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Effect of sowing methods, nutrients and seed rate on mungbean (*Vigna radiata* (L.) Wilczek) growth, productivity and water-use efficiency

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Abstract: A experiment comprising of 18 treatments i.e. two sowing methods (flat bed - 30 cm spacing, and raised-bed with two mungbean *(Vigna radiata*) rows bed^{-1} on 67.5 cm including 30 cm furrow), three seed rates (10, 15 and 20 kg ha^{-1}) and three nutrient treatments (6.25 + 20.0, 9.38 + 30.0 and 12.5 + 40.0 kg N+P_2O_5 ha^{-1}) was conducted at the Punjab Agricultural University, Ludhiana, India during *kharif* 2007 to 2009. The mungbean grain yield recorded in 2008 was similar in 2009 but higher than 2007. The increase of 3.94% in grain yield was recorded in raised-bed than in flat bed. The grain yield recorded with seed rate of 20 kg ha^{-1} was higher than with 10 kg ha^{-1} but similar with 15 kg ha^{-1} in 2006 and 2008. The grain yield recorded with 12.5 kg N + 40 kg P_2O_5 ha^{-1} was higher ($p<0.05$) than other treatments. Raised-bed planting with 33.3% lesser irrigation water used recorded 3.91% lesser water use than flat bed planting and 9.77% higher water use efficiency (WUE) ($p<0.05$) as compared to flat bed planting. Seed rate of 20 kg ha^{-1} recorded 35.9 and 8.9% higher ($p<0.05$) WUE than with 10 and 15 kg ha^{-1}. The highest WUE was recorded with 12.5 kg N + 40 kg P_2O_5 ha^{-1} which was higher ($p<0.05$) than 6.25 kg N + 20 kg P_2O_5 ha^{-1} but at par with 9.38 kg N + 24 kg P_2O_5 ha^{-1}.

Keywords: Mungbean, Nutrients, Raised-bed sowing, Sowing methods, Water use efficiency

INTRODUCTION

Rice (*Oryza sativa*) - wheat (*Triticum aestivum*) (RW) cropping system is practiced on an area of 13 M ha in the Indo-Gangetic Plains (IGP) of South Asia (Timsina and Connor 2001 ; Bhatt *et al*., 2016). The continuous practising of this system has, however, resulted in a number of problems such as development of hardpan, low water- and fertilizer-use efficiency, emergence of insect pests, as well as environmental pollution through emission of greenhouse gases. Furthermore, there is great concern about groundwater depletion in the IGP, especially in NW India, where the RW system is prevalent (Ambast *et al.*, 2006, Rodell *et al*., 2009). Out of 145 blocks (one block -30,000 ha) in the Indian Punjab, 103 blocks are critical wherein the water extraction is far greater than recharge (Hira, 2009). The RW cropping system in NW India is exhaustive, high water requiring and depletes soil nutrients to a great extent (Hira, 2009). Thus, to maintain soil fertility, improve nutrient and water-use efficiency, and maintain the sustainability of RW cropping system on a long-term basis, it is essential to include a leguminous crop such as mungbean (*Vigna radiata* (L.) Wilczek) which not only improves the soil fertility but also leaves residual nitrogen to the succeeding crops (Baijukya *et al*., 2005; Shah *et al*., 2003).

India is the largest producer and consumer of pulses in the world. The estimated demand of pulses (grain legumes) in India is around 18 million tons against a production of around 17.2 million tons. The gap between demand and supply is met by import of pulses from different countries (Anonymous, 2003a).

Being a pulse crop, mungbean can play an important role in the nitrogen economy by virtue of its ability to fix atmospheric nitrogen in symbiotic association with *Rhizobium* (Vance, 1991). Although this crop is self supporting for nitrogen in its later stages, some starter dose of N is required for its early growth.

The raised-beds for the production of irrigated non-rice crops were started in heavy clay soils in Australia during 1970s (Maynard, 1991). Research has shown that it is now possible to extend this method of establishing crops to other crops like mungbean (Ram *et al*., 2012). The raised-bed planting systems have a number of advantages like better irrigation management, increased availability of nutrients to crop roots, better crop establishment, better weed management through inter-raised-bed cultivation and less soil compaction (Aggarwal *et al*., 2000). A change from growing crops on the flat to raised-beds offers more effective control of irrigation water and drainage thereby reducing aeration stress and increasing yield.

Seed rate, by maintaining plant population to an optimum level, plays an important role in the growth and

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development of a crop by affecting plant density and, in turn, moisture, nutrient and space availability (Panwar and Sharma 2004). It is an established fact that the plant population should be kept optimum to obtain high grain yield (Kabir and Sarkar, 2008; Singh *et al*. 2011a). Although 20 kg ha^{-1} seed rate has been determined to be optimum for mungbean crop sown on flat bed (Anonymous, 2013b), there is no information on the seed rate requirement for raised bed planted crop. Nitrogen and phosphorous nutrition also influence productivity of mungbean (Singh *et al*., 2011b).
The seed rate and nutrient requirements may vary with the establishment methods because of differential growth habits of the crop in those methods. Thus, an experiment was conducted from 2007 to 2009 with the objectives of determining optimum seed rate and nutrient requirements for mungbean under different establishment methods.

MATERIALS AND METHODS

Site description: A field experiment was conducted at the Punjab Agricultural University, Ludhiana (36°56' N, 75°52' E and altitude 247 m above the mean sea level), India during rainy season of 2007 to 2009. The soil in the experimental field was loamy sand, low in organic carbon and medium in available phosphorus and potassium (Table 1.). The region has a sub-tropical climate, with hot, dry to wet summers (June–October) and cool, dry winters (November–April). Average annual rainfall is 650 mm, with 44% of pan evaporation. The depth to the groundwater was over ≥15 m. The weekly mean maximum temperature ranged from 29.5 to 38.4°C and weekly mean minimum temperature ranged from 14.0°C to 29.3°C during the study period (Fig. 1 a). Total rainfall during the crop season was 320.1, 635.2 and 777.4 mm in 2007, 2008 and 2009, respectively (Fig. 1b).

Experimental design and treatments: A experiment comprising of 18 treatments i.e. two sowing methods (flat bed - 30 cm spacing, and raised-bed with two mungbean *(Vigna radiata)* rows bed^{-1} on 67.5 cm including 30 cm furrow), three seed rates (10, 15 and 20 kg ha^{-1}) and three nutrient treatments (6.25 + 20.0, 9.38 + 30.0 and 12.5 + 40.0 kg N+P_2O_5 ha^{-1}) was conducted. The recommended nutrient dose for mungbean for the region is 12.5 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1}. The experiment was conducted in a split plot design with three replications. Sowing methods and seed rates were in main plots and nutrient doses in sub-plots.

Crop management: This experiment was conducted on same site in wheat -mungbean rotation in which maize received 120 kg N and 62.5 kg P_2O_5/ha. In mungbean, a pre-sowing irrigation of 100 mm was applied. The mungbean crop (variety PAU 911) was sown on 7-12 July and harvested on 1-8 October in different years of experimentation. The seed was treated with Captan @ 3 g per kg seed to control seed-borne diseases like seed rot and seedling blight. The nutrients and seed rate were applied as per treatments. Nitrogen and phosphorus were applied through urea (46% nitrogen) and single superphosphate (16% P_2O_5) respectively at the time of sowing. Raised beds were formed with a bed former. Stomp 30 EC (pendimethalin) herbicide @ 0.45 kg ha^{-1} was applied using 500 litres of water as pre-emergence on the day of sowing followed by one hoeing (four weeks after sowing) to control weeds. Thiodan 35 EC (endosulfan) @ 2.5 litre ha^{-1} was sprayed twice to control pod borers. To control whitefly 625 ml of Rogor (dimethoate) ha^{-1} was applied twice during the season.
Differential irrigation water was applied in different establishment methods (Table 2). In 2007, 150 mm of irrigation in raised bed and 225 mm in flat layouts were applied. In 2008 and 2009 as rainfall was well distributed, no post-sowing irrigation was applied.

Measurements and calculations: The data on plant height and pods per plant were collected from five randomly selected plants per plot at the time of harvest. For data on number of seeds per pod, 20 pods per plot were selected. From the total produce of each plot, 100 seeds were counted and weighed to express 100-seed weight. The data on biological and grain yield were collected after sun drying the bundles. Soil samples were taken from various depths, i.e. 0-180 cm depth, for moisture content at sowing and at harvesting. Amount of irrigation water applied to each plot was measured with Parshall flume. Water use and water-use efficiency were calculated by using the following formulas:

Water use = (Difference in moisture content at sowing and at harvest + seasonal rainfall + irrigation water applied).

Water-use efficiency (kg ha^{-1} mm^{-1}) = Grain yield/ water use 1

Statistical analysis: All the data collected were subjected to analysis of variance (ANOVA) using the SAS (SAS Institute Inc., Cary, NC, USA) statistical package. Comparison of treatment means was made by use of least significant difference (*l.s.d.*) at $p \leq 0.05$ keeping years in main plot, sowing methods and seed rates in sub plot and nutrient dose in sub-sub plot.

RESULTS

Growth, yield attributes and yield

Season: In 2008, the tallest plants and the highest pods per plant were recorded which were statistically on par in 2009 but was significantly higher than in 2007 (Table 3). In 2009, the highest pods per plant were recorded which were statistically on par (p<0.05) in 2008 but was significantly higher than in 2007. The highest seeds per pod and 100-seed weight were recorded in 2008 which were significantly(p<0.05) higher than in 2007 and 2009. The highest grain yield was recorded in 2008 which was statistically on par in 2009 but significantly(p<0.05) higher than 2007.

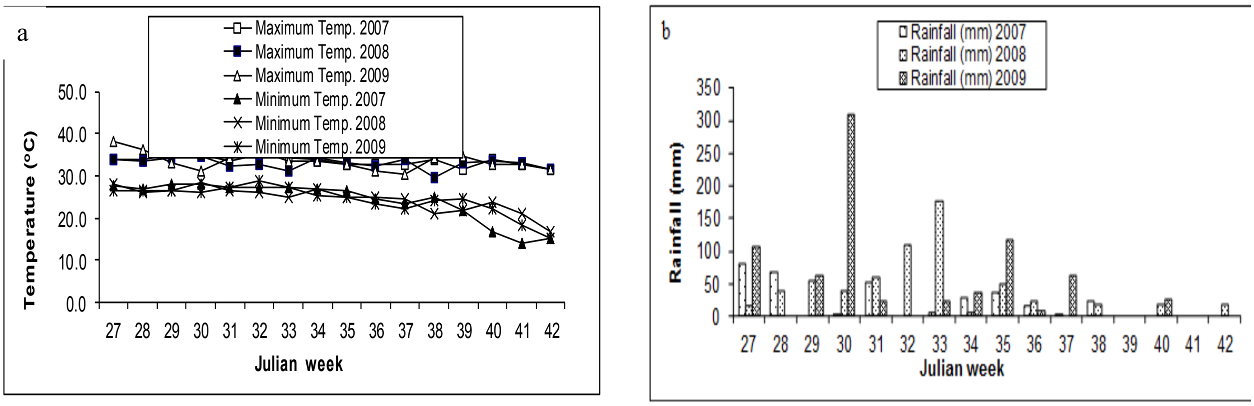

Fig. 1. *Weekly mean maximum and minimum temperatures (a) and weekly rainfall (b) during the crop season in 2006 to 2009.*

Method of sowing: Sowing or establishment methods play an important role on growth, yield and yield attributes of mungbean. The plant height was significantly ($p<0.05$) higher in raised bed sowing method than flat bed sowing (Table 3). Other characters like secondary branches, pods per plant, seeds per pod and 100-seed weight were found to be non-significant ($p<0.05$). The seed yield was not significantly ($p<0.05$) influenced by sowing method however, an increasing trend in favour of raised bed sowing was recorded. Though on the yield attributing characters basis, the differences between two planting systems were non-significant ($p<0.05$), yet the cumulative effect of the yield attributes might have contributed towards 3.94% increase in the grain yield with raised bed sowing.

Effect of seed rate: The seed rate significantly influenced the mungbean plant height and pods per plant (Table 3). The tallest plants were recorded in seed rate of 20 kg ha^{-1} which was statistically ($p<0.05$) at par with seed rate of 15 kg ha^{-1} and significantly higher than seed rate of 10 kg ha^{-1}. The pods per plant were the highest with seed rate of 10 kg ha^{-1} which was sig-

Table 1. Physico-chemical properties of the soil used in the experiment.

Depth(cm)	Texture	pH	Organic carbon (%)	P (kg ha^{-1})	K (kg ha^{-1})
0-15	Loamy sand	8.1	0.27	18.3	230.1
15-30	Loamy sand	7.9	0.22	17.2	228.9

Table 2. Irrigation water applied and per cent saving in water as influenced by sowing method.

Treatment	Post-sowing irrigation water applied (mm)				% saving in irrigation water
	2007**	2008***	2009***	Mean	
Flat bed	225	0	0	94	
Raised-bed	150	0	0	63	33.3

** Three post-sowing irrigations (each 50 mm in raised-bed and 75 mm in flat bed), *** No irrigation

Table 3. Effect of different treatments on plant, yield attributes yield, water use and water use efficiency of mungbean (Pooled mean of three year).

Treatment	Plant height (cm)	Secondary branches plant^{-1}	Pods plant^{-1}	Seeds pod^{-1}	100-seed weight (g)	Grain yield (kg ha^{-1})	Water use (mm)	Water use efficiency (kg ha^{-1}mm^{-1})
Year								
2007	58.6b	3.9c	16.2b	9.8c	2.1c	1109b	573.6c	1.94a
2008	66.9a	5.8a	18.6a	10.8a	3.6a	1328a	673.3b	1.97a
2009	66.8a	5.2b	20.0a	10.1b	3.0b	1293a	833.4a	1.55b
Method of sowing								
Flat bed	63.1b	4.8a	18.1a	10.2a	2.9a	1219a	707.2a	1.74b
Raised-bed	65.0a	4.8a	18.3a	10.2a	2.9a	1267a	679.5b	1.91a
Seed rate (kg ha^{-1})								
10	62.8b	4.8a	19.1a	10.2a	2.9a	1054c	693.3a	1.53b
15	64.5a	4.8a	18.2b	10.2a	2.9a	1258b	693.3a	1.84a
20	65.1a	4.9a	17.5b	10.3a	2.9a	1417a	693.3a	2.08a
Nutrient level (N + P_2O_5 kg ha^{-1})								
6.25 + 20	63.3b	4.8a	16.8c	10.2a	2.9a	1145c	693.3a	1.68b
9.38 + 30	63.7b	4.8a	18.2b	10.2a	2.9a	1249b	693.3a	1.83ab
12.5 + 40	65.3a	4.9a	19.8a	10.2a	2.9a	1335a	693.3a	1.95a

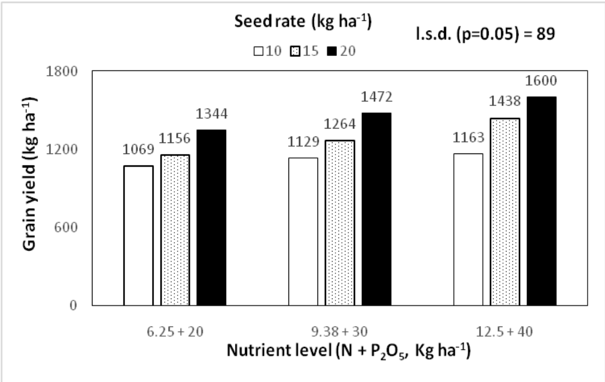

Fig. 2. *Interaction effect of nutrient level and seed rate on grain yield of mungbean in 2009.*

nificantly ($p<0.05$) higher than with 15 and 20 kg ha^{-1}. The difference in the pods plant^{-1} in 15 and 20 kg seed ha^{-1} was statistically non-significant. Secondary branches per plant (Table 3), seeds per pod and 100-seed weight were not significantly ($p<0.05$) influenced by seed rate in our study. The grain yield recorded with seed rate of 20 kg ha^{-1} was the highest which was significantly higher than in 10 kg and 15 kg ha^{-1}. Seed rate of 15 kg ha^{-1} produced significantly ($p<0.05$) higher grain yield than with 10 kg ha^{-1}.

Effect of nutrient levels: The treatment 12.5 kg N + 40 kg P_2O_5 ha^{-1} recorded taller plants than other treatments (Table 3). The pods plant^{-1} were the highest with 12.5 kg N + 40 kg P_2O_5 ha^{-1} which was significantly ($p<0.05$) higher than in 6.25 kg N + 20 kg P_2O_5 ha^{-1} but statistically on par in 9.38 N + 30 P_2O_5 ha^{-1}. The highest grain yield was recorded with 12.5 kg N + 40 kg P_2O_5 ha^{-1} which was significantly ($p<0.05$) higher than other treatments. The grain yield obtained in 9.38 kg N + 30 kg P_2O_5 ha^{-1} was significantly ($p<0.05$) higher than with 6.25 kg N + 20 kg P_2O_5ha^{-1}.

Interaction effects: During 2008 interaction effect between sowing methods and nutrient levels was significant ($p<0.05$) (Table 4). At lower levels of nutrients, the sowing methods responded almost similarly, however at 12.5 N + 40 kg P_2O_5 ha^{-1} the raised bed planting produced significantly lower grain yield than flat bed planting. During 2009 the interaction between sowing methods and seed rates was significant ($p<0.05$) (Table 5). Sowing methods responded similarly at 10 and 15 kg seed rate ha^{-1}, however, at the seed rate of 20 kg ha^{-1}, the raised bed planting produced significantly higher grain yield than flat bed system. The grain yield recorded at 20 kg ha^{-1} seed rate with 12.5 kg N + 40 kg P_2O_5 ha^{-1} was significantly ($p<0.05$) higher than that recorded at all other combinations of seed rates and nutrient levels in 2009 (Fig 2.).

Irrigation water applied and water use efficiency (WUE): There was economy of 33.3% of irrigation water applied in raised beds than in flat layouts which resulted in 3.91% lower water use in raised beds which was significantly lower than in flat planting (Table 2). On the basis of three-year mean, the raised-bed planting system with the use of 33.3% less irrigation water resulted in 9.77% higher water use efficiency (Table 3). The WUE recorded in 20 kg ha^{-1} was statistically ($p<0.05$) on par with 15 kg seed ha^{-1} but was significantly higher than 10 kg ha^{-1} seed rate. Seed rate of 20 kg ha^{-1} recorded the highest WUE which was 35.94 and 8.9% higher than with 10 and 15 kg ha^{-1} seed rate. The WUE recorded in 12.5 kg N + 40 kg P_2O_5 ha^{-1} was significantly ($p<0.05$) higher than in 6.25 kg N + 20 kg P_2O_5 ha^{-1} but statistically on par with 9.38 kg N + 30 kg P_2O_5 ha^{-1}. WUE in the 12.5 kg N + 40 kg P_2O_5 ha^{-1} treatment was 10.07 and 6.56% higher than that recorded in 9.38 kg N + 30 kg P_2O_5 ha^{-1} and 6.25 kg N + 20 kg P_2O_5 ha^{-1}, respectively.

DISCUSSION

Growth, yield attributes and yield

Seasons: In 2008, the tallest plants and the highest yield attributes like pods per plant were recorded which were similar in 2009 but was significantly higher than in 2007. It was due to well distributed rainfall in 2008 and 2009.The higher grain yield in 2008 might be due to higher seed per pod and 100-seed weight. Lower grain yield in 2007 was due to comparatively less yield attributes.

Method of sowing: Significantly higher plant height in raised bed sowing method might be due to higher light interception in the canopy of raised bed planted crop. The 3.94% increase in the grain yield with raised bed sowing could be due to improvement in growth attrib-

Table 4. Interaction effect of sowing method and nutrient levels on grain yield (kg ha^{-1}) of mungbean.

	Nutrient levels (N + P_2O_5 kg ha^{-1})		
Sowing method	**6.25 + 20**	**9.38 + 30**	**12.5 + 40**
	2007		
Flat bed	1044a	995a	1111a
Raised-bed	1089a	1258a	1153a
	2008		
Flat bed	1128c	1325b	1564a
Raised-bed	1226bc	1342b	1383b
	2009		
Flat bed	1201a	1241a	1366a
Raised-bed	1178a	1335a	1434a

Table 5. Interaction effect of sowing method and seed rate on grain yield (kg ha^{-1}) of mungbean.

	Seed rate (kg ha^{-1})		
Sowing method	**10**	**15**	**20**
	2007		
Flat bed	832a	1112a	1206a
Raised-bed	900a	1153a	1447a
	2008		
Flat bed	1226a	1350a	1440a
Raised-bed	1127a	1358a	1465a
	2009		
Flat bed	1125d	1277c	1407b
Raised-bed	1116d	1295c	1537a

utes by proper physiological processes and build up of food material. Increase in yield attributes and yield of pigeonpea due to broad-bed and furrow system of planting was also reported (Kantwa *et al*., 2006; Malik *et al*., 2006). Significantly higher seed yield of summer mungbean and soybean under raised bed than flat bed sowing method on a loamy sand also reported (Ram *et al*., 2001; Singh *et al*., 2011b). In rainy season the furrows in bed planting act as drainage channel, especially in heavy-textured soils resulting in significant benefits of raised beds methods. In our study the soil was light in texture so the adverse effect of waterlogging in flat bed planting and conversely the beneficial effect of furrows in raised beds was not observed. Comparatively higher grain yield of mungbean under raised bed sowing in loamy sand soils has also been reported from other North Indian conditions (Dhindwal *et al*., 2006; Singh *et al*., 2011a). In contrary to our results some scientists reported that broad-bed planting recorded significantly higher grain yield of mungbean from sandy loam soils than flat bed sowing (Kumar *et al*., 2012).

Effect of seed rate: The taller plants recorded in higher seed rate might be due to higher plant competition for light in higher seed rate than in lower seed rate. The higher plant height (48.2 cm) in mungbean in 50 kg ha^{-1} than in 30 kg ha^{-1} seed rate (44.3 cm) was also observed by some workers (Mondal *et al*., 2012). The pods per plant were the highest with lowest seed rate which might be due to more availability of space, moisture, nutrients and light in seed rate of 10 kg ha^{-1}. By increasing plant density in mungbean, pods per plant and yield per plant decreased (Panwar and Sisobi, 1987). Similar to our findings it was reported that plant density had a significant but small effect on seed number per pod (Bing *et al*. 2010). However, it was recorded higher seeds per pod in seed rate of 10 kg ha^{-1} as compared in higher seed rate (Dainavizadeh and Mehranzadeh, 2013). The grain yield recorded with 20 kg seed ha^{-1} was higher than other seed rates might be due to higher plant population per unit area. The importance of appropriate planting density in ensuring optimum plant population per unit area of mungbean and increasing grain yield has been well documented (Kabit and Sarkar, 2008). As per our results, there are reports that seed of 20 kg ha^{-1} seems optimum due to the most desirable population in the existing environmental conditions of Quetta from Iran (Mansoor *et al*., 2010). Number of branches $plant^{-1}$, pod length, grain yield $plant^{-1}$ and harvest index were significantly higher in seed rate of 20 kg ha^{-1} as compared to 30 and 40 kg ha^{-1} due to greater light interception and increased photosynthetic activity due to the availability of greater space and lesser competition for nutrients (Mansoor *et al*., 2010).

Effect of nutrient levels: Application of 12.5 kg N + 40 kg P_2O_5 ha^{-1} recorded taller plants, higher pods $plant^{-1}$ and higher grain yield, might be due to higher amount of nutrition available for the growth and development of the crop. Nutrient dose of 12.5 kg N + 40 kg P_2O_5 ha^{-1} has been found optimum for obtaining higher grain yield and net returns in mungbean on loamy sand soils (Singh *et al*., 2011a). However, non-significant difference with increase in nitrogen level from 36 to 58 kg ha^{-1} for this crop on sandy soils were also reported (Tickoo *et al*., 2006).

Interaction effects: At 12.5 N + 40 kg P_2O_5 ha^{-1} the raised-bed planting produced higher grain yield than flat bed planting was be due to better utilization of nutrients. During 2009, raised bed planting responded better with seed rate of 20 kg ha^{-1} than at 10 and 15 kg seed rate ha^{-1}. Higher grain yield in raised bed planting system might be due to proper aeration and better light interception within the canopy of the crop in this planting system. It was reported better light interception by soybean under raised bed planting system (Ram *et al*., 2011). The grain yield recorded at 20 kg ha^{-1} seed rate with 12.5 kg N + 40 kg P_2O_5 ha^{-1} was significantly higher than that recorded at all other combinations of seed rates and nutrient levels in 2009.

Irrigation water applied and water use efficiency (WUE): About 3.91% lower water use in raised beds which was significantly lower than recorded in flat planting was due to less amount of irrigation water applied in the raise-bed planting method. The reports of 33.3% saving in irrigation water applied in maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system at an experimental site near our study area was also reported (Ram *et al*., 2012). Higher water use efficiency in raised-bed planting was due to higher grain yield and lower amount of irrigation water applied. The WUE recorded in 20 and 15 kg seed ha^{-1} was similar but was higher than 10 kg ha^{-1} seed rate was be due to higher seed yield. The higher WUE in 12.5 kg N + 40 kg P_2O_5 ha^{-1} was due to higher productivity of mungbean with high nutrient dose.

Conclusion

As per our studies on loamy sand soil, the raised bed planting saves 33.3% of irrigation water applied and recorded 9.77% higher water use efficiency than in flat bed planting system which is required in the areas where water is becoming limited for agriculture. The raised beds for mungbean are likely to perform even better on fine-textured soils prone to water logging, which generally yields poorly on conventional, flat layouts during the monsoons of northwestern India (Dhadli *et al*., 2009). Seed rate is an important monetary input which sincreases the cost of cultivation and excessive vegetative growth. The seed rate of 20 kg ha^{-1} under different planting systems was found to be optimum for getting better yield. Being leguminous crop, mungbean can be raised using 12.5 kg N and 40 kg P_2O_5 ha^{-1} nutrient dose. However, there is a need to conduct this type of study in other parts of India where rice-wheat-mungbean or other cropping systems involving mungbean are important and where water and soils are becoming limited.

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