Effect of spacing and plant density on yield performance of determinate soybean variety Tarkari Bhatmas-1 under mid hill condition

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Abstract
Field experiments consisting nine spacing: three row to row (inter row: 43 cm, 50 cm and 60 cm) and three plant to plant (intra row: 10 cm, 15 cm and 20 cm) with plant population ranging from 8-23/m^2 were evaluated in randomized complete block design (RCBD) with four replications from 2014-2016 in Agronomy Farm, Lalitpur, Nepal. Seeds were sown on 29 May 2014, 31 May 2015 and 26 May 2016. Chemical fertilizers 30 N:60 P_2O_5:30 K_2O kg/ha were applied as basal dose. Combined analysis showed significant variation in final plant stand, grain yield and numbers of pod/plant amongst different inter row and intra row spacing, while other parameters were not statistically significant. Grain yields were at par at inter row spacing of 43-60 cm and intra row spacing of 10-15 cm (11-23 plants/m^2). Grain yield was reduced by 7-21% when intra row spacing was more than 10 cm, with the greatest reduction in wider intra row spacing of 20 cm. Greater number of pods/plant in wide spacing indicated the ability of soybean to compensate for low plant population to some extent. Plant grew taller in narrow intra row spacing than wider spacing, but seed size was not affected by spacing. Wider intra row spacing was found to have greater influence in term of grain yield than inter row spacing in case of early maturing determinate variety under Khumaltar condition. Inter row spacing of 43-60 cm and intra row spacing of 10-15 cm were found to be optimum for early maturing determinate soybean under Kathmandu valley and similar environments.

Keywords: Determinate, plant density, soybean, spacing, yield

Introduction

Soybean (*Glycine max* L. Merr) is the fifth important grain legume in terms of acreage after lentil, grass pea, pigeon pea and black gram. In 2018/19, soybean was cultivated in 25179 ha with production of 31567 t and productivity of 1254 kg/ha (MoALD, 2020). Soybean is an important summer legume in mid hills and valley which occupies about 80% of total soybean area and production. Some of the major production constraints are mungbean yellow mosaic virus (terai, inner terai), anthracnose, pod blight, bacterial pustule, frog eye leaf spot (mid hill), pod blight, hairy caterpillar, flower drop, micronutrient deficiencies and soil moisture stresses (Shrestha *et al*., 2012). Soybean plays an important role in the hill cropping system, where it is mostly grown in mixture with maize, relay crop in maize or in paddy bund. However, soybean is becoming popular as sole crop in terai and inner terai due to high yield potential and high demand of soya meal in poultry industry. Though globally soybean contributes 25% of the edible oil, and about two-thirds of the world's protein concentrate for livestock feeding (Agarwal *et al*., 2013) soybean is considered as grain legume crop in Nepal as domestic production is consumed either as roasted beans or green pods as vegetables, processed products: tofu, soya milk, nugget or as livestock and poultry feed to some extent.

Nepal Agricultural Research Council (NARC) had released seven soybean varieties (1977-2006) for cultivation in terai and mid hills under sole, bund planting and intercropping with maize. These released varieties are mostly of photosensitive, medium maturity with indeterminate growth habit except Tarkari Bhatmas-1. Best time of sowing Tarkari Bhatmas is third week of Baisakh for seed type and third week of Jestha for fresh pod (AGD, 2019). General recommendation of soybean seed is 60 kg/ha to maintain 400,000 plant population/ha with spacing of 50 cm x 5 cm (Chaudhari, 1984b). Varietal characteristics, planting time and growing environments (temperature, rainfall, soil etc) seems to have profound effect on yield performance of soybean as shown in various research conducted in Nepal and elsewhere. Higher yield of soybean in narrow inter row spacing of 35 cm than wide spacing of 60 cm under Rampur

condition might be due to short growing period available under terai condition. Similar yield increase in narrow row spacing in early planted as compared to wider spacing or low plant population had been reported by Matsuo *et al*., (2018) and Staggenborg *et al*., (2008). Intra row spacing of 40 cm gave higher seed yield in Lumle and Pakhribas conditions (LAC, 2039; Kelly, 1977). Extremely low plant population ($6/m^2$) in wider row spacing 60 cm x 20 cm might have attributed to poor seed yield in Pakhribas condition. In case of tall and late maturing Lumle-1 variety, wider intra row spacing of 20 cm (inter row 50 cm) produced the highest grain yield as compared to farmers practice of random planting and narrow intra row spacing of 10 cm (Chand *et al*., 1993). Optimum soil moisture is required for germination; however, excess soil moisture inhibits seedling emergence, damage to cotyledons, and early determinate variety is more prone to waterlogging that results in retardation of growth and consequently a complete crop failure. Optimum population or plant spacing varied depending upon growing environments, time of planting and varieties. Most of the recommendations on plant spacing made so far were for medium to late maturing indeterminate varieties, therefore early determinate soybean variety Tarkari Bhatmas-1 was evaluated to find out optimum plant population and planting geometry under mid hill condition.

Materials and Methods

Field experiments were conducted to evaluate the optimum plant population in soybean variety Tarkari Bhatmas-1 under upland condition at Khumaltar during 2014 to 2016. Total of nine spacing: three inter row i.e., row to row spacing of 43 cm, 50 cm and 60 cm, and three intra row i.e., plant to plant spacing within a row of 10 cm, 15 cm and 20 cm, with plant population ranging from 80,000 to 3,30,000 per hectare were evaluated in randomized complete block design with four replications (Table 1). Plot size of 4 m x 3 m was used. Chemical fertilizers of 30 N: 60 P_2O_5:30 K_2O kg/ha were applied at the time of land preparation. Sowing was done on 29 May 2014, 31 May 2015 and 26 May 2016. Seeds were treated with Bavistin @ 2 g/kg seed before seeding, while insecticide Furadan granules were applied in open furrow at the time of sowing. Thinning was done to retain single plant per hill after about a month of seeding. Cultural operation such as weeding and earthing up were done when needed. Ten plants were randomly selected for measuring plant height, number of pods/plant, unfilled pods/plant, number of branches/plant, number of seeds/pod at physiological maturity. Final plant stand was counted from inner rows excluding one border row at each side. Grain yield and straw dry matter were recorded from net plot area (excluding 1 border row at each side). Two hundred seeds were counted to estimate 100 seed weight. Grain yield and seed weight were adjusted to 12% moisture content. Subsample straw was oven-dried to estimate straw dry matter yield.

Table 1. Spacing, number of rows per 12 m^2 and plant population used in the experiment

SN	Spacing (cm)		Treatment	Population/ha	No. of rows	Plant stand/m^2
	Row	Plant to plant				
1	43	10	43 cm x 10 cm	2,30000	7	23
2	43	15	43 cm x 15 cm	1,50,000	7	16
3	43	20	43 cm x 20 cm	1,10,000	7	12
4	50	10	50 cm x 10 cm	2,00000	6	20
5	50	15	50 cm x 15 cm	1,30,000	6	13
6	50	20	50 cm x 20 cm	1,00000	6	10
7	60	10	60 cm x 10 cm	1,60,000	5	17
8	60	15	60 cm x 15 cm	1,10,000	5	11
9	60	20	60 cm x 20 cm	80,000	5	8

Weather condition

During cropping season i.e., from third week of June to September mean maximum temperatures were 28.6 ^oC in 2014, 28.8 ^oC in 2015 and 27.9 ^oC in 2016, while mean minimum temperatures were 20.5 ^oC, 19.9 ^oC and 20 ^oC, respectively in 2014, 2015 and 2016 (data not shown). Similarly, total growing period

rainfall from seeding to maturity were 678 mm in 2014 (29 May to 19 Sept), 659 mm in 2015 (31 May to 19 Sept) and 813 mm in 2016 (26 May to 16 Sept) (data not presented). Mean minimum temperature was slightly lower while slightly greater mean maximum temperatures were recorded in 2015 as compared to 2014 and 2016 (Figure 1). Total rainfall received from seeding to vegetative stage were 214 mm, 326 mm and 259 mm, respectively in year 2014, 2015 and 2016 (data not shown). Similarly, rainfalls during reproductive stages were 464 mm in 2014, 334 mm in 2015 and 554 mm in 2016.

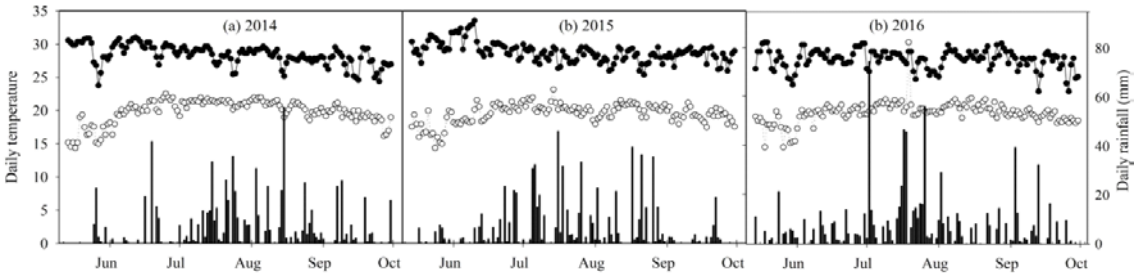

Fig. 1: Daily mean maximum (-●-), minimum (-○-) temperatures and rainfall (solid bar) during soybean growing season in Khumaltar (2014-2016)

Results and discussion

Crops reached 50% flowering and 90% maturity in 50 and 110 days after sowing (data not presented). Plant population at harvest varied significantly in all year, with highest numbers of plants at harvest (16-24/m^2) in narrow spacing of 43-50 cm x 10 cm and the lowest of 9-14/m^2 in wider spacing of 50-60 cm x 20 cm (Table 2). Grain yield did not vary significantly among spacing in 2014 (Table 4) that might be due to relatively higher number of plants at harvest in wider spacing than prescribed. In 2015, mean grain yield was 1991 kg/ha was reported in narrow spacing of 43 cm x 10-15 cm, 50 cm x 10 cm and the lowest of 1516 kg/ha in wider intra row spacing of 20 cm. In 2016, mean grain yield lower in wider spacing of 60 cm x 20 cm than other spacing studied.

Table 2. Plant population at harvest and grain yield as affected by spacing in soybean variety Tarkari Bhatmas-1 at Khumaltar (2014-2016)

SN	Spacing (inter row x intra row)	Plant stand at harvest (m^2)			Grain yield (kg/ha)		
		2014	2015	2016	2014	2015	2016
1.	43 cm x 10 cm	24	16	20	2441	1986	2660
2.	43 cm x 15 cm	19	14	18	2543	1925	2472
3.	43 cm x 20 cm	18	11	15	2483	1522	2525
4.	50 cm x 10 cm	23	17	17	2486	2061	2481
5.	50 cm x 15 cm	18	12	15	2665	1729	2533
6.	50 cm x 20 cm	14	11	14	2153	1546	2840
7.	60 cm x 10 cm	21	12	15	2662	1786	2724
8.	60 cm x 15 cm	17	10	13	2616	1749	2502
9.	60 cm x 20 cm	13	9	12	2473	1480	1704
	Spacing p value	<.001	<.001	0.007	0.118	0.048	0.008
	LSD (<0.05)	5	3	4	-	397	500
	CV (%)	17	16	19	9	16	14

Combine analysis showed non-significant difference in plant height, number of main branches/plant, unfilled pods/plant, 100 seed weight, straw dry matter and harvest index among spacing treatments except pods/plant, final plant stand and grain yield (Figure 3, Tables 3, 4). Spacing x year interaction was significant for grain yield and seed weight (Tables 3, 4). The mean values for final plant stand showed decreasing trends with increasing intra row plant to plant spacing in all three inter row spacing (Figure 2a). Final plant stand ranged from 15-20/m^2 in spacing of 43-60 cm x 10 cm and spacing of 43-50 cm x 15 cm as compared to wider spacing of 50-60 cm x 20 cm (11-13/m^2).

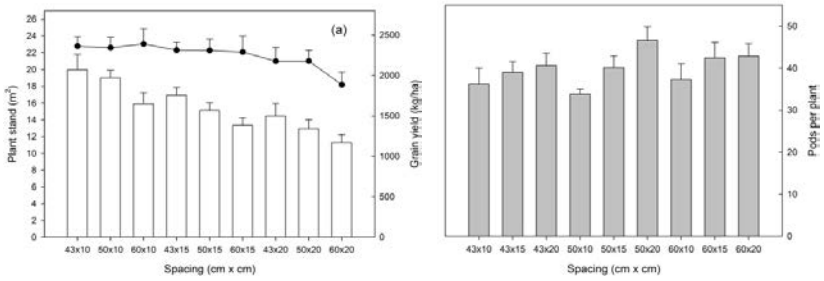

Fig. 2: (a) Mean plant stand at harvest (open bar), grain yield (-●-), and (b) pods/plant of soybean variety Tarkari Bhatmas-1 as affected by inter and intra row spacing at Khumaltar (2014-16)

Plants grew taller in narrow intra row spacing of 10-15 cm as compared to wider intra row spacing of 20 cm (Table 3). Number of pods/plant was higher in wider intra row spacing of 15-20 cm, while narrow intra row spacing of 10 cm had comparatively low pods (Figure 2b). There was a general trend of decrease in plant height with increasing intra row spacing, while higher number of pods/plant with increasing intra row spacing. Mean number main branches/plant, unfilled pods/plant, 100 seed weight and HI ranged from 2-3 4-6, 22.2 g and 0.43, respectively among various spacing. Minimum straw dry matter production in wider spacing of 60 cm x 20 cm (2221 kg/ha) and the maximum in narrow spacing of 43 cm x 10 cm (2783 kg/ha) might be related to plant stand and plant height. Grain yield was significantly low in wider intra row spacing of 20 cm only (Figure 2a). In early maturing short statured determinate variety, plant density of 15-20/m^2 with the best arrangement inter row spacing of 43-60 cm and intra row spacing of 10-15 cm was found to be optimum in terms of grain yield production than wider intra row spacing of 20 cm where plant population was less than 11/m^2. Plant population did not have any influence on plant height, number of main branches/plant, unfilled pods/plant, 100 seed weight, straw dry matter and harvest index might be due to determinate growth habit and short growing season. However, soybean showed greater plasticity or has capacity to attain grain yield in lowest plant population as low plant density was often compensated by increased number of primary and secondary branches (Carpenter and Board, 1997; Subedi *et al*., 1992 and Enyi, 1973), greater number of filled and total pods/plant (Subedi *et al*., 1992 and Enyi, 1973). Weber *et al.,* (1966) reported more severe plant competition at higher plant densities and hence taller plants, few branches, lodged more, and set fewer pods and seed thus low seed yield as compared to lower densities.

Table 3. Yield and yield parameters of soybean variety Tarkari Bhatmas-1 in Khumaltar (2014-2016)

SN	Treatments	Plant height (cm)	Unfill pods/plant	100 seed weight (g)	Straw dry matter (kg/ha)	HI
	Spacing (S)					
1.	43 cm x 10 cm	51	5	22.3	2783	0.43
2.	43 cm x 15 cm	50	5	22.1	2663	0.43
3.	43 cm x 20 cm	47	6	22.3	2659	0.41
4.	50 cm x 10 cm	50	5	22.7	2595	0.44

SN	Treatments	Plant height (cm)	Unfill pods/plant	100 seed weight (g)	Straw dry matter (kg/ha)	HI
5.	50 cm x 15 cm	49	5	22.4	2645	0.43
6.	50 cm x 20 cm	47	6	21.9	2732	0.41
7.	60 cm x 10 cm	51	4	22.4	2645	0.44
8.	60 cm x 15 cm	45	6	22.0	2521	0.45
9.	60 cm x 20 cm	47	5	22.1	2221	0.43
	Mean	49	5	22.2	2607	0.43
	Year					
1.	2014	51	4	23.3	2959	0.43
2.	2015	43	6	20.7	2136	0.42
3.	2016	51	6	22.7	2727	0.45
	Spacing (S) - p value	0.420	0.220	0.436	0.117	0.22
	LSD (<0.05)	-	-	-	-	-
	Year (Y) - p value	<.001	<.001	<.001	<.001	0.004
	LSD (<0.05)	3.4	0.8	0.38	204	0.02
	S*Y - p value	0.993	0.799	0.011	0.473	0.853
	LSD (<0.05)	-	-	1.15	-	-
	CV (%)	15	33	4	17	9

There was a positive correlation of plant population with plant height (r^2=0.32**), grain yield (r^2=0.35**), seed weight (r^2=0.24**) and straw dry matter (r^2=0.36**), but negative with numbers of pods (r^2=-0.21**), unfilled pods (r^2=-0.17**) and number of main branches (r^2=-0.18**). However, Enyi (1973) reported decreased total dry matter/plant, number of nodes/plant, number of pods/plant and number of branches/plant in soybean var. 3H55F4/149/1 with increasing plant population from 7 to 44/m^2. Low light intensity under the plant may lead to a reduction in the number of side branches, number of pods/plant and number of nodes with pods (Enyi, 1973). There was a significant variation in parameters recorded among years (Table 3) while spacing x year interaction was significant for maturity days, grain yield and seed size (Tables 4). In 2015, crop grew shorter, matured early, reduce grain yield by 42% and seed size by 10-13% as compared to year 2014, 2016 (Table 4). In year 2015, total rainfall received from seeding to vegetative period was 20-34% greater than the rainfall received during the same period in 2014 and 2016. On the other hand, reproductive period was much drier in 2015 as indicated by 39-66% less rainfall stage as compared to 2014 and 2016. In 2015, excess soil moisture during early growth period might have resulted in low plant density, while soil moisture deficits during reproductive period might have contributed to poor growth, early maturity, lighter seed weight and low dry matter production than 2014 and 2016.

Table 4. Yield and yield parameters of soybean variety Tarkari Bhatmas-1 at Khumaltar

Year	Final stand (m^2)	Flowering days	Maturity days	Main branch/ plant	Seeds /pod	Pods/ plant	Grain yield (kg/ha)
2014	19	50	110	2	2.0	35	2503
2015	12	51	108	2	2.0	38	1754
2016	15	49	113	3	2.4	46	2493
Mean	15	50	110	2	2.1	40	2250
Spacing (S) - p value	<.001	0.976	0.002	0.137	0.573	0.043	0.007
LSD (P<0.05)	2	-	0.57	-	-	7.4	256.3
Year (Y) - p	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Year	Final stand (m^2)	Flowering days	Maturity days	Main branch/ plant	Seeds /pod	Pods/ plant	Grain yield (kg/ha)
value							
LSD (P<0.05)	1.3	0.5	0.3	0.3	0.05	4.3	148
S x Y - p value	0.866	0.848	<.001	0.604	0.641	0.878	0.024
LSD (P<0.05)	-	-	0.3	-	-	-	420.9
CV (%)	18	2	1	29	5	23	14

Conclusion

In soybean, varietal traits, planting time, soil type and growing season temperatures and rainfall determine the success of the crop. In photo insensitive determinate variety Tarkari Bhatmas-1, intra row spacing of 43-60 cm and intra plant spacing of 10-15 cm was with plant density of 11-23/m^2 was found optimum in terms of grain yield under Kathmandu valley and similar environments. Intra row spacing seems to be more critical as compared to inter row spacing as intra row spacing of greater than 15 cm drastically reduced plant density and thus significant reduction in grain yield. Greater number of pods/plant were recorded when intra row spacing increased from 10 cm to 15 cm thereby compensating for low plant population.

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