International Journal of

Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

International Journal of Agricultural Research 5 (5): 259-267, 2010
ISSN 1816-4897

Replacing Rice with Soybean for Sustainable Agriculture in the Indo-Gangetic Plain of India: Production Technology for Higher Productivity of Soybean

Guriqbal Singh
Department of Plant Breeding and Genetics,
Punjab Agricultural University, Ludhiana, 141004, India

Abstract: The aim of the study was to know the production potential of soybean and see if soybean could be grown successfully as an alternate to rice. Therefore, 8 field experiments were conducted during 1999 to 2001 on a loamy sand soil to find out optimum time of sowing, best genotype, optimum plant population, adequate seed rate and row spacing for achieving high yields of soybean. The grain yields of the crop sown on 24 May (1798 kg ha^{-1}), 8 June (1828 kg ha^{-1}) and 24 June (1878 kg ha^{-1}) were on par, however, 8 July (1364 kg ha^{-1}) sowing produced the lowest yield. Genotypes SL 459, SL 517, SL 525, SL 295 and PK 416 were high yielders (1456-2526 kg ha^{-1}). Plant populations of 0.45 (1584 kg ha^{-1}) and 0.60 million plants ha^{-1} (1609 kg ha^{-1}) were on par in grain yield and produced higher yields than 0.30 million plants ha^{-1} (1436 kg ha^{-1}). Row spacings of 45 and 60 cm and seed rates of 62.5, 75 and 87.5 kg ha^{-1} or 50, 62.5 and 75 kg ha^{-1} produced similar grain yields. Results from the present studies indicate that suitable production technology is available for achieving high grain yields of soybean and thus, it has a great potential for replacing some of the area currently under rice.

Key words: Genotypes, plant population, rice, row spacing, sowing time, soybean

INTRODUCTION

The Indo-Gangetic Plain (IGP) is spread over four countries, viz., Bangladesh, India, Nepal and Pakistan. In India, IGP, extends from 21°31' to 32°20' N and 73°16' to 89°52' E and is spread over the states of Punjab, Haryana, Delhi, Uttar Pradesh, Uttaranchal, Bihar and West Bengal and small parts of Jammu and Kashmir, Himachal Pradesh and Rajasthan (Ali *et al*., 2000). The Western part of IGP (Punjab, Haryana, Delhi and Western Uttar Pradesh) has a semi-arid climate with annual rainfall of 500-800 mm, whereas the Eastern part (Eastern Uttar Pradesh, Bihar and West Bengal) experiences a humid climate with annual rainfall of 1000-2000 mm. In moving from West to East, the soil texture becomes heavier and drainage is impeded and agricultural productivity and farm returns also show a declining trend from the Western to Eastern IGP.

In the Indian IGP, rice (*Oryza sativa*) occupies 24.8 million ha^{-1} and wheat (*Triticum aestivum*) 21.1 million ha^{-1}, accounting for 58 and 84%, respectively of the country's total area (Ahlawat *et al*., 1998). Though, there are many cropping systems yet rice-wheat is the predominant cropping system, occupying about 10 to 10.5 million ha^{-1} in the Indian IGP (Ali *et al*., 2000; Gupta *et al*., 2007) and 13 million ha in South Asia and 21 million ha^{-1} in the Asian subtropics (Pathak *et al*., 2006). The rice-wheat cropping system, was a long history in the Indian IGP, as it has been practiced in Uttar Pradesh since 1872 and in Punjab and

West Bengal since 1920 (Gill, 1994). The major expansion of this system has taken place since the 1960's with the availability of high-yielding, semi-dwarf, short-duration varieties of rice and wheat, which are highly responsive to fertilizers and irrigation. This system is more popular in the non-traditional rice-growing states of Punjab, Haryana and Uttar Pradesh and less in traditional rice-growing states of Bihar and West Bengal. A quantum jump in the production of rice and wheat has helped greatly in achieving the food self-sufficiency in the country.

The growth rates of rice and wheat yields are either stagnating or declining. The productivity of these crops in some parts of India has already ceased to increase and in a few states it has shown declining trends. Cultivation of these crops has become less profitable. Cultivation of rice is considered to be more dangerous than wheat to sustainable agriculture because: (1) Rice is a high water-demanding crop. To meet its water requirement lot of ground water is pumped out, with the result water table is going deep (Jeevandas *et al.*, 2008). There are fears that Punjab, the most forward state in agriculture in the country, may become desert due to continuous pumping out of large volume of water. (2) Before transplanting rice seedlings, puddling is done, which results in creation of a hard pan in the soil. This hard pan is not broken with normal cultivation, with the result waterlogging takes place in low area in succeeding wheat crop, thereby decreasing its yield. (3) Cultivation of rice makes conditions conducive for the multiplication of insect pests and diseases. Rice cultivation has also other negative roles such as (1) increased population of mosquitoes due to stagnating water which helps in their breeding, (2) increased incidences of deficiencies of micronutrients in the crops and (3) gluts in the market due to over-production of rice, thereby causing market problems and social tensions.

Due to above reasons, it is felt that for sustainable agriculture rice must be replaced with some other crops. Soybean (*Glycine max*) offers a good alternative to rice because being a grain legume it will not only meet its own nitrogen requirement to a great extent through biological nitrogen fixation but it will also leave considerable amounts of nitrogen in soil and in crop residues for utilization for the succeeding crops (Herridge *et al.*, 2008). India imports vegetable oil, so soybean production in the country will not only help in meeting vegetable oil requirements but also save foreign exchange.

To make any crop successful in any area it is a must to have good genotypes and improved production technology for realizing good yields. Planting date (De Bruin and Pedersen, 2008a; Cox *et al.*, 2008), seed rate (De Bruin and Pedersen, 2008a, b), row spacing (De Bruin and Pedersen, 2008b) and genotypes (De Bruin and Pedersen, 2009) are known to influence the grain yield considerably. Therefore, eight field experiments were conducted to find out optimum time of sowing, best genotype, optimum planting density, adequate seed rate and row spacing for achieving high yields of soybean.

MATERIALS AND METHODS

Field experiments were conducted on a loamy sand soil during kharif (rainy) season of 1999 to 2001 at the Punjab Agricultural University, Ludhiana (36°56' N, 75°52' E and altitude 247 m), India.

The date of sowing×genotype trial comprising four dates of sowing (24 May, 8 and 24 June and 8 July) and three genotypes (PK 416, SL 295 and SL 459) was conducted during 1999 to 2001 in a split plot design by keeping dates of sowing in main plots and genotypes in the sub-plots. Sowing was done in rows 45 cm apart using 87 kg seed rate ha^{-1}.

Table 1: Meteorological data during crop season, 1999 to 2001

	Temp. (°C)			Rainfall (mm)	
Month	Min.	Max.	Relative humidity (%)	Received	Departure from normal
1999					
June	24.6	36.9	55	24.4	-45.0
July	26.7	33.9	71	359.2	+127.1
August	25.5	33.8	77	68.6	-111.1
September	24.7	34.1	74	92.6	-9.2
October	17.5	33.1	64	0.0	-6.0
2000					
June	27.1	36.1	62	88.2	+11.8
July	26.8	33.2	80	189.4	-42.7
August	26.0	34.1	79	120.8	-58.9
September	22.7	34.0	73	139.2	+37.4
October	18.5	33.8	62	0.0	-6.0
2001					
June	30.5	35.3	67	221.0	+154.6
July	29.9	33.3	83	383.8	+151.7
August	30.3	35.3	78	312.5	+33.8
September	28.8	33.8	70	28.6	-73.2
October	25.6	29.7	65	0.0	-6.0

The genotype×row spacing×seed rate trial tested two genotypes (SL 295 and SL 459), three seed rates (62.5, 75 and 87.5 kg ha^{-1} during 1999 and 50, 62.5 and 75 kg ha^{-1} during 2000) and two row spacings (45 and 60 cm) in a split plot design. The row spacings were assigned in the main plots whereas genotypes and seed rates were kept in the sub-plots.

The genotype×planting density trial, conducted during 1999 to 2001, the performance of different genotypes (SL 459, PK 416, PK 1042, Pusa 16, Pusa 9702 during 1999; SL 459, PK 416, PK 1042, Pusa 16, SL 295, PK 1225 during 2000 and SL 459, PK 416, PK 1042, Pusa 16, SL 517, SL 525, SL 528, PK 1251 during 2001) was tested under three planting densities (0.30, 0.45 and 0.60 million plants ha^{-1}) in a split plot design by keeping genotypes in main plots and planting densities in the sub-plots. The sowing was done in rows 45 cm apart using a higher seed rate (100 kg ha^{-1}) and 15 to 20 days after sowing thinning was done to maintain the desired plant population as per the treatments.

In all the trials, a fertilizer dose of 30 kg N and 60 kg P_2O_5 ha^{-1} was applied at the time of sowing. Irrigation was applied as and when required. Two hand weedings were done 30 and 45 days after sowing to control weeds. Plant protection measures were used to control insect pests as per the recommendations. Meteorological data recorded during the crop season are given in Table 1. The data were analyzed to compare treatment means as per the standard procedures.

RESULTS

Date of Sowing×Genotype Studies

During 1999 and 2001 the crop sown on 8 June yielded the highest and it was on par with 24 May and 24 June sowings (Table 2). However in 2000, 24 June sowing yielded the highest and all other sowing dates were significantly inferior to it. There was drastic reduction in yield with 8 July sowing. On the basis of mean of 3 year data the differences among 24 May, 8 and 24 June were not so high, but 8 July sowing was considerably inferior to these three dates of sowing. In general, with delay in sowing with each date from 24 May, plant height, pods plant^{-1}, 100 seed weight and biological yield decreased (Table 3).

Table 2: Grain yield of soybean as influenced by dates of sowing and genotypes

	Grain yield (kg ha^{-1})			
Treatments	1999	2000	2001	Mean
Dates of sowing				
24 May	1964.0	2017.0	1414.0	1798
8 June	2019.0	2048.0	1419.0	1828
24 June	1870.0	2402.0	1363.0	1878
8 July	1432.0	1939.0	723.0	1364
S.E.D.	117.1	87.5	181.6	
Genotypes				
SL 295	1563.0	1814.0	993.0	1456
SL 459	2082.0	2561.0	1670.0	2104
PK 416	1819.0	1930.0	1026.0	1591
S.E.D.	80.4	106.5	118.7	

Table 3: Effect of date of sowing and genotypes on the plant traits, biological yield and harvest index of soybean in 2001

Treatments	Plant height (cm)	Pods $plant^{-1}$	100-seed weight (g)	Biological yield (kg ha^{-1})	Harvest index (%)
Dates of sowing					
24 May	89.70	46.70	9.700	6088.0	23.2
8 June	74.00	38.00	9.590	5274.0	26.9
24 June	56.40	39.80	9.110	4326.0	31.5
8 July	41.70	31.80	8.850	2182.0	33.1
S.E.D.	2.51	3.05	0.207	656.9	
Genotypes					
SL 295	64.60	36.00	10.370	3716.0	26.7
SL 459	63.20	43.50	7.880	5711.0	29.2
PK 416	68.50	37.80	9.680	3977.0	25.7
S.E.D.	1.11	2.85	0.198	362.4	

Table 4: Effect of genotypes, row spacings and seed rates on the grain yield of soybean

	Grain yield (kg ha^{-1})		
Treatments	1999	2000	Mean
Genotypes			
SL 295	1508.0	1559.0	1533
SL 459	1826.0	2450.0	2138
S.E.D.	125.8	141.0	
Row spacing (cm)			
45	1744.0	2051.0	1897
60	1590.0	1959.0	1774
S.E.D.	111.7	57.3	
Seed rate (kg ha^{-1})			
50.0	-	1921.0	-
62.5	1640.0	2106.0	1873
75.0	1762.0	1987.0	1874
87.5	1599.0	-	-
S.E.D.	117.5	132.8	

Genotype SL 459 was the highest yielder during all 3 years of investigation (Table 2) and it was significantly superior to both the other genotypes. Genotype SL 295 was the lowest yielder. The PK 416 produced the tallest plants (Table 3). However, SL 459 had the highest number of pods $plant^{-1}$, biological yield and harvest index.

Genotype×Row Spacing×Seed Rate Studies

Genotype SL 459 produced significantly higher grain yield than SL 295 during both the years of investigation (Table 4); averaged over 2 year data the increase was 39.4%. Both the row spacings produced statistically the same yield. Similarly, different seed rates also failed to influence the grain yield significantly.

Table 5: Effect of genotypes and plant population on the grain yield of soybean

	Grain yield (kg ha^{-1})			
Treatments	1999	2000	2001	Mean
Genotypes				
SL 459	2101.0	2526.0	2320.0	2315
PK 416	1750.0	1804.0	1333.0	1629
PK 1042	1687.0	1300.0	375.0	1120
Pusa 16	707.0	1089.0	913.0	903
Pusa 9702	1160.0	-	-	-
SL 295	-	1915.0	-	-
PK 1225	-	1819.0	-	-
SL 517	-	-	2479.0	-
SL 525	-	-	2409.0	-
SL 528	-	-	1076.0	-
PK 1251	-	-	355.0	-
S.E.D.	182.1	196.5	220.9	
Plant population (million plants ha^{-1})				
0.30	1327.0	1669.0	1314.0	1436
0.45	1580.0	1793.0	1381.0	1584
0.60	1536.0	1765.0	1527.0	1609
S.E.D.	84.8	65.3	78.4	

Table 6: Effect of genotypes and plant population on the plant traits, biological yield and harvest index of soybean in 2001

Treatments	Plant height (cm)	Pods $plant^{-1}$	100-seed weight (g)	Biological yield (kg ha^{-1})	Harvest index (%)
Genotypes					
SL 459	74.80	39.90	8.120	8187.0	28.3
PK 416	76.60	44.00	10.040	5708.0	23.3
PK 1042	67.80	32.10	9.260	2725.0	13.7
Pusa 16	68.30	34.00	9.080	3644.0	25.0
SL 517	80.90	47.10	9.050	9017.0	27.4
SL 525	81.70	36.20	9.680	8266.0	29.1
SL 528	74.00	35.50	7.240	5619.0	19.1
PK 1251	68.70	36.30	9.000	2074.0	17.1
S.E.D.	3.49	3.67	0.225	908.6	
Plant population (million plants ha^{-1})					
0.30	71.90	39.20	8.920	5285.0	24.8
0.45	74.70	38.20	9.030	5722.0	24.1
0.60	75.70	37.00	8.860	5959.0	25.6
S.E.D.	1.73	1.02	0.087	180.1	

Genotype×Plant Population Studies

There was a large genotypic variation in the grain yield during all 3 years of the study (Table 5). Some of the genotypes like SL 459, SL 517, SL 525 and SL 295 were quite high yielders. There was large year to year variation in the grain yield in some of the genotypes like PK 416 and PK 1042.

Plant population of 0.45 and 0.60 million plants ha^{-1} produced more than 0.30 million plants ha^{-1}. On the basis of mean of 3 year data plant population of 0.45 and 0.60 million plants ha^{-1} produced 10.3 and 12.0% higher yield than 0.30 million plants ha^{-1}. As the plant population increased, plant height and biological yield increased whereas, the number of pods $plant^{-1}$ decreased (Table 6).

DISCUSSION

Grain yields were generally comparable with 24 May, 8 and 24 June sowings, however, 8 July sowing produced the lowest yield (Table 2). Delayed sowings result in lower grain yields of soybean (Yunusa and Ikwelle, 1990; Bastidas *et al*., 2008; Cox *et al*., 2008;

De Bruin and Pedersen, 2008a). In the present study, on the basis of 3 year data, compared to 24 June sowing there was 27.3% reduction in the grain yield with 8 July sowing. In earlier studies also, it has been reported that the crop sown late (10 July) may produce 20-30% lower grain yield than the timely (26 June) sown crop (Yunusa and Ikwelle, 1990). Late sowings may produce lower grain yields due to a variety of reasons including shortening of growth period (Purcell *et al.*, 2002), less accumulation of photo-synthetically active radiation (Purcell *et al.*, 2002) and less number of heat units and helio-thermal units (Dhingra *et al.*, 1995). Furthermore, with delay in sowing, plant height, diameter and node number of main stem (Kang *et al.*, 1998), total dry matter yield (Dhingra *et al.*, 1995), 100-seed weight (Kang *et al.*, 1998) and pods plant^{-1}, seeds pod^{-1} and 100-seed weight (Jasani *et al.*, 1994) decrease, ultimately resulting in lower yields. In the present study also, with the delay in sowing plant height, pods plant^{-1}, 100-seed weight and biological yield decreased (Table 3), which were responsible for low grain yields. With delay in sowing harvest index improved (Table 3), possibly due to better source-sink relationship. In 2000, lower grain yields of 24 May and 8 June sowings than 24 June sowing could possibly be due to low rainfall in July (Table 1).

Results have shown that 0.45 and 0.60 million plants ha^{-1} were on par, both being significantly better than 0.30 million plants ha^{-1} in influencing the grain yields of soybean (Table 5). Grain yield of soybean increased with increase in the plant density from 0.222 to 0.666 million plants ha^{-1} (El Din *et al.*, 1997) or 0.166 to 0.476 million plants ha^{-1} (El Douby *et al.*, 2002) or 0.296 million plants ha^{-1} to 0.444 million plants ha^{-1} (Bhosale *et al.*, 1995). Other researchers have also reported that the grain yields of soybean were similar with 0.40 and 0.60 million plants ha^{-1} and higher than those with 0.20 million plants ha^{-1} (Rani and Kodandaramiah, 1997).

Higher plant population had higher grain yield (Table 5) as well as biological yield (Table 6) due to higher plant stand per unit area. Plant height increased with higher plant population (Table 6), possibly due to competition amongst plants for sunlight. However, at higher plant population the number of pods plant^{-1} decreased (Table 6), due to competition amongst plants for resources like nutrients, moisture, light and space. Though lower plant density may result in higher mean number of branches, pods and seeds per plant; weight of pods and seeds per plant and 100-seed weight (El Douby *et al.*, 2002) possibly due to low inter plant competition, yet the grain yields on per unit area basis are lower due to inadequate plant population. Dry matter accumulation plant^{-1}, number and dry weight of nodules plant^{-1} (Dubey and Billore, 1993), number of branches and pods plant^{-1} (Kang *et al.*, 1998; Ball *et al.*, 2000) and number of seeds pod^{-1} (Kang *et al.*, 1998) decrease with an increase in plant density. However, on a per unit area basis these parameters show an increasing trend with increasing plant density and thus resulting in higher grain yield at higher plant population, as observed in the present investigation (Table 5).

Genotype SL 459 was tested in all the experiments during all the years of investigation and it produced the highest grain yields in every trial (Table 2, 4 and 5). Based on mean data it produced 44.5% (Table 2) and 39.4% (Table 4) higher grain yields than SL 295 and 32.2% (Table 2) and 42.1% (Table 5) higher grain yields than PK 416. Genotypes of soybean do differ in grain yields (El Douby *et al.*, 2002; De Bruin and Pedersen, 2009). High yields in some of the genotypes may be due to better growth, higher tolerance to diseases, adequate crop duration, etc. Genotypes do differ in leaf area index, crop growth rate and net assimilation rate. Genotypes having such type of better physiological parameters are expected to yield higher. Different genotypes may require different plant population and row spacing to yield optimally depending upon their growth habit. In the present study, however, there was no significant interaction between genotypes and plant population, or genotypes and seed rates, thus showing that different genotypes had similar requirements of plant population/seed rate.

Mungbean yellow mosaic is a serious disease in soybean. The lower yields of some of the genotypes observed in this study (Table 5) were mainly due to the incidence of this disease. However, at Hisar (Haryana), also a location in IGP, genotypes PK 416 and PK 1024 yielded quite high (Singh *et al*., 1993) as there the incidence of this disease is generally less.

Soybean, being a grain legume, has the ability to fix atmospheric nitrogen in the soil in association with *Bradyrhizobium* rhizobia. The amounts of nitrogen so fixed may be 125-180 kg N ha^{-1} (Saxena and Chandel, 1997). Apart from it, a considerable amount of leaf fall occurs, which results in the addition of organic matter in the soil, thus leading to improvement in soil fertility as well as physical properties of the soil. The succeeding crop requires lesser amount of nitrogenous fertilizers and thus cost of production of the cropping system is reduced, resulting in higher profitability.

There may be some other crops which may compete with soybean for replacing rice; the potential crops could be mungbean (*Vigna radiata*), black gram (*Vigna mungo*) and pigeonpea (*Cjanus cajan*). All these are grain legumes (pulses), which are used as whole or split pulse (*dal*). However, as compared to these crops soybean has much greater scope as it has diverse uses including soya oil, soya milk, soya cheese, soya chunks, soya granules, etc. Small-scale soybean processing plants are establishing in the Indo-Gangetic Plain of India. Consumers like soybean-based products and in the years to come their demand is going to increase. India imports vegetable oil, involving lot of foreign exchange. With the production of soybean, the country can meet vegetable oil requirements to a great extent. Furthermore, foreign exchange will also be saved.

Water requirement of soybean is much less than that of rice. Soybean is grown during rainy (monsoon) season; in case rains are well distributed there may not be any need to apply irrigation. In case of scarce rainfall, 2-3 irrigations may be needed by the crop. However, in case of rice submerged conditions are maintained throughout the crop-growing season, which requires huge amount of water.

Soil and climatic conditions are suitable for growing soybean in the Indian IGP. In the present study, very high yields of soybean were obtained (Table 2, 4 and 5). At other locations, which also fall in the Indian IGP, quite high yields of soybean have been reported: e.g., at Hisar (Haryana) 19.79-33.17 q ha^{-1} (Chhokar *et al*., 1997), New Delhi 19.15-24.57 q ha^{-1} (Kewat and Pandey, 2001), Palampur (Himachal Pradesh) 18.3-20.1 q ha^{-1} (Sharma and Bhardwaj, 1998), Pantnagar (Uttranchal) 20.34-39.14 q ha^{-1} (Saxena and Chandel, 1997). This shows that there is a considerable potential of soybean in the IGP. The above yield potentials show that very good production technology is available to realize high yields.

There is a need to popularize soybean cultivation in the IGP. Assured marketing and remunerative price are two important factors for making soybean cultivation successful on a large acreage. Furthermore, setting up of processing industries may help in increasing consumption of soybean products by people. Once the demand for soybean produce is established for soybean processing industry for local use and export purpose more and more area is expected to come under soybean in the IGP of India. It is neither advised nor required to replace lot of area currently under rice with soybean. However, even if some of the area under rice is replaced with soybean, it is expected to have beneficial effects on sustainable agriculture in the region in the long run.

REFERENCES

Ahlawat, I.P.S., M. Ali, R.L. Yadav, J.V.D.K. Kumar Rao, T.J. Rego and R.P. Singh, 1998. Biological Nitrogen Fixation and Residual Effects of Summer and Rainy Season Grain Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain. In: Residual Effects of Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain, Kumar Rao, J.V.D.K, C. Johansen and T.J. Rego (Eds.). Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, pp: 31-54.

Ali, M., P.K. Joshi, S. Pande, M. Asokan, S.M. Virmani, R. Kumar and B.K. Kandpal, 2000. Legumes in the Indo-Gangetic Plain of India. In: Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain – Constraints and Opportunities, Johansen, C., J.M. Duxbury, S.M. Virmani, C.L.L. Gowda, S. Pande and P.K. Joshi (Eds.). ICRISAT, Patancheru and Cornell University, New York, Ithaca, pp: 35-70.

Ball, R.A., L.C. Purcell and E.D. Vories, 2000. Crop ecology, production and management: Short-season soybean yield compensation in response to population and water regime. Crop Sci., 40: 1070-1078.

Bastidas, A.M., T.D. Setiyono, A. Dobermann, K.G. Cassman, R.W. Elmore, G.L. Graef and J.E. Specht, 2008. Soybean sowing date: The vegetative, reproductive and agronomic impacts. Crop Sci., 48: 727-740.

Bhosale, A.S., B.S. Jadhav, B.R. Patil and B.D. Kumbhojkar, 1995. Response of soybean to plant populations and fertilizers in Sub-Montane Zone of Maharashtra. J. Maharashtra Agric. Univ., 20: 129-130.

Chhokar, R.S., R.S. Balyan and S.S. Pahuja, 1997. Nutrient removal by weeds in soybean (*Glycine max*) under integrated weed management. Indian J. Agron., 42: 138-141.

Cox, W.J., E. Shields and J.H. Cherney, 2008. Planting date and seed treatment effects on soybean in the Northeastern United States. Agron. J., 100: 1662-1665.

De Bruin, J.L. and P. Pedersen, 2008a. Soybean seed yield response to planting date and seeding rate in the Upper Midwest. Agron. J., 100: 696-703.

De Bruin, J.L and P. Pedersen, 2008b. Effect of row spacing and seeding rate on soybean yield. Agron. J., 100: 704-710.

De Bruin, J.L. and P. Pedersen, 2009. New and old soybean cultivar responses to plant density and intercepted light. Crop Sci., 49: 2225-2232.

Dhingra, K.K., H. Kaur, L.K. Dhaliwal and J. Singh, 1995. Phenological behavior and heat unit requirement of soybean genotypes under different dates of sowing. J. Res. Punjab Agric. Univ., 32: 129-135.

Dubey, S.K. and S.D. Billore, 1993. Effect of biological pressure on nodulation pattern of soybean [*Glycine max* (L.) Merrill] genotypes. Agric. Sci. Digest. Karnal, 13: 191-194.

El Din, G.M.S., K.A. El Douby, E.A. Ali and M.S.A. Mohamed, 1997. Response of some soybean cultivars to plant population density. Ann. Agric. Sci., Moshtohor, 35: 131-142.

El Douby, K.A., S.H. Mansour and A.A. Zohry, 2002. Effect of plant density on some soybean cultivars under two planting dates. Egypt. J. Agric. Res., 80: 275-291.

Gill, K.S., 1994. Sustainability Issues Related to Rice-Wheat Production System. In: Sustainability of Rice-Wheat Production Systems in Asia, Paroda, R.S., T. Woodhead and R.B. Singh (Eds.). RAPA Publication, Bangkok, pp: 36-60.

Gupta, R.K., Yadvinder-Singh, J.K. Ladha, Bijay-Singh, J. Singh, G. Singh and H. Pathak, 2007. Yield and phosphorus transformations in a rice-wheat system with crop residue and phosphorus management. Soil Sci. Soc. Am. J., 71: 1500-1507.

Herridge, D.F., M.B. Peoples and R.M. Boddey, 2008. Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil, 311: 1-18.

Jasani, K.P., M.P. Patel and H.S. Patel, 1994. Response of soybean to dates of sowing and seed rates on yield and quality. Gujarat Agric. Univ. Res. J., 19: 108-110.

Jeevandas, A., R.P. Singh and R. Kumar, 2008. Concerns of groundwater depletion and irrigation efficiency in Punjab agriculture: A micro-level study. Agric. Econ. Res. Rev., 21: 191-199.

Kang, Y.K., M.R. Ko, N.K. Cho and Y.M. Park, 1998. Effect of planting date and planting density on growth and yield of soybean in Cheju island. Korean J. Crop Sci., 43: 44-48.

Kewat, M.L. and J. Pandey, 2001. Effect of pre-emergence herbicides on weed control in soybean (*Glycine max*). Indian J. Agron., 46: 327-331.

Pathak, H., C. Li, R. Wassmann and J.K. Ladha, 2006. Simulation of nitrogen balance in rice-wheat systems of the Indo-Gangetic Plains. Soil Sci. Soc. Am. J., 70: 1612-1622.

Purcell, L.C., R.A. Ball, J.D. Reaper and E.D. Vories, 2002. Radiation use efficiency and biomass production in soybean at different plant population densities. Crop Sci., 42: 172-177.

Rani, B.P. and D. Kodandaramiah, 1997. Performance of soybean genotypes under different plant population levels in the Krishna-Godavari zone of Andhra Pradesh. J. Oilseeds Res., 14: 44-46.

Saxena, S.C. and A.S. Chandel, 1997. Effect of micronutrients on yields, nitrogen fixation by soybean (*Glycine max*) and organic carbon balance in soil. Indian J. Agron., 42: 329-332.

Sharma, C.M. and S.K. Bhardwaj, 1998. Effect of phosphorus and zinc fertilization on yield and nutrient uptake in wheat (*Triticum aestivum*) and their residual effect on soybean (*Glycine max*). Indian J. Agron., 43: 426-430.

Singh, R.C., M. Singh and V.P. Singh, 1993. Response of soybean genotypes to planting density. Leg. Res., 16: 135-138.

Yunusa, I.A.M. and M.C. Ikwelle, 1990. Yield response of soybean (*Glycine max* (L.) Merr.) to planting density and row spacing in a semi-arid tropical environment. J. Agron. Crop Sci., 164: 282-288.