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Research Article

Effect of Nitrogen Management on Yield and Water Productivity of *Rajmash* (*Phaseolus vulgaris*) in Sub-humid Climate of Indian Punjab

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ABSTRACT

A field experiment was conducted during 2017 and 2018 to assess the impact of nitrogen management on the growth, yield and water productivity of the *rajmash* (*Phaseolus vulgaris* L.). The experiment was carried out at Punjab Agricultural University Regional Research Station, Gurdaspur, situated in the undulating plain zone of Indian Punjab, in randomized complete block design with twelve treatments replicated thrice. The perusal of data revealed that nitrogen application rate and timings significantly affected the plant height at 60 days after sowing of *rajmash*, where highest plant height, number of seeds per pod and pod length were observed with the application of 51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering. The grain yield, stover yield and water productivity were significantly higher in treatment T_8 where 51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering was applied over the control. The agronomic efficiency data showed that the nitrogen @ 51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering may be recommended for growing *rajmash*. Further long-term studies are recommended to study the environmental aspects of nitrogen application.

Key words: Growing Degree Days, Heat use efficiency, Nitrogen management, *Rajmash*, Water productivity

Introduction

Sustainable and eco-friendly crop production strategies are the important issues those must be considered while adopting short and long-term practices in agricultural systems. The use of chemical fertilizers, in particular, nitrogen fertilizers has significantly affected the growth and yield of many agricultural crops (Singh and Hadda, 2014, Singh and Sharma, 2020). The nutrient management of crops to realize higher yield and quality while maintaining or improving soil fertility status needs new fertilizer formulation and advanced application methods. The nutrient use efficiency of many fertilizers is quite low, particularly under arid to semi-arid climates with calcareous and saline soils (Marschner, 2011; Souri *et al*., 2017). Improved soil application techniques such as deep banding placement, foliar application, pellet or coated fertilizers, are suitable practices for increasing fertilizer use efficiency. The foliar application of mineral nutrients to the plants is also considered efficient method for enhancing nutrient use efficiency. However, all plants respond differently to foliar nutrient application, thus considered complementary to soil fertilizer application (Fernandez and Ebert, 2005).

Rice-wheat cropping system is the major cropping system followed in the Punjab, which

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has not only improved farm income and made self-sufficient in term of food security but also lead to several problems such as declining water table, deteriorating soil health, imbalanced use of agrochemicals. Thus, to combat with the problems associated with rice-wheat monoculture, crop diversification is the need of hour. *Rajmash* (*Phaseolus vulgaris*) being a crop of tropical environment is being introduced to in the sub-mountain undulating zone of Punjab as an alternative to high water and resource consuming crops such as wheat and spring maize. MacWilliam *et al*. (2014) also reported that if some of the area under wheat crops is replaced, it will reduce the negative environmental impacts on global warming, input use, environmental quality, and human health and also lead to economic benefits resulted from low N fertilizer use and high yields.

The pulses are mostly grown on marginal and sub-marginal lands without proper inputs over the globe due to high return from high yielding cereals. In India, pulses are grown over an area of about 23 million hectares with productivity of 443.5 kg ha^{-1} (FAOSTAT, 2019). Among pulses, *rajmash* is becoming popular with the farmers due to its high returns than that of other pulse crops. In India, *rajmash* is cultivated mainly in Jammu and Kashmir, Himachal Pradesh, Utter Pradesh and some parts of Maharashtra, Andhra Pradesh, Western and Eastern Ghats and North-East plains with frost free and mild winter. Also, Bedoussac *et al*. (2015) reported that the total N fixed is generally higher in sole crop legumes than that in intercropped legumes, the quantity of N fixed in soil is higher in intercrops, as the cereal takes up any mineral N in the soil, forcing the legume to rely on biological nitrogen fixation. Rajmash lacks nodulation thus unable to symbiotically fix atmospheric nitrogen, so it responds to application of nitrogenous fertilizers. In addition, nitrogen losses from cropping system depends on soil N status, applied N fertilizer or manure, and their interaction with management interventions such as tillage, irrigation and environmental factors (Henault *et al*., 2012). Thus, to reduce nitrogen losses and achieve remunerative yields, the present investigation was carried out to assess the impact of nitrogen management on the growth, yield and water productivity of the Rajmash in northern zone of Punjab.

Material and Methods

Experimental site and treatment details

The experiment was carried out at Punjab Agricultural University Regional Research Station, Gurdaspur, Punjab (32°03′ N and 75°25′ E) situated in the north eastern region of Indian Punjab during 2017 and 2018 rabi season. The experimental site has been characterised as semi-arid sub humid climate with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March months. The area receives 75 per cent of the average annual rainfall in July to September months. The average weekly weather condition during the crop growth period of 2017 and 2018 is presented in Figure 1.

The soil at Gurdaspur has been classified as fine loamy, non-calcareous, mixed, hypertermic typic Haplustalfs with silt loam texture (41% sand, 39% silt and 20% clay). The soil of experimental site is alluvial, sandy loam in texture having soil pH 7.3, EC 0.18 dS m^{-1}, organic carbon 0.49%, available phosphorus 33.5 kg ha^{-1}, available potassium 105.5 kg ha^{-1}, and plant available water in soil profile (180 cm depth) was 21.8 cm.

The sowing of *rajmash* was done in first week of February in the year of 2017 and 2018 using randomized complete block design with treatments such as T_1-Control, T_2-17.3 kg N ha^{-1} (B-basal) + 17.3 (35 DAS) kg N ha^{-1}, T_3-34.5 kg N ha^{-1} (B) + 34.5 kg N ha^{-1} (35 DAS), T_4-51.8 kg N ha^{-1} (B) + 51.8 kg N ha^{-1} (35 DAS), T_5: 69 kg N ha^{-1} (B) + 69 kg N ha^{-1} (35 DAS), T_6-34.5 kg N ha^{-1} (B) + 34.5 kg N ha^{-1} (35 DAS)+ 1 spray (2% urea) at flowering, T_7-34.5 kg N ha^{-1} (B) + 51.8 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering, T_8-51.8 kg N ha^{-1} (B) + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering, T_9-51.8 kg N ha^{-1} (B) + 51.8 kg N ha^{-1} (35 DAS) + 1

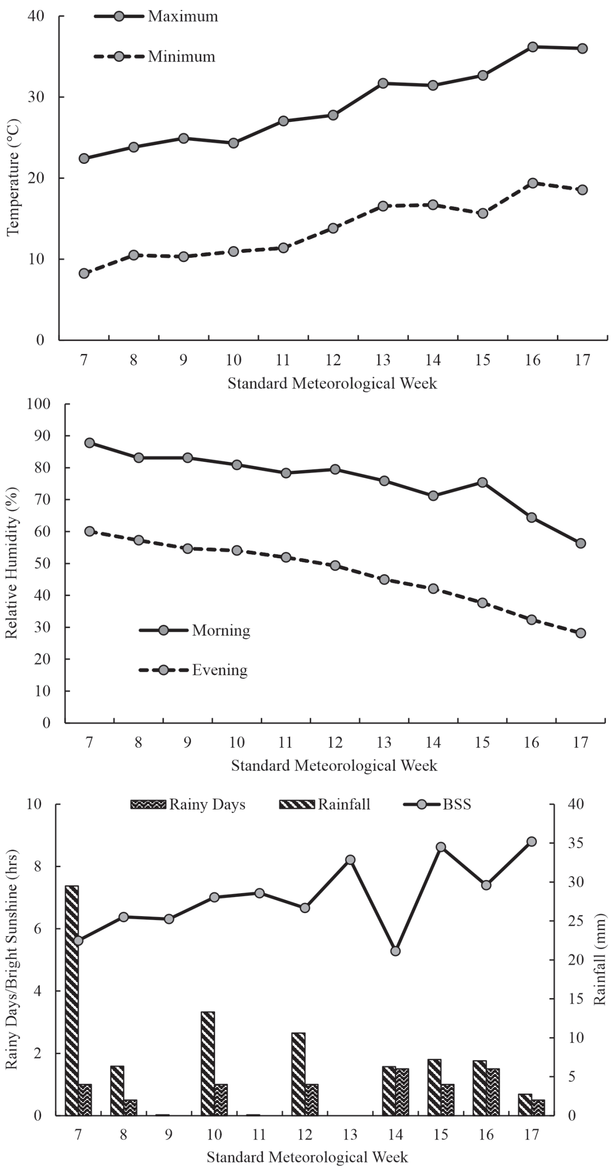

Fig. 1. Average weekly weather condition of 2017 and 2018 seasons during *rajmash* growing period

spray (2% urea) at flowering, T_{10}-69 kg N ha^{-1} (B) + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering, T_{11}- 69 kg N ha^{-1} (B) + 51.8 kg N ha^{-1} (35 DAS) + 1 spray (2% urea), at flowering, T_{12}- 69 (kg N ha^{-1} (B) + 69 kg N ha^{-1} (35 DAS) + 1 spray (2% urea)at flowering and treatments were replicated thrice.

Crop husbandry

The sowing was done in furrows 60 cm apart with plant to plant spacing of 5-7 cm with seed rate of 30 kg ha^{-1}. The nitrogen fertilizer was applied as per treatments, while phosphorus was applied @250 kg superphosphate per hectare. The gap filling was done within the 7-10 days after sowing of the experiment. The experiment was kept weed free by two hand weeding done 15 days and 35 days after sowing.

Soil, plant and water measurements

Soil samples were randomly collected before planting at (0-15 cm) depth for soil fertility analysis. The randomly selected five plants were tagged to measure the plant height. The number of pods per plant and number of seeds per pod were counted from the tagged plants. The 1000 grain weight, grain yield, and stover yield were recorded from each plot. The initial soil moisture content was measured on dry weight basis up to the depth of 1.5 m at the time of sowing and harvesting of the experiment. The irrigation depth was assumed to be 30 mm, was applied on basis of prevailing weather condition. Equal depth of irrigation water was applied to all plots. Water productivity was computed as the ratio of grain yield to consumptive water use. Rainfall was measured to Agromet Observatory situated about 200 m away from the site was used for computation of water productivity. Partial factor productivity (PFP_N) (Dobermann, 2007) was calculated as ratio of grain yield to the amount of nitrogen applied. Agronomic Efficiency (AE) (Dobermann, 2007) was calculated AE = $(Y-Y_0)/F$, where Y is yield of plots with application of fertilizer, Y_0 is yield from control plot and F is fertilizer (nitrogen) applied. Accumulated growing degree days and phenothermal unit were calculated. Heat use efficiency was calculated as the ratio grain yield and accumulated growing degree days.

Statistical analysis

The experiment was conducted using randomized complete block design with three replicates for two years, i.e. 2017 and 2018. The experimental data was pooled and subjected to analysis of variance according to procedure given by Gomez and Gomez (1983) using PROC ANOVA in SAS 9.1. Means were compared using Duncan Multiple Range Test (DMRT).

Table 1. Effect of nitrogen application rate and timings on the growth and yield attributes of Rajmash

Treatment	Plant height at 30 DAS (cm)	Plant height at 60 DAS (cm)	Number of Pods per plant	Number of seeds per pod	Pod length (cm)
T_1-Control	16.3a	34.9c	4.7d	2.33a	7.33a
T_2-17.3 (B-basal) + 17.3 (35 DAS) kg N ha^{-1}	18.0a	37.9abc	5.1bcd	3.33a	9.33a
T_3-34.5 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS)	16.3a	37.2abc	5.3bcd	3.67a	8.66a
T_4-51.8 (B) kg N ha^{-1} + 51.8 kg N ha^{-1} (35 DAS)	16.1a	36.2bc	5.3bcd	3.67a	9.00a
T_5: 69 (B) kg N ha^{-1} + 69 kg N ha^{-1} (35 DAS)	16.4a	38.2ab	5.9bcd	3.67a	10.0a
T_6-34.5 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS)+ 1 spray (2% urea) at flowering	16.6a	37.5abc	5.7bcd	4.00a	9.67a
T_7-34.5 (B) kg N ha^{-1} + 51.8 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering	18.1a	38.2ab	7.9a	4.00a	9.33a
T_8-51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering	18.7a	40.5a	6.0bcd	4.33a	10.7a
T_9-51.8 (B) kg N ha^{-1} + 51.8 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering	17.3a	39.7a	7.0ab	3.67a	9.67a
T_{10}-69 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering	17.7a	39.5a	5.0cd	3.67a	10.0a
T_{11}- 69 (B) kg N ha^{-1} + 51.8 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering	15.7a	38.7ab	6.8ab	4.00a	10.3a
T_{12}- 69 (B) kg N ha^{-1} + 69 kg N ha^{-1} (35 DAS) + 1 spray (2% urea)at flowering	17.0a	40.3a	5.7bcd	3.34a	10.0a
CV (%)	15.3	4.87	18.2	23.7	14.74
P<F	0.95	0.03	0.03	0.46	0.40

The different letters in each column of experimental factors show significant differences at probability level.

Results and Discussion

The plant height at 30 days after sowing was not significantly affected by the application of nitrogen during both the years (Table 1). However, highest plant height of 18.7 cm was observed in the treatment T_8. The perusal of the data revealed that nitrogen application has significantly affect on the plant height at 60 days after sowing of *rajmash*, where significantly higher plant height was observed in the treatment T_8 (40.5 cm) than that in control. However, plant height at 30 days after sowing in T_8 treatment was statistically at par with the treatments T_2, T_3, T_5, T_6, T_7, T_9, T_{10}, T_{11} and T_{12}. The increase in plant height under higher nitrogen application rate indicates maximum vegetative growth of the plants at high nitrogen availability in the soil plant system. The results corroborate with the finding of the Behura *et al*. (2006) and Singh *et al*. (2006). The number of pods per plant was significantly high in the treatment $T_{7,}$ followed by T_9 treatment. The treatment T_9 andT_{11} were statistically similar to the treatment $T_{7.}$ Prajapati *et al*. (2003) and Behura *et al*. (2006) also reported higher number of pods per plant and number of seeds per pod with application of nitrogen. The data on number of seeds per pod revealed that the number of seeds per pod was recorded significantly higher in the treatment T_8 than that in control plot, however treatment T_8 was statistically at par with the treatment $T_{6,}$ $T_{7,}$ and $T_{11.}$ The highest pod length was achieved in the treatment T_8 followed by T_5, T_{10}, T_{11} and $T_{12,}$ however the treatments were not significantly different among themselves for pod length at 5% level of significance. Dhanjal *et al*. (2001) and Prajapati *et al*. (2003) also observed a linear increase in the number of pod $plant^{-1}$ upto the N dose of 120 kg ha^{-1} in French bean on a sandy loam soil. Veeresh (2003) also reported increase

Table 2. Effect of nitrogenapplication rate andtimings on yield, yield attributes and water productivity of Rajmash

Treatments	1000 grain weight (g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index	Water productivity (kg ha^{-1} mm^{-1})	Partial factor productivity (PFP_N) (kg ha^{-1} kg^{-1}N)
T_1	86.3b	649.2c	1019.2b	0.67a	3.80b	
T_2	106.8ab	721.5bc	1119.6ab	0.67a	4.23ab	20.91
T_3	105.1ab	797.7abc	1260.3ab	0.60a	4.67ab	11.50
T_4	111.0a	846.8abc	1372.2ab	0.60a	4.97ab	8.18
T_5	119.7a	811.7abc	1374.7ab	0.60a	4.77ab	5.88
T_6	122.5a	812.1abc	1366.1ab	0.60a	4.80ab	11.77
T_7	116.8a	959.9ab	1575.8a	0.63a	5.63a	11.13
T_8	123.0a	994.2a	1590.8a	0.63a	5.83a	11.53
T_9	125.2a	932.2ab	1594.4a	0.60a	5.50a	9.01
T_{10}	116.8a	894.8abc	1434.7ab	0.63a	5.26ab	8.65
T_{11}	119.0a	908.0abc	1460.5ab	0.63a	5.33ab	7.52
T_{12}	120.9a	956.7ab	1559.0a	0.63a	5.63a	6.93
CV (%)	10.3	9.88	13.4	18.6	9.88	
P>F	0.03	<0.05	0.05	0.99	<0.13	

in number of pods and branches of French bean with application of 80 kg N ha^{-1}.The data further revealed that the 1000-grain weight was significantly low in control and highest in the treatment T_9, which was statistically at par with the T_4, T_5, T_6, T_7, T_8, T_{10}, T_{11} and T_{12}. Singh and Singh (2000) and Veeresh (2003) also found an increase in grain weight at higher rates of nitrogen application.

The highest grain yield was observed in the treatment T_8 and it was significantly higher than the control and statistically at par with T_7, T_9, T_{10}, T_{11} and T_{12} (Table 2). Singh and Singh (2000) also reported improvement in yield and yield attributes with increasing nitrogen rate upto 120 kg ha^{-1}.The stover yield was significantly higher in the treatment T_9 and at par with T_8 as compared to the control treatment. The results reported by Singh *et al*. (2006) also showed that nitrogen application significantly improved the biomass yield of french beans at Varanasi. The increase in the *rajmash* grain and stover yield with application of nitrogenous fertilizer might be due to the higher availability of N resulted in an increase in number of branches per plant and plant height, that has improved the production of photosynthates and number of pods per plant, which was reflected on the grain and stover yield. The nutrient uptake, nutrient use efficiency and productivity can be enhanced with foliar spray of nitrogen in addition to soil application (Fernandez and Ebert, 2005). Thus, the treatment T_8 with application of 86.3 kg N ha^{-1} (51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering was resulted in highest crop yield (Table 2). Aslani and Souri (2018) also reported higher yield with foliar application of nutrients. The role of nitrogen in synthesis of phytohormone (Marschner, 2011), cell membrane stability, and production and utilization of photosynthesis and metabolism (Souri *et al*., 2017) might also played key roles in higher yields achievement through nitrogen application in the present investigation. The harvest index was not found to be significantly affected by the nitrogen application. Similarly, Meseret and Amin (2014) and Gifole *et al*. (2011) didn't found any significant effect of fertilizer application on the harvest index of French beans.

The Water Productivity (WP_{I+R}) was significantly higher in the treatment T_8 as compared to the control treatment. The water productivity in the treatment T_7, T_9 and T_{12} were statistically at par among themselves (Table 2). The water productivity was improved due to the higher availability of nitrogen resulted in higher crop yield from the application of nitrogen fertilizer. Singh and Hadda (2014) also observed improvement in water productivity with the application of nitrogen fertilizer.

The Partial Factor Productivity (PFP_N) as an extended indicator, shows how productive are the treatment per unit nutrient input. The data on the Partial Factor Productivity (PFP_N) (Table 2) revealed highest factor productivity along with highest grain yield was observed in the T_8 treatment (11.53) after T_2. The agronomic efficiency reveals the information on how productive a particular treatment is, over the control treatment. The agronomic efficiency data (Fig. 2) followed quadratic function, where yield increased with application of urea reaching the plateau and decline under higher dose of urea. The data revealed that the treatment T_8 may be recommended to achieve higher yield as compared to the other treatments.

The nitrogen application dose and time has significantly affected the physiological maturity of the rajmash. The data revealed that the crop took significantly higher number of days to mature in the treatment T_{12} (68 days) as compared to control, followed by T_8 (67 days), T_9 (67 days), T_{11} (67 days) and T_7 (66 days) (Table 3). The treatment T_1 acquired significantly lower number

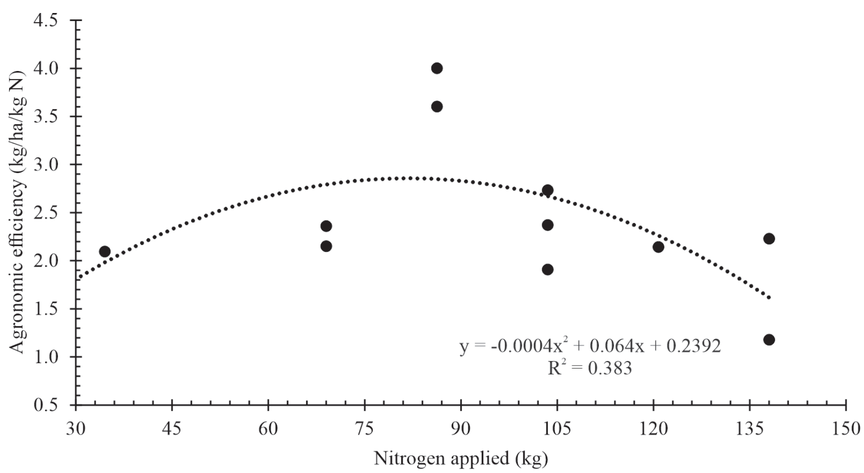

Fig. 2. Agronomic efficiency of *rajmash* as influenced by nitrogen application

Table 3. Effect of nitrogen application timings on phenology and heat use efficiency of Rajmash

Treatments	Days to emergence	Days to flowering	Days to physiological maturity	Accumulated Growing degree days (°C days) (at maturity)	Phenothermal Unit (°C-days-hours)	Heat use efficiency (kg grain ha^{-1} °C-day^{-1})
T_1	6a	31.3b	63.0c	903.7d	10941.0	0.095b
T_2	6a	34.3a	64.0bc	917.7cd	11125.7	0.116a
T_3	6a	33.6ab	64.7bc	933.7abcd	11333.7	0.116ab
T_4	6a	34.0ab	65.0abc	943.3abcd	11459.0	0.118a
T_5	6a	34.0ab	65.0abc	942.3abcd	11446.7	0.127a
T_6	5a	33.3ab	65.0abc	942.3abcd	11446.7	0.130a
T_7	6a	34.3a	65.7abc	958.3abcd	11657.0	0.122a
T_8	6a	35.0a	67.3ab	996.3abc	12157.0	0.123a
T_9	6a	35.7a	67.7ab	982.0abcd	11966.3	0.128a
T_{10}	5a	35.7a	66.3abc	975.3abcd	11877.3	0.119a
T_{11}	6a	35.3a	67.3ab	1000.0ab	12200.7	0.119a
T_{12}	6a	35.7a	68.3a	1020.3a	12465.0	0.119a
CV (%)	13.2	4.28	2.80	4.32		8.72
P>F	0.95	0.05	0.05	0.05		0.05

of days (63 days) to reach physiological maturity and it was statistically at par with the T_2, T_3, T_4, T_5 and T_6 treatments. The growing degree days accumulated under various treatments were higher in the T_{12} treatment and it was statistically at par with the T_7 to T_{11}. The crop sown under the T_1 treatment accumulated lowest number of growing degree days during its entire growth period. The treatments T_1 to T_7 were statistically at par with each other in accumulation of growing degree days. From the data, it was clear that more the number of days taken by crop to complete maturity, more the growing degree days accumulated by the crop. The heat use efficiency of crop was highest in the treatment T_6 (0.13 kg grain ha^{-1} ^oC-day^{-1}) followed by T_9 (0.128 kg grain ha^{-1} ^oC-day^{-1}) and T_5 (0.127 kg grain ha^{-1} ^oC-day^{-1}) treatment that was significantly higher as compared to the control but at par with each other.

Conclusion

The highest number of pods per plant, number of grains per pod, pod length, grain yield and stover yield were achieved with the application of 51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering (treatment T_8). The highest water productivity (5.83 kg ha^{-1} mm^{-1}) was also observed with the application of 51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering (treatment T_8).The agronomic efficiency indicated that the application of 86.3 kg urea (51.8 (B) kg N ha^{-1} + 34.5 kg N ha^{-1} (35 DAS) + 1 spray (2% urea) at flowering) may be recommended to achieve highest yield and water productivity. The future challenge is the expansion of area and production of rajmash crops in sustainable manner, while minimizing environmental impacts associated with irrigation and nitrogen use.

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