximum to the growth and nutrients uptake by crop (Verma and Idnani, 2012) [19]. The farmers on the other hand apply water to the crop without regard to whether the plant actually needs water at that stage. Thus, there is a great need of an appropriate irrigation scheduling to get higher production with better post-harvest characteristic.

Materials and Methods

The present field experiment was conducted during the *rabi* season (2015-16) at Agronomy Research Farm, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Faizabad (U.P.). The field was well drained and properly leveled. The soil of experimental field was silt loam, low in organic carbon (0.35%) and available N (147.5kg/ha), medium in P_2O_5 (14.50kg/ha) and K_2O (210.1kg/ha) having alkaline pH (8.0). The experiment was conducted in split plot design with 4 replications. The experiment comprised 18 treatment combinations keeping the irrigation methods *viz*., M_1 (Regular furrow irrigation method), M_2 (Alternate furrow irrigation method) and moisture regime I_1 (6 cm irrigation at 0.8 IW/CPE), I_2 (6 cm irrigation at 1.0 IW/CPE)and I_3 (6 cm irrigation at 1.2 IW/CPE) as main plot and 3 nitrogen levels such as N_1 [Recommended dose of N through Urea (150kg/ha)], N_2 (75% dose of N through Urea+25% N through FYM) and N_3 (50% dose of N through Urea+50% N through FYM) in sub-plots. Required quantities of nitrogen as per treatment through urea were applied in two split doses as top dressing and at the time of earthing and FYM was incorporated 15 days before the planting of potato. At the time of sowing uniform application of fertilizer was given as per treatment as basal dressing in all the plots. Kufri Badshah, a medium duration variety @ 25q seed tuber/ha was used for sowing and furrows were opened at a distance of 60 × 15cm with the help of furrow opener. The crop was grown with recommended practices. Irrigations were applied by tubewell by measuring with the help of V-notch as per treatment. Earthing was done at 35 days after planting with the help of 'Kudal'. Indofil M-45 @ 2kg/ha was sprayed against late blight disease.

Five tagged plants were taken for fresh weight at the time of haulms cutting. The plant was weighted on physical balance and their average fresh weight per plant was worked out for presenting in the table for result purpose.
The dry matter accumulation in tubers was determined on the fresh weight basis. Five samples of 100g tubers from each treatment were taken, cut into small pieces and dried in oven at 65± 2 ^{0}C for 8-10 hours per day till the complete drying to have constant weight and dry weight and dry matter per cent was calculated as:

$$\text{Dry weight content (\%)} = \frac{\text{Dry matter of tuber (g)}}{\text{Fresh weight of tuber (g)}}$$

After dry matter calculation the same sample was kept for starch estimation. The sugars present into samples were leached out, the starch was hydrolyzed and estimated as invert sugar using the following formula:
Starch (%) = Reducing sugar x 0.95
The reducing sugar content was estimated by dinitrosalysilic acid (DNS) re-agent method described by Ranganna (1986) [11].

The benefit cost ratio was computed adopting following formula

$$\text{Benefit: cost ratio} = \frac{\text{Net return(Rs/ha)}}{\text{Cost of cultivation(Rs/ha)}}$$

Results and Discussion

Growth parameters

Perusal of data presented in Table 1 clearly indicated that the plant height (cm), number of haulms and number of leaves at 60 DAP and fresh weight of haulms (dehaulming stage, g/m) was influenced significantly due to the various irrigation methods, moisture regimes and nitrogen management practices. The maximum plant height (46.7cm), number of haulms (36.1/m), number of leaves (352.7/m) and fresh weight of haulms (383.8g/m) was recorded in regular furrow method (M_1) which was significantly higher than alternate furrow method (M_2), while lowest plant height (43.3cm), number of haulms (33.5/m), number of leaves (327.2/m) and fresh weight of haulms (356.2g/m) was recorded in alternate furrow method (M_2). Regarding the different moisture regimes the maximum plant height (47.2cm), number of haulms (36.3/m) and number of leaves (355.0/m) at 60 DAP and fresh weight of haulms (386.4g/m) was recorded in moisture regime I_2 (1.0 IW/CPE ratio) which was significantly higher than I_1 (1.0 IW/CPE) and I_3 (1.2 IW/CPE) while lowest plant height (42.7cm), number of haulms (33.4/m), number of leaves (326.3/m) and fresh weight of haulms (355.1g/m) was recorded with I_3 (1.2 IW/CPE). The increased weight of potato haulms was might be probably due to production of more number of haulms, leaves and taller plants. Patel *et al.* (2000) [8] and Yadav *et al.* (2003) [20] also made similar observations in potato. The data revealed that the maximum plant height (47.8cm), number of haulms (36.9/m) and number of leaves (360.9/m) at 60 DAS and fresh weight of haulms (392.8/gm) was recorded in N_2 nitrogen management practice (75% dose of N through Urea+25% N through FYM) which was significantly higher than N_1 nitrogen management practice (RDN through Urea i.e. 150kg/ha) and N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM) while lowest plant height (42.0cm), number of haulms (33.4/m), number of leaves (316.0/m) and fresh weight of haulms (344.8g/m) was recorded N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM). The increase in growth parameters might be because of better photosynthetic activities in large photosynthetic area. Since, nitrogen is basic minerals associated with synthesis of protoplasm and in primary synthesis of amino acid. It is also an established fact that plant supplied with abundant nitrogen through urea and FYM would assimilate more photosynthates and better translocation resulting in higher vegetative growth. Pandey *et al.* (2007) [7] also reported the similar results.

Number of superior grade tubers (>75g)/hill, Weight of superior grade tubers (kg/plot) and Tuber yield (q/ha)

Critical analysis of data presented in Table 2 clearly indicated that number of tubers/hill and weight of tubers (kg/plot) of superior grade (>75g) was influenced significantly by various irrigation methods, moisture regimes and nitrogen management practices. The maximum number of tubers/hill and weight of tubers (kg/plot) of superior grade of 1.23 and 1.59, respectively was found in regular furrow method (M_1), which was significantly superior over alternate furrow method (M_2), while the lowest number of tubers/hill and weight of tubers (kg/plot) of superior grade of 1.16 and 1.47, respectively was recorded in alternate furrow method (M_2). It might be due to the fact that the ridges under alternate furrow irrigation are relatively dried at one of the sides and becomes compact which may not allow the proper development of tubers. Kumar *et al.* **(**2013) [5] also recorded the similar findings. Regarding the different moisture regimes the maximum number of tubers/hill and weight of tubers (kg/plot) of superior grade of 1.23 and 1.65 respectively, was recorded in moisture regime I_2 (1.0 IW/CPE ratio) which was significantly higher than I_1 (1.0 IW/CPE) and I_3 (1.2 IW/CPE), while the lowest number of tubers/hill and weight of tubers (kg/plot) of superior grade of 1.16 and 1.44 respectively, was recorded in I_3 (1.2 IW/CPE). Taller plants and higher number of leaves under higher moisture regime manufactures larger quantity of photosynthates, which converted and translocated in the tubers during metabolic processes of plants, resulting in more number of tubers/hill and heavier weight/tuber. Our results are in close conformity with the findings of Patel and Patel (2001) [9]. The data collected revealed that the maximum number of tubers/hill and weight of tubers (kg/plot) of superior grade of 1.29 and 1.63, respectively was recorded in N_2 nitrogen management practice (75% dose of N through Urea+25% N through FYM) which was significantly superior over N_1 nitrogen management practice (RDN through Urea i.e. 150 kg/ha) and N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM), while the lowest number of tubers/hill and weight of tubers (kg/plot) of superior grade of 1.10 and 1.44 respectively, was recorded in N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM). It might be due to the increase in the photosynthetic activity of the plant which enhance with the supply and availability of nutrients, which helps in increasing the plant height, number of leaves and number of tubers/hill and per plot. These findings were also supported by Sarkar *et al.* (2011) [12] and Yaseen *et al.* (2011) [21].

A significant increase in the tuber yield was observed in regular furrow method (M_1) over alternate furrow method (M_2), although the pace of increment was 7.77%. Sarker *et al.* (2019) [13] also mentioned that alternate furrow irrigation method gave the highest potato yield in Bangladesh. Among the different moisture regimes, significantly maximum tuber yield was observed in I_2 (1.0 IW/CPE ratio), which was 4.8% and 8.8% higher over I_1 (1.0 IW/CPE) and I_3 (1.2 IW/CPE), respectively. Regarding different nitrogen management practices, the incorporation of 25% N through FYM (N_2) resulted into significantly higher tuber yield over N_1 nitrogen management practice (RDN through Urea i.e. 150kg/ha) and N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM). This treatment out-yielded N_1 and N_3 by 7.1% and 12.1%, respectively.

Dry matter in tuber (%), Starch content in tuber (%) and Water use efficiency (kg/ha-mm)

Dry matter in tuber (%), Starch content in tuber (%) as influenced by various irrigation methods, moisture regimes and nitrogen management have been presented in Fig. 1. The maximum dry matter accumulation (%) and starch content in tuber (%) was found in alternate furrow method (M_2), which was superior over regular furrow method (M_1), while the lowest dry matter accumulation of 18.9% and 12.9% starch content in tuber was recorded in regular furrow method (M_1). Regarding the different moisture regimes, the maximum dry matter (%) and starch content in tuber (%) of 19.3 and 13.3, respectively was recorded with 1.0 IW/CPE ratio (I_2) followed by I_1 (0.8 IW/CPE) and I_3 (1.2 IW/CPE), while the lowest amount of dry matter (%) and starch content in tuber (18.6 and 12.6%), respectively was recorded in I_3 (1.2 IW/CPE). The highest values under I_2 might be due to adequate supply of water under moderate moisture regime, further increase in water content (1.2 IW/CPE) resulted into a slight decrease in dry matter content of the tuber. Singh and Arora (1980) [15] also reported the similar results. Data collected also revealed that the maximum amount of dry matter (%) and starch content in tuber (%) of 19.3 and 13.1, respectively was recorded in N_2 nitrogen management practice (75% dose of N through Urea+25% N through FYM) followed by N_1 nitrogen management practice (RDN through Urea i.e. 150kg/ha) and N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM)), while the lowest amount of dry matter in tuber (%) and starch content in tuber (%) of 18.6 and 12.7, respectively was recorded in N_3 nitrogen management practices (50% dose of N through Urea+50% N through FYM). Little variation in dry matter content under various nitrogen managements treatments may be probably due to the fact that an adequate supply of nitrogen which takes part in the process of synthesis of protoplasm which largely made up of water. It also favours the formation and transfer of sugars in plants and requires in carbohydrate metabolism, which ultimately might have reduced the dry matter content in tubers. Similar findings were also reported by Kavadias *et al.* (2012) [4]. Ramirez *et al.* (2004) [10] and Tajner-Czopek *et al.* (2005) concluded that the application of nitrogen increases the water content of the tuber, which hydrolyses the starch into sugar, thus starch content decreases with increasing doses of nitrogen.

Water use efficiency

Water use efficiency as influenced by various irrigation methods, moisture regimes and nitrogen management have been presented in Fig. 2. Critical analysis of data revealed that the highest water use efficiency (104.53 kg/ha-mm) was recorded under alternate furrow irrigation as compared to regular furrow irrigation in which it was 73.22 kg/ha-mm. An examination of data also indicates that water use efficiency decreased with increasing level of moisture. The maximum water use efficiency (83.62 kg/ha-mm) was recorded under 0.8 IW/CPE moisture regime followed by 1.0 and 1.2 IW/CPE moisture regime in which it was 73.70 and 62.11 kg/ha-mm, respectively. This might be due to the fact that the water is lost more through leaching and evapotranspiration in case of increased water apply in regular furrow irrigation method, 1.0 and 1.2 IW/CPE in comparison to alternate furrow irrigation method and 0.8 IW/CPE. Maximum water use efficiency of 74.93 kg/ha-mm was noticed when 75% of N was applied through Urea and 25% through FYM (N_2) followed by N_1 and N_3 nitrogen management treatments in which it was 69.95 and 68.03 kg/ha-mm, respectively. He highest water use efficiency under this treatment was might be due to the fact that the nutrient is supplied more efficiently without much more losses through leaching and immobilization. Similar findings was also reported by Ati *et al.* (2012) [3]

Economics: Net return (Rs/ha) and benefit cost ratio as influenced by various irrigation methods, moisture regimes and nitrogen management have been presented in Table 3. The maximum net return and benefit cost ratio as influenced by different treatment combinations was recorded with regular furrow method (M_1) in combination with I_2 (1.0 IW/CPE ratio) and N_2 nitrogen management practice (75% dose of N through Urea+25% N through FYM) (86446Rs/ha and 1.33) followed by M_1I_2 N_2 and $M_2I_2N_2$ (82896, 1.25 and 80846 and 1.23, respectively), while the minimum net return and B;C ratio was recorded under $M_2I_3N_3$ treatment combination. Similar findings was also reported by Kumar *et al.* (2013) [5].

Therefore, it can be concluded that regular furrow method (M_1), moisture regime I_2 (1.0 IW/CPE ratio) and integration of nitrogen (75% N through Urea+25% N through FYM) seems to be best for getting the higher tuber yield and yield attributes in the silt loam soils of U.P.

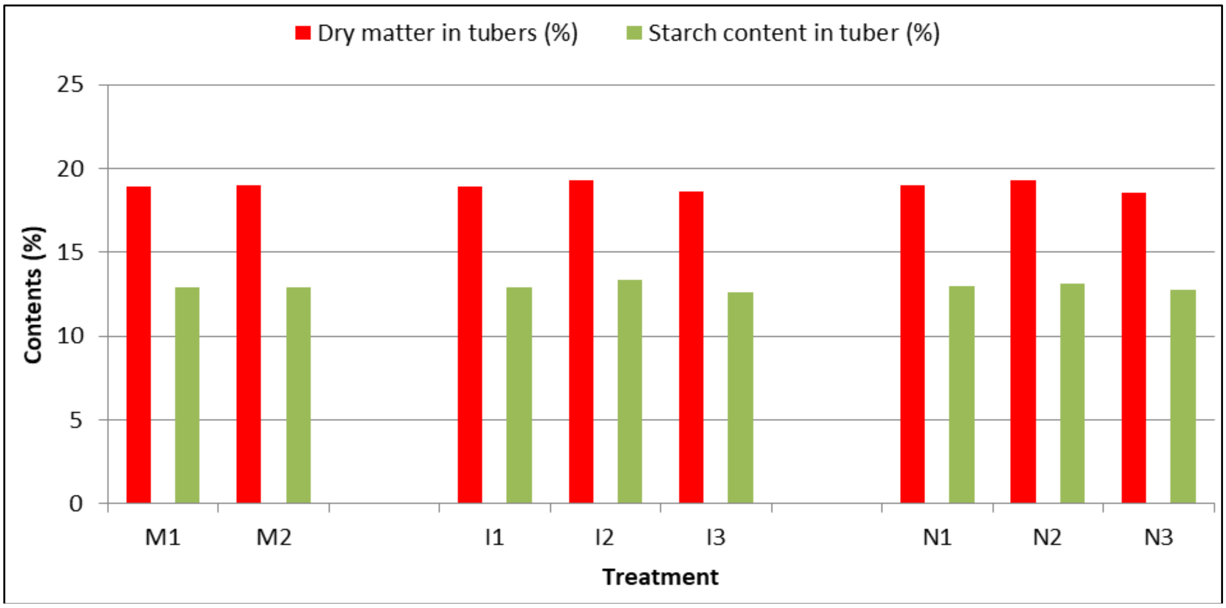

Fig 1: Dry matter accumulation (%) and starch content in tuber (%) as influenced by irrigation methods, moisture regimes and nitrogen management

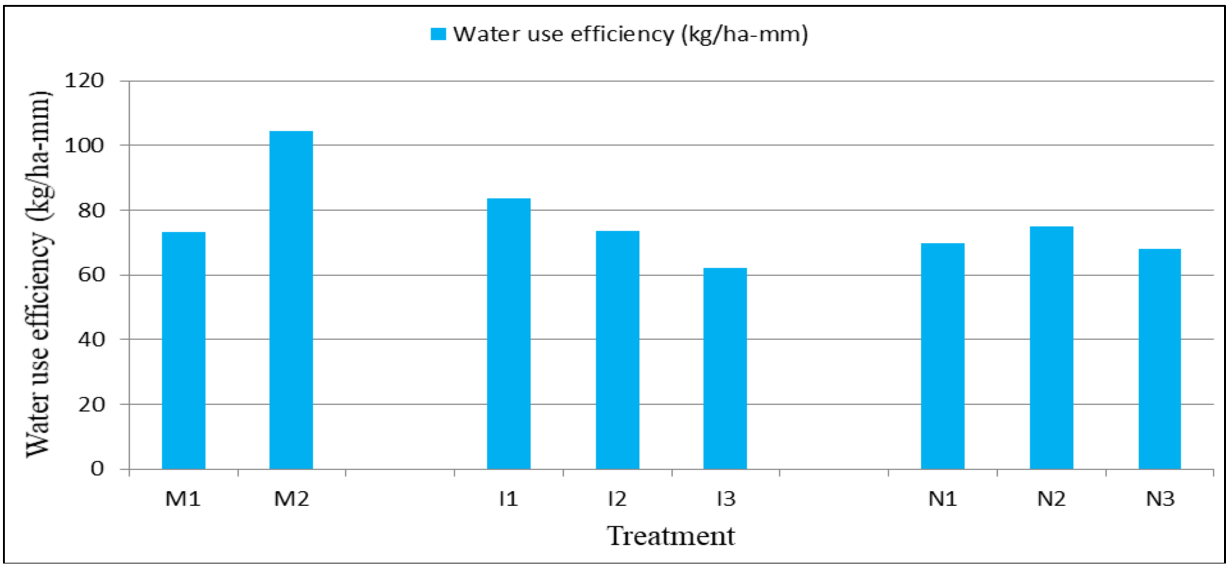

Fig 2: Water use efficiency (kg/ha-mm) as influenced by irrigation methods, moisture regimes and nitrogen management

Table 1: Plant height, number of haulms, number of leaves and dry weight of potato haulms as influenced by irrigation methods, moisture regimes and nitrogen management

Treatment	Plant height (cm)	Number of haulms (m^{-1})	Number of leaves (m^{-1})	Fresh weight (g/m^2) of haulms (dehaulming stage)
	60 DAS			
Irrigation methods				
M_1	46.68	36.10	352.71	383.84
M_2	43.32	33.50	327.2	356.16
S.Em±	0.64	0.44	4.09	4.15
CD at 5%	1.94	1.34	12.33	12.52
Moisture regimes				
I_1	44.95	34.66	338.66	368.55
I_2	47.19	36.34	335.03	386.36
I_3	42.72	33.40	326.31	355.10
S.Em±	0.70	0.54	5.01	5.09
CD at 5%	2.10	1.64	15.11	15.34
Nitrogen management				
N_1	45.25	35.09	343.05	372.55
N_2	47.77	36.94	360.93	392.78
N_3	41.98	33.37	316.02	344.77
S.Em±	0.65	0.54	5.35	5.51
CD at 5%	1.88	1.55	15.34	15.82

Table 2: Number of tubers/hill, weight of tubers (kg/plot) and Tuber yield (q/ha) as influenced by irrigation methods, moisture regimes and nitrogen management

Treatment	Number of superior grade tubers (>75g)/hill	Weight of superior grade tubers (kg/plot)	Tuber yield (q/ha)
Irrigation methods			
M_1	1.23	1.59	352.71
M_2	1.16	1.47	327.2
S.Em±	0.01	0.02	4.09
CD at 5%	0.04	0.07	12.33
Moisture regimes			
I_1	1.18	1.53	338.66
I_2	1.23	1.65	335.03
I_3	1.16	1.44	326.31
S.Em±	0.01	0.32	5.01
CD at 5%	0.05	0.09	15.11
Nitrogen management			
N_1	1.18	1.53	343.05
N_2	1.29	1.63	360.93
N_3	1.10	1.44	316.02
S.Em±	0.01	0.01	5.35
CD at 5%	0.05	0.05	15.34

Table 3: Net return and benefit cost ratio as influenced by irrigation methods, moisture regimes and nitrogen management

Treatment	Net return (Rs/ha)	Benefit: Cost ratio
$M_1I_1N_1$	75324	1.20
$M_1I_1N_2$	86446	1.33
$M_1I_1N_3$	69216	1.03
$M_2I_1N_1$	58174	0.93
$M_2I_1N_2$	65896	1.02
$M_2I_1N_3$	51966	0.77
$M_1I_2N_1$	73974	1.16
M_1I_2 N_2	82896	1.25
$M_1I_2N_3$	67966	0.99
$M_2I_2N_1$	69974	1.10
$M_2I_2N_2$	80846	1.23
$M_2I_2N_3$	63766	0.94
$M_1I_3N_1$	63924	0.99
$M_1I_3N_2$	72046	1.07
$M_1I_3N_3$	57616	0.83
M_2I_3 N_1	56674	0.88
M_2I_3 N_2	65046	0.97
M_2I_3 N_3	50716	0.73

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