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Stability of Yield under Submergence and High Population Conditions in Soybean [*Glycine max* (L.) Merrill]

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ABSTRACT

Twenty five newly developed strains of soybean were grown under three conditions (control, excess moisture and high plant population) to assess their stability with regards to yield and yield attributing traits in randomized block design with three replications during kharif *2011. Analysis of variance for all the eleven characters for each environment and on pooled basis indicated substantial amount of variability for yield and most of the yield contributing traits except for biological yield per plant in environment III (high plant population) and pooled environments. Genotype x environment interaction was found non-significant for all the characters. The regression or genotypes × environment (linear) mean sum of squares were significant for most of the characters except for days to maturity, number of seeds per pod, seed yield per plant, 100 seed weight and harvest index. The genotypes RVS 2007-1, RVS 2007-2, RVS 2007-4, JS 20-53, JS 20-86, JS 20-59, JS 95-60 and RVS 2001-4 showed stability for most of the yield and yield components and could be suitable for commercial cultivation as well as for inclusion in further breeding programme as donor parents.*

Key words: Mean regression, seed yield, soybean, stability

Soybean [*Glycine max* (L.) Merrill] is one of the oldest legumes in the history of crop cultivation and belongs to the family Fabaceae. It occupies an important position among the grain legumes due to its economic importance (Dugje *et al*., 2009) and it is the world's leading source of oil and protein. It has the highest protein content (40%) of all food crops and next to groundnut in terms of oil content (20 %) among food legumes.

Gene expression is subject to modification by the environment. Therefore, genotypic expression of the phenotype is environmentally dependent (Kang, 1998). The development of new cultivars involve breeding of cultivars with desired characteristics such as high economic yield, tolerance or resistance to biotic and abiotic stresses, traits that add value to the product and the stability of these traits in target environments.

Stability in yield of a cultivar across a range of production environments is very important for recommending them for cultivation. The

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cultivars must have the genetic potential for superior performance under ideal growing conditions, and must also produce acceptable yield under less favourable environments. Therefore, a stable genotype can be referred to as the one that is capable of utilizing the resources available in high yielding environment and has a mean performance that is above average in all environments (Eberhart and Russell, 1966). Sustainable yield level can be achieved through stable performance of genotypes over environments.

MATERIAL AND METHODS

A field experiment was conducted at RAK College of Agriculture, Sehore during *kharif* 2011. The experiment was laid out in completely randomized block design with three replications. Twenty five newly developed strains were evaluated under three conditions namely, prevailing environmental conditions (F_1), high soil moisture (F_2) (at 20, 40 and 60 days waterlogged) and high plant population (F_3) (6, 50,000/ hectare). Each genotype was sown in four rows plot of 2 meter length with 45 cm row to row and 3-4 cm plant to plant distances. The fertilizer dose of 20:60:20:20:: $N:P_2O_5:K_2O:S$ kg per ha was applied uniformly and recommended package of practices were adopted for optimum crop growth and

Table 1. Analysis of variance for each environment (Mean sum of squares)

Source of variation	**Environments**					
	Prevailing		**Excess moisture**		**High plant population**	
	Genotype	**Error**	**Geno**type	**Error**	**Genotype**	**Error**
df	**24**	**48**	**24**	**48**	**24**	**48**
Days to 50% flowering	27.69**	0.57	27.55**	0.59	35.36**	0.64
Days to maturity	61.39**	0.57	63.65**	0.68	61.55**	0.54
Plant height (cm)	53.92**	8.60	35.01**	6.86	53.34**	9.22
Nodules (No/plant)	250.20**	16.34	79.06**	14.94	118.80**	9.64
Primary branches (No/plant)	1.63**	0.38	1.05**	0.28	0.97**	0.27
Pods (No/plant)	182.27**	6.04	97.27**	0.45	118.34**	5.77
Biological yield (g /plant)	44.16**	7.77	24.29**	7.08	29.68	6.38
Seeds (No/pod)	0.14**	0.06	0.12**	0.04	0.04**	0.03
Seed yield (g /plant)	10.12**	1.56	7.39**	1.34	7.61**	1.14
100 seed weight (g)	8.29**	0.32	6.41**	0.42	6.26**	0.35
Harvest index (%)	48.46**	25.64	82.03**	20.41	48.74**	21.22

***Significant at P + 0.01*

Table 2. Analysis of variance for stability with regards to yield and its components in soybean (mean sum of squares)

Source of variation	Degree of freedom	Days to 50 % flowering	Days to maturity	Plant height (cm)	Nodules (No/ plant)	Branches (No/ plant)	Pods (No/ plant)
Genotype	24	28.65**	61.36**	43.88**	129.90**	0.97**	122.76**
Environment	2	11.64**	17.34**	293.36**	714.25**	8.84**	325.84**
Genotype x environment	48	0.77	0.41	1.77	9.72	0.12	4.93
Pooled error	144	0.60	0.60	8.23	13.64	0.31	5.44
Environment + Genotype x environment	50	1.21	1.09	13.43	37.91	0.47	17.76
Environment (linear)	1	23.31**	34.92**	586.70**	1428.53**	17.68**	651.65**
Genotype x environment (linear)	24	1.06**	0.28	2.14*	15.00**	0.18**	6.61**
Pooled deviation	25	0.46**	0.52**	1.34	4.27	0.05	3.11**
Pooled error MSS for testing pooled deviation MSS		0.20	0.20	2.74	4.54	0.10	1.81
	Degree of freedom	**Biological yield (g/plant)**	**Seeds (No/pod)**	**Seed yield (g/plant)**	**100 seed weight (g)**	**Harvest index (%)**	
Genotype	24	24.68**	0.05**	7.36**	6.72**	37.75**	
Environment	2	20.65	0.03**	14.25**	0.79**	135.53**	
Genotype x environment	48	4.01	0.02	0.50	0.13	10.99	
Pooled error	144	7.08	0.04	1.34	0.36	22.42	
Environment + Genotype x environment	50	4.67	0.02	1.05	0.15	15.98	
Environment (linear)	1	41.30**	0.07**	28.51**	1.57**	271.07**	
Genotype x environment (linear)	24	2.60*	0.02	0.40	0.14	8.18	
Pooled deviation	25	5.20	0.02	0.58	0.10**	13.26**	
Pooled error MSS for testing pooled deviation MSS		2.36	0.01	0.44	0.12	7.47	

**Significant at p = 0.05; **Significant at p = 0.01* plant protection under rainfed condition. Observations on yield and yield attributes were recorded on five competitive plants at the time of harvest from each plot. The analysis of variance was computed as per method given by Panse and Sukhatme (1967). The stability analysis was carried out as per procedure outlined by Eberhart and Russell (1966).

RESULTS AND DISCUSSION

The pooled analysis of variance of yield and yield contributing traits (Table 1) indicated that the genotypes differed

Table 3. Grouping of soybean genotypes based on of regression coefficient and deviation from regression showing suitability for different environmental conditions

Characters	Genotypes stable over Environment (gi>mean, bi=1,s2di=0)	Genotypes stable for poor Environment (gi >mean, bi<1,s2di=0)	Genotypes stable for favourable Environment (gi>mean, bi>1,s2di=0)
Days to 50 % Flowering	JS 95 60, RVS 2007-3,JS 9305, JS 2079	RVS 2007-7,JS 20-71, RVS 2007-1, RVS 2007-4	NRC-7, JS 20-59, JS 20-73
Days to maturity	RVS 2007-4, JS 95-60, JS 93-05, RVS 2001-4	RVS 2007-6, RVS 2007-5, JSD 20-50	RVS 2007-3, JS 20-53, JS 20-69
Primary Branches (No/plant)	RVS 2001-4, NRC-37, JS - 335, RVS 2007-4	RVS 2007-5, RVS 2007-6, RVS 2007-7, JS 20-80	JS 20-71, JS 20-86, JS 20-69
Plant height (cm)	JS 20-71, JS 97-52, JS 20-71	JS 20-87, JS 20-86, JS 20-69, RVS 2007-5	RVS 2007-6, JS 20-59, RVS 2007-7
Nodules (No/plant)	JS 95-60, JS 20-59	RVS 2007-1, RVS 2007-3, JS 20-87, JS 20-80	RVS 2007-2, RVS 2007-5, NRC-7, JS 20-71, JS 20-73
Pods (No/plant)	RVS 2001-4, JS 20-59, JS 20-69, JS 20-87	RVS 2007-2, RVS 2007-3, JS 20-50	BRAGG, NRC -7, JS 20-71
Seeds (No/plant)	JS 20-53, JS 20-50	RVS 2007-3, RVS 2007-5, JS 20-86	RVS 2007-6, RVS 2007-7, JS 20-69, JS 20-71
Biological yield (g/plant)	JS 20-79, JS 97-52, RVS 2007-7	RVS 2007-2, JS 20-50, JS 20-69, JS 20-73	RVS 2007-1, RVS 2007-7, NRC-7, JS 20-80
100 seed weight (g)	RVS 2007-2, js 20-79, RVS 2007-1	RVS 2007-6, JS 20-73, JS 20-86	RVS 2007-5, RVS 2001-4, JS 20-71
Harvest index (%)	RVS 2007-2, NRC-37, RVS 2007-1	RVS 2007-7, JS 20-80, JS 20-87	RVS 2007-3, JS 20-73, JS 20-69
Seed yield (g/plant)	RVS 2007-2, RVS 2001-4, JS 20-71	JS 20-80, JS 20-79, RVS 2007-6	RVS 2007-5, RVS 2007-7, NRC-7

Table 4. Stability of different varieties for different traits

Genotype	Days to 50% flowering	Days to maturity	Plant height (cm)	Nodules (No/ Plant)	Primary branches (No/ plant)	Pods (No/ plant)	Biological yield (g/plant)	Seeds (No/ pod)	Seed yield/ (g/ plant))	100 seed weight (g)	Harvest index (%)	Total stable characters
RVS2007-1	-	+	+	+	+	+	+	+	+	+	+	10
RVS2007-2	+	+	+	+	+	-	+	+	+	+	+	10
RVS2007-3	+	-	+	+	+	+	+	-	+	+	-	8
RVS2007-4	-	+	+	+	+	+	-	+	+	+	+	9
RVS2007-5	+	+	+	+	+	+	+	-	+	-	-	8
RVS2007-6	+	+	-	+	+	+	+	-	+	+	+	9
RVS2007-7	-	+	+	-	+	-	-	+	+	-	-	6
JS95-60	+	+	+	+	+	+	+	+	+	+	+	10
JS93-05	+	+	+	+	+	+	-	+	+	-	+	9
JS335	+	+	+	+	+	+	-	+	+	+	+	10
JS97-52	+	+	+	+	+	-	+	+	+	-	+	9
BRAGG	+	+	-	+	+	+	-	+	-	-	+	7
NRC-37	+	+	+	+	+	+	-	+	+	+	+	10
NRC-7	-	+	+	-	+	+	-	-	-	+	+	6
RVS2001-4	+	+	+	+	+	-	+	+	+	-	-	8
JS20-50	+	+	+	+	+	+	+	+	-	-	-	8
JS20.53	+	-	+	+	+	+	+	+	+	+	-	9
JS20-59	-	+	-	+	+	+	+	+	+	+	+	9
JS20-69	+	-	+	+	+	-	-	-	+	+	-	6
JS20-71	-	+	+	-	-	+	+	-	+	-	+	6
JS20-73	-	-	+	-	+	+	-	+	+	-	-	5
JS20-79	+	+	+	+	+	-	+	+	+	+	-	9
JS20-80	+	+	+	+	+	+	-	+	-	+	-	8
JS20-86	+	-	+	+	-	-	+	-	+	-	+	6
JS20-87	+	+	+	+	+	+	+	-	+	+	+	10
Total stable genotypes	**18**	**20**	**22**	**21**	**23**	**18**	**15**	**17**	**21**	**15**	**15**	

significantly for all the characters except biological yield per plant in high plant population. The interaction of genotype x environment means sum of square were also found non-significant for all the characters. The response of genotype to changing environment was measured by the environmental linear effect, which showed statistically significant for all the characters (Table 2).

The stability parameters namely, mean regression coefficient (b) and deviation from regression S^2d for all characters of each genotype were computed (Table 3). The substantial magnitudes of deviation from linearity for all characters were observed suggesting large fluctuation in the expression of all characters over environments. Stability parameters worked out for all the 25 genotypes for yield and its component traits showed that the genotype namely RVS 2007-1, RVS 2007-2, JS 95 60, NRC 37 and JS 20-87 were stable for 10 characters studied. Genotypes RVS 2007-4, RVS 2007-6, JS 93-05, JS 20-53, JS 20-59 and JS 20-79 exhibited stable performance for nine characters including seed yield per plant. Genotypes RVS 2007-3, RVS 2007-5 and RVS 2001-4 exhibited stability for eight characters including seed yield per plant. JS 20-73 was found to be least stable showing stability only for five characters including seed yield per plant.

In respect of stability of different traits it was found that number of primary branches per plant remained stable in most of the genotypes (23) followed by plant height (22), number of nodules per plant (21) and seed yield per plant (21) (Table 4). Days to maturity was found stable in 20 genotypes while days to 50 per cent flowering and number of pods per plant in 18 genotypes. Biological yield per plant, 100 seed weight and harvest index were found least stable character, which was stable only in 15 genotypes.

For the development of improved varieties, genotype x environment interaction had been of great importance to the plant breeder. When genotype are compared over a series of environments relative ranking usually differ which causes difficulty in demonstrating the significant superiority of one genotype over the other. For reducing the impact of genotype x environment interaction breeders select stable genotypes, which will interact less with the environment in which they are likely to be grown. Under present investigation adaptive potential and relative stability of 25 strains of soybean for yield and its contributing traits have been determined. The pooled analysis of variance carried out to know the response of different characters to various environmental factor, revealed that genotype × environment interactions were non-significant for all the character which indicated that these traits were well adapted and showed least effect to the changes in the environmental conditions. However, significant genotype x environment interaction for most of the yield and yield attributing characters were reported in earlier studies (Rawat *et al.*, 2001; Joshi *et al.*, 2005; Mahajan *et al.*, 2006; Ramana and Satyanarayana, 2006; Pan *et al.*, 2007: Ramteke and Husain, 2008).

Variances due to genotype × environment (linear) was significantly different for days to 50 per cent flowering, plant height, number of nodules per plant, number of primary branches per plant, number of pods per plant and biological yield per plant. It indicated the differential response of genotypes to varying environment conditions. Similar result also reported by Ramana (2006).

According to Eberhart and Russell (1966) an ideal genotype is one having high mean ($\bar{X}$), unit regression coefficient (b =1) and least deviation ($\bar{S}_d^2$) around the regression slope, *i.e.* mean deviation square from regression not significantly different from zero. Therefore, it implies that while selecting varieties, predicting rate of seed yield in a given environment, mean values, regression slope of the genotypes and deviation from regression should be considered. The stable genotypes identified from the present investigation are RVS 2007-1, RVS 2007-2, RVS 2007-4, JS 95-60, RVS 2001-4 and JS 20-53, which are suitable for growing over of wide range of environments of Madhya Pradesh.

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Economic Optimization of Sulphur and Boron for Soybean in Different Agro-climatic Regions of India

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ABSTRACT

Field experiments were conducted during rainy seasons of 2007 and 2008 at different locations exhibiting diverse agro-climatic conditions of India to optimize the sulphur (S) and boron (B) application levels for sustainable soybean production. There was progressive increase in soybean yield with increasing levels of S and B up to a certain limit and there after it declined in different zones. The response to S application varied from 2.3 (North plain zone) to 48.1 (North eastern zone) per cent as compared to control. However, the corresponding response to boron application ranged from 0.44 to 28.9 per cent in North plain and Southern zones, respectively. The relationship between yield and levels of S and B was found to be curvilinear in all the zones. The economic optimum level of sulphur was 35.8, 61.2, 33.9 and 27.3 kg per ha in north plain, north eastern, central and southern zones of India, respectively. The economic optimum level of boron was found to be 0.95, 0.09, 1.20 and 0.83 kg per ha for north plain, north eastern, central and southern zones of India, respectively. The application of 30-40 kg per ha S and 1.50 to 2.00 kg B per ha were able to sustain the soybean productivity. The higher agronomic efficiency was achieved with the application of 20-30 kg S per ha and 0.5 to 1 kg B per ha. The highest incremental benefit cost ratio (IBCR) was achieved with application of 10 kg S per ha in central and southern zones, while it was maximum with 30 kg S in north plain and north eastern zones. However, the higher IBCR was associated with 0.5 kg B per ha in all the zones except north plain zone where it was with 1.0 kg B per ha.

Key words: Agronomic efficiency, boron, economic optimum level, physical optimum level, sulphur, stability, sustainable yield index

Sulphur and micronutrient deficiencies have been reported in intensive, irrigated production systems globally and in Indian soils and are reported as the main causes for yield plateauing or declining yield levels (Takkar *et al.*, 1989; Katyal and Rattan, 2003). In India, analysis of 2.52 lakhs surface soil samples from different parts of the country revealed the predominance of Zn deficiency in divergent soils. Of these samples 49, 12, 4, 3, 33 and 41 per

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cent soils are tested to be deficient in available Zn, Fe, Mn, Cu, B and S, respectively (Singh, 2004). Sulphur has become one of the major limiting secondary nutrients for oilseeds in recent years due to its widespread deficiency (Hegde and Murthy, 2005). While, much attention has been paid to correcting S and micronutrient deficiencies in irrigated systems (Takkar, 1996), little attention has been devoted to diagnose micronutrient deficiencies in the rainfed systems of the Semi-Arid Tropic (SAT) regions in India. It is well recognized that productivity of SAT soils is low due to water shortage. However, apart from water shortages, low soil fertility also limits crop productivity in the SAT regions (Hegde, 1998; Rego *et al*., 2007). Moreover, due to low crop productivity in the rainfed regions, it is assumed that mining of secondary and micronutrients is much less as compared to irrigated agriculture (Rego *et al.*, 2003). In the SAT regions, higher productivity levels are achieved when the soil and water conservation practices are implemented along with nutrient management (Wani *et al*., 2003). Srinivasarao *et al.* (2008) revealed that the significant yield responses of finger millet, maize, sunflower, soybean, groundnut and chickpea to application of Zn, B and S. There was significant residual effect of B and S applied to rainy season soybean on post-rainy season chickpea. Results also showed that application of Zn, B and S along with N+P was economical and critical for higher and sustained productivity of rainfed crops in semi-arid regions of India.

Intensification of systems pushing yields upward demands precise management of fields for optimum levels macro, secondary and micro-nutrients. In these high yielding situations, levels of nutrients thought to be adequate may, in fact, be limiting plant growth. The information on S and B requirement by soybean is sporadic; hence, the present investigation was carried out in different agro-climatic conditions of the country to optimize the sulphur and boron requirement of soybean in India.

MATERIAL AND METHODS

A field study was carried out during 2007 and 2008 in different agro-climatic conditions under All India Co-ordinated Research Project on Soybean to study the effect of different levels of S and B on sustaining the soybean productivity under rainfed conditions. Five levels each of S (0, 10, 20, 30 and 40 kg S/ha) and B (0, 0.5, 1, 1.5 and 2 kg B/ha) were laid out in factorial randomized block design with three replications. The source of S and B were gypsum (18 % S) and borax (11 % B). The experiment was conducted in four zone of country *viz*., North plain zone (Pantnagar, Ludhiana and Delhi), North eastern zone (Ranchi and Imphal), Central zone (Sehore, Kota and Parbhani) and Southern zone (Dharwad, Coimbatore and Bengaluru). The recommended package of practices was adopted for raising the soybean during *kharif* and *wheat* in *rabi* during both the years. The recommended dose of nitrogen, phosphorus and potassium were applied through di-ammonium phosphate and muriate of potash.

The yield data was pooled over the years (2007 and 2008) and centres across each zone. The relationship between soybean yield and levels of S and B was worked out zone-wise using the quadratic equation Y = a+b1+b2+b1^2 + b2^2 + b1b2. The zone-wise agronomic efficiency of sulphur and boron, additional returns and incremental cost benefit ratio (IBCR) were worked out by using the standard procedures. The sustainable yield index (SYI) and stability of the treatments were determined by using the centre-wise data of the respective zone. The yield stability was computed following simple regression coefficient and mean over the years (Finlay and Wilkinson, 1963). The sustainable yield index was also computed (Singh *et al.*, 1990). For the calculation of economics of the treatments, the prevailing market prices of inputs were considered.

RESULTS AND DISCUSSION

North plain zone

Application of 30- 40 kg S per ha recorded significantly higher seed yield of soybean, however, differences between 30 and 40 kg S per ha were found to be non-significant. In case of B, different levels did not influence the soybean yield significantly (Table 1). The interaction of S and B was found significant. The significantly highest soybean yield was recorded with application of 30 kg S per ha and 2.0 kg B per ha as compared 0 kg S per ha with 0, 0.5, 2.0 kg B per ha; 20 kg S per ha with 0.5, 1.0, 1.5 and 2.0 kg B per ha, and 30 kg S per ha with 0.5, 1.0 and 1.5 kg B per ha.

The relationship between S and B levels and soybean yield was found to be

Table 1. Effect of S and B levels on soybean seed yield (kg/ha) in north plain zone (mean data of Pantnagar, Ludhiana and Delhi)

Treatment *S level (kg/ha)*	*Boron level (kg/ha)* **0**	**0.5**	**1.0**	**1.5**	**2.0**	**Mean**	**% change over control**
	Soybean seed yield (kg/ha)						
0	1720	1991	2044	2159	1075	1995	
10	2047	1847	1938	1903	1972	1942	-
20	2091	1981	1972	1971	2023	2040	2.26
30	2109	2047	2165	2076	2182	2106	5.56
40	2163	2018	2097	2069	2136	2107	5.61
Mean	2026	1976	2043	2035	1878	2038	
% change over control	**-**	**-**	**0.85**	**0.44**	**-**		
	S and B level		S x B interaction				
SEm (±)	23.07		51.59				
CD (P = 0.05)	**64.59**		**144.46**				

Y= 1903.15 +10.81s + 18.75b – 0.203s^2 – 83.314b^2 +5.140sb (R^2= 0.390); Physical optimum level: S = 40.163 kg/ha, B = 1.096 kg/ha; Economic optimum level: S = 35.75 kg/ha, B = 0.946

Table 2. Effect of S and B levels on sustainability yield index, agronomic efficiency and economics of soybean in north plain zone

Treatment	Yield (kg/ha)	SYI	B	Yield change over control (kg/ha)	Agronomic efficiency (kg/kg)	Additional returns (Rs/ha)	Additional cost (Rs/ha)	ICBR
S level (kg/ha)								
0	1995	0.48	1.234	-	-	-	-	-
10	1942	0.52	1.029	-	-	-	230	-
20	2040	0.59	0.889	45	2.25	90	460	0.20
30	2106	0.61	0.898	111	3.70	2220	690	3.22
40	2107	0.61	0.882	112	2.80	2240	920	2.43
Mean	2038	-	-	-	-	-	-	-
B level (kg/ha)								
0.0	2026	0.53	1.075	-	-	-	-	-
0.5	1976	0.52	1.064	-	-	-	450	-
1.0	2043	0.55	1.053	17	17.00	340	900	0.38
1.5	2035	0.55	1.027	9	6.00	180	1350	0.13
2.0	1878	0.63	0.719	-	-	-	1800	-
Mean	**2038**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Soybean @ Rs. 20 per kg, S @ Rs. 23 per kg (gypsum @ Rs 3/kg) and B @ Rs.900 per kg (Borax @ Rs 90/kg) curvilinear and the equation was- Y= 1903.15 +10.81s + 18.75b – $0.203s^2$ – $83.314b^2$ +5.140sb (R^2= 0.390), which indicated that the physical optimum level of sulphur and boron for soybean were 40.16 and 1.09 kg per ha, respectively. The economic optimum level of sulphur and boron were 35.75 and 0.946 kg per ha, respectively.

The application of sulphur either @ 30 or 40 kg S per ha showed the highest sustainability yield index (0.61) as compared to control and 10 kg S per ha (Table 2). Stability coefficient (b) indicated that the application of sulphur @ 20 kg per ha and above did well under unfavourable environmental conditions while the lower levels performed better under favourable conditions. The application of S @ 30 kg per ha brought out the stable soybean production and also showed the higher agronomic efficiency as compared to other levels. The application of B @ 2 kg per ha brought out the maximum sustainability to soybean production which performed better under unfavourable environments as compared to other levels of B. The highest agronomic efficiency of B recorded was at 1.0 kg per ha.

North eastern zone

Application of 10, 20, 30 and 40 kg S per ha increased the soybean seed yield to the tune of 12.4, 27.4, 43.1 and 48.1 per cent as compared to control (Table 3). Significantly higher seed yield (2,361

Table 3. Effect of S and B levels on soybean seed yield (kg/ha) in north eastern zone (mean of Ranchi and Imphal)

Treatment	**Boron level (kg/ha)**						**% change over control**
S level (kg/ha)	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**Mean**	
			Soybean seed yield (kg/ha)				
0	1475	1672	1591	1546	1686	1594	-
10	1712	1644	1851	1919	1819	1792	12.42
20	1697	2048	2048	2160	2080	2031	27.42
30	1719	2218	2390	2570	2309	2281	43.10
40	1902	2291	2499	2498	2468	2361	48.11
Mean	1701	1974	2076	2138	2072	2012	
% change over control	-	16.05	22.05	25.69	21.81		
	S and B level		S x B interaction				
SEm (±)	43.80		97.94				
CD (P = 0.05)	**122.64**		**274.24**				

Y= 1420.77 + 18.51s + 466.49b – $0.137s^2$ – $205.14b^2$ + 6.258sb (R^2= 0.928); Physical optimum level: S = 63.230 kg/ha, B = 0.163 kg/ha; Economic optimum level: S = 61.24 kg/ha; B = 0.092 kg/ha

Table 4. Effect of S and B levels on sustainability yield index, agronomic efficiency and economics of soybean in north eastern zone

Treatment	Yield (kg/ha)	SYI	b	Yield change over control (kg/ha)	Agronomic efficiency (kg/kg)	Additional returns (Rs/ha)	Additional cost (Rs/ha)	ICBR
level (kg/ha)								
0	1594	0.31	2.442	-	-	-	-	-
10	1792	0.54	1.238	198	19.80	3960	230	17.21
20	2031	0.69	0.851	437	21.85	8740	460	19.00
30	2281	0.83	0.572	687	22.90	13740	690	19.91
40	2361	0.87	0.539	767	19.18	15340	920	16.67
Mean	2012	-	-	-	-	-	-	-
B level (kg/ha)								
0.0	1701	0.36	2.347	-	-	-	-	-
0.5	1974	0.68	0.857	273	546.00	5460	450	12.13
1.0	2076	0.72	0.840	375	375.00	7500	900	8.33
1.5	2138	0.77	0.667	437	291.33	8740	1350	6.47
2.0	2072	0.72	0.928	371	185.50	7420	1800	4.12
Mean	**2012**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Soybean @ Rs.20 per kg, sulphur @ Rs. 23 per kg (gypsum @ Rs 3/kg) and boron @ Rs.900 per kg (Borax @ Rs 90/kg)

kg/ha) was recorded with 40 kg S per ha which remained at par with 30 kg S per ha (2,281 kg/ha). The application of B increased the seed yield up to 1.5 kg B per ha and thereafter it was declined. The magnitude of increase in yield varied from 16.0 to 25.7 per cent as compared to control. The highest seed yield was recorded with 1.5 kg B per ha. The interaction of S and B was found significant. The highest seed yield (2,570 kg/ha) was recorded with 30 kg S per ha and 1.5 kg B per ha, which remained at par with 2.0 and 1.0 kg B per ha.

Relationship between soybean yield and levels of S and B was found to be curvilinear and the equation was- $Y= 1420.77 + 18.51s + 466.49b - 0.137s^2 - 205.14b^2 + 6.258sb$ ($R^2= 0.928$). The physical optimum level of sulphur and boron was 63.23 kg S per ha and 0.16 kg B per ha for the north eastern zone. Similarly, the economic optimum level of S and B were 61.24 and 0.092 kg per ha, respectively.

Sustainability yield index, linearly increased with increasing levels of S and the highest sustainable yield index (0.87) was noticed with 40 kg S per ha (Table 4). The most stable performance of soybean production was observed with application of 20 kg S per ha and higher levels of S performed well under unfavourable environments. The maximum agronomic efficiency was recorded at 30 kg S per ha and at higher levels the efficiency declined. The sustainability of soybean yield increased as the levels of boron increased up to 1.5 kg B per ha and thereafter it decreased. Application of B @ 2.0 kg per ha showed the most stable performance of soybean production. Soybean did well under unfavourable environments when B was applied at any of the level. The decrease in agronomic efficiency of boron with further increase in levels indicated that the highest agronomic efficiency was associated with 0.5 kg B per ha.

Central zone

Sulphur and boron application brought out significant variations in soybean yield (Table 5). Increasing levels of S application (10 to 40 kg S /ha) increased the seed yield of soybean from 8.1 to 17.2 per cent over control. The highest seed yield (2,218 kg/ha) was recorded with 40 kg S per ha, which was statistically at par with its lower level (30 kg S/ha). Soybean yield increased as the levels of boron increased up to 1.0 kg per ha; a slight decrease with further increase in its levels was observed. The magnitude of increase in soybean yield varied from 7.7 to 12.0 per cent as compared to control. The interaction of S and B was found significant for soybean yield. The maximum soybean yield was recorded when 30 kg S per ha was applied along with 1.0 kg per B per ha.

The relationship between soybean yield and levels of S and B was found to be curvilinear and the equation was - $Y= 1719.37 + 18.08s + 376.74b - 0.234s^2 - 133.43b^2 + 0.932sb$ ($R^2= 0.836$). The physical optimum level of sulphur and boron was found to be 36.07 and 1.285 kg per ha, respectively. Similarly, the economic optimum levels of S and B were 33.94 S per ha and 1.20 kg B per ha.

The sustainable yield index linearly increased as the levels of S increased up to 30 kg per ha (Table 6). Application of S @ 30 kg per ha and control performed better under unfavourable environmental conditions, while remaining treatments did well under favourable conditions. However, the application of 10, 30 or 40 kg S per ha were found equally stable with regards to soybean yield as evidenced from the stability coefficient (b). The agronomic efficiency of sulphur decreased with the increasing S levels, which indicated that the highest agronomic efficiency was associated with 10 kg S per ha. The sustainability yield index increased as the levels of B increased and the highest was recorded with application of 2.0 kg B per ha. Application of B @ 2 kg per ha or control did well under unfavourable environmental conditions while remaining treatments performed better under favourable conditions. The maximum agronomic efficiency was recorded when 1.0 kg B per ha was applied and the any deviation from this level led to declination in agronomic efficiency. Jadhav *et al*. (2009) also observed that the recommended NPK + boron @ 2 kg per ha produced significantly higher yield of soybean over recommended NPK at Parbhani.

Southern zone

Soybean yield increased as the levels of S increased up to 30 kg per ha. Further increase in S levels decreased the yield (Table 7). The magnitude of increase varied from 10.2 to 24.2 per cent. The maximum soybean yield was recorded with 30 kg S per ha. In case of B, the significantly highest yield (1,531 kg/ha;

Table 5. Effect of S and B levels on soybean seed yield (kg/ha) in central zone (mean of Sehore, Kota and Parbhani)

Treatment	**Boron level (kg/ha)**						**% change**
S level (kg/ha)	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**Mean**	**over control**
			Soybean seed yield (kg/ha)				
0	1770	1905	1865	2033	1887	1892	-
10	1911	1950	2072	2165	2130	2045	8.09
20	1906	2232	2316	2180	2188	2165	14.43
30	1935	2190	2326	2169	2244	2172	14.80
40	2172	2162	2277	2293	2185	2218	17.23
Mean	1939	2088	2171	2168	2126	2098	
% change over control	-	7.68	11.96	11.81	9.64		
	S and B level		S x B interaction				
SEm (±)	17.06		38.15				
CD (P = 0.05)	**47.77**		**106.81**				

$Y = 1719.37 + 18.08s + 376.74b - 0.234s^2 - 133.43b^2 + 0.932sb$ ($R^2 = 0.836$); Physical optimum level: S = 36.07 kg/ha, B = 1.285 kg/ha; Economic optimum level: S = 33.94 kg/ha, B = 1.120 kg/ha

Table 6. Effect of sulphur and boron levels on sustainability yield index, agronomic efficiency and economics of soybean in central zone

Treatment	Yield (kg/ha)	SYI	b	Yield change over control (kg/ha)	Agronomic efficiency (kg/kg)	Additional returns (Rs/ha)	Additional cost (Rs/ha)	ICBR
S level (kg/ha)								
0	1892	0.46	0.891	-	-	-	-	-
10	2045	0.48	1.040	153	15.30	3060	230	13.30
20	2165	0.50	1.118	273	13.65	5460	460	11.87
30	2172	0.54	0.954	280	9.33	5600	690	8.11
40	2218	0.54	1.012	326	8.15	6520	920	7.09
Mean	2098	-	-	-	-	-	-	-
B level (kg/ha)								
0.0	1939	0.47	0.901	-	-	-	-	-
0.5	2088	0.49	1.035	149	298.00	2980	450	6.62
1.0	2171	0.50	1.129	232	232.00	4640	900	5.16
1.5	2168	0.51	1.054	229	152.66	4580	1350	3.39
2.0	2126	0.54	0.898	187	93.50	3740	1800	2.08
Mean	**2098**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Soybean @ Rs.20 per kg, sulphur @ Rs. 23 per kg (gypsum @ Rs 3/kg) and boron @ Rs.900 per kg (Borax @ Rs 90/kg)

Table 7. Effect of sulphur and boron levels on soybean seed yield (kg/ha) in southern zone (mean of Dharwad, Coimbatore and Bengaluru)

Treatment	**Boron level (kg/ha)**						**% change over control**
S level (kg/ha)	**0**	**0.5**	**1.0**	**1.5**	**2.0**	**Mean**	
			Soybean seed yield (kg/ha)				
0	1232	1189	1267	1082	1088	1171	
10	1037	1469	1451	1386	1106	1290	10.16
20	1165	1672	1599	1372	1213	1404	19.90
30	1300	1699	1621	1538	1294	1490	24.24
40	1204	1625	1504	1539	1204	1415	20.83
Mean	1188	1531	1488	1383	1181	1354	
% change over control	-	28.87	25.25	16.41	-		
	S and B level		S x B interaction				
SEm (±)	21.55		48.18				
CD (P=0.05)	**60.34**		**134.92**				

Y= 1040.28 + 17.96s +611.59b – 0.296s² – 329.66b² + 0.780sb (R^2 = 0.786); Physical optimum level: S = 29.161 kg/ha, B = 0.893; Economic optimum level: S = 27.30 kg/ha, B= 0.827kg/ha

28.87 %) was recorded with application of 0.5 kg B per ha and further increase in levels caused significant seed yield reductions in soybean. The interaction effect of S and B on soybean yield was found significant. The maximum soybean yield was recorded with 30 kg S per ha and 0.5 kg B per ha. Sarkar *et al* (2002) also reported that the application of sulphur and boron 30 and 1 kg per ha individually or in combination was found to be best with respect to soybean yield.

The relationship between yield and S and B levels was found curvilinear and the equation was - $Y= 1040.28 + 17.96s +611.59b – 0.296s^2 –329.66b^2 + 0.780sb$ (R^2= 0.786). The physical optimum level of S and B was found to be 29.2 and 0.894 kg per ha, respectively. Similarly, the economic optimum dose of S and B was 27.3 and 0.827 kg per ha, respectively.

The sustainability yield index increased as the levels of S increased, however, the magnitude of difference between 30 and 40 kg S per ha was marginal (Table 8). Application of S above 20 kg S per ha performed better under unfavourable environmental conditions and remaining treatments did well under favourable environmental conditions. The most stable performance of soybean was noticed with application of 30 kg S per ha. The agronomic efficiency increased with increasing levels of S up to 30 kg per ha. The application of B @ 1.0 kg per ha showed the highest sustainability yield index (0.57) and also indicated that the any deviation from this level caused drastic reduction in sustainable yield index. The application of B either@ 1 or 2 kg B per ha performed very well under unfavourable environmental conditions. However, the B levels of 0.5 to 1.5 kg per

Table 8. Effect of sulphur and boron levels on sustainability yield index, agronomic efficiency and economics of soybean in southern zone

Treatment	Yield (kg/ha)	SYI	b	Yield change over control (kg/ha)	Agronomic efficiency (kg/kg)	Additional returns (Rs/ha)	Additional cost (Rs/ha)	ICBR
S level (kg/ha)								
0	1171	0.40	1.096	-	-	-	-	-
10	1290	0.48	1.085	119	11.90	2380	230	10.35
20	1404	0.50	1.132	233	11.65	4660	460	10.13
30	1490	0.56	0.989	319	15.95	6380	690	9.24
40	1415	0.57	0.672	244	6.10	4880	920	5.30
Mean	1354	-	-	-	-	-	-	-
B level (kg/ha)								
0.0	1188	0.42	1.053	-	-	-	-	-
0.5	1531	0.55	1.092	343	686.00	6860	450	15.24
1.0	1488	0.57	0.915	300	300.00	6000	900	6.67
1.5	1383	0.48	1.092	195	130.00	3900	1350	2.89
2.0	1181	0.46	0.813	-	-	-	1800	-
Mean	**1354**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Soybean @ Rs.20 per kg, sulphur @ Rs. 23 per kg (gypsum @ Rs 3/kg) and boron @ Rs.900 per kg (Borax @ Rs 90/kg)

Table 9. Summary of S and B response across different agro-climatic soybean growing zones of India

Zone/ Centre	Quadratic equation	Economic optimum level (kg/ha)		SYI	IBCR
		S	B		
North plain	$Y = 1903.15 + 10.81s + 18.75b - 0.203s^2 - 83.314b^2 + 5.140sb$ ($R^2 = 0.390$)	35.75	0.95	0.56	1.95
North eastern	$Y = 1420.77 + 18.51s + 466.49b - 0.137s^2 - 205.14b^2 + 6.258sb$ ($R^2 = 0.928$)	61.24	0.09	0.65	18.19
Central zone	$Y = 1719.37 + 18.08s + 376.74b - 0.234s^2 - 133.43b^2 + 0.932sb$ ($R^2 = 0.836$)	33.94	1.12	0.50	10.09
Southern	$Y = 1040.28 + 17.96s + 611.59b - 0.296s^2 - 329.66b^2 + 0.780sb$ ($R^2 = 0.786$)	27.30	0.83	0.50	8.76

ha were more or less equally stable with reference to soybean yield. The agronomic efficiency of B decreased as the levels of boron increased. When comparing the zonal differences, the highest economic optimum level of S and B was recorded in North eastern and Central zones, respectively (Table 9). The most sustainable soybean production was found to be in North eastern zone followed by North plain zone. However, the highest IBCR was recorded in North eastern zone followed by Central zone.

On the basis of two years results over the locations under diverse agro- ecological regions indicated that the soybean required higher dose of sulphur and boron. The yield enhancement was observed to the tune of 2.3 to 48.1 per cent and 0.4 to 28.9 per cent due to applied sulphur and boron, respectively. The economic optimum level of S and B was found to be 35.4 and 0.95 kg per ha for north plain zone, 61.24 and 0.09 kg per ha for north eastern zone, 33.9 and 1.12 kg per ha for central zone and 27.3 and 0.82 kg per ha for southern zone, respectively. In general, agronomic efficiency of sulphur and boron decreased invariably with their increasing levels in all the zones. The sustainability of soybean yield could be achieved with the application of 30-40 kg S per ha and 1.5 to 2 kg B per ha. The results suggested that the application of sulphur and boron is essential to achieve the profitable productivity of soybean across different agro-climatic zones in India.

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Assessment of Soybean Varieties for Nutrient Tolerance in Black Clay Soils

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ABSTRACT

Field experiments were conducted to assess the poor/low soil fertility tolerance abilities of soybean varieties. A novel approach was applied to identify the poor soil fertility tolerant and susceptible soybean varieties. Results revealed that the SL 525 and PS 1347 produced significantly highest yield under unfertilized as well as fertilized conditions. The lowest yield was recorded with MAUS 61 under fertilized conditions. The maximum yield loss was recorded with JS 97-52. The soybean varieties were categorized based on maximin-minimax method, and the varieties like SL 525 and PS 1347 were categorized as resistant to poor soil fertility and high yielding, while JS 95-60, RKS 18, MAUS 61 and JS 97-52 were categorized as sensitive to poor soil fertility (susceptible) and low yielding. Variety JS 97-52 was found to be the most susceptible to poor soil fertility and low yielder among the soybean varieties.

Key words: Relative yield, susceptible, tolerant, variety

Wide-spread nutrient/ multi-nutrient deficiencies, particularly in semi-arid tropics, have been reported in Indian soils (Saharawat *et al*., 2010; http://www.fao.org/docrep/009/a0257e/A0257E02.htm; Singh, 2008). Application of fertilizers is not a totally successful strategy in alleviating micronutrient deficiency because of agronomic, economic, and environmental factors (Mortvedt, 1994; Graham and Rengel, 1993; Hacisalihoglu, 2002). A more efficient and sustainable solution to micronutrient deficiency limitations to crop production is the development and use of micronutrient-efficient plant genotypes that can more effectively grow on soil with low phyto-available macro- and micro- nutrient contents, which would reduce fertilizer inputs and protect the environment as well. Selection of plant genotypes that can tolerate low nutrient supply may increase productivity on low fertility soils and reduce fertilizer requirements (Gourley *et al*., 1994). One of the most important adaptive responses for crop plants involves their ability to deal with soil-

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mediated abiotic stresses involving deficient levels of macro- and micro- nutrients in the soil. Plant species vary significantly in tolerance to macro- and micro- nutrients deficiency; some are able to cope up with low micronutrients availability, and thus, grow well even when other species or cultivars suffer reduced yield due to macro- and micro- nutrient deficiency (Graham and Rengel, 1993). Exploiting genetic diversity of plants for enhanced productivity in poor fertility soils is desirable. Variation among plant germplasm in the ability to acquire nutrients from the soil has been investigated for decades (Godwin and Blair, 1991). There are several key mechanisms that could be involved in nutrient efficiency (Baligar *et al*., 2001; Fageria and Baligar, 2003; Khoshgoftarmanesh *et al*., 2004a, 2006b). In recent years, more attention has been paid to nutrient efficiency.

Plant efficiency for nutrient uptake and utilization may improve yield potential in situations of soil nutrient stress, reducing plant demands for a given level of crop yield. Differences in grain yield among soybean cultivars for phosphorus (P), potassium (K) and N efficiencies were also reported by several researchers (Raper and Barber, 1970; De Mooy *et al*., 1973; Sabbe and Delong, 1998; Sarawgi and Tripathi, 1998; Hanumanthappa *et al.*, 1999; Ogburia *et al*., 1999) in field experiments. Soybean genotypes with tolerance to low nutrient levels could become an important tool in integrated nutrient management strategies with minimum use of fertilizers which may offer a low cost production technology. The objective of these studies was to assess the variability of six soybean cultivars based on their response to fertilizer application alone and in conjunction with farmyard manure.

METHODS AND MATERIALS

The data compiled from experiments conducted during 2009-11 at different centres of All India Coordinated Research Project on Soybean under different agro-climatic regions on six soybean varieties grown under different fertility levels with and without FYM along with absolute control for assessing their tolerance to low levels of nutrients. Soybean varieties namely, PS 1347 and SL 525 (Pantnagar and Ludhiana), JS 97 52 and RKS 18 (Ranchi and Raipur), JS 95-60 (Sehore, Kota and Amaravati) and MAUS 61 (Dharwad, Pune, Bangaluru and Coimbatore) were grown in 3 randomized blocks under 75 per cent recommended dose of fertilizers (RDF), RDF (Anonymous, 2014) and 125 per cent RDF with and without FYM @ 5 t/ha) and absolute control. FYM alone was applied @ 10 t/ha. Soybean crop was raised with the standard recommended package of practices. The varieties were categorized tolerant and susceptible to nutrients based on maxmin-minimax method (Odulaja and Nokoe, 1993) as described below:

a. Calculate per cent yield loss for each variety on the basis of yields obtained under fertilized and unfertilized conditions.
b. Identify a tolerant/resistant check (an entry giving highest yield under unfertilized (control) condition.
c. Identify a susceptible check (an entry showing maximum per cent yield loss).

d. Calculate Relative Yield (RY) of the entry relative to tolerant/resistant check as RYi = 100Yi / Yr; where, Yi is the yield of the entry and Yr is the yield of tolerant/resistant check, both under unfertilized condition.

Calculate per cent yield loss (RP) of *ith* entry relative to a susceptible check as RPi = 100Pi/Ps; where, Pi is per cent yield loss of the i th entry and Ps is per cent yield loss in susceptible check.

e. Plot a scatter diagram keeping RY on vertical axis and RP on horizontal axis.

f. Divide the diagram into 4 quadrants by drawing perpendicular lines from RY = 75 (which implies that minimum acceptable yield under weedy check condition should be at least 75 % of the yield under weed free condition) and from RP = 25 (which implies that maximum acceptable yield loss is 25 %). Each quadrant of 'maximin – minimax plot' so prepared will house variety of a specific category.

Table 1. Yield and percent yield loss of soybean varieties grown under different fertility levels

Variety	**Yield (kg/ha)**							
	Without FYM			**With FYM**			**FYM alone**	**Control**
	75 % RDF	**RDF**	**125 % RDF**	**75 % RDF**	**RDF**	**125 % RDF**		
PS 1347	2135	2124	2266	2127	2148	2306	2239	1892
SL 525	2130	2196	2192	2072	2169	2158	2139	1971
JS 97-52	1512	1817	1886	1684	1890	1973	1378	1092
RKS 18	1540	1716	1712	1694	1838	1866	1544	1161
JS 95-60	1603	1811	1852	1659	1922	1927	1479	1232
MAUS 61	1457	1489	1508	1558	1594	1637	1468	1126
	Per cent yield loss (kg/ha)							
	Without FYM			**With FYM**			**FYM alone**	**Relative yield**
	75 % RDF	**RDF**	**125 % RDF**	**75 % RDF**	**RDF**	**125 % RDF**		
PS 1347	12.84	12.26	19.77	12.42	13.53	9.49	18.34	95.99
SL 525	8.07	11.42	11.21	5.12	10.05	9.49	8.52	100.00
JS 97-52	38.52	66.39	72.79	54.28	73.16	80.76	26.25	55.38
RKS 18	32.70	47.80	47.52	45.97	58.38	60.79	33.05	58.88
JS 95-60	30.11	47.00	50.32	34.66	56.01	56.41	20.05	62.51
MAUS 61	29.40	32.23	33.93	38.37	41.56	45.38	30.37	57.13

Table 2. RP in soybean varieties under different fertility levels

Variety	RP (%)						
	Yield without FYM (kg/ha)			Yield with FYM (kg/ha)			FYM alone @ 10 t/ha
	75 % RDF	RDF	125 % RDF	75 % RDF	RDF	125 % RDF	
PS 1347	33.34	18.47	27.34	22.88	18.49	11.75	55.49
SL 525	20.94	17.20	15.51	9.44	13.73	11.75	25.79
JS 97 52	100.01	100.00	100.69	100.01	99.99	100.00	79.42
RKS 18	84.89	72.00	65.74	84.69	79.80	75.28	99.99
JS 95 60	78.18	70.79	69.61	63.85	76.55	69.85	60.66
MAUS 61	76.31	48.55	46.93	70.68	56.81	56.19	91.90

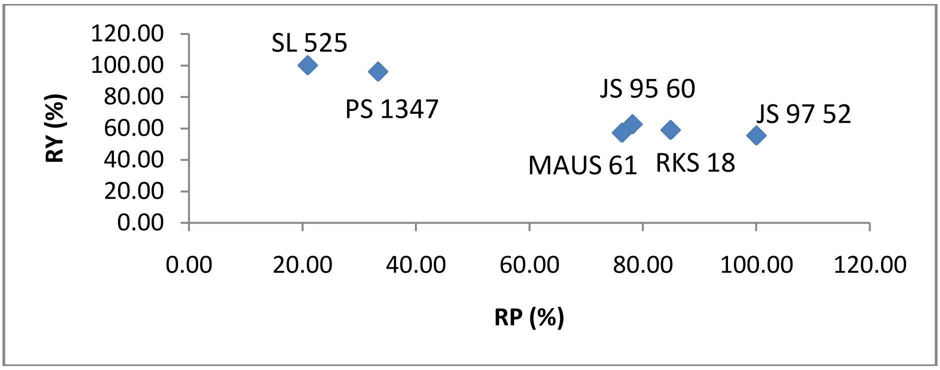
RESULTS AND DISCUSSION

The highest yield was recorded by soybean cultivar SL 525 (80.49 %) closely followed by PS 1347 (73.26 %), while soybean cultivar JS 97-52 recorded the lowest yield under unfertilized conditions (Table 1). SL 525 and PS 1347 yielded higher (36.07 to 52.52 %) than MAUS 61 under differently fertilized treatments. The remaining varieties oscillated in between.

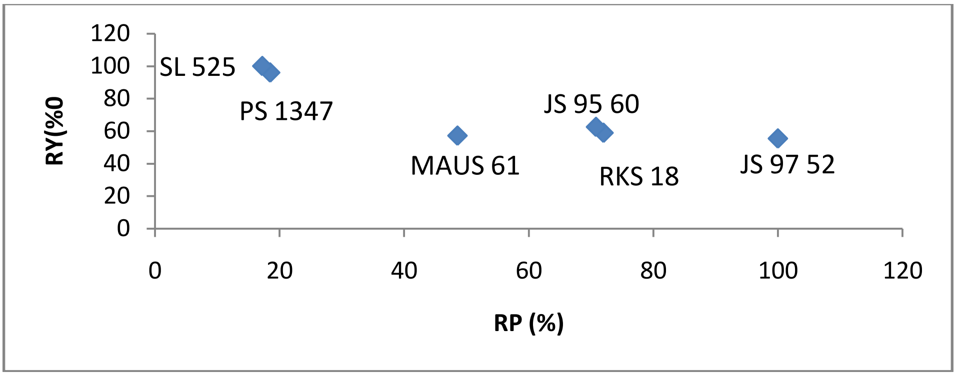
The highest yield loss was recorded with JS 97-52 in all the treatments, while it was highest in RKS 18 when compared under alone FYM treatment. The lowest yield reduction was observed in variety SL 525.

The relative soybean seed yield was computed in comparison with highest yielder cultivar SL 525 under unfertilized conditions. The highest relative yield percentage was associated with PS 1347 followed by JS 95-60, RKS 18, MAUS 61 and JS 97-52. The per cent yield loss (RP) values were found to be lower in case of fertilizer + FYM (Table 2). The lowest values of RP were recorded in SL 525 and PS 1347 and higher values were with RKS 18.

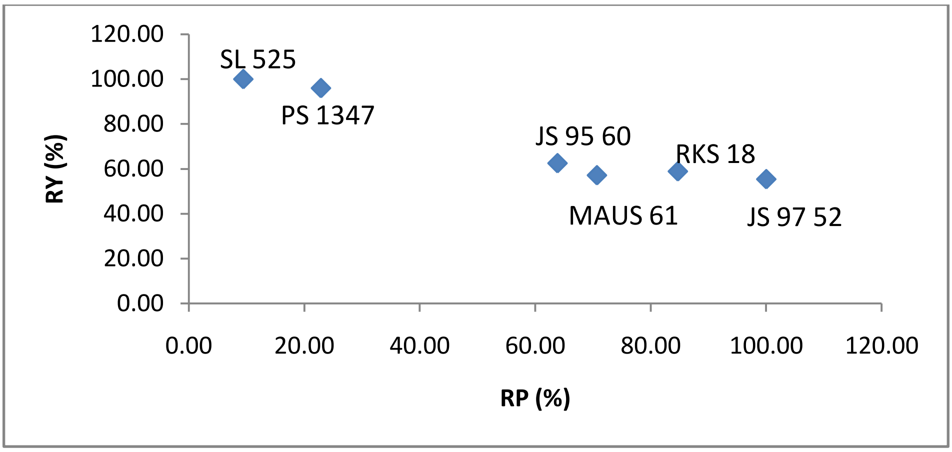
The values of RY and RP were plotted in scattered diagram and varieties have been categorized in different groups (Fig. 1). Soybean variety SL 525 and PS 1347 were found to be highest yielder and also tolerant/resistant to lower fertility levels. The remaining four varieties (JS 95-60, RKS18, MAUS 61 and JS 97-52) may be grouped under the category of low yielder and susceptible to lower fertility



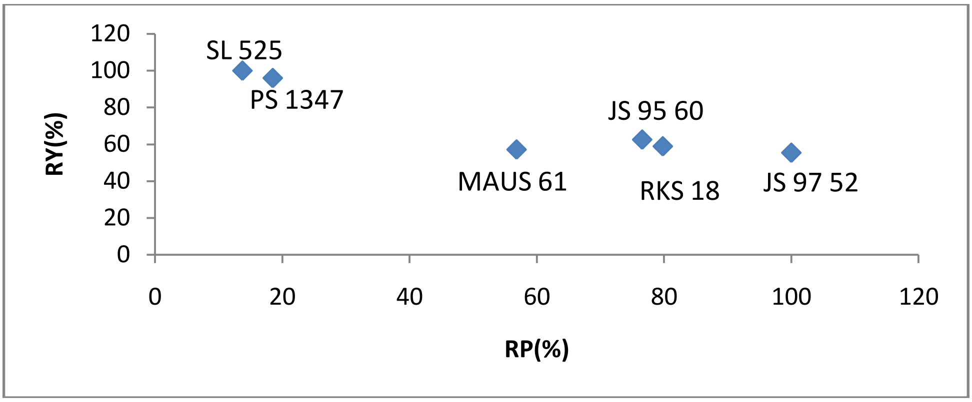
75% RDF vs Control



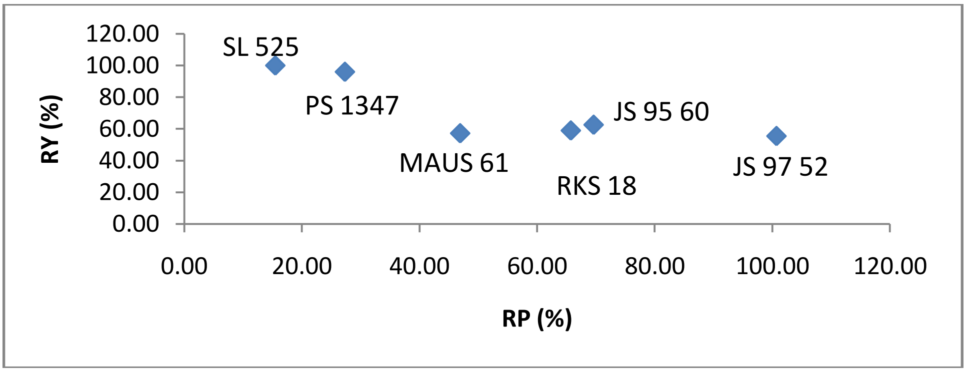
RDF vs Control



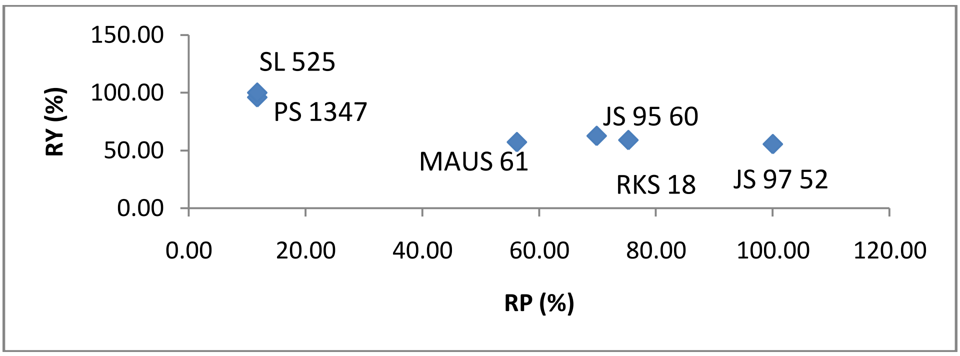
75% RDF + FYM



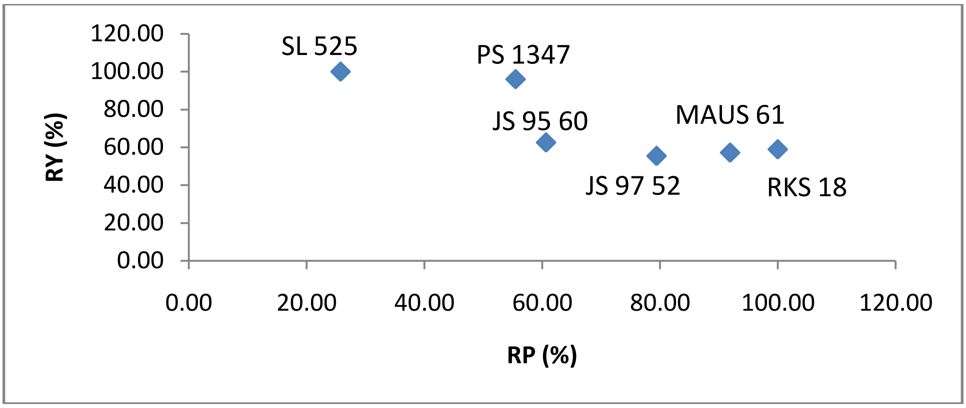
RDF + FYM vs Control



125% RDF vs control



125% RDF + FYM vs control



FYM vs Control

Fig. 1. Categorization of low fertility tolerant soybean varieties

levels or unfertilized conditions. Varieties susceptible or sensitive to unfertilized conditions meant that fertilizer application is essential to achieve higher yields.

There are a number of potential adaptive mechanisms that nutrient -efficient plants can employ for better growth on low-nutrients levels in soils, including changes in root morphology and architecture, root symbiosis, activation of nutrients transporters, enhancement of internal activity, and secretion of organic acids in to the rhizosphere. The variable response amongst the soybean genotypes in response to nutrients were also reported by earlier researchers (Purcell *et al*., 2000; Lin *et al*., 2000; Ohki *et al*., 1980). Plant species and genotypes within species can differ widely in their tolerance to excess nutrients (Foy *et al*., 1988) or susceptibility to its deficiency (Graham, 1988) in the soil in which they grow. Often these differences are hereditary (Broadley and White, 2005; Pittman, 2005).

On the basis of foregoing results it could be concluded that the soybean genotypes SL 525 and PS 1347 were found to be able to produce higher yield even in poor fertility of black clay soils, while soybean cultivars JS 95-60, RKS 18, MAUS 61 and JS 97-52 were sensitive to poor soil fertility and needed fertilizer in appropriate quantity for realizing better production.

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Effect of Seed Treatments on Incidences of Insect Pests and Spiders on Soybean

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ABSTRACT

A field experiment on the seed treatments was conducted during rainy season of 2012 in Madhya Pradesh, India. Efficacies of four treatments namely, seed treatment with Thiamethoxam or Imidacloprid, conventional method by spraying insecticides (foliar sprays of Quinalphos followed by Chlorpyriphos at 20 and 50 day-old crop, respectively) and an untreated control on various insect-pest incidences were assessed. Seed treatments with Thiamethoxam and Imidacloprid were effective in minimizing the stem fly and white fly incidences during the early crop growth stage. Furthermore, incidences of defoliators which appeared from the middle of the crop stage were also low in seed-treated blocks. The order of the seed yields was as follows; seed treatment with Thiamethoxam (1,753 kg/ha), conventional method (1,718), seed treatment with Imidacloprid (1,615) and untreated control (1,538). The results suggested that the seed treatment, especially with Thiamethoxam, is an alternative method to replace foliar applications of non-selective insecticides at early growth stage.

Key words: Economics, foliar spray, insect pest complex, natural enemies, seed treatment

Soybean is the main rainy season crop of the Madhya Pradesh, India. The present area under soybean in the state is 5.67 million ha with production of 6.28 million ton and productivity 1,108 kg/ha (Anonymous, 2012). Productivity of soybean is less than the potential yield of recommended varieties. Damage by insect- pests is one of the major factors causing low productivity of soybean in India. It is serious threat to the production by increasing cost of cultivation and impairing quality of the produce in many ways (Singh *et al*., 2000). During the introduction of soybean in India in the early1970's, only about a dozen of minor insect-pests were recorded, while in1997 this number swelled to an alarming figure of 270, beside 1 mite, 2 millipedes, 10 vertebrates and 1 snail (Singh, 1999).

[1to4]Principal Scientists; [5]JICA Expert; [6]JICA Chief Advisor; Paper presented in SOYCON 2014

Amongst 130 insect-pests recorded on soybean in Madhya Pradesh (Singh and Verma,1988) stem fly [*Melanagromyza sojae* (Zehnt)], girdle beetle (*Oberea brevis* Swead), green semiloopers [*Chrysodeixis acuta* (Walk)], *Gesonia gemma*, Swinhoe, tobacco caterpillar [*Spodoptera litura* (Fab.)], Bihar hairy caterpillar [*Spilosoma oblique* (Walker)], blue beetle (*Cneorane* sp.), white fly [*Bemisia tabaci* (Gennadius)], and jassids (*Apheliona maculose* Distant) have been recorded as major pests causing severe losses to soybean crop (Singh and Singh, 1987; Singh *et al*., 1989; Choudhary and Shrivastava, 2007a and 2007b). However, major pest species may differ depending on localities.

Several insecticides were identified and recommended for management of major insect- pests through soil application, foliar sprays or seed treatment (Joshi and Patel, 2011; Singh *et al*., 2000). In nature, bioagents including parasitoids, predators and insect pathogen influence the population of the insect pests. Activity of such biocontrol agents, however, is hampered due to indiscriminate use of chemical insecticides (Sharma and Ansari, 2007). Pest resurgences due to non-selective insecticide sprays are reported in soybean production (Bueno *et al*., 2013; Shi *et al*., 2012). In particular, foliar spray of insecticides in early crop stage is famous for causing serious pest resurgence in Asian rice production (Way and Heong, 1994; Heong, 2009). Foliar sprays of organophosphorus insecticides in early soybean growth are very common in Madhya Pradesh. Therefore, present study was undertaken to evaluate effect of insecticide for seed treatments on various insect pests and a natural enemy as a possible measure for replacement of foliar sprays.

MATERIAL AND METHODS

Experiment field and treatments

The experiment was carried out on the experimental field of JNKVV, Jabalpur, Madhya Pradesh during rainy season of 2012. The trial was laid out in completely randomized design with four replications. Soybean variety JS 97 52 was sown on June 22 in plot size of 10 m x 13 m with row to row spacing of 45 cm. Soybean started to flower on August 16 and was harvested on October 12. There were four treatments: seed treatment with Thiomethoxam @ 3 g per kg seed, seed treatment with Imidacloprid @ 5 ml per kg seed, foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS and untreated check.

Surveys of insect pest and spider population

Weekly surveys of major insect-pests and spiders (one of the representative of natural enemies) were carried out to determine efficacy of seed treatments. Incidence of insect-pests and spiders were observed as given below.

***B. tabaci* and *A. maculose*:** Number of nymphs and adults were eye counted on 3 leaves per plant from 10 randomly selected plants per plot.

Defoliator pests and predatory spiders: Observations on larval population of leaf eating caterpillars, beetles and spiders were recorded from five randomly selected spots of one meter row length in each plot leaving border rows by shaking the plants gently over a white observation sheet (1.0 m x 0.5 m) placed between the rows. Average number of larvae and spiders found per meter row length (mrl) was worked out.

M. sojae: To record the infestation of *M. sojae* and tunnel in stem caused by its maggots, 10 plants per plot were uprooted at random at 25, 50 DAS and also at harvest and split open vertically. Plant height and tunnel length were measured for calculating per cent stem tunnelling.

Economics

We calculated overall economics in each treatment. Cost of additional yield due to the treatment was obtained, regarding the price of soybean grain as Rs. 30 per kg. The price of Thiomethoxam and Imidacloprid were Rs. 1,651 and Rs. 480 per ha, respectively. Total prices of Quinalphos and Chlorpyriphos was Rs. 744 per ha. Cost of treatment in foliar sprays of Quinalphos and Chlorpyriphos included the price of chemicals and the cost of labour. Labour cost for chemical treatment was taken as Rs. 600 per ha. Net returns (Rs/ha) is defined as "cost of additional yield" minas "cost of treatment. Benefit-cost ratio (B/C ratio) was calculated as "Net returns" divided by "Cost of treatment".

Statistical analysis

We summarized and analyzed insect incidence data according to two soybean developing stage; vegetative stage (five observations from 20 DAS until

Table 1. Incidence of major insect pests and spiders on soybean at vegetative stage

Treatment	*Chrysodeixis acuta* (No /mrl)	*Spodoptera litura* (No /mrl)	*Bemisia tabaci* (No/leaf)	Spider (No /mrl)
Seed treatment with Thiomethoxam @ 3 g/kg seed	0.90 (1.18)[b]	0	1.90 (1.54)[ab]	0.83
Seed treatment with Imidacloprid @ 5 ml/kg seed	0.76 (1.12)[ab]	0.10	1.90 (1.54)[a]	0.97
Foliar sprays of Quinalphos 25 EC @ 1 l/ha at 20 DAS and Chlorpyriphos 20 EC @ 1.5 l/ha at 50 DAS	0.32 (0.90)[a]	0	2.34 (1.67)[ab]	0.74
Untreated check	0.89 (1.18)[b]	0.02	2.46 (1.72)[b]	0.86
SEm (±)	0.05	0.01	0.05	0.04
C D (P = 0.05)	**0.24**	**NS**	**0.26**	**NS**

DAS- Days after sowing; Figures indicate the means of five observations; Figures in parenthesis arethe square root transformed values; mrl - per meter row length flowering) and reproductive stage (six observations from flowering to maturity). Data of insect-pest and spider occurrences were transformed into square root and per cent data into angular values before analysis. Treatments were compared using critical difference at 5 per cent level of significance through PROC GLM by SAS 9.3 software (SAS, 2009).

RESULTS AND DISCUSSION

Incidence of major insect-pests and spiders

Observations recorded at vegetative growth period (Table 1) revealed that in general, the populations of insect-pests and spiders were very low during this period. Mean larval population of *C. acuta* was significantly less in foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS (0.32/mrl) followed by seed treatment with Imidacloprid @ 5 ml per kg seed (0.76/mrl) and was at par. While maximum population was recorded in seed treatment with Thiomethoxam @ 3 g per kg seed (0.90/mrl) and untreated check (0.89/mrl) which was at par with seed treatment with Imidacloprid @ 5 ml per kg seed. Seed treatment with Imidacloprid @ 5 ml per kg seed recorded significantly less population of *B. tabaci* (1.60/leaf) as compared to untreated check (2.46/leaf). *B. tabaci* population in seed treatment with Thiomethoxam @ 3 g per kg seed and foliar sprays of

Table 2. Incidence of major insect pests and spiders on soybean at reproductive stage

Treatment	*Chrysodeixis acuta* (No /mrl)	*Spodoptera litura* (No /mrl)	*Bemisia tabaci* (No/leaf)	Spider (No /mrl)
Seed treatment with Thiomethoxam @ 3 g/kg seed	2.53 (1.74)^{b}	1.26(1.33)	4.33(2.19)^{b}	1.96(1.56)
Seed treatment with Imidacloprid @ 5 ml/kg seed	2.13 (1.62)^{ab}	1.11(1.27)	4.30(2.19)^{b}	1.96(1.56)
Foliar sprays of Quinalphos 25 EC @ 1 l/ha at 20 DAS and Chlorpyriphos 20 EC @ 1.5 l/ha at 50 DAS	1.68 (1.48)^{a}	1.40(1.38)	3.74(2.06)^{a}	1.55(1.43)
Untreated check	3.94 (2.11)^{c}	1.86(1.53)	5.41(2.43)^{c}	1.95(1.57)
SEm (±)	0.05	0.08	0.03	0.05
C D (P = 0.05)	**0.16**	**NS**	**0.09**	**NS**

DAS- Days after sowing; Figures indicate the means of five observations; Figures in parenthesis are the square root transformed values; mrl - per meter row length

Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS were intermediate among treatments. Incidences of *S. litura* and spiders was very low (0 to 0.1 and 0.74 to 0.97/mrl, respectively) in all the treatments and differences were not significant.

Mean population densities at reproductive growth period (flowering and podding stage) (Table 2) showed that the population levels of the insect-pests increased slightly but still remained low. Mean larval population of *C. acuta* was significantly lower in three chemically treated plots (1.68 to 2.53/mrl), than untreated check (3.94/mrl). Foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS attained the minimum population (1.68/mrl). Incidence of *S. litura* was low in all the treatments and the differences were non-significant. For *B. tabaci*, foliar sprays of

Table 3. Efficacy of chemical treatments on damage by the stem fly, *Melanagromyza sojae*

Treatment	25 DAS		50 DAS		At harvest	
	Plant infes-tation (%)	Stem tunne-lling (%)	Plant infes-tation (%)	Stem tunne-lling (%)	Plant infes-tation (%)	Stem tunne-lling (%)
Seed treatment with Thiomethoxam @ 3 g/kg seed	0	0	20.0 (26.5)[a]	1.9	80.0	11.5
Seed treatment with Imidacloprid @ 5 ml/kg seed	2.5	0.4	20.0 (26.5)[a]	1.6	80.0	12.8
Foliar sprays of Quinalphos 25 EC @ 1 l/ha at 20 DAS and Chlorpyriphos 20 EC @ 1.5 l/ha at 50 DAS	10.0	3.5	22.5 (28.2)[a]	2.5	70.0	7.5
Untreated check	2.5	0.7	62.5 (52.3)[b]	5.2	85.0	14.7
SEm (±)	5.2	0.3	3.3	0.2	7.6	0.3
C D (P = 0.05)	**NS**	**NS**	**10.2**	**NS**	**NS**	**NS**

DAS-days after sowing; Figures in parentheses are arcsin transformed values; NS: Non- significant

Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS, seed treatment with Imidacloprid @ 5 ml per kg seed and seed treatment with Thiomethoxam @ 3 g per kg seed recorded significantly less population compared to untreated check (5.41 /leaf) and again foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS attained the minimum. Occurrences of *O. brevis*, *G. gemma*, *S. oblique*, *Cneorane* sp. and *A. maculose* were very low or none throughout the crop season in this experiment.

Damage by *M. sojae*

Soybean damage by *M. sojae* recorded at 25, 50 DAS and at harvest (Table 3) revealed that at 25 DAS, there was no plant infestation in seed treatment with Thiomethoxam @ 3 g per kg seed (Thiomethoxam). Plant infestations were very low at 2.5 per cent in seed treatment with Imidacloprid@ 5 ml per kg seed and untreated check. Maximum infestation was observed in foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS (10.0%), however the value did not differ significantly from those in other

Table 4. Grain yield and economics in insecticide treatments

Treatment	Yield (kg/ha)	Additional yield over control (kg/ha)	Cost of additional yield (Rs/ha)	Cost of treat-ment (Rs/ha)	Net returns (Rs/ha)	B:C ratio
Seed treatment with Thiomethoxam @ 3 g/kg seed	1,753 [a]	215	6,444	1,651	4,793	2.90
Seed treatment with Imidacloprid @ 5 ml/kg seed	1,615 [ab]	77	2,310	480	1,830	3.81
Foliar sprays of Quinalphos 25 EC @ 1 l/ha at 20 DAS and Chlorpyriphos 20 EC @ 1.5 l/ha at 50 DAS	1,718 [a]	180	5,401	1,344	4,057	3.01
untreated check	1,538 [b]	-	-	-	-	-
SEm (±)	34					
C D (P = 0.05)	179					

Cost of soybean grain is regarded as Rs. 30/kg; Cost of treatment includes cost of chemicals and labor cost; Costs of chemicals and labours were described in the text; B/C ratio: Benefit-cost ratio treatments. Stem tunnel damages were also low in all treatments, ranging from 0 to 3.5 per cent, which were not significantly different among treatments.

At 50 DAS, significant less plant infestations were observed in three chemically treated plots (25 to 28 %) than that in untreated check (62.5%). Tunnel damages varied from 1.6 to 5.2%, but they did not differ significantly.

At harvest, plant infestations increased to 70 to 80 per cent in all the treatments. Tunnel damages, however, were not so high, ranging from 7.5 to 14.7 per cent. No significant difference among treatments was observed both in plant infestations and tunnel damages.

Yield and economics

Seed treatment with Thiomethoxam @ 3 g per kg seed T1 (Thiomethoxam) recorded maximum seed yield (1,753 kg/ha), followed by foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS and seed treatment with Imidacloprid @ 5 ml per kg seed. Minimum yield was recorded in untreated check (1,538 kg/ha). Seed yields in seed treatment with Thiomethoxam @ 3 g per kg seed and foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS were significantly higher than that in untreated check. Maximum net returns was obtained from seed treatment with Thiomethoxam @ 3 g per kg seed (Rs 4,793) with cost benefit ratio (B/C) of 2.90, followed by foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS (Rs 4,057) with B/C ratio at 3.01. It was minimum in seed treatment with Imidacloprid @ 5 ml per kg seed (Rs 1,830) with B/C ratio of 3.81 (Table 4).

Effect of seed treatments

We considered seed treatments as a possible alternate method of the foliar sprays to control early pests, because seed treatment seems less influence on natural enemy fauna without direct contact of the chemicals on natural enemies. In fact, in the vegetative stage populations of *B. tabaci* and damage by *M. sojae* in the plots treated with Thiomethoxam and Imidacloprid were low as compared to untreated check, confirming that seed treatments with these chemicals are effective to reduce some of important early pests. Efficacy of seed treatment with Thiomethoxam on reducing incidence of *B. tabaci* and *M. sojae* were also reported in other literatures (Dey *et al.*, 2006; Dey *et al.*, 2008; Kumar *et al.*, 2009; Siddiqui and Trimohan, 2000).

At the reproductive stage of soybean, the densities of *C. acuta* and *B. tabaci* in seed treatment with Thiomethoxam @ 3 g per kg seed and seed treatment with Imidacloprid @ 5 ml per kg seed were also lower than those in untreated check. Since the efficacy of seed-treated chemicals is considered to be reduced due to decrease in concentration over time. As the plant matures, in case of Thiomethoxam, less insecticide is available for uptake and translocation within the plant and concentration in plant material rapidly declined in soybean (Piitz, 2012). Although the reason of low pest incidences in seed treatment with Thiomethoxam @ 3 g per kg seed and seed treatment with Imidacloprid @ 5 ml per kg seed treatments is not clear, this may suggest seed treatments did not provide unfavorable influence on natural enemies.

Notwithstanding what we had expected, in this experiment there was no evidence of resurgence occurred in foliar sprays of Quinalphos 25 EC @ 1 l per ha at 20 days after sowing (DAS) and Chlorpyriphos 20 EC @ 1.5 l per ha at 50 DAS, where non-selective organo-phosphorus insecticides were sprayed twice: spider population was not different among treatments and even lower populations of *B. tabaci* and *C. acuta* in this treatment than in untreated check were found in the reproductive stage. However, resurgences due to chemical sprays were often reported in soybean production in other countries (Bueno *et al.,* 2013; Shi *et al.,* 2012; Avila and Rodriguez-del-Bosque, 2005). In addition, lower parasitoidation by dipteran *Sturmia* spp. with no predatory spider population in the chemical insecticide sprayed fields as compared to the field where seed was treated with Thiamethoxam were reported in India (Sharma and Ansari, 2007). Therefore, the possibility of the resurgence due to the conventional method should be further tested. As for sprays of non-selective insecticides, other side effects including farmer's health risk and possible environmental contamination should be also taken into consideration.

The present result indicated that seed treatment can be an alternative method to replace foliar applications of non-selective insecticides in the early growth stage from the aspect of economics. Particularly in seed treatment with Thiomethoxam @ 3 g per kg seed, yield increased and thus the net returns became maximum. Seed treatment with Imidacloprid @ 5 ml per kg seed also attained plus net returns. The reason for yield increase in chemical-treated treatments is not clear, because the density of any of the major insect pests was not high even in untreated check. Probably, damage by various insect pests was suppressed in chemical-treated plots, and yields increased totally.

Much higher seed yield of soybean as compared to the average yield (1,108 kg/ha) in Madhya Pradesh was obtained even in untreated check. This may be mainly due to the face that occurrences of major insect pests were low in this experiment. There was no single species which made serious damage on soybean in the experiment field. Insect-pest incidences varied by places and years, but soybean production without insecticide application might be one of choices in Madhya Pradesh in the season when insect pest levels are low.

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Screening of Soybean Varieties against Leaf Eating Caterpillars and Classification in to Resistance Groups Based on Yield Potential and Loss

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ABSTRACT

In search of host plant resistance against leaf eating caterpillars, seven varieties of soybean were screened at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during kharif *2011 and 2012. These varieties were classified into resistance groups based on their natural yield potential and yield loss due to leaf eating caterpillars. The varieties JS 335, RKS 18, JS 93-05, MAUS 61, DSb 21, DSb 1 and Bragg did not differ significantly with each other in respect to loss in seed yield. Whereas, the population of leaf eating caterpillars under protected and unprotected conditions differed significantly among the varieties and it was 0.75 and 6.66 larvae per meter row length, respectively. The per cent defoliation of varieties with varied caterpillar population showed the least per cent defoliation in varieties DSb 21 (16.67 %) and DSb 1 (21.11 %) as compared to other varieties and are categorised as resistant genotypes and JS 335 and JS 93-05 which have recorded highest per cent leaf damage (40.56 %) categorised as susceptible genotypes. All the seven varieties were rated as tolerant and high yielding genotypes as per maxmini-minimax method.*

Key words: Resistance groups, screening, soybean varieties, yield potential

Soybean (*Glycine max* [L.] Merrill) is a unique crop with high nutritional value, providing 40 per cent protein and 20 per cent edible oil besides minerals and vitamins. It ranks first among the oilseeds in the world as well as in India. In India it is grown in 10.27 m ha with production of 11.0 m t and an average yield of 1,071 kg per ha (Anonymous, 2013). Soybean accounts more than 0.22 m ha area with production of 0.23 m t in Karnataka. The major soybean varieties grow in India are JS 335, RKS 18, MAUS 61, DSb 21, JS 93-05 and Bragg, which are found to be infested by leaf eating caterpillars.

The leaf eating caterpillars *Spodoptera litura* (Fab), *Thysanoplusia orichalcea* (Fab) and *Spilarctia obliqua*

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(Walk) are major defoliators damaging the foliage, flower and tender pods causing significant yield loss (Singh and Singh, 1990). In case of heavy attack, the caterpillars are also found to feed on flowers and pods (Anonymous, 2007). *T. orichalcea* damages the crop from August to September during *kharif* and March to May during *rabi* season. The infestation can result into 30 per cent undeveloped pods and about 50 per cent yield loss (Harish, 2008). The tobacco caterpillar, *S. litura* is a serious pest and its incidence was observed in all the soybean growing areas of northern Karnataka, which feeds on leaves and tender pods, consequently damaging 30 to 50 per cent of the pods (Anonymous, 2007). The Bihar hairy caterpillar, *S. obliqua* is a voracious feeder which feeds gregariously on soybean leaves and causing 40 per cent defoliation of leaf area.

In agricultural research, usually the experiments are carried out for the purpose of selecting varieties resistant to major insect-pests and diseases. The classification of these varieties for resistance was based on yield loss in comparison with actual potential yield. The variables used for classifying the varieties into resistance group are usually the yield losses and yield potentials of the varieties under consideration (Rao *et al*., 1989, Prakasa Rao, 1989). A variety may have relatively high yield loss but still produce high yield, on the other hand a variety with relatively low yield loss may yield below average. It is, therefore, important for selection purposes to give attention simultaneously to both yield potential and yield loss under pest attack. Hence, keeping this approach in view the present study was under taken to classify the varieties in to resistant groups.

MATERIAL AND METHODS

A field experiment was conducted in two Factorial Randomized Block Design having protected and unprotected conditions as one factor and varieties JS 335, RKS 18, JS 93-05, MAUS 61, DSb 21, DSb 1 and Bragg as second factor with three replications in plot size of 2.1 m x 5.0 m area with a spacing of 30 cm x 10 cm during *kharif* seasons of 2011 and 2012 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad to screen the varieties against leaf eating caterpillars. The recommended package of practices was followed in establishing the plant population except the insect-pest management in unprotected plots. In protected plots insect-pest management was taken based on economic threshold level of pests.

Per cent defoliation and seed yield was recorded in each genotype from both protected and unprotected plots at an interval of 15 days and analyzed with AICRPS method and Maximin – Minimax method (Odulaja and Nokoe, 1993).

Maximin-Minimax method

The main purpose of selection for resistance is to maximise yield while minimising yield loss. It can be conceptualized as maximization of minimum expected yield (maximin) and minimization of maximum excepted yield loss (minimax). The maximin approach is to obtain the yield potential of each variety relative to the resistant check, while the minimax approach is to obtain percentage yield loss relative to the susceptible check.

The relative yield of i th variety may be obtained as $RYi = 100\ Yi/Y_R$, where Yi is the yield of i th variety under unprotected conditions and Y_R is the yield of resistant check. Similarly, the relative percentage yield loss is calculated as $RPi = 100\ Pi/Ps$, where Pi is the per cent yield loss in i th variety and Ps in the susceptible check.

In the absence of susceptible and resistant checks against target pest the highest yielding variety under exposure to the pest is designated as the resistant check and variety with the highest percentage yield loss is designated as the susceptible check. The higher the value of relative yield (RY) and the lower relative yield loss (RP) for any variety, the more acceptable the variety for selection and based on this the varieties are categorized in to resistant and high yielding (R-HY), susceptible high yielding (S-HY), resistant low yield (R-LY) and susceptible low yielding (S-LY). Setting a priori an acceptable lower limit, L, for RY and upper limit, U, for RP, a scatter plot of RY against RP, maximin-minimax plot can be divided into quadrants (Fig.1) (Odulaja and Nokoe, 1993).

RESULTS AND DISCUSSION

The results revealed that with

Table 1. Field screening of soybean varieties against leaf eating caterpillars under protected and unprotected condition

Varieties	Leaf eating caterpillars # (No/mrl)		
	Protected	Unprotected	Mean
JS-335	0.92 (1.19)*	7.01 (2.74)	3.97 (2.11)
DSb-1	0.76 (1.12)	6.72 (2.68)	3.74 (2.05)
DSb-21	0.79 (1.14)	6.85 (2.71)	3.82 (2.07)
MAUS-61	0.69 (1.09)	6.56 (2.66)	3.63 (2.03)
JS-93-05	0.83 (1.15)	6.74 (2.69)	3.79 (2.07)
RKS-18	0.68 (1.09)	6.42 (2.61)	3.55 (2.01)
Bragg	0.58 (1.04)	6.33 (2.60)	3.46 (1.98)
Mean	**0.75 (1.11)**	**6.66 (2.67)**	**3.70 (2.05)**
		SEm (±)	**CD (P=0.05)**
Varieties		0.053	**NS**
Protection level		0.29	**0.080**
Interaction		0.076	**NS**

* *Figures in brackets are* $\sqrt{x+0.5}$ *transformed values; N.S. = Non-significant; #Leaf eating caterpillars: Spdoptera litura* (Fab.), *Thysanoplusia orichalcea* (Fab.), *Spilarctia obliqua*

respect to population of leaf eating caterpillar per mrl as influenced by different varieties in the protected and unprotected conditions, significant differences were observed between the protection and unprotection levels only but no significant differences were noticed between varieties as well as interaction effects.

The mean number of leaf eating caterpillars per mrl in protected and unprotected conditions was 0.75 and 6.66, respectively with significant differences between each other. Highest number of leaf eating caterpillars (3.97 l/mrl) were noticed in JS 335 variety and all varieties were on par with each other and overall per cent increase recorded was 88.77 per cent in the unprotected plot over protected ones (Table 1).

All the varieties did not differ significantly with respect to leaf damage due to leaf eating caterpillars, whereas, significant differences were observed between the levels of protection and varieties. Similar observations were made by Harish (2008) who reported that no significant difference with larval population throughout the cropping season and the level of infestation in the varieties *viz*., DSb 1, Bragg, JS 93-05 and JS 335 and were on par with each other.

Irrespective of varieties, the population of leaf eating caterpillars in protected plots (0.75 l/mrl) was significantly lower compared to in unprotected plots (6.66/mrl). The population of leaf eating caterpillars per mrl was non-significant in protected plots among different genotypes. The infestation was ranged from 0.58 larvae per mrl to 0.92 larvae per mrl (JS 335). However, under unprotected condition also there was no significant deference with respect to population of leaf eating

Table 2. Defoliation of soybean varieties by leaf eating caterpillars under protected and unprotected condition

Varieties	Defoliation (%)			AICRPS Category
	Protected	Unprotected	Mean	
JS-335	18.89** 25.68)	62.22** (52.08)	40.56 (39.53)[a]	HS
DSb-1	4.44 (12.00)	21.11 (27.24)	12.78 (20.93)[de]	HR
DSb-21	2.22 (7.01)	16.67 (24.02)	9.45 (17.89)[e]	HR
MAUS-61	10.00 (18.26)	40.00 (39.21)	25.00 (29.98)[b]	MS
JS-93-05	13.33 (21.31)	46.67 (43.07)	30.00 (33.19)[b]	HS
RKS-18	7.78 (16.11)	36.67 (37.24)	22.23 (28.11)[bc]	MR
Bragg	5.56 (13.48)	27.78 (31.73)	16.67 (24.08)[cd]	MR
Mean	**8.88 (17.33)**	**35.87 (36.78)**	**22.38 (28.22)**	**-**
		SEm (±)	**C D (P=0.05)**	
Varieties		1.291	**3.754**	
Protection level		0.690	**2.010**	
Interaction		1.826	**NS**	

***Mean of two years; *Figures in parentheses are angular transformed values; HS = Highly susceptible; MS = Moderately susceptible; MR= Moderately resistant; R = Resistant; HR = Highly resistant* caterpillars in different genotypes. The minimum number of leaf eating per mrl (6.33 l/mrl) was recorded in Bragg followed by RKS 18 (6.42 l/mrl) and maximum of 7.01 l per mrl was in JS 335.

Per cent defoliation in different soybean varieties under protected and unprotected condition

Significant differences were observed between the protected and unprotected conditions and also among the varieties. The per cent defoliation differed in different levels of protection irrespective of varieties. Unprotected plots recorded significantly higher per cent defoliation as (35.87 %) compared to protected plots (8.88 %). This accounted to 77.21 per cent higher defoliation in unprotected plot over protected plots across different varieties.

The per cent defoliation differed statistically in different varieties irrespective of protection levels. Among the different varieties maximum per cent defoliator (40.56 %) was recorded in JS 335. The varieties MAUS 61 and JS 93-05 were on par with each other by recording 25 and 30 per cent defoliation. The varieties RKS 18, Bragg, DSb 1 and DSb 21 recorded 22.23, 16.67, 12.28 and 9.45 per cent defoliation, respectively (Table 2). Based on these variables, DSb 1 and DSb 21 were categorized as highly resistant, Bragg as resistant category, RKS 18 as moderately resistant, MAUS 61 as moderately susceptible, JS 335 and JS 93-05 as highly susceptible category.

Harish (2008) also reported that 14.33, 21.33 and 28.67 per cent defoliation in KHSb 2, DSb 1 and Bragg varieties, respectively. Whereas, JS 335 and Monetta recorded 66.67 per cent and 63.37 per cent defoliation, respectively.

Similar observations were made

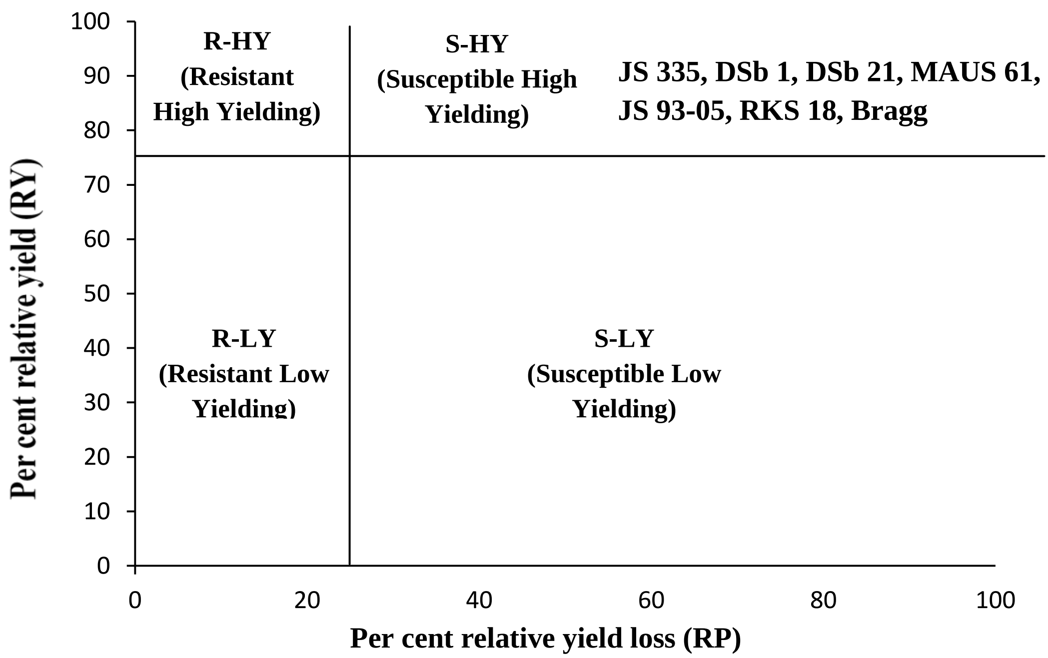

Fig. 1: Maximin-Minimax plot for classification of varieties based on yield potential and loss

Table 3. Seed yield and yield loss of soybean varieties under protected and unprotected condition

Varieties	Yield (kg/ha) Protected		Yield (kg/ha) Unprotected		Yield loss (%)		Relative yield (%) (RY)		Relative yield loss (%) (RP)		Category
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	
JS 335	2351.11	2315	1811.74	1780	22.94	23.11	100.00	98.07	66.04	80.90	S-HY
DSb 1	2262.54	2230	1793.65	1760	20.72	21.00	99.00	96.97	59.65	73.50	S-HY
DSb 21	2229.84	2410	1653.97	1815	25.82	24.68	91.29	100.0	74.34	86.38	S-HY
MAUS 61	2116.51	2210	1696.51	1730	19.84	21.72	93.64	95.32	57.12	76.02	S-HY
JS 93-05	2176.83	2185	1686.35	1575	22.53	27.92	93.08	86.78	64.86	97.72	S-HY
RKS 18	2212.06	2290	1443.49	1680	34.74	26.63	79.67	92.56	100.00	93.20	S-HY
Bragg	2086.03	2170	1473.65	1550	29.35	28.57	81.34	85.40	84.50	100.0	S-HY

S-HY: Susceptible high yielding

by Garewal *et al*. (2003) who reported that JS 71-05 was highly resistant and NRC 25 was resistant to green semiloopers. JS 71-05 and NRC 33 were highly resistant, and NRC 18 and NRC 7 were resistant to tobacco caterpillar. Hag *et al*. (1984) who noticed good tolerance capacities at both flowering and poding stages in Caribe VCF-1 (BP-2) and F-76-8827 soybean cultivars against *S. litura*.

Maximin-Minimax method

The seed yield of protected and unprotected plots was recorded from varieties for yield potential and loss assessment. In both protected and unprotected plots, JS 335 recorded highest yield of 2,351 and 1,812 kg per ha, respectively. The per cent yield loss due to leaf eating caterpillars in different varieties ranged from19.84 (MAUS 61) to 34.74 (RKS 18). The varieties Bragg, DSb 21, JS 335, JS 93-05 and DSb 1 recorded a loss of 29.35, 25.82, 22.94, 22.53 and 20.72 per cent, respectively. The maximum relative yield (RY) loss was recorded by JS 335 and per cent relative yield loss recorded was maximum in variety RKS 18. By putting an acceptable lower limit, *L* = 75 per cent for relative yield (RY) and upper limit *U* = 25 per cent for relative per cent (RP) yield loss, a scattered plot was drawn against *RY* and *RP* (Fig. 1). As per the maximin-minimax method all seven varieties (JS 335, DSb 1, DSb 21, MAUS61, JS 93-05, RKS 18 and Bragg) fell under second quadrant (S-HY) and rated as susceptible high yielding, *i.e.* tolerant to insect-pest complex (Table 3).

Similar method was followed by Sharma (1996), who reported that 'maximin-minimax' approach to classify the genotypes into resistant groups was based on yield component and the entire insect-pest complex. It is possible to identify genotypes which are resistant/tolerant to a location-specific pest complex with good yield potential. Using this approach, cultivars JS 335, NRC 2 and L 129 were classified as tolerant to insect damage (Sharma, 1996). Similar reports were also made by Salunke *et al*. (2002). Harish (2008) reported that the genotypes JS 335, DSb 1, PK 1029, JS (SH) 93-05, Monetta and Bragg were rated as susceptible and high yielding, *i.e.* tolerant to insect pest complex.

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Production and Marketing of Soybean in Akola District of Maharashtra: An Economic Analysis

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ABSTRACT

This study on production and marketing of soybean in the Akola district of Maharashtra is based on the data collected from 90 soybean producers in the tehsils of Balapur, Barshitakli and Akola of Akola district during 2013-14. The results of the study revealed that soybean cultivation in Maharashtra is a profitable enterprise as the returns per rupee invested have been found to be Rs 1.08 on overall basis, varying from Rs 1.13 on small farms to Rs 1.14 on large farms. The costs on machine labour (15.52 %) and hired labour (11.50 %) have emerged as the major components in the total operational costs. The producers have been found to follow two channels for marketing of soybean; Channel -I: farmer to wholesaler to processor, Channel -II: farmer to commission agent to wholesaler to processor. The marketing cost was found to be higher in Channel - II due to involvement of additional middlemen. The study has suggested that the measures need to be adapted to increase assess of farmers to market information and they should be motivated to market the produce collectively to reduce the cost of transportation.

Key words: Economic analysis, economic viability, Maharashtra, marketing channel, price spread, soybean

Soybean (*Glycine max*) is known as the "Golden bean" and "Miracle crop" of the 20th century because of its varied uses. Maharashtra and Madhya Pradesh are the two major soybean producing states and currently contribute more than 80 per cent to the total area and production of soybean in India (Anonymous, 2012). In Maharashtra, soybean is mainly grown in the districts of Akola, Washim, Amravati and Nagpur. The area, production and productivity of soybean in India as well as in Maharashtra have shown a consistent increase over a period of time (Ajjan *et al.*, 2011). Since, the information on production, productivity and marketing are important, the present investigation was taken up to study the cost of cultivation of soybean in Akola district, the marketing behavior of soybean

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growing farmers, the costs and returns and the price spread in the marketing of soybean. The instability in area under soybean cultivation was very high during the initial phases but declined over time. Soybean production in the country has grown at the rate of 11.5 per cent annually during the period 1980-2012 (Sharma and Dupare, 2013).

MATERIAL AND METHODS

Akola district was selected purposively based on higher concentration of area under soybean cultivation as compared to other districts. Three tahsils, namely Balapur, Barshitakli and Akola of Akola district were selected purposively. From these tehsils, nine villages were selected for the study based on the criteria of maximum production and sale of soybean. A list of soybean growing farmers from these villages was prepared and a total of 90 farmers [20 small (<2 ha), 36 medium (2-4 ha) and 34 large (>4 ha)] were selected randomly in proportion to their total number in each farm size group. For the study, primary data relating to agricultural year 2013-14 were collected from the selected farmers, wholesalers and processors through personal interview using a set of pretested schedules developed specially for the purpose. The market behavior of the soybean growing farmers and breakup of the consumer price, *viz*. producer share in consumer's rupee, costs of marketing and margins of different intermediaries involved in soybean marketing channels were worked out.

Cost concepts

The cost of cultivation of soybean was worked out by using by Commission on Agriculture Cost and Prices (CACP) concept.

Cost $\boldsymbol{A_1}$ = All actual expenses in cash and kind incurred in production by the producer. The items covered in cost A1 are costs on: i) third human labour, ii) hired bullock labour., iii) owned bullock labour, iv) home produced/purchased seed, v) plant protection chemicals, vi) home produced/purchased manure, vii) fertilizers, viii) insecticides and pesticides, ix) depreciation on farm machinery, equipment and farm building, x) irrigation, xi) land revenue, land development tax and other taxes, xii) interest on working capital, xiii) interest on crop loan and xiv) miscellaneous expenses.

Cost $\boldsymbol{A_2}$ = Cost A_1 + Rent paid for leased-in land

Cost $\boldsymbol{B_1}$ = Cost A_1 + Interest on value of owned capital assets (excluding land)

Cost $\boldsymbol{B_2}$ = Cost B_1 + Rental value of owned land (net of land revenue) and rent paid for leased-in land

Cost $\boldsymbol{C_1}$ = Cost B_1 + Imputed value of family labour.

Cost $\boldsymbol{C_2}$ = Cost B_2 + Imputed value of family labour

Cost $\boldsymbol{C_2^*}$ = Cost C_2 + estimated by taking into account or actual wage rate whichever is higher

Cost $\boldsymbol{C_3}$ = Cost C_2^* + 10 per cent Cost C_2^* to (on account of managerial functions performed by farmers)

RESULTS AND DISCUSSION

In overall variable costs (Table 1), the expenditure was highest on machine labour (15.52 %), followed by seed (14.22 %), total hired human labour (11.5 %) and fertilizer (8.85 %). Thus, machine labour

Table 1. Variable and fixed costs (Rs /ha) in cultivation of soybean crop

S. No.	Particulars	Farm-size groups			
		Small (<2 ha)	Medium (2-4 ha)	Large (>4 ha)	Overall
1	2	3	4	5	6
A	**Variable costs**				
1	Hired human labour				
a	Male	859.20 (3.75)	1507.34 (6.26)	2332.04 (8.55)	1674.86 (6.77)
b	Female	664.00 (2.90)	1080.61 (4.49)	1563.49 (5.73)	1170.45 (4.73)
2	Family Labour				
a	Male	1488.00 (6.49)	1044.49 (4.34)	669.04 (2.45)	1001.21 (4.05)
b	Female	756.00 (3.30)	403.06 (1.67)	118.05 (0.43)	373.82 (1.51)
3	Bullock Labour	1332.00 (5.81)	1212.24 (5.03)	916.66 (3.36)	1127.19 (4.56)
4	Machinery Labour	3157.80 (13.78)	3300.00 (13.71)	4804.06 (17.62)	3836.60 (15.52)
5	Seeds	3584.00 (15.64)	3500.00 (14.54)	3493.10 (12.81)	3516.06 (14.22)
6	Manures	1344.00 (5.87)	1338.78 (5.56)	1380.95 (5.07)	1355.87 (5.48)
7	Fertilizer				
a	N	892.96 (3.90)	855.37 (3.55)	743.30 (2.73)	821.39 (3.32)
b	P	1258.63 (5.49)	1251.72 (5.20)	1484.44 (5.44)	1341.17 (5.42)
c	K	16.74 (0.07)	29.43 (0.12)	30.26 (0.11)	26.92 (0.11)
8	Plant Protection	969.80 (4.23)	1224.03 (5.08)	1233.48 (4.52)	1171.10 (4.74)
9	Repairing Charges	208.60 (0.91)	333.25 (1.38)	358.19 (1.31)	314.97 (1.27)
10	Others	98.84 (0.43)	105.33 (0.44)	112.80 (0.41)	106.71 (0.43)
	Total Variable costs	**16630.57** **(72.58)**	**17185.65** **(71.38)**	**19239.86** **(70.57)**	**17838.32** **(72.15)**

Table 1 contd.

1	2	3	4	5	6
B	**Fixed costs**				
1	Interest on Working Capital	883.89	968.92	1132.74	1011.91
		(3.86)	(4.02)	(4.15)	(4.09)
2	Depreciation	344.94	410.61	426.28	401.94
		(1.51)	(1.71)	1.56)	(1.63)
3	Land Revenue	38.72	40.22	41.78	40.48
		(0.17)	(0.17)	(0.15)	(0.16)
4	Rental Value of Land	4656.98	5066.72	5836.13	4969.54
		(20.32)	(21.04)	(21.41)	(20.10)
5	Interest on Fixed Capital @ 10% / Annum	357.66	404.86	587.13	463.23
		(1.56)	(1.68)	(2.15)	(1.87)
	Total Fixed costs	**6282.19**	**6891.33**	**8024.06**	**6887.10**
		(27.42)	**(28.62)**	**(29.43)**	**(27.85)**
	Total (A+B)	**22912.76**	**24076.98**	**27263.92**	**24725.42**
		(100.00)	**(100.00)**	**(100.00)**	**(100.000)**

Note: Figure in parentheses indicates per cent to the total cost

Table 2. Cost of cultivation (Rs/ha) of soybean crop

Particulars	**Farm-size groups**			
	Small (<2 ha)	**Medium (2-4 ha)**	**Large (>4 ha)**	**Overall**
Cost 'A_1'	15615.40(63.72)	17117.63(64.65)	20011.79(65.26)	17877.15(64.72)
Cost 'A_2'	19929.04(81.32)	21751.87(82.15)	25722.18(83.89)	22846.69(82.71)
Cost 'B_1'	20536.04(83.80)	22540.87(85.13)	26634.18(86.86)	23641.71(85.59)
Cost 'B_2'	20574.76(83.96)	22581.09(85.28)	26675.96(87.00)	23682.19(85.74)
Cost 'C_1'	21684.76(88.49)	23425.09(88.47)	27085.96(88.33)	24421.35(88.42)
Cost 'C_2'	22278.65(90.91)	24070.98(90.91)	27875.79(90.91)	25110.06(90.91)
Cost 'C_3'	24506.51(100.00)	26478.07(100.00)	30663.37(100.00)	27621.06(100.00)

Note: Figure in parentheses indicates per cent to the total cost was main component of variable cost. The higher use of machine labour on small, medium and large farms was attributed to lesser use of bullock labour, *i.e.* 4.56 per cent at overall and small (5.81 %), medium (5.03 %) and large (3.36 %), respectively.

Another major component of the variable cost was hired human labour, which was maximum on large (14.29 %), followed by medium (10.75 %) and small (6.65 %) farms. The share of cost of plant protection in variable cost ranged from 4.23 to 5.08 per cent on different farm size groups with the overall value of 4.74 per cent. The rental value of land was major component of the overhead costs. Its share was 20.32 per cent, 21.04 per cent and 21.41 per cent on small, medium and large farms, respectively. The results are in conformity with findings of Singh and Singh (2001).

The overall total cost on culti-vation (Cost C_3) of soybean crop was found to be Rs 27,621.06 per ha, being highest on large (Rs 30,663.37/ha) followed by medium (Rs 26,478.07/ha) and small (Rs 24,506.51/ha) farms. The overall Cost A1 was found to be Rs 17,877.15 per ha, and was also highest on large farms (Rs 20,011.79/ha), followed

Table 3. Returns (Rs/ha) from cultivation of soybean crop

S. No	Particulars	Size of Land holding			
		Small	Medium	Large	Overall
A	Value of main Produce	27520.00	30103.00	34651.00	29466.42
B	Value of by Produce	654.18	538.61	616.43	593.69
C	Gross Returns	28174.18	30641.61	35267.43	30060.11
D	Net return over cost				
1	Cost 'A_1'	12558.78	13523.98	15255.64	12182.96
2	Cost 'A_2'	7901.80	8457.27	9419.52	7213.42
3	Cost 'B_1'	7294.80	7668.27	8507.52	6121.61
4	Cost 'B_2'	7256.08	7628.05	8465.74	6081.13
5	Cost 'C_1'	6146.08	6784.05	8055.74	5341.98
6	Cost 'C_2'	5552.20	6138.16	7265.90	4653.27
7	Cost 'C_3'	3290.00	3687.82	4465.75	2112.58
E	Returns per rupee				
1	Cost 'A_1'	1.80	1.79	1.76	1.68
2	Cost 'A_2'	1.39	1.38	1.36	1.32
3	Cost 'B_1'	1.35	1.33	1.32	1.26
4	Cost 'B_2'	1.35	1.33	1.32	1.25
5	Cost 'C_1'	1.28	1.28	1.30	1.22
6	Cost 'C_2'	1.25	1.25	1.26	1.18
7	Cost 'C_3'	1.13	1.14	1.14	1.08

Table 4. Marketing cost (Rs/q) of soybean in Channel- I and Channel- II

Particulars	Channel- I				Channel- II				
	Cost borne by			Consumer cost	Cost borne by				Consumer cost
	Farmer	Wholesaler	Processor		Farmer	Commission Agent	Wholesaler	Processor	
Transportation	8 (9.64)	7.5 (9.15)	9 (30.00)	24.5 (12.56)	8 (10.26)	7 (30.43)	7.5 (9.49)	9 (30.00)	31.5 (15.00)
Godown charge	-	7.5 (9.15)	6 (20.00)	13.5 (6.92)	-	-	7.5 (9.49)	7 (23.33)	14.5 (6.90)
Market fee	13 (15.66)	13 (15.85)		26 (13.33)	13 (16.67)	-	13 (16.46)	-	26 (12.38)
Naka	5(6.02)	-	-	5(2.56)	5(6.41)	-	-	-	5 (2.38)
Commission	40 (48.19)	43 (52.44)	-	83 (42.56)	37 (47.44)	-	40 (50.63)	-	77 (36.67)
Loading + unloading, sieving, weighing, *etc.*	10 (12.05)	6 (7.32)	10 (33.33)	26 (13.33)	9 (11.54)	12 (52.17)	7 (8.86)	9 (30.00)	37 (17.62)
Miscellaneous expenditure	7 (8.43)	5 (6.10)	5 (16.67)	17 (8.72)	6 (7.69)	4 (17.39)	4 (5.06)	5 (16.67)	19 (9.05)
Total	83 (42.56)	82 (42.05)	30 (15.38)	195 (100)	78 (37.14)	23 (10.95)	79 (37.62)	30 (14.29)	210 (100)

Note: Figure in parentheses indicates per cent to the total consumer cost by medium (Rs 17,117.63/ha) and small (Rs 15,615.40/ha) farms. The share of Cost B_2 in total cost was 85.74 per cent on overall basis and it ranged from 83.96 per cent on small farms to 87.00 per cent on large farms, depicting a direct relationship with farm size (Table 2). The results are in confirmatory of the findings by Jaiswal and Hugar (2011).

Returns from soybean crop

The overall gross income from soybean cultivation was found to be Rs 30,060.11 per ha (Table 3) in the study area. The overall returns over Cost A_1 have been found to be Rs 12,182.96 per ha and the overall returns over Cost C_3 was Rs 21,12.58 per ha. The returns per rupee in overall level over Cost A1 were found to be 1.68. The results are in conformity with findings of Wankhade (2007).

Costs, margins and price spread in marketing of soybean crop

It was found that farmers adopt following two important channels for marketing of soybean, where, processor was the ultimate consumer.

Channel- I: Farmer to wholesaler to processor

Channel- II: Farmer to commiss- ion agent to wholesaler to processor

The marketing cost in both channels was worked out and is presented below.

Channel- I: The marketing cost incurred (Table 4) revealed that the total cost in marketing of soybean at village level was Rs 195 per q among the two intermediaries in this channel, the maximum marketing cost (Rs 83/q) due to commission and wholesaler had to pay Rs 82 per q. It was noted that commission alone accounted for the maximum share (42.56 %) in the total marketing cost followed by market fee and loading, unloading, sieving, weighing, *etc*. (13.33 %) and transportation charge (12.56 %). Godown charges amounted to 6.92 per cent of the total marketing costs. The processor had

Table 5. Price spread (Rs /q) of soybean in Channel- I and Channel- II

Particular	Channel I	Channel II
Producer's share	1972 (77.3)	2107 (82.58)
Cost incurred by		
a) Farmer	78 (3.06)	83 (3.25)
b) Commission Agent	23 (0.9)	-
c) Wholesaler	79 (3.1)	82 (3.21)
d) Processor	30 (1.18)	30 (1.18)
Total cost	180 (7.06)	195 (7.64)
Margin earned by		
a) Commission Agent	149.6 (5.86)	-
b) Wholesaler	112.9 (4.43)	112.9 (4.43)
c) Processor	136.5 (5.35)	136.5 (5.35)
Total margin	399 (15.64)	249.4 (9.78)
Consumer's price	2551 (100.00)	2551 (100.00)

Note: Figure in parentheses indicates per cent to the consumer's rupee to bear 15.38 per cent of the total marketing costs.

Channel- II: The total cost incurred in marketing of soybean (Table 4) was Rs 210 per q. The maximum marketing cost (Rs 79/q) was borne by the wholesaler followed by farmer (Rs 78/q) due to the payment of commission and marketing fee. In the total marketing cost, the commission accounted for the highest share (36.67 %) followed by loading, unloading, sieving, weighing, *etc* (17.62 %) and transportation charges (15.00 %). The stockholder-wise break up indicated that the highest cost was borne by the wholesaler (37.62 %) followed by producer-farmer (37.14 %), processor (14.29 %) and commission agent (10.95 %). These results are in confirmatory of the findings by Pawar *et al*. (1999).

Price spread

Channel- I: The details of price spread of marketing of soybean in Channel- I (Table 5) showed that the soybean - farmer got Rs 2,106.71 per q (82.58 %) out of the consumer price of Rs 2,551/q. The marketing costs incurred by the farmer, wholesaler and processor were 3.25 per cent, 3.21 per cent and 1.18 per cent, respectively of the price paid by the consumer. These together accounted for 7.64 per cent of the consumer price. In the total marketing margin of 249.39 per q, the share was higher in processor (Rs 136.45/q, 5.35%) than of wholesaler (Rs 112.94, 4.43 %).

Channel- II: The details of price spread in marketing of soybean in Channel- II (Table5) showed that the soybean- farmer got Rs 1,972.11 per q out of the consumer price of Rs 2,551.1 per q. The marketing costs incurred by the farmer, commission agent, wholesaler and processor were worked out be 3.06 per cent, 0.90 per cent, 3.10 per cent and 1.18 per cent, respectively of the price paid by the consumer. The total marketing costs and marketing margins accounted for 7.06 per cent and 15.64 per cent respectively in the consumer's price. In the total marketing margin of Rs 398.99 per q, the share was highest in commission agent (Rs 149.6/q, 5.86 %), followed by processor (Rs 136.45/ q, 5.35 %) and wholesaler (Rs 112.94/q, 4.43 %). The findings of Meena *et al*. (2013) are in conformity of these results.

The study revealed that soybean cultivation is a profitable enterprise in Akola district of Maharashtra. The net income on overall basis was found to be Rs 2112.58 per q, ranging from Rs 3290.00 per q on small farm to Rs 4465.75 per q large farm. The marketing cost has been found Rs 195.97 per q at channel I. The marketing cost has been found to be higher by Rs 15 per q when soybean was sold through Channel-II due to involvement of additional middlemen in this channel. The study on price spread in marketing of soybean in two channels has shown significant differences in margins of intermediaries. Of the consumer rupee, the commission agent received 5.86 per cent share, processor received 5.35 per cent share and wholesaler received 4.43 per cent share. The producer's share in consumer's rupee in the sale of soybean directly in the market was higher i.e. 82.58 per cent in Channel- I as compared to 77.30 per cent in Channel-II. The study suggests that improvement in transportation infrastructure, provision of subsidies on inputs to farmers by the government and provision of physical facilities like storage around market may help in to increasing marketing efficiency of commodities like soybean.

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Growth Performance of Soybean in Western Vidarbha

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ABSTRACT

Soybean, also known as the 'miracle bean', occupies almost 60 per cent of the total world production of oilseeds and is considered as the most important source of protein and oil. The present study has analysed the growth and instability of area and productivity soybean. The study also examines the interaction effect of area production and productivity on output of soybean. The results of the study showed that the highest increasing trend of 33.02 and 32.86 per cent per annum in area and production for soybean was observed in Buldhana district at an overall period. The higher variability in production was observed in Buldhana (37.06 %) and Akola (29.77 %) districts. During study period, the area effect (33.10 %) was most responsible factor for increasing soybean production in western Vidharba (Amravati division).

Key words: Decomposition analysis, growth performance, soybean

Soybean, also known as the 'miracle bean', occupies almost 60 per cent of the total world production of oilseeds and is considered as the most important source of protein and oil. The expansion of area under soybean took place at quite a fast rate in absolute as well as relative terms specifically after mid 1980's. Maharashtra and Madhya Pradesh are the two major soybean producing states and currently contributes more than 80 per cent to the total area and production of soybean in India.

Maharashtra being a major soybean producing state with higher productivity, soybean cultivation is concentrated in two regions (Vidarbha and Marathwada) located in the eastern part of Maharashtra. Around 80 per cent of the soybean production of the state is contributed by these regions.

Growth in soybean with stability has been a matter of concern in the recent years. Instability in soybean production has become an extremely sensitive issue in recent times with serious social and political ramifications. The variation in soybean production among regions is due to uncertain weather conditions. Thus, analytical studies related to production growth would provide valuable information for future planning and projections of soybean output. There are many factors such as introduction of high

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yielding varieties, increasing irrigation facilities, better brands of fertilizers and manures, better prices and market facilities for soybean that promote soybean production. Keeping this in view, the objectives of the present study were (i) to examine the district-wise growth pattern of area, production and productivity, (ii) to estimate district-wise instability of soybean, and (iii) to assess the relative contribution of area and yield towards output of soybean.

MATERIAL AND METHODS

Collection of data

The present study was restricted to only five districts, namely Akola, Amravati, Buldhana, Washim and Yavatmal of Amravati division which comes under Western Vidarbha region. Due to formation of Washim district in 1998-99, the area, production and productivity of soybean of Washim district has been merge with parent district Akola and the same was analyzed up to the period of study. The study was based on time series secondary data pertaining to the period 1991-92 to 2010-11 and the period was sub-divided into two periods (Period I - 1991-92 to 2000-01, Period II - 2001-02 to 2010-11, Overall III –1991-92 to 2010-11). Time series secondary data on area, production and productivity of soybean was obtained from many published sources (GoM, 1999; GoM, 2012).

Growth rate analysis

The compound growth rates of area, production and productivity of soybean crop was estimated with the following exponential models.

$$Y = ab^t$$

$$\log Y = \log a + t \log b$$

$$CGR = (\text{Antilog} b - 1) \times 100$$

Where, CGR (%) = Compound growth rate; t = time period in year; y = area/production/productivity; a and b = regression parameters

The significance of regression coefficient ('b_i') for growth rate is tested using the student 't' statistics.

$[t_{cal} = bi/S.E.(bi)]$ has the Student's t-distribution with degrees of freedom n − k − 1.

If $t_{cal} \leq t_{tab}$, the value of the test statistics has fallen in the field of accepting null hypothesis and stated that 'b_i' is non-significant.

If $t_{cal} \geq t_{tab}$, the value of the test statistics has not fallen in the field of accepting null hypothesis and stated that 'b_i' is significant.

Instability analysis

To measure the instability in area, production and productivity, an index of instability (Coppock, 1962) was used as a measure of variability.

The algebraic form of equation is as follows:

$$V \log = \frac{\sum \left[\log \left(\frac{X_{t+1}}{X_t}\right) - m \right]^2}{N-1}$$

$$CII = [\text{Antilog}(\sqrt{V\log} - 1)] \times 100$$

Where, X_t = Area/production /productivity in the year t; N = Number of years; m = Arithmetic mean of differences between the log of X_t and X_{t-1}, X_{t-2}, etc.; V log = Logarithmic variance of the series

Decomposition analysis

To measure the relative contribution of area and yield to the total output change for soybean crop, the decomposition analysis model as given below was used (Minhas, 1964; Kalamkar *et al.*, 2002)

$P_o = A_o \times Y_o$, and
$P_n = A_n \times Y_n$ ------------------ (1)

Where, A_o and A_n represent the area and Y_o and Y_n represent the yield in the base year and n^{th} year, respectively.

$P_n - P_o = \Delta P$
$A_n - A_o = \Delta A$
$Y_n - Y_o = \Delta Y$ --------------------- (2)

Upon simplification of equation (1) and (2), it could be written as:

$P_o + \Delta P = (A_o + \Delta A)(Y_o + \Delta Y)$

Hence,

$$P = \frac{Ao\Delta Y}{\Delta P} * 100 + \frac{Yo\Delta A}{\Delta P} * 100 + \frac{\Delta Y \Delta A}{\Delta P} * 100$$

Change in production = Yield effect +area effect +interaction effect

Thus, the total change in production can be decomposed into three components *viz.*, yield effect, area effect and the interaction effect due to change in yield and area.

RESULTS AND DISCUSSION

The magnitude of agricultural development would be visualized through the relative changes in area, production and productivity of soybean over a period of time. In this context, growth rates have been computed.

Growth performance

The growth performance of soybean pertaining to two periods and overall period (Table 1) revealed that during the period-I, the growth rates for area and production were recorded very high in Buldhana district compared to other districts of Amravati division. However, significant growth rates in the productivity were recorded in Yavatmal

Table 1. District-wise compound growth rate for soybean

Particulars		Buldhana	Akola	Amravati	Yavatmal	Amravati Division
Period -I	Area	83.76***	39.06***	21.62***	41.02***	28.71***
	Production	85.82***	45.96***	24.49***	50.01***	34.68***
	Yield	1.13 NS	4.98*	6.24 NS	6.42*	4.65 NS
Period - II	Area	15.25***	14.99***	10.41***	17.18***	14.04***
	Production	10.26 NS	8.84 NS	10.88 NS	8.44 NS	9.61 NS
	Yield	-4.33 NS	-5.35 NS	0.43 NS	-7.46 NS	-3.89 NS
Overall	Area	33.02***	29.61***	10.98***	22.76***	18.36***
	Production	32.86***	28.89***	12.13***	19.85***	18.49***
	Yield	-0.12 NS	-0.56 NS	0.83 NS	-2.38 NS	0.11 NS

****Significant at 1% level; ** Significant at 5 % level; * Significant at 10 % level; NS- Non-Significant*

(6.42 %/annum) and Akola (4.98 %/annum) which were statistically significant at 10 per cent level of significance while non-significant growth was observed in Amravati (6.24 %/ annum), and Buldhana (1.13%/annum).

During the period II, the picture changed drastically, the compound growth rates of productivity registered negative growth rates except Amravati district and non-significant growth for production in all the districts of Amravati division and division as a whole, which were statistically non-significant. However, the growth rates were positively significant for area during the second period of study for all the districts of Amravati division and division as a whole. Whereas, Yavatmal recorded highest significant growth in area followed by Buldhana, Akola and Amravati districts.

The growth rates of area and production of soybean for overall period were found positive and significant in all the districts of Amravati division as well as division as a whole. Whereas, the compound growth rates for productivity were found negative in all districts of Amravati division except Amravati district. The declined growth in area and production of soybean in the post 2000 decade as compared to earlier decade with negative growth in productivity of

Table 2. District-wise Coppock's instability index for area, production and productivity of soybean in Western Vidarbha

Name of district	Particulars	Coppock's instability index (%)		
		Period I (1991-92 to 2000-01)	Period II (2001-02 to 2010-11)	Overall (1991-92 to 2010-11)
Buldhana	Area	49.10	11.62	30.85
	Production	54.07	22.52	37.06
	Yield	13.48	24.63	19.85
Akola	Area	17.90	11.74	16.47
	Production	18.79	19.36	29.77
	Yield	15.16	21.41	17.34
Amravati	Area	11.36	11.62	11.74
	Production	14.31	20.97	17.64
	Yield	14.88	22.64	18.74
Yavatmal	Area	12.56	12.95	13.09
	Production	16.36	17.89	17.22
	Yield	14.78	20.81	17.72
Amravati Division	Area	12.01	11.60	11.92
	Production	14.98	18.88	16.95
	Yield	14.31	20.99	17.28

soybean was also reported by Kajale and Shroff (2013). During this period compound growth rates for area and production were found highest in Buldhana district (33.02 and 32.86 %/annum, respectively) and were statistically highly significant. Amravati division as a whole also recorded the significant positive growth in area and production (19.14 and 18.36 %/annum, respectively) except productivity (0.11 %/annum), which was statistically non-significant. Therefore, the growth rate of productivity is declining revealing that growth rate of area expansion is more than that of production. This calls for a strategy for arresting the decline in yield observed for the post 2000 period (during 2001-02 to 2010-11).

Instability for production

The instability index was used to measure the magnitude of instability (stable or unstable) in area, production and productivity. This index is a close approximation of the average year to year percentage variation adjusted for trend. Thus, the instability index for area, production and productivity of soybean is computed by using "Coppock's instability Index" (Table 2).

Analysis of results revealed that highest instability during period I for area and production was observed in

Table 3. District wise co-efficient of correlation for the period 1991-92 to 2010-11

Districts	Particulars	Correlation between	
		Area and production	Production and productivity
Buldhana	Period I	0.91***	0.48
	Period II	0.41	0.74***
	Overall	0.74***	0.64***
Akola	Period I	0.99***	0.59*
	Period II	0.38	0.67**
	Overall	0.78***	0.44***
Amravati	Period I	0.88***	0.61*
	Period II	0.35	0.85***
	Overall	0.68***	0.67***
Yavatmal	Period I	0.91***	0.81***
	Period II	0.39	0.40
	Overall	0.72***	0.18
Amravati Division	Period I	0.94***	0.71***
	Period II	0.37	0.72***
	Overall	0.74***	0.58***

****Significant at 1% level; ** Significant at 5% level; * Significant at 10 % level*

Buldhana district (49.10 and 54.07 %, respectively), while higher instability in productivity of soybean observed in Akola district (15.16 %). However, least variability for area, production and productivity was observed in Amravati district. During period II, Yavatmal district registered higher instability in area among all the districts while, Buldhana district recorded highest instability in production and productivity. For overall period, Buldhana district recorded highest instability in area, production and productivity (30.85 %, 37.06 % and 19.85 %, respectively) followed by Akola district. The division as a whole also registered similar instability for area, production and productivity except Buldhana and Akola district. The higher instability in area, production and productivity of soybean in Buldhana district was also reported by Shende *et al*. (2011).

Correlation analysis

The analysis to correlation between (i) Area and production and (ii) Production and productivity has been worked out to assess the strength of relationship between each pair of characteristic for study period (Table 3).

The data revealed that the relationship between area and

Table 4. Per cent contribution of area, yield and their interaction for increasing production of soybean

Period	Particulars	Buldhana	Akola	Amravati	Yavatmal	Amravati Division
Period-I (1991-92 to 2000-01)	Area Effect	88.29	62.35	71.69	57.98	62.36
	Yield Effect	0.05	2.08	5.57	2.05	4.38
	Interaction Effect	11.67	35.56	22.73	39.97	33.26
Period-II (2001-02 to 2010-11)	Area Effect	71.40	78.16	37.41	91.64	63.75
	Yield Effect	8.94	7.45	35.08	2.93	14.31
	Interaction Effect	19.66	14.39	27.50	5.43	21.94
Overall (1991-92 to 2010-11)	Area Effect	36.10	42.87	29.42	50.60	33.10
	Yield Effect	0.09	0.27	9.17	0.92	2.66
	Interaction Effect	63.81	56.86	61.41	48.47	64.24

production were stronger than that between production and productivity in all most all districts of Amravati division. Thus, the results were indicative of fact that the growth in the output of soybean need grater bearing on the technological developments than on the area planted under soybean.

Decomposition analysis

An analysis of growth in area, production and productivity of soybean crop indicated the general pattern of growth and the direction of changes in area and productivity. But this does not evaluate the contribution of area and productivity to the production growth.

There are many factors which affect the growth of crop output. These factors (area, yield and their interaction) believed to affect the production of crop have been considered in present study. It is helpful in reorienting the programmes and setting priorities of agricultural development so as to achieve higher growth rates of agricultural production. The relative contribution of area, yield and their interaction to change in production of soybean crop is presented in table 4.

The decomposition analysis of output growth of soybean revealed that during period I, the area effect (88.29 %) was most responsible for increasing production of soybean in Buldhana district with yield effect 0.05 per cent. Interaction effect was positive for all the districts of Amravati division; however, area effect was greater than the yield effect. It indicated that area was a driving force in the differential production of soybean in all the districts of Amravati division as well as division as a whole during the first period. On the contrary in period II, it was noticed that area effect was found highest in Yavatmal, Akola and Buldhana district (91.64 %, 78.16 % and 71.40 %, respectively) and was responsible for increasing production of soybean while, yield and interaction effect were observed to be highest in Amravati district (35.08 % and 27.50 %) followed by Buldhana (8.94 and 19.66 %) and Akola (7.45 % and 14.39 %), respectively.

During overall period, the area effect (33.10 %) was most responsible for increasing soybean production in Amravati division with positive yield and interaction effect of 2.66 and 64.24 per cent, respectively. The area effect was found highest in Yavatmal district (50.60 %). The yield effect was found highest for Amravati district (9.17 %) and the interaction effect was found highest in Buldhana district (63.81 %).

The highest increasing trend in area and production for soybean was observed in Buldhana district during period I and at an overall period. The higher inconsistency in area, production and productivity of soybean at an overall period was observed in Buldhana followed by Akola district. The relationship between area and production showed stronger relationship than that between production and productivity in all most all districts of Amravati division. The increase in per cent contribution of area during period I and period II was more responsible for increased soybean production, while per cent contribution of area and yield (interaction effect) at an overall period was most responsible for increase in output of soybean production in all the districts of Amravati division and division as a whole.

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Extent of Adoption of Improved Soybean Production Practices in Sagar District of Madhya Pradesh

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ABSTRACT

This study was conducted during 2008-09 in five villages of district Sagar of Vindhyan pleatue agro-climatic zone of Madhya Pradesh. Assessment of the overall adoption level of recommended soybean production practices by the respondents revealed that most of the respondents had medium level of adoption (45 %) followed by low (37 %) and high (18 %). Of the twelve improved production practices, adoption level was satisfactory only in chemical pest control (90 %), use of recommended herbicides (70 %), timely sowing (82 %) and seed treatment with fungicides (60 %). Other better adopted practices were line sowing (45 %), inter cropping (32 %) and manual weed management (25 %). Very low priority was given by the farmers on use of optimum seed rate (11 %), balanced use of fertilizers (8 %), need based irrigation and provision of proper drainage (2 %) and integrated pest management (2 %).

Key words: Adoption level, production technology, soybean

Madhya Pradesh occupies 0.318 million ha of area under soybean with 0.232 million tonnes production with the average productivity of 775 kg per ha (SOPA, 2013). The studies conducted in the past (Ahirwar *et al.*, 2007; Dixit *et al.*, 2009; Meena *et al.*, 2012) have indicated that the adoption of recommended soybean cultivation practices gives high yields and additional income to the farmers. Soybean productivity achieved by the farmers at present, is far below the potential yield. This can be enhanced by adoption of all the recommended production technologies by large number of farmers. In general, recommended soybean production technologies are either not adopted by the farmers in its totality or they modify these recommendations suiting to their socio-economic and situational factors. This is primarily because of lack of awareness and knowledge about them. Keeping this in view, a study was undertaken to know the status on the extent of adoption of recommended soybean cultivation practices.

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MATERIAL AND METHODS

This study was conducted during 2008-09 in five randomly selected villages, *viz.* Badaua, Mankyai, Kanheragaon, Semadhana and Rajauaa of Jasi nagar block of district Sagar, which lies in Vindhyan Pleatue agro-climatic zone of Madhya Pradesh. Twenty respondents from each of the five selected villages (totaling 100) were randomly selected to study their adoption level about eleven recommended soybean cultivation practices (Table 2). An interview schedule was used to collect the data, which were analyzed and discussed by working out per cent values.

RESULTS AND DISCUSSION

Overall adoption levels

The overall assessment of adoption level of respondents on soybean recommended cultivation practices revealed that majority of the respondents (45%) had medium level of adoption followed by low (37%) and high (18%). This indicated that there exists a large scope to increase adoption levels of recommended soybean cultivation practices among respondents. These findings are in line with findings of Singh and Varashney (2010) and Dwivedi *et al*. (2010) who have also reported medium level of adoption of recommended practices.

Practice-wise adoption level

***Preparatory tillage*:** Soybean requires a good seedbed preparation with a reasonable fine structure. Therefore, land should be well levelled and be free from stubbles. One deep summer ploughing with mould board plough and two harrowing for soybean crop is recommended (Singh *et al.,* 2004). The present study revealed that only 25 per cent farmers ploughed their field as has been recommended whereas, majority of the farmers (75 %) followed maximum tillage practices (Table 1).

***Use of improved varieties*:** Selection of suitable varieties is very important for getting higher yield. The recommended disease and insect resistant/tolerant varieties of soybean are JS 335 (resistant to stem fly, bacterial pustule and bacterial blight), JS 71-05 (resistant to girdle beetle and Myrothecium leaf spot), JS 97-52(resistant to YMV, root rot and bacterial pustule), NRC 12 (resistant to stem fly, YMV, bacterial blight), JS 93-05 (resistant to major diseases), JS 95-60 (resistant to YMV), NRC 37 (moderately resistant to collar rot, bacterial pustule), and Indira soy 9 (moderately resistant to girdle beetle, leaf folder), *etc* (Raghu *et al*., 2008; http/www.nrcsoya.nic.in/ district-wise varieties). Soybean varieties, namely JS 335, JS 93-05, JS 95-60 and JS 97-52 are recommended for Sagar region (http/www.dacnet.nic.in; Raghu *et al*., 2008). A perusal of the data indicated that 35 per cent farmers adopted the recommended varieties for cultivation. The reason for lower adoption of recommended varieties was non-availability of seeds in time and lack of knowledge about improved varieties. Non-descriptive and old varieties were adopted by remaining 65 per cent of the farmers (Table 1).

Seed rate: To achieve a desired plant density, seed rate of soybean is decided on the basis of germination percentage,

Table 1. Practice-wise adoption level of imparted technologies

Recommended cultivation practices	Adoption percentage
Preparatory tillage	
(i) As recommended	25
(ii) Below/above recommended	75
Use of improved varieties	
(i) As recommended	35
(ii) Use of non descriptive/old varieties	65
Seed rate	
(i) As recommended	11
(ii) Above recommended	89
Time of sowing	
(i) Timely sowing	82
(ii) Late sowing	18
Sowing method	
(i) Line sowing	95
(ii) Broadcasting	05
Intercropping	
(i) As recommended	32
(ii) Not adopted	68
Seed treatment	
(i) With fungicides (thiram/bavistin)	60
(ii) Not treated	25
(iii) With rhizobium and PSB cultures and fungicides	15
Fertilizer dose	
(i) Balanced	08
(ii) Imbalanced	92
Water management	
(i) Need based irrigation and provision of proper drainage	02
(ii) Not adopted	98
Weed management	
(i) Manually	25
(ii) With recommended herbicides	70
(iii) No weed management	05
Plant protection measures	
(i) Integrated pest management	02
(ii) Chemical control	90
(iii) Components below than the recommendation	08

seed size and sowing time. If seed is of 80 per cent germination, 60-75 kg seeds per ha is required. The present study showed that the majority of the farmers (89 %) adopted higher seed rate than the recommended. Only 11 per cent of respondents used seed at recommended rate (Table 1).

***Time of sowing*:** Timely sowing is one of the most important factors for maximum yield of soybean because most of the varieties of soybean are sensitive to photoperiod and require short day conditions for flowering. The recommended time of sowing of soybean crop is up to first week of July. Before onset of monsoon, early June planting requires pre-sowing irrigation and also takes longer period to mature and is highly susceptible to yellow mosaic virus (Singh *et al.,* 2004), and hence pre-monsoon sowing must be avoided. The study brought out that the 82 per cent of the farmers planted their crop at recommended time, while rest 18 per cent farmers planted later. Most of the farmers were much concerned about importance of timely sowing as delayed sowing may shun the operation due to possible incessant rainfall in the month of July.

Sowing method: It is one of the important management factors, which has a direct effect on seed requirement, plant establishment, performance of cultural operations and efficiency of production inputs. Line sowing at row to row spacing of 30 to 45 cm, plant to plant spacing of 5 cm at depth of 3-4 cm with seed drill or behind the plough is recommended. After every 15 rows, one row space to facilitate plant protection measures in the standing crop is ideal. It could be seen (Table 1) that 95 per cent respondents were adopted recommended sowing method and rest of the respondent were non-adopters.

Intercropping: Recommended intercropping of soybean either with pigeon pea or maize or sorghum in row configuration of 4:2 ratio leads to yield advantage. Present study indicated that majority of the farmers (68 %) did not adopt intercropping practices, whereas only 32 per cent farmers practiced intercropping with pigeon pea. The lower adoption might be due to limited awareness and knowledge of farmers about the benefits of intercropping (Table 1).

Seed treatment/inoculation: To manage the loss of seedlings due to fungal attack, the seed treatment with fungicides (thiram + bavistin in 2:1 ratio @ 3 g/kg seed) followed by seed inoculation with bio-fertilizers (rhizobium and PSB @ 5-10 g/kg seed) for efficient atmospheric nitrogen fixation and making phosphorus available is recommended. The analysis revealed that the practice of seed treatment with fungicides was adopted by the 60 per cent of the farmers, while 15 per cent farmers had adopted seed inoculation with PSB and seed treatment with fungicide (Table 1). Twenty five per cent non-adopters were either not convinced of the practice or lacking the knowledge of advantages of seed treatment and seed inoculation.

Fertilizer dose: As per recommendation, 20 kg N, 60 kg P_2O_5, 20 kg K_2O and 20 kg S need be applied to meet the crop requirement. As evident from the data (Table 1), only few respondents (8 %) resorted to this practice, whereas majority of them (92 per cent) were using imbalanced fertilizer dose. This brought out lack of awareness and knowledge about importance of balanced dose of fertilizers.

Water management: During *kharif*, normally soybean crop does not require any irrigation. However, if there is a long spell of drought, particularly at the time of pod filling, irrigation is desirable. During excessive rains, proper drainage is also equally important. The information generated in the study showed that very few (only 2 %) of the farmers applied the recommended need based irrigation and provided proper drainage (Table 1). This might be partly due to non-availability of irrigation water or tendency to save water for following *rabi* crops.

Weed management: Weeds compete with crop plants for various production resources such as nutrients, moisture, sunlight, space and consequently reduces yield. Soybean crop is very sensitive to early weed competition and may reduce yield by 40-45 per cent depending upon the intensity, nature and duration of weed competition (Singh *et al.,* 2004). Soybean field should be kept free from weeds for the first 30 to 45 days after sowing. As per recommendation, two manual weeding 20 and 40 days after sowing are generally sufficient for the management of weeds (Singh *et al*., 2004; Hand Book of Agriculture, ICAR, 2009). Wherever hand weeding is not feasible, use of Trifluralin @ 1 kg a.i. per ha as pre-plant incorporation or Pendimethalin @ 1 kg a.i. per ha as pre-emergence spray or Imazethapyr @ 0.1 kg a.i. per ha as post – emergence at 15 to 20 days after sowing (Hand book of Agriculture, ICAR, 2009) is recommended. Nearly 70 per cent farmers were found adopting recommended herbicide as a chemical weed control while 25 per cent farmers are applying manual weed management and remaining 5 per cent farmers did not show their concern for this (Table 1).

Plant protection measures: Stem fly, girdle beetle, green semilooper, tobacco catterpiller, rust, sclerotium stem rot, myrothecium leaf spot and yellow mosaic are major biotic stresses in soybean crop. Collection and destruction of girdle beetle infested plant parts, egg masses and gregariously feeding larvae of hairy catterpillar should be done. Spray of neem seed kernel extract (NSKE) @ 5 per cent is recommended for the management of early stage of larvae and sucking pest. Application of Furadan 3G/Phorate 10 G @ 10 kg per ha as soil application is recommended for the control of stemfly, girdle beetle and sucking pest. In the standing crop for controlling defoliaters tobacco catterpiller, semiloopers, stemfly, girdle beetle and hairy catterpillar, Ethofenprox 10 EC @ 1 lit per ha or Triazophas 40 EC @ 625 ml per ha are recommended and Hexacanozole 5 per cent EC @ 0.1 per cent or Propiconazole 25 EC @ 500 ml per ha or Triademifon 25 per cent EC @ 1000 ml per ha are recommended for the control of rust in rust prone areas. Carbendazim @ 0.1 per cent is quite effective against foliar diseases after 35 and 50 days after sowing. An ideal integrated pest management (IPM) module for soybean crop has been also developed (Integrated Pest Management Package for Soybean, 2001;

Saini, 2002; Raghu *et al*., 2008). As regards to plant protection measures the data revealed that 90 per cent farmers followed chemical plant protection measures, whereas 8 per cent farmers adopted plant protection practices below recommendation and a very few respondents (2 %) adopted as recommended major IPM components. The reason of not using recommended plant protection measures were mostly attributed by the farmers to the lack of knowledge about importance of IPM module and lack of conviction. The findings were in accordance with respect of Dwivedi *et al*. (2010) and Dhole *et al*. (2009).

Majority of the soybean growers fell under medium level of overall adoption of recommended technology followed by low and high levels. Majority of the farmers had high technological gap in fertilizer dose, selection of varieties, deep ploughing in summer, preparatory tillage and use of IPM module in soybean production technology due to lack of knowledge and conviction in the new technology. Therefore, for enhancing the production and productivity of soybean crop, strategies should be worked out to motivate farmers for adoption of more and more recommended technologies.

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Influence of Fast and Slow Growing Rhizobia for Growth, Symbiotic Efficiency and Yield in Soybean [*Glycine max* (L.) Merrill]

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Key words: *Bradyrhizobium*, grain yield, nodulation, soybean

Soybean [*Glycine max* (L.) Merrill], "The Wonder Crop", is a subtropical legume, which was introduced in India as an important pulse and oilseed crop of *kharif* season. Application of *Rhizobium* as seed inoculant is one of the most essential component in integrated nutrient management in pulses. Rhizobial inoculation had been found to augment N supply to the crops to an extent of 20-50 kg per ha (Hooda *et al.,* 1995). High symbiotic effective rhizobial inoculation is common practice in agricultural legume production (Catroux *et al.,* 2001), which requires survival and establishment of inoculated rhizobia in the soil environment (Ozawa *et al.,* 1999 and Da and Deng, 2003). The soybean host genotype is also known to influence the competitive ability of inoculated strains (Tang, 1979 and Appunu *et al.,* 2008). Successful establishment of inoculant strain in the target legume root region must be dependent on the presence of compatible microbial population in the rhizosphere. Nodulation competitiveness is an essential additional characteristic required by inoculants (Bloem and Law, 2001) and could vary depending upon the soil type, root zone temperature and presence of native rhizospheric bacterial populations. The competitiveness of inoculated strain is usually assessed by deducing the intrinsic antibiotic resistance spectra of the individual strain (Keyser and Li, 1992). Since the soil harbors certain ineffective nodule forming native rhizobia, so the rate of of effective nodules and increase in nitrogen fixation largely depends upon the formation competitiveness of inoculated effective strains that are to be screened and should replace the existing standard strains being used in soybean.

Despite the considerable capacity for acquiring nitrogen from SNF (Wani *et al.,* 1995), the inoculation of soybean with

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rhizobial strains does not necessarily result in yield increase. Nevertheless, the significance of rhizobia forming root nodules and growth enhancement in soybean has been reported by several workers (Saeki *et al*., 2006 and Appunu and Dhar, 2006). Hence, there is a need to develop strategies that enhance the competitive ability of introduced strains for successful management of symbiotic association with selected soybean cultivar.The present study was therefore designed to study the effect of fast and slow growing rhizobia on growth, symbiotic efficiency, and yield, and to use them as inoculants.

Field experiment was conducted at the Pulse Research Farm, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, during *kharif* 2010-11 to investigate the effect of three native *Bradyrhizobium* (LSBR 3) and *Ensifer* sp. (LSER 7 and LSER 8) and their multinoculant treatment (LSBR 3 + LSER 7 + LSER 8 + DS 1 + SB 271) along with uninoculated control. Experiment was conducted in split plot design with four replications in short duration (SLE 27) and long duration (SL 744) varieties of soybean. Recommended agronomic practices were followed for raising the soybean crop. Sowing was done on 26 June, 2010. Seeds were sown 2.5-5.0 cm deep in lines 45 cm apart with a plant to plant spacing of 4-5 cm. Soybean seeds were inoculated with charcoal based inoculants with different cultures of *Bradyrhizobium* and *Ensifer* sp. as per treatment along with multi-inoculant and uninoculated control. Charcoal carrier based culture packets of soybean rhizobia were prepared according to Somasegaran and Hoben (1994). Broth culture (30 ml) of different strains of *Bradyrhizobium* and *Ensifer* spp. (1×10^9 cells/ml) were inoculated in each pre-sterilized packet (100 g) to attain recommended moisture level of 50 per cent. After 4 weeks of storage, the population of rhizobia in inoculants was 1×10^9 cells per g of carrier (charcoal) in each treatment. At the time of sowing, 20 g charcoal based formulation of each inoculant, from above mentioned packets was used per kg of soybean seeds for inoculation in each treatment. In mutiinoculant treatment each inoculant was applied in equal ratio (1:1:1:1:1) and seeds were air dried at room temperature under shade and sown within two hours. Observation for plant height, dry weight of shoot and root, number and dry weight of nodules were recorded at both vegetative (55 days after sowing, DAS) and flowering stage (90 DAS) for SL 744 and vegetative (35 DAS) and flowering stages (50 DAS) for SLE 27. Leghaemoglobin (Wilson and Reisenauer, 1963) and chlorophyll content (Witham *et al.,* 1971) were recorded at flowering stage of both the varieties. Seed yield was recorded at the harvesting stage. The data was analyzed as per standard statistical procedure and CPCS 1 software by using SPD. Critical difference (CD) at 5 per cent level was calculated.

Effect on growth attributes

Significant difference in heights of plants in different treatments and varieties was recorded (Table 1). Plants of SL 744 variety showed significantly more height than SLE 27 variety. Among treatments, plants receiving LSER 8 treatment gained maximum height (30 cm in SLE 27 and 49.3 cm in SL 744) followed by LSER 7 (28 cm in SLE 27 and 47.3 cm in SL 744) and LSBR 3 (26.6 cm in SL27 and 40.0 cm in SL 744). Multiinoculant treatment was on par with various single inoculants for plant height. These results are supported by the findings of Khondaker *et al.* (2003), who reported similar results in both soybean and pea. The lowest height was observed in the control treatment. Plants receiving SB 271 treatment showed minimum height among treated plants (24 cm in SLE 27 and 31 cm in SL 744). Giri and Joshi (2010) also observed that rhizobial inoculated plants gave significantly higher shoot/root length as compared to uninoculated control in soybean and pea. Inoculation of soybean plants with *Bradyrhizobium* and *Ensifer* sp. showed increased dry weight of shoot as compared to uninoculated control. There was an increase in dry weight of shoot with various treatments at flowering stage over vegetative stage. A significant difference in dry weight of shoot was observed for different treatments over uninoculated control. Inoculation with LSER 8 gave maximum shoot dry weight (9.7g/plant in SLE 27 and 14.8 g/plant in SL 744), whereas LSER 7 and LSBR 3 were found to be on par. Similar results were also reported by Seneviratne *et al.* (2000) and Rahmani and Rastin (2001) and Tahir *et al* (2009) in soybean. Bai *et al.* (2002) and Okereke *et al.* (2001) reported 29 per cent and 2-130 per cent increase in shoot dry weight following the inoculation with *B. japonicum*, respectively. The results are in close agreement with Appunu *et al.* (2008), who also reported that soybean plants inoculated with *B. japonicum* strain ASR0 11 produced higher plant dry matter accumulation and it emerged as the best criteria for selecting most effective legume-*Rhizobium* association in any given physical and biological conditions.

Root dry weight increased significantly in plants receiving different treatments (Table 1). Similar results were also reported by Seneviratne *et al.* (2000) and Rahmani and Rastin (2001) in soybean. At both the stages, in both varieties, maximum root dry weight was recorded in LSER 8. At vegetative stage, LSER8 showed 0.778 g per plant and 0.902 g per plant of dry root weight in SLE 27 and SL 744, respectively whereas at flowering stage, it showed 1.99 g per plant (SLE 27) and 2.27 g per plant (SL 744) of root dry weight. However, non- significant difference was recorded for dry weight of root with LSBR 3 and LSBR 7 treatments. A significant difference also existed between the varieties at vegetative stage but was found non-significant at flowering stage. Increase in dry weight of roots was also observed in *Rhizobium* inoculated legumes by Ogutcu *et al.* (2008) and Elkoca *et al.* (2008) in chickpea, which may be ascribed to ability of *Rhizobium* to conserve carbohydrates. All the treatments except *Bradyrhizobium* strain SB 271 in SLE 27 significantly increased the total chlorophyll content over uninoculated control in all the treatments, but were found non-significant for the varieties. Maximum mean chlorophyll content was recorded in LSER 8 (2.25 and 2.49 mg/g fresh weight of leaves at vegetative and flowering stage, respectively) followed by LSER 7 (2.14 and 2.40 mg/g fresh weight of leaves at vegetative and flowering stage, respectively) and LSBR 3 (1.73 and 2.31 mg/g fresh

Table 1. Evaluation of *Bradyrhizobium* and *Ensifer* sp. inoculation on growth parameters in soybean

Treat-ments	Plant height (cm)			Dry weight of shoot/plant (g)						Dry weight of root/plant (g)						Total Chlorophyll content (mg/g fresh weight of leaves)					
	SLE 27	SL 744	Mean	SLE 27	SL 744	Mean	SLE 27	SL 744	Mean	SLE 27	SL 744	Mean	SLE 27	SL 744	Mean	SLE 27	SL 744	Mean	SLE 27	SL 744	Mean
	35 DAS	65 DAS		35 DAS	65 DAS		50 DAS	90 DAS		35 DAS	65 DAS		50 DAS	90 DAS		35 DAS	65 DAS		50 DAS	90 DAS	
Control	22.6	28.0	25.3	3.8	4.6	4.2	7.8	8.6	8.2	0.642	0.810	0.726	0.890	0.948	0.92	1.10	1.31	1.20	1.62	1.97	1.79
SB 271	24.0	31.0	27.5	4.1	4.9	4.5	8.1	8.9	8.7	0.687	0.825	0.756	0.918	1.10	1.00	1.49	1.53	1.51	1.80	2.08	1.94
DS 1	25.6	34.0	29.8	4.6	5.1	4.8	8.5	9.8	9.1	0.710	0.869	0.789	1.23	1.43	1.33	1.57	1.69	1.63	1.90	2.25	2.07
MI	26.0	36.6	31.3	4.9	5.5	5.4	8.9	11.2	10.0	0.745	0.880	0 .812	1.71	1.82	1.76	1.61	1.78	1.69	1.92	2.41	2.16
LSBR 3	26.6	40.0	33.3	5.2	5.9	5.5	9.0	14.1	11.5	0.765	0.888	0.822	1.88	2.10	1.99	1.65	1.81	1.73	2.10	2.52	2.31
LSER 7	28.0	47.3	37.6	5.6	6.3	5.9	9.3	14.5	11.9	0.776	0.891	0.833	1.95	2.17	2.06	2.10	2.18	2.14	2.17	2.64	2.40
LSER 8	30.0	49.3	39.6	5.9	6.6	6.2	9.7	14.8	12.2	0.778	0.902	0.840	1.99	2.27	2.13	2.22	2.29	2.25	2.19	2.80	2.49
Mean	26.04	38.02		4.92	5.5		8.7	11.7		0.729	0.865		1.50	1.69		1.67	1.79		1.95	2.38	
CD (P = 0.05)	Variety (V): **9.6**, Treatment (T): **3.9**, V×T: **5.6**			Variety (V): NS Treatment (T): **0.59** V×T: NS			Variety (V): **0.529** Treatment (T): **1.0** V×T: **1.5**			Variety (V): **0.107** Treatment (T): **0.024** V×T: NS			Variety (V): **NS** Treatment (T): **0.198** V×T: NS			Variety (V): NS Treatment (T): **.220** V×T: NS			Variety (V): NS Treatment (T): **.199** V×T:NS		

Table 2. Evaluation of *Bradyrhizobium* and *Ensifer* sp. inoculation on symbiotic parameters in soybean

Treat-ments	**Number of nodules/plant (NN)**						**Dry weight of nodule /plant (mg)**						**Leghaemoglobin content (mg/g fresh weight of nodules)**					
	SLE 27	**SL 744**	**Mean**	**SLE 27**	**SL 744**	**Mean**	**SLE 27**	**SL 744**	**Mean**	**SLE 27**	**SL 744**	**Mean**	**SLE 27**	**SL 744**	**Mean**	**SLE 27**	**SL 744**	Mean
	35 DAS	**65 DAS**		**50 DAS**	**90 DAS**		**35 DAS**	**65 DAS**		**50 DAS**	**90 DAS**		**35 DAS**	**65 DAS**		**50 DAS**	**90 DAS**	
Control	11.0	12.8	11.9	26.2	36.7	31.4	16.0	22.8	19.4	65.5	87.8	76.6	2.12	3.39	2.75	3.36	5.97	4.66
SB 271	12.9	14.6	13.7	30.8	40.8	35.8	23.1	24.1	23.6	70.0	99.5	84.7	2.62	3.73	3.17	4.27	6.88	5.57
DS 1	14.8	18.1	16.5	31.4	43.3	37.3	30.9	32.5	31.7	82.0	117.2	99.6	2.85	3.92	3.38	4.46	7.02	5.74
MI	16.8	23.1	19.9	33.0	42.3	37.6	34.6	40.5	37.5	92.6	122.5	107.5	2.93	4.02	3.47	4.52	7.23	5.87
LSBR 3	15.3	18.0	16.6	35.7	46.0	40.8	38.8	45.6	42.2	102.0	128.8	115.4	3.42	5.70	4.56	5.10	7.72	6.41
LSER 7	18.6	23.3	20.9	39.3	49.3	44.3	33.1	50.6	41.8	108.0	133.7	120.8	3.20	5.86	4.53	5.58	8.52	7.10
LSER 8	20.5	26.6	23.5	38.5	50.3	44.4	38.1	51.5	44.8	103.2	134.5	118.6	3.68	5.91	4.79	5.80	8.40	7.16
Mean	15.8	19.5		33.48	44.10		30.6	38.2		89.0	117.6		2.97	4.64		4.75	7.391	
CD (P = 0.05)	Variety (V): NS Treatment (T):**3.1** V×T: NS			Variety (V): **9.6** Treatment (T): **2.5** V×T**: NS**			Variety (V): **5.4** Treatment (T): **4.9** V×T: **NS**			Variety (V): **10.7** Treatment (T): **4.9** V×T: NS			Variety (V): **0.94** Treatment (T)**: 0.26** V×T: 0.37			Variety (V): **1.17** Treatment (T**): 0.21** V×T:NS		

weight of leaves at vegetative and flowering stage, respectively) in both the varieties. This improvement in chlorophyll content may be due to increased N uptake by a larger root surface area associated with additional root hairs and lateral root development and/or to BNF, either directly by the inoculant strains or indirectly by stimulating BNF activity of the associated rhizosphere community (Somani, 2005).

Effect on symbiotic traits

The number of nodules was increased by *Bradyrhizobium* and *Ensifer* sp. inoculation at both stages over uninoculated control (Table 2). At vegetative stage, a significant difference was observed for all treatments except the local reference culture SB 271 in both varieties over uninoculated control. Response of various inoculants in variety SL 744 was better for nodule number than SLE 27 at both stages. Difference for nodule number was non-significant between varieties at vegetative stage. Maximum mean number of nodules was produced by LSER 8 (23.5 NN/plant) followed by LSER 7 (20.9 NN/plant) and LSBR 3 (16.6 NN/plant). Multiinoculant treatment recorded 23.3 NN per plant which was on par with LSER 8 (*Ensifer* sp.) with variety SL 744.

At flowering stage, the number of nodules was higher at flowering stage than vegetative stage. Almost similar trend in nodulation was observed with various treatments as seen at vegetative stage. Inoculation with LSER 8 (44.4 nodules/plant) and LSER 7 (44.3 nodules/plant) showed significant increase in mean nodule number over uninoculated control (31.4 nodule/plant). Differences for nodule number between the varieties were significant at flowering stage. Higher nodulation in inoculated plant could be attributed to the availability of large number of effective and infective rhizobia (Khurana and Sharma, 1998 and Appunu *et al.,* 2009) in soybean rhizosphere.

On overall mean, *Ensifer* and *Bradyrhizobium* sp. inoculation treatment increased the dry weight of nodules significantly in comparison to uninoculated control at both vegetative and flowering stages (Table 2). Treatments differed significantly from each other at both stages over uninoculated control. Varieties differed significantly for dry weight of nodule. Like number of nodules, the dry weight of nodule was also seen more in SL 744. Maximum enhancement of nodule dry weight was recorded in both the varieties at both stages with inoculation of LSER 8 (ranged from 38.1 mg/plant to 134.5 mg/plant) followed by LSER 7 (33.1mg/plant to 133.7 mg/plant) followed by LSBR 3 (38.8mg/plant to 128.8mg/plant). Similar results were observed by Shivananda *et al.* (2000) in soybean due to larger bradyrhizobial population which infected more root hairs enhancing the nodule number, ultimately contributing to the higher dry matter of nodules per plant. Other studies also reported significant increase in soybean growth parameters and yield due to the inoculation of bradyrhizobial isolates (Purcino *et al.,* 2000, Okereke *et al.,* 2001 and Pant and Prasad, 2004). Appunu *et al.* (2008) reported that *B. japonicum* ASR0 11 strain recorded the highest nodulation with all six cultivars of soybean. Multiinoculant treatment did not improve nodule dry weight significantly as compared to single inoculation.

At vegetative stage, significant improvement in leghaemoglobin content was noted in MI, LSER 8, LSER 7 and LSBR 3 over the reference culture SB 271 and DS 1 (Table 2). Varieties differed non-significantly from each other. Maximum amount of leghaemoglobin was observed in LSER 8 (3.68 mg/g in SLE 27 and 5.91 mg/g fresh weight of nodules in SL 744) followed by LSBR 7 (3.20 mg/g in SLE 27 and 5.86 mg/g fresh weight of nodules in SL 744) and LSBR 3 (3.42 mg/g in SLE 27 and 5.70 mg/g fresh weight of nodules in SL 744).

Table 3. Evaluation of *Bradyrhizobium* and *Ensifer* sp. on grain yield in soybean

Treatments	Grain yield (kg/ha)		
	SLE 27	**SL 744**	**Mean**
Control	780	2166	1473
SB 271	800	2205	1502
DS 1	804	2256	1530
MI	823	2285	1554
LSBR 3	828	2298	1563
LSER 7	840	2320	1580
LSER 8	865	2358	1611
Mean	820	2269	
CD (P = 0.05)	Variety (V): **52.1**, Treatment (T):**43.5**, V×T: NS		

At flowering stage all treatments significantly increased leghemoglobin content over uninoculated control. Multiinoculant treatment did not improve leghaemoglobin content as compared to individual strain of *Bradyrhizobium* or *Ensifer* sp. Significant difference was also observed at both vegetative and flowering stage among the varieties. Enhanced leg-haemoglobin content in various rhizobial treatments might be due to effective nodulation and symbiotic nitrogen fixation. Deka and Azad (2006) have also reported that leghaemoglobin has a positive correlation with N_2 fixation and nitrogenase activity in nodules.

Effect on grain yield

On the basis of pooled mean, inoculants LSER 8 significantly increased grain yield by 9.3 per cent. Whereas, LSER 7 and LSBR 3 showed 7.2 per cent and 6.1 per cent increase in grain yield over uninoculated control (Table 3). The increase in yield due to rhizobial inoculation was due to its superiority over native rhizobia in soybean. Improvement in grain yield due to *Rhizobium* inoculation has been reported in legumes (Elkoca *et al*., 2008; Togay *et al*., 2008; El Hadi and Elsheikh, 1999). Improvement in grain yield due to inoculation with *Rhizobium* may be ascribed to better nodulation of roots and its culmination in more N_2 fixation that in turn has a significant effect on grain yield. Yield levels of different treatments were low in SLE 27 (extra short duration, 110 days) variety of soybean as compared to SL 744 (long duration, 140 days). Similar genetic variation in biomass production and seed yield has already been reported by earlier workers (Appunu *et al*., 2008; Shivnanda *et al*., 2000). This data is further supported from Kumar *et al*. (1996) in pigeonpea, who reported that long duration genotype derived about 35 per cent of total N from atmosphere whereas short duration genotype derived 15 per cent from atmosphere and extra short duration genotype had negligible N derived from N_2 fixation (Appunu *et al*., 2008; Tahir *et al*., 2009). Low yield levels in SLE 27 variety might be due to low nodule number, nodule dry weight, leghaemoglobin content and dry matter production in comparison to long duration variety of SL 74.

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Growth, Productivity and Economics of Soybean Genotypes under Varying Planting Densities

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Soybean [*Glycine max* (L.) Merrill] is an important oilseed crop widely grown as a valuable source of protein and oil for human nutrition. In Uttarakhand, it is cultivated over an area of 12 thousand hectares with production of 18 thousand tonnes and productivity of 1,500 kg per ha (DAC 2011-12). The unavailability of quality seed, poor or higher plant population, imbalanced fertilizer use and inadequate or non-use of plant protection measures are the major factors limiting soybean production in the region. Adjusting planting density is an important tool to optimize crop growth and the time required for canopy closure in addition to achieve maximum biomass and grain yield (Liu *et al*., 2008). Numerous studies have previously emphasized the significance of optimum plant population for better growth expression and productivity enhancement (Egli, 1988).

Selection of suitable genotypes plays a vital role in crop production, particularly in new areas of introduction. The choice of right genotypes of soybean helps to augment crop productivity by 20-25 per cent. Thus, the value of stable and high yielding genotypes has been universally recognized as an important non-monetary input for boosting the production of any crop. Therefore, present investigation was conducted to study the effect of planting density on growth, yield and economics of soybean genotypes under agro-climatic conditions of North Western Himalayas.

A field experiment was conducted during *kharif* 2012 at the experimental farm of the ICAR – Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora. The site is located at 29° 36′ N latitude and 79° 40′ E longitude at an elevation of 1,250 m above mean sea level. The soil of the experimental site was silty clay loam with pH 6.2, having low level of available nitrogen (172 kg N/ha), medium level of available phosphorus (21.3 kg P_2O_5/ha) and potash (183.5 kg K_2O/ha). The experiment was laid out in split plot design with three replications. The treatments consisted of three planting

[1]*Senior Scientist,* [2]*Scientist,* [3]*Principal Scientist and Head*

densities (0.30, 0.45 and 0.60 m plants/ha) as main plots while five soybean genotypes (VL Soya 47, VL Soya 59, VL Soya 63, VL Soya 65 and VL Soya 76) as sub-plots. The crop was sown in rows 45 cm apart by *kera* method using 125 kg seed per ha. Later on, when the plants were 3-4 leaf stage, the desired plant population was maintained by keeping plant to plant spacing at 7.5, 5.0 and 3.5 cm, respectively as per treatments. The other agronomic practices were followed as per recommendations. The crop was sown at the first shower of monsoon on 7 July, 2012 and harvested on 20 October, 2012. A total of 682.2 mm rainfall with 41 rainy days was received during the whole cropping season.

Representative plant samples were taken at 15 days interval starting from 30 DAS to 60 DAS to work out relative crop growth rate (RGR) and mean crop growth rate (CGR). The plant samples were first sun dried and thereafter, at 65^{o} C for 48 h in oven to achieve a constant weight before taking dry weight. Observations on component traits *viz*., plant height, yield attributes and yield were taken at the time of harvesting of the crop. Treatment wise monetary returns were worked out taking into consideration the market price of crop produce and inputs used. The rainwater use efficiency (RWUE) was computed as a ratio of yield and crop seasonal rainfall (Rockstrom *et al*., 2003). Statistical methods based on analysis of variance technique as described by Panse and Sukhatme (1985) were employed and the treatment differences were tested by least significant difference at 5 per cent of probability.

Effect of Plant Density

The total dry matter accumulation decreased with the increase in plant population (Table 1). Averaged across tested genotypes, significantly higher mean dry matter accumulation was recorded in treatments accommodating 0.30 million plants per ha closely followed by 0.45 million per ha planting density. Both these treatments were significantly superior to 0.60 m plants per ha. The mean crop growth rate (CGR) increased significantly with increasing levels of plant density and it was comparatively higher during periodic interval between 45-60 DAS than that of 30-45 DAS. However, relative crop growth rate (RGR) was not influenced significantly. Among other growth parameters, plant height increased, while number of branches per plant significantly decreased with increase in level of plant density. The CGR and plant height of soybean increased as plant density increased (Sekimura *et al*., 2000; Shamsi and Kobraee, 2009).

Increase in planting density from 0.30 to 0.60 million per ha resulted into decreased values of all the yield attributes *viz*., number of pods per plant, pod length, number of seeds per pod and seed index (Table 2). The reduction in these yield attributes was comparatively higher from 0.45 to 0.60 than 0.30 to 0.45 m plants per ha. Increased plant competition under higher population for growth resources might have culminated in poor dry matter production, fewer pods and lesser branches, taller plants, and higher pod shedding than compared to when soybean was grown at low populations. Board and Harville (1996) and Shamsi and Kobraee (2009) have also indicated a decrease in number of pods per plant as plant density increased. Under higher plant densities, there is increased competition for resources suggesting low

Table 1. Effect of planting density on growth of different soybean genotypes

Treatment	Dry matter (g/plant)			Mean CGR ($g/m^2/day$)		Mean RGR (g/g/day)		Plant height (cm)	Branches (No/plant)
	30 DAS	45 DAS	60 DAS	30-45 DAS	45-60 DAS	30-45 DAS	45-60 DAS		
Plant density (m/ha)									
0.30	1.77	3.74	6.22	3.95	4.96	0.050	0.035	49.48	6.59
0.45	1.62	3.34	5.93	5.17	7.77	0.049	0.039	53.11	6.17
0.60	1.47	3.00	5.50	6.10	10.01	0.048	0.042	57.64	5.85
SEm (±)	0.05	0.10	0.10	0.13	0.35	0.001	0.002	1.04	0.04
CD (P=0.05)	**0.19**	**0.39**	**0.38**	**0.52**	**1.39**	**NS**	**NS**	**4.08**	**0.17**
Genotype									
VL Soya 65	2.01	4.13	6.19	6.22	6.21	0.048	0.027	54.98	4.53
VL Soya 76	2.01	4.02	6.34	5.85	6.87	0.046	0.031	58.49	7.36
VL Soya 47	1.45	3.07	5.49	4.70	7.26	0.050	0.039	55.53	6.93
VL Soya 59	1.29	2.72	5.59	4.18	8.64	0.050	0.048	49.36	6.11
VL Soya 63	1.34	2.87	5.82	4.42	8.92	0.051	0.048	48.69	6.09
SEm (±)	0.05	0.09	0.16	0.17	0.61	0.001	0.003	1.01	0.19
CD (P=0.05)	**0.13**	**0.28**	**0.47**	**0.50**	**1.79**	**0.002**	**0.008**	**2.96**	**0.56**

dry matter assimilation in seeds leading to less seed weight

Consistent and significant increase in seed yield was observed with the increase in planting density up to 0.45 million per ha; however, further increase in plant population exhibited adverse impact on soybean yield. Significantly higher seed yield (2,242 kg/ha) was recorded with 0.45 million per ha planting density elucidating 5.6 and 10.2 per cent higher yield advantage over treatments involving 0.30 and 0.60 million plants per ha, respectively. Significant improvement in harvest index was noticed with the reduction in plant density. Ball *et al.* (2000) reported that increasing plants population reduced yield of individual plants but increased yield per unit of area. The results are in close conformity with that of Rahman *et al.* (2004) who reported that plant density up to 0.40 million per ha gave the highest yield but above this plant density no yield advancement was achieved.

The cost of cultivation increased with increasing levels of planting density and was highest in 0.60 million per ha (Table 3). Highest gross returns, net returns and B:C ratio was recorded under 0.45 million per ha followed by 0.30 million per ha. The net returns and B:C ratio under 0.45 million per ha were at par with 0.30 million per ha while significantly superior than 0.60 million per ha. Higher gross returns, net returns and B:C ratio under 0.45 m plants per ha might be due to the reason that there was

Table 2. Effect of planting density on yield attributes and yields of different soybean genotypes

Treatment	**Pods (No/ plant)**	**Pod length (cm)**	**Seeds (No/ pod)**	**Seed index (g/100 seeds)**	**Seed yield (kg/ha)**	**Straw yield (kg/ha)**	**Harvest index (%)**
Plant density (m/ha)							
0.30	63.83	3.76	2.56	17.10	2117	2045	50.72
0.45	59.63	3.70	2.49	16.86	2242	2295	49.29
0.60	54.52	3.58	2.41	16.52	2013	2178	47.84
SEm (±)	0.24	0.03	0.02	0.10	43	66	0.35
CD (P=0.05)	**0.95**	**0.12**	**0.10**	**0.40**	**169**	**NS**	**1.37**
Genotype							
VL Soya 65	44.47	3.50	2.26	18.38	1479	1696	46.59
VL Soya 76	66.49	3.83	2.69	16.01	2431	2426	50.08
VL Soya 47	69.38	3.73	2.57	16.37	2336	2283	50.61
VL Soya 59	57.02	3.64	2.42	15.81	2167	2090	50.92
VL Soya 63	59.27	3.68	2.50	17.56	2206	2369	48.23
SEm (±)	1.20	0.02	0.04	0.19	48	54	0.17
CD (P=0.05)	**3.49**	**0.07**	**0.11**	**0.56**	**140**	**158**	**0.49**

proportionately less increase in cost of 0.45 m plants per ha compared to more increase in seed and straw yields. The highest rain water use efficiency (3.29 kg/ha/mm) was recorded under 0.45 m plants per ha and it followed by 0.30 m plants per ha (3.10 kg/ha/mm) and 0.60 m plants per ha (2.95 kg/ha/mm).

Effect of genotypes

Genotypes exhibited significant differences for dry matter accumulation, CGR and RGR with respect to the observations taken at fortnightly interval from 30 to 60 DAS (Table 1). VL Soya 76 and VL Soya 65 being at par recorded significantly higher dry matter accumulation than VL Soya 47, 59 and 63 at 30 and 45 DAS, however, at 60 DAS, only VL Soya 65 was at par with these genotypes. During 30-45 DAS, CGR was relatively higher under VL Soya 76 and 65 while it was comparatively more under genotypes VL Soya 47, 59 and 63 during 45-60 DAS. Higher values of CGR were observed during 45-60 DAS as compared to 30-45 DAS, which might be attributed to better source: sink ratio through better translocation of metabolites and utilization of growth resources. Saxena *et al.* (2013) reported more stage based energy utilization/exploitation referring towards production (earlier half) and expansion of primary plant parts (leaves, stem, primary branches, *etc.*). He further stressed that with the passage of time, the value of RGR decreased due to increase in

Table 3. Effect of planting density on economics and rain water use efficiency of different soybean genotypes

Treatment	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Rainwater use efficiency (kg/ha/mm)
Plant density (m/ha)					
0.30	27269	50971	23702	1.86	3.10
0.45	28643	54217	25574	1.89	3.29
0.60	29433	48907	19474	1.66	2.95
SEm (±)	-	1071	1072	0.04	-
CD (P=0.05)	**-**	**NS**	**4207**	**0.15**	**-**
Genotype					
VL Soya 65	27343	35591	8248	1.30	2.17
VL Soya 76	28967	58826	29859	2.03	3.56
VL Soya 47	28810	56440	27631	1.96	3.42
VL Soya 59	28528	52292	23764	1.83	3.18
VL Soya 63	28593	53674	25081	1.88	3.26
SEm (±)	-	1170	1170	0.04	-
CD (P=0.05)	**-**	**3416**	**3416**	**0.12**	**-**

relative dry matter of the plants. VL Soya 76 produced significantly taller plants (58.49 cm) with more number of branches per plant (7.36) and was at par with VL Soya 47. VL Soya 65 recorded lowest number of branches per plant (4.53). Differential behaviour in growth habit of soybean genotypes may be attributed to their genetic makeup (Singh *et al.*, 2013)

Across varying planting densities, yield, yield attributes and harvest index of soybean were significantly influenced by genotypes under study (Table 2). The genotype VL Soya 76 recorded highest number of pods per plant (69.38), pod length (3.83 cm) and number of seeds per pod (2.69) and was significantly superior to rest of the genotypes. Though VL Soya 65 recorded highest seed index (18.38 g/100 seed) but was worst in terms of pods per plant, pod length and number of seeds per pod. Among all the genotypes, VL Soya 76 was found superior with respect to seed (2,431 kg/ha) and straw (2,426 kg/ha) yields indicating 4.0, 9.4, 11.4 and 39.2 per cent yield superiority over VL Soya 47, 63, 59 and 65, respectively. Harvest index was highest with genotype VL Soya 59 (50.92 %) and minimum in VL Soya 65 (46.59 %). Better expressions of growth and yield attributes finally culminated in higher yield in genotypes VL Soya 76 and 47. Saxena *et al.* (2013) have also reported genotypic difference in seed yield of soybean.

There was not much difference in the cost of cultivation for different genotypes, however, gross returns, net returns and B: C ratio differed significantly across the genotypes (Table 3). The highest gross returns (Rs 58,826/ha), net returns (Rs 29,859/ha) and B:C ratio (2.03) were recorded with VL Soya 76 attributing its statistically higher economic and biological yields.

The genotype VL Soya 65 resulted in lowest monetary returns. VL Soya 76 was found to be the most efficient genotypes with respect to rain water use efficiency (3.56 kg/ha/mm) among all the tested genotypes.

From the study, it could be concluded that among soybean genotypes, VL Soya 76 produced highest seed yield (2,431 kg/ha) with B:C ratio of 2.03 while among planting densities, 0.45 million/ha resulted into maximum seed yield (2,242 kg/ha) with B:C ratio of 1.89.

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Soybean Research 13(1): 89-93 (2015)

Effect of Different Varieties and Plant Densities on Growth and Yield of Soybean [*Glycine max* (L.) Merrill]

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In the past few years, the area under soybean crop is increasing consistently Marathwada and Vidharbha region of Maharashtra, particularly by replacing cotton crop (http://articles.economic-times.indiatimes. com/2012-10-02/news, http://www. icar. org.in/files/state-spec-ific/ chapter/80). Although, soybean performs very well in these regions, it got heavily infested in *kharif* 2008 by hairy caterpillar (*Amsacta moorei*) due to high plant population in addition to prevailing high humidity consequent upon higher rainfall. The recommended spacing of soybean crop is 45 cm x 5 cm. However, for small seeded popular varieties (NRC 37, MACS 7, MACS 58, Vishwas, Vijay and Vishal) in the region, farmers invariably use high seed rate leading to higher plant density in the recommended spacing. This provides salutary conditions for infestation with defoliators. Hence, to evaluate the optimum plant spacing for two popular varieties of soybean, the present investigation was undertaken.

A field experiment was conducted during *kharif* 2009 at the College of Agriculture, Latur. The soil of experimental plot was deep black (Vertisols) with good drainage. The experiment was laid out in factorial randomized block design with three replications. There were eight treatment combinations with two varieties (JS 335 and MAUS 71) and four spacing (45 cm x 5 cm, 45 cm x 7.5 cm, 45 cm x 10 cm and 45 cm x 12.5 cm). The crop was sown on 01st July, 2009 by hand dibbling. Recommended dose of fertilizers (30:60:30:–N:P_2O_5:K_2O kg/ha) was applied as basal. The seeds were treated with Thirum 80 WP @ 3 g per kg seeds followed by inoculation with cultures of *Bradyrhizobium japonicum* and phosphorus solubilizing bacteria before sowing. The observations on growth / yield attributing characters and yield were taken at harvest stage of crop by randomly selecting five plants per plot. Oil content in soybean seed was estimated

[1,2and 3]*Assistant Professors;* [4]*Head of the Department (Agronomy)* by Nuclear Magnetic Resonance (NMR) instrument at Agriculture Research Station, Raichur (Karnataka). The nitrogen content in seed analyzed by micro-Kjeldhal method (AOAC, 1972) was utilized to work out protein content using factor 5.71 (Sadasivam and Manickam, 1976). Data obtained on various variables were analyzed by analysis of variance method (Panse and Sukhatme, 1967)

Effect of varieties

Evaluated varieties differed non-significantly in respect of growth/yield attributing characters and yield (seed, straw and biological). However, the variety MAUS 71 showed numerically superior values over JS 335 (Table 1 and 2). Although, the two varieties evaluated did not differ significantly in seed yield per plant, seed yield per ha and straw yield per ha, MAUS 71 had a numerical edge over JS 335. MAUS 71 had significantly higher protein (38.04 %) and oil (19.10 %) contents over the JS 335 (Table 2).

Effect of plant densities

Non-significant differences were

Table 1. Growth/yield attributing characters as influenced by varieties and spacing

Treatments	Plant height (cm)	Functional leaves (No/ plant)*	Branches (No/ plant)	Nodules (No/ plant)**	Total dry matter (g/ plant)	Pods (No/ plant)	Seed index (g/100 seeds)
Variety							
JS 335	28.95	15.90	4.45	13.58	17.44	36.21	9.2
MAUS 71	29.23	16.93	4.45	18.16	17.69	37.73	9.6
SEm (±)	0.61	0.86	0.22	2.48	1.00	1.49	0.98
CD (P= 0.05)	**N S**	**N S**	**N S**	**N S**	**N S**	**N S**	**N S**
Spacing							
45 cm x 5.0 cm	29.36	14.70	3.83	10.66	14.21	30.16	9.1
45 cm x 7.5 cm	30.00	15.96	4.26	14.83	17.43	36.50	9.4
45 cm x 10 cm	28.80	17.60	5.06	20.83	19.93	40.76	9.6
45 cm x 12.5 cm	28.20	17.40	4.66	17.16	18.31	40.53	9.5
SEm (±)	0.86	1.22	0.96	2.38	1.41	2.10	1.39
CD (P= 0.05)	**NS**	**NS**	**0.96**	**7.15**	**4.29**	**6.38**	**N.S.**
***Interaction* (V x S)**							
SEm(±)	1.22	1.73	0.45	3.06	2.00	2.98	1.97
CD (P= 0.05)	**N S**	**N S**	**N S**	**N S**	**N S**	**N S**	**N S**

**at 60 Days after sowing; ** at 75 days after sowing*

Table 2. Yield and quality of soybean as influenced by varieties and spacing

Treatments	Seed yield (g/plant)	Seed yield (kg/ ha)	Straw yield (kg/ha)	Harvest index (%)	Oil content (%)	Protein content (%)
Variety						
JS 335	6.08	1103	1774	38.34	18.35	37.06
MAUS 71	6.65	1196	1873	38.97	19.10	38.04
SEm ($\pm$)	0.54	46	49	-	0.09	0.15
CD (P= 0.05)	**N S**	**N S**	**N S**	**-**	**0.21**	**0.24**
Spacing						
45 cm x 5.0 cm	4.70	1092	1695	39.18	18.53	35.78
45 cm x 7.5 cm	5.79	1286	2041	38.64	18.95	36.88
45 cm x 10 cm	8.09	1305	2113	38.18	19.02	38.88
45 cm x 12.5 cm	6.87	916	1444	38.79	19.41	38.66
SEm ($\pm$)	0.76	65	69	---	0.12	0.11
CD (P= 0.05)	**2.31**	**196**	**210**	**---**	**0.29**	**0.24**
Interaction (V x S)						
SEm ($\pm$)	1.08	91	98	---	0.15	0.14
CD (P=0.05)	**N S**	**N S**	**N S**	**---**	**N S**	**N S**

observed between plant height and functional leaves with respect to plant spacing. Planting soybean at 45 cm x 10 cm recorded the maximum number of branches per plant, nodules per plant, pods per plant and total dry matter per plant, which were at par with other spacing except that of 45 cm x 5.0 cm. This might be due to availability of more space and other favorable conditions for crop due to increasing plant spacing. It was reported by Khurana *et al*. (1984) and Patoliya (1988) that number of branches per plant varied from variety to variety and also due to different plant spacing. Hudge *et al*. (1982) and Pople (1986) as well reported that different cultivars differed significantly in total dry matter production. The increase in number of pods and other attributes with increase in spacing can be justified by the enhanced growth and optimum utilization of natural resources like soil moisture, nutrients and solar radiation.

Similar to growth/yield attributes, planting at 45 cm x 10 cm led to highest seed yield per plant, seed yield per ha and straw yield per ha. Seed and straw yields per ha under this spacing was on par with 45 cm x 7.5 cm, but significantly superior over 45 cm x 5.0 cm and 45 cm x 12.5 cm. This indicated that when planting is resorted to dibbling method, higher and lower plant to plant distances are not to be adopted. Better yield contributing characters like branches per plant, pods per plant, seed index and harvest index under 45 cm x 10 cm followed by 45 cm x 7.5 cm might have resulted in higher productivity in these spacing. Khelkar *et al*. (1991) also reported that yield attributes were higher with lower plant densities and the higher seed yield with closer row spacing. These findings are also in confirmation with the findings reported by Deshmukh (1972) and Gupta *et al.* (1973).

The oil and protein contents were also found higher by adopting 45 cm x 10 cm spacing. However protein and oil contents were at par with 45 cm x 12.5 cm and 45 cm x 7.5 cm, respectively, and were significantly superior over other two spacing.

Interaction effect

The interaction effect between varieties and spacing on growth/yield attributes and yield was non-significant.

The results of the study suggest that higher yield and higher protein and oil contents can be achieved by dibbling soybean variety MAUS 71 with 45cm x 10cm spacing.

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Seasonal Incidence of Major Insect-pests of Soybean (*Glycine max* L.) and their Correlation with Weather Parameters

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Key words: Insects, seasonal incidence, soybean, weather parameters

Soybean [*Glycine max* (L.) Merrill] has emerged as one of the major rainy season crops of India covering 10.7 million ha (Anonymous, 2013). Damage due to insect-pests is an important limiting factor in realizing the yield potential of the improved cultivars of soybean. During the crop season insect-pest population always fluctuate as influenced by the abiotic and biotic factors. The knowledge on the seasonal incidence of key insect-pests will certainly be helpful in formulating the management strategies. In central India blue beetle (*Cneorane* sp.), green semilooper (*Chrysodeixis acuta* Walker) and girdle beetle (*Obereopsis brevis* Swedenbord) are amongst the key pests in soybean. The present study was under taken to study the seasonal incidence of the key insect-pests and their relationship with weather parameters.

Field trials were conducted at the research farm of College of Agriculture, Indore (Madhya Pradesh) during the rainy season of the year 2009 in a completely randomized block design with four widely adopted soybean cultivars; JS 335, JS 95-60, JS 93-05, and JS 97-52. The experiment was replicated thrice in 6 m x 3 m plots. Soybean crop was raised with the full package of practices except the application of insecticides. The number of larvae of green semilooper and the adults of blue beetle per one meter row length at three random points per replication were recorded at weekly intervals. In case of girdle beetle, per cent infestation was recorded based on the symptoms of damage. Data pertaining to the weather parameters namely, minimum and maximum temperatures, rainfall and relative humidity were obtained from the Meteorological Observatory at College of Agriculture, Indore. To measure the degree of closeness of the linear relationship between the insect populations and the weather parameters Pearson's correlation coefficient was worked out.

Blue beetle infestation in all the four varieties was observed from11 days after germination (DAG) *i.e.,* in the

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Table 1. Correlation (r) coefficient of insect attack with the climatic parameters

Meteorological parameters	Blue beetle adults/mrl	Defoliators larvae/mrl	Girdle beetle % infestation
Minimum temperature	0.321**	0.154*	0.096 NS
Maximum temperature	-0.597**	-0.448**	0.276**
Relative humidity	0.079 NS	0.098 NS	-0.115 NS
Rainfall	0.086 NS	-0.076 NS	-0.060 NS

***Significant at P = 0.05; *Significant at p = 0.01; NS = Non- significant*

second week of July [28th Standard Meteorological Week (SMW)] (Fig. 1). In the variety JS 335 a higher population of 5.45 beetles per mrl was observed in 29th SMW and in the variety JS 97-52, a higher population was observed in 31st SMW. In the remaining two varieties, JS 93-05 and JS 95-60 there was only one peak in 31st and 32nd SMW, respectively. In all the varieties blue beetle population was low from 35 SMW onwards. Blue beetle population was highest in the cultivar JS 335 (3.42 adults/mrl) followed by JS 95-60 (2.93 adults/mrl), JS 93-05 (2.79 adults/mrl) and JS 97-52 (2.15 adults/mrl).

Population of the blue beetle had a positive and highly significant association with the minimum temperature (0.321) and negative association with the maximum temperature (-0.597). Rainfall and relative humidity showed a non-significant correlation with the blue beetle population (Table 1). Chaturvedi *et al.* (1998) also recorded the appearance of blue beetle in soybean just after the emergence of the cotyledons in the last week of the July with maximum population in the second week of August. Singh (1998) reported severe infestation of blue beetle in Bhopal, Raisen and Sehore districts of Madhya Pradesh with an average population of 3.47 to 4.37 beetles per mrl causing damage to cotyledons and trifoliate leaves. Earlier at Sehore, Madhya Pradesh, Singh and Singh (1989) estimated less than 4 adults per mrl as economic threshold level for blue beetle.

The infestation of green semilooper was observed from second week of July (28th SMW) onwards (Fig. 1) and ranged between 0.70 and 1.32 larvae per mrl. The semilooper population increased gradually reaching the peak in 32nd or 33rd SMW. In 37th SMW, the larval population ceased in the varieties JS 93-05 and JS 95-60. It was found that the varieties JS 335 and JS 97-52 harboured a population of 2.3 and 3.20 larvae per mrl respectively, while at 38th SMW, only JS 97-52 harboured green semilooper (3.12 larvae/mrl). Chaturvedi *et al.* (1998) also reported the activity of green semilooper was up to the 3rd week of September at Sehore. Correlation between the green semilooper population and the minimum temperature (0.154) was positive and significant. On the other hand the semilooper population showed a highly significant negative (-0.448) relationship with the maximum temperature while the relative humidity and rainfall showed a

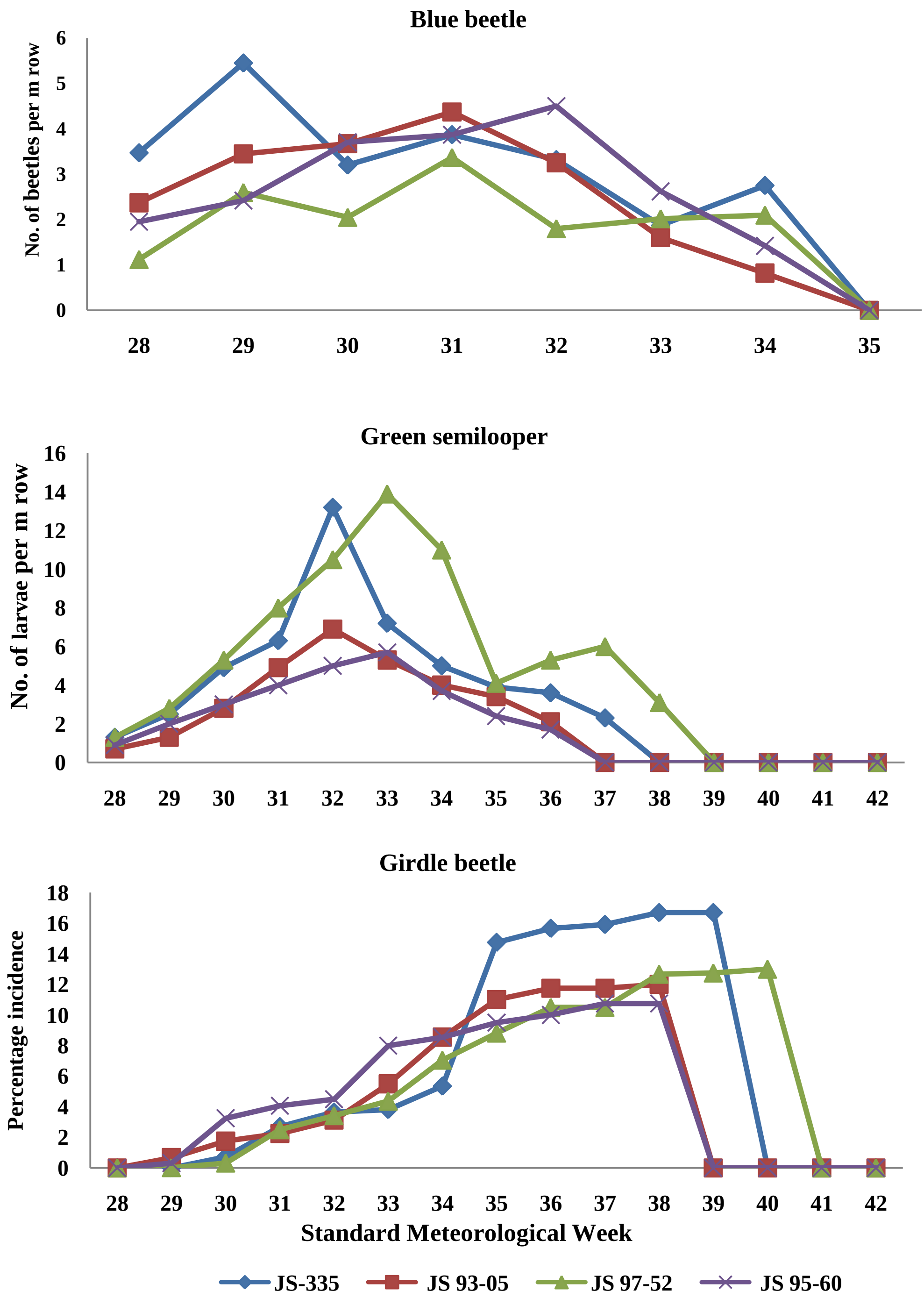

Fig. 1. Seasonal incidence of, blue beetle, green semilooper and girdle beetle in soybean during year 2009 at Indore

non-significant correlation (Table 1).

The infestation of girdle beetle was observed from second week of July (29th SMW) onwards in all the varieties (Fig. 1). Thereafter, the infestation increased gradually and reached up to 16.70 per cent in the variety JS 335, followed by JS 97-52 (13%), JS 93-05 (12%) and JS 95-60 (10.75%) in 39th SMW. Girdle beetle infestation demonstrated a highly positive significant association with the maximum temperature (0.276) and insignificant correlation with minimum temperature, relative humidity and rainfall (Table 1). The plant infestation by girdle beetle has been reported to be 43.10 per cent (Singh and Singh, 1996) and 9.8 per cent (Gupta *et al.,* 2000) in different parts of Madhya Pradesh. Maturity duration of the soybean cultivars and their reaction to insect feeding (resistance or tolerance), weather parameters, and the action of natural enemies play an important role in determining the insect-pest load. Higher incidence of the blue beetle adults during early vegetative phase of the crop is understandable by its preference to tender foliage. Cultivars JS 335 and JS 72-52 supported both the green semiloopers and girdle beetle feeding for longer probably due to their longer maturity period as compared to JS 93-05 and JS 95-60. Population build up of green semilooper between 32nd to 34th SMW is may be due to generation advancement and existence of favourable factors such as growing foliage, congenial temperature and humidity regimes. However, simultaneous increase in density dependent factors namely, larval parasitism and infection by entomopathogenic fungi, *Nomuraea rileyi* in particular, could have resulted in the fall of population its peak level.

The data engendered in the present experiments and aforesaid discussion suggests that to contain the increasing populations of blue beetle and semiloopers, management measures should be undertaken during the 28th-29th SMW in both the short and long duration soybean cultivars. Whereas, in long duration cultivars, one more intervention may be required in 33rd–34th SMW to prevent from the damage by girdle beetle damage and later generations of green semiloopers.

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Efficacy of Different Insecticide Seed Dressers on Early Pest Complex of Soybean

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Soybean was introduced as commercial crop in India in 1970. The area under soybean cultivation in the country has increased from 7.71 (2005) to 10.18 (2011) million hectares and this expansion was mainly observed due to increase in area in Maharashtra, Rajasthan, Tamil Nadu and Andhra Pradesh. In 2011, soybean covered an area of 3.07 million ha in Maharashtra with production of 4.03 million tonnes and productivity of 1,312 kg per ha and occupied second position in India (Anonymous, 2012).

Taware *et al*. (2000) tested efficacy of some insecticides as seed treatment, soil application and spraying at early crop stage against early season insect-pests of soybean. The highest seed yield (3,548 kg/ha) was recorded by foliar spray of chlorpyriphos @ 1.5 kg a.i. per ha at 8-10 days after germination (DAG) followed by thiamethoxam as seed treatment @ 3 g and 5 g per kg and phorate 10 G @ 10 kg per ha as soil application before sowing.

Hence, an investigation on efficacy of different insecticide seed dressers on early pest complex of soybean was conducted during *kharif* 2012 at College Agriculture, Nagpur under randomized block design with eight seed treatments replicated thrice. The treatments were comprised of thiamethoxam 35 FS @ 0.9 and 1.05 g per kg seed, thiamethoxam 25 WG @ 1.33 and1.50 g per kg seed, imidacloprid 70 WS @ 12 g per kg seed, carbosulphon 25 EC @ 6 ml per kg seed, chloropyriphos 20 EC @ 4 ml per kg seed and a untreated control. The test variety was JS 335 raised following standard package of practices.

Observations on population of sucking pests (aphids, jassids, thrips and whitefly) were recorded from 10 days after sowing (DAS) at one week interval from three compound leaves (upper, middle, lower) per five plant from each plot. Numbers of insects (nymphs or adults) were noted early in the morning and cumulative population of sucking pest per leaf per plant was subjected to statistical analysis.

Infestation by leaf miner was

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recorded by counting total number of healthy leaves and infested leaves on randomly selected five plants in each plot and computed as per cent leaves infestation.

Stem fly infestation per meter row length was recorded by counting total number of plants and infested plants from three randomly selected rows in each plot and expressed in per cent.

The data collected during the course of experimentation were subjected to statistical analysis with appropriate transformation for interpretation of results based on randomized block design in order to test level of significance among the various treatments (Gomez and Gomez, 1984).

Cumulative mean of five observations recorded on population of aphids *(Aphis* spp.*)* per leaf after 10 days of sowing at an interval of one week revealed that all the treatments were significantly superior over control. Imidacloprid 70 WS @ 12 g per kg recorded significantly lowest (0.226) aphid population per leaf and was at par with thiamethoxam 25 WG @ 1.50 g per kg (0.279), thiamethoxam 25 WG @ 1.33 g per kg (0.301), thiamethoxam 35 FS @1.05 g per kg (0.319), thiamethoxam35 FS @ 0.9 g per kg (0.341), carbosulfan 25 EC@6 ml per kg (0.417), and chlorpyriphos 20 EC @ 4 ml per kg (0.497), respectively. In comparison, the untreated control treatment showed higher population of aphids (1.323/leaf). From the above results, it was noticed that the seed treatment with insecticides proved better to manage aphid population. The seed treatment with imidacloprid 70 WS @ 12 g per kg was superior to other treatments for the control of aphids. These results are in line with those reported by Vadodariya *et al*. (2001), wherein they found that seed treatment with thiamethoxam and imidacloprid kept the population of aphid below ETL on cotton up to 30, 50 and 60 days after germination. Ganage (2009) also reported that seed treatment with thiamethoxam 35 FS @ 6 g per kg and thiamethoxam 35 FS @ 6 g per kg were superior to all other treatment for the control of aphids.

All the treatments were significantly superior over control in recording of lower population (per leaf) of jassids (*Amrasca bigutulla bigutulla)*. The treatment imidacloprid 70 WS @12 g per kg recorded the lowest population (0.235/leaf) of jassids, which was at par with thiamethoxam 25 WG @1.50 g per kg (0.270/leaf), thiamethoxam 25 WG @ 1.33 g per kg (0.328/leaf), thiamethoxam 35 FS @ 1.05 g per kg (0.377/leaf), thiamethoxam 35 FS @ 0.9 g per kg (0.395/leaf), carbosulfan 25 EC @ 6 ml per kg (0.441/leaf), and chlorpyriphos 20 EC @ 4 ml per kg (0.457/leaf). Highest jassid population per leaf was observed in untreated control (1.359/leaf). These results are in corroboration with the findings of Ahire (2008) and Wadnerkar *et al*. (2004), who reported that thiamethoxam (Taurus 25 WG) @ 150 and 75 was found to be superior over imidacloprid 17.8 SL and dimethoate 30 EC in reducing population of jassids on soybean.

Cumulative population of five observations on population of thrips (*Thrips tabaci)* also showed that all the

Table 1. Effect of different seed dressers on sucking pests on soybean

Treatment	Cumulative mean population of sucking pests					
	Aphids	Jassids	Thrips	White fly	Leaf minor	Stemfly
	(No/leaf)				(No/ plant))	(No/ row)
Thiomethoxam 35 PS @ 0.9 g/kg seed	0.341 (0.916)	0.341 (0.916)	0.341 (0.916)	0.341 (0.916)	0.341 (0.916)	0.341 (0.916)
Thiamethoxam 35 FS @ 1.05 g/kg seed	0.319 (0.903)*	0.319 (0.903)*	0.177 (0.822)	0.368 (0.931)	15.93 (23.58)	7.01 (15.35)
Thiamethoxam 25 WG@ 1.33 g/kg seed	0.301 (0.894)	0.328 (0.909)	0.154 (0.808)	0.314 (0.902)	13.23 (21.33)	6.85 (14.94)
Thiamethoxam 25 WG @ 1.50 g/kg seed	0.279 (0.852)	0.270 (0.877)	0.111 (0.781)	0.283 (0.884)	09.26 (17.72)	6.33 (14.57)
Imidacloprid 70 WS@ 12 g/kg seed	0.226 (0.851)	0.235 (0.857)	0.088 (0.766)	0.252 (0.867)	05.26 (13.26)	5.26 (13.26)
Carbosulfan 25 EC @ 6 ml/kg seed	0.417 (0.957)	0.417 (0.956)	0.286 (0.886)	0.404 (0.950)	22.60 (28.38)	8.23 (16.67)
Chlorpyriphos 20 EC@ 4 ml/kg seed	0.497 (0.998)	0.490 (0.994)	0.305 (0.890)	0.448 (0.973)	24.80 (29.86)	8.43 (16.88)
Untreated control	1.323 (1.350)	1.359 (1.362)	1.323 (1.350)	1.399 (1.378)	26.60 (31.04)	10.03 (18.46)
SEm (±)	0.132	0.142	0.106	0.147	0.992	1.492
C D (P = 0.05)	**0.377**	**0.445**	**0.322**	**0.467**	**0.467**	**4.521**

Figures in parentheses are square root and arc sin transformed values.

treatments were significantly superior over control in recording of lower population of thrips over untreated control. The treatment imidacloprid 70 WS @12 g per kg was significantly superior in recording of lowest population of thrips (0.088/leaf) and was at par with seed treatment with thiamethoxam 25 WG @ 1.50 g per kg (0.111/leaf), thiamethoxam 25 WG @ 1.33 g per kg (0.154/leaf), thiamethoxm 35 FS @ 1.05 g per kg (0.177/leaf), thiamethoxam 35 FS @ 0.9 g per kg (0.274/leaf), carbosulfan 25 EC @ 6 ml per kg (0.286/leaf), and chlorpyriphos 20 EC @ 4 ml per kg (0.305/leaf). Highest thrips population per leaf was observed in untreated control (1.323/leaf). Wadnerkar *et al*. (2004) observed that seed treatment of soybean with thiamethoxam (Taurus 25 WG) @ 150 and 75 g a.i were found to be superior over imidacloprid 17.8 SL and dimethoate 30 EC in reducing thrips population. Similar results are also reported by Ahire (2008) and Ganage (2009) who found that all the seed treatments (thiamethoxam 35 FS and thiamethoxam 70 WS @ 6 g kg, 2g /kg seed each) and imidacloprid 70 WS@ 12 g per kg were found significantly superior over control in reducing of thrips population.

Observation recorded on white fly *(Bemicia tabaci)* population brought out that all the treatments differed non-significantly from each other and from untreated control. But, the seed treated with imidacloprid 70 WS @12 g per kg showed numerically lowest population. Other studies (Virkar, 2004; Wadnerkar *et al.,* 2004) showed that seed treatment with thiamethoxam 25 WG was most effective treatment than others including control in reducing white fly population on soybean.

Per cent leaves infestation of leaf miner *(Biolobata subseciviella)* revealed that the seed treatment with imidacloprid 70 WS @ 12 g per kg was highly significant in recording lowest infestation (5.26 % leaf infection/per plant). The efficacy of other treatments in order was, thiamethoxam 25 WG @ 1.50 g per kg seed (9.26 % leaf infection/plant), thiamethoxam 25 WG @ 1.33 g per kg seed (13.23 % leaf infection/ plant), thiamethoxam 35 FS @ 1.05 g per kg (15.93 % leaf infection/plant), thiamethoxam 35 FS @ 0.9 g per kg (19.50 % leaf infection/plant), carbosulfan 25 EC @ 6 ml per kg (22.60 % leaf infection/plant) and chlorpyriphos 20 EC @ 4 ml per kg (24.80 % leaf infection/plant). Highest per cent leaves infestation was noticed in untreated control (26.60 % leaf infection/plant). Seed treatment with thiamethoxam 25 WG was also found effective in reducing the infection of leaf minor by other workers (Virkar, 2004; Ahire, 2008; Ganage, 2009).

Cumulative mean per cent plant infestation by stem fly (*Melanagromyza sojae*) also showed that all the seed treatment chemicals were superior in reducing the inflection over control. The treatment imidacloprid 70 WS @ 12 g per kg seed was significantly superior to all the treatment and recorded lowest (5.26 % plant infestation per row length) and was at par with thiamethoxam 25 WG @ 1.50 g per kg (6.33 %) followed by thiamethoxam 25 WG @ 1.33 g per kg recorded (6.85 %), thiamethoxam 35 FS @ 1.05 g per kg (7.01 %), thiamethoxam 35 FS @ 0.9 g per kg (7.12%), which were on par with each other, but were significantly superior to carbosulfan 25 EC @ 6 ml per kg (8.23%), and chlorpyriphos 20 EC @ 4 ml per kg (08.43 %. The highest per cent plant infestation due to stemfly was recorded in untreated control plots (10.03 %). The results of present investigation indicated that seed dressers showed significant effect in reducing stem fly infestation particularly imidacloprid and thiomethoxam and gets support from earlier work (Singh *et al*., 2000; Solunke *et al*., 2004).

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Microwave Drying Kinetics of Okara

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Okara is the by-product of soymilk manufacture. After soymilk extraction, quite a lot of valuable nutrients remain in okara, which can be used for various value added food products. Okara has a nut-like taste and exhibits low solubility in water (Prestamo *et al.*, 2007). Nutritionally okara contains approximately 29 per cent protein, 11 per cent fat and 60 per cent dietary fibre on dry weight basis (Wachiraphansakul and Devahastin, 2005). Okara produced just after extraction of soymilk contains around 75-80 per cent moisture. The need for application of further processing/ preservation techniques is indispensable to maintain its quality. Among the several methods to lower water activity, drying is one of the most commonly adopted methods for extending the shelf life of food and food products. Conventional methods of drying such as sun drying and cabinet drying have shown to result in problems of colour discoloration, loss in nutritive value and those associated with long drying time (Moses *et al.*, 2013). Microwave drying of foods is an innovative approach, highly dependent on the dielectric properties of food. It is known to reduce drying time, thereby permitting minimal effect on product quality. The multiple benefits offered also include, good process control (Duan *et al.*, 2010), better product quality (Arslan and Musa-Özcan, 2010), lower energy consumption (Raghavan *et al.*, 2010) and higher energy efficiency (Li *et al.*, 2011). The technique is commercially widespread and research has justified its use in various agricultural commodities (Mollekopf *et al.*, 2011).

There has been a good record of work done in the development of models pertaining to drying of several agricultural commodities including; bamboo shoots (Bal *et al.*, 2010), spinach (Dadali *et al.*, 2008), sweet potatoes (Doymaz, 2011), soybeans (Gowen *et al.*, 2008) and nuts (Moreira *et al.*, 2005). These relationships can be successfully used in explaining drying kinetics under varying conditions. However, microwave drying

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kinetics of okara has not been reported to date. Hence, the objective of this study was to study the drying kinetics of okara for varying microwave output power levels.

Okara manufacture

Two kg of soybean grains purchased from the local market (Madurai, India) were soaked in water (1: 3) for 6 h prior to soymilk extraction using soymilk plant (Model: SC-20, Pristine Plants India Pvt. Ltd.) was used for soymilk extraction. Resulting slurry removed from the grinder/cooker through a butterfly valve affixed at the bottom of the vessel was filtered in mechanical filter press to obtain the residue (okara). About 11.5 l of soymilk and 1.75 kg of okara was obtained.

Microwave drying of okara

Microwave drying experiment was performed in a domestic microwave oven IFB, Model: 30SC3 (Table 1) consisting of a magnetron that generates microwave energy, a wave guide to carry this energy to the oven cavity and, a wave stirrer to ensure exposure uniformity. All experiments were commenced with 50 g sample spread uniformly over a dish. The samples were exposed for varying time intervals as required for five power levels ranging from 180 W – 900 W. All experiments were replicated thrice.

Drying kinetics

The initial and final moisture contents of sample were determined using standard AOAC procedures (AOAC, 1995) and were noted as change in grain mass with respect to drying time. Moisture content of okara (kg water / kg dry matter) was determined using eq. 1.

Table 1. Microwave drying experimental set-up technical specifications

Capacity	30 L
Power source	230 V – 50 Hz
Microwave output power	900 W
Microwave frequency	2450 MHz
Cavity	Stainless Steel
Outer dimension	300 x 539 x 438 mm

$$M = \frac{(W_o - W) - W_i}{W_i} \qquad [1]$$

Where, 'M' is moisture content of okara (kg water/ kg dry matter), 'W_o' is initial weight of sample, 'W' is amount of water removed, 'W_i' is dry matter present in sample. Drying rate (R) was calculated using eq. 2.

$$R = \frac{M_t - M_{t+dt}}{dt} \qquad [2]$$

Where, 'M_t' is moisture content at any time't' and 'M_{t+dt}' is the moisture content at time't+dt'. Dimensionless moisture ratio (MR) was calculated using Eq. 3.

$$MR = \frac{(M_t - M_e)}{(M_o - M_e)} \qquad [3]$$

where 'M_t' is moisture content of okara at specified time (kg water/ kg dry matter), 'M_o' is initial moisture content and 'M_e' is EMC (Equilibrium Moisture Content) of okara. Dried okara appeared light-brown in colour.

Validation of models with microwave drying data

Curve fitting (MR *vs* time) of microwave drying was performed using six different empirical models (Table 2). Non-linear least squares regression analysis was conducted using MATLAB version 2010*b*. Non-linear regression was based on Levenberg–Marquardt algorithm (Marquardt, 1963). Variation of drying constant and coefficients in these models with varying power levels were described by several empirical models. The term '*k*' in these models denotes drying rate constant (s^{-1}) and is of particular interest in microwave drying.

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N}\left(MR_{e,i} - MR_{p,i}\right)^2\right]^{0.5} \quad [4]$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{e,i} - MR_{p,i}\right)^2}{N-n} \quad [5]$$

$$RSS = \sum_{i=1}^{N}\left(MR_{e,i} - MR_{p,i}\right)^2 \quad [6]$$

$$R^2 = \frac{RSS}{TSS} \quad [7]$$

where, '$MR_{e,i}$' is experimental moisture ratio, '$MR_{p,i}$' is predicted moisture ratio, 'N' is number of experimental data points, 'n' is number of parameters and 'TSS' is total sum of squares. Model giving minimum $RMSE$, RSS and highest regression coefficient (R^2) value was considered to offer the best fit indicating that the model is able to aptly represent experimental data.

A model is acceptable when statistical parameters that denote the relationships between experimental and predicted values lie within acceptable limits (Noomhorm and Verma, 1986). Hence, statistical analysis was performed to check validity of these empirical models. Goodness of dring model fit to represent the drying kinetics were analysed using root mean square error (RMSE, eq. 4), Chi-square value (χ^2, eq. 5), residual sum of squares (RSS, eq. 6) and coefficient of determination (R^2, eq. 7) values. Use of above statistical techniques has been employed to justify goodness of fit for drying kinetics model (Karim and Hawlader, 2005). These parameters can be used to evaluate the experimental results for selecting the best fit equation to describe microwave drying curves of soybean okara.

Table 2. Mathematical models used for validating the drying data

Model	Name	Equation	References
1	Newton	$MR = exp(-k.t)$	O' Callaghan *et al.* (1971)
2	Logarithmic	$MR = (a.\exp(-k.t)) + c$	Yagcioglu *et al.* (1999)
3	Page	$MR = exp(-k.t^n)$	Page (1949)
4	Wang and Singh	$MR = 1 + (a.t) + (b.t^2)$	Wang and Singh (1978)
5	Henderson and Pabis	$MR = a.exp(-k.t)$	Henderson and Pabis (1961)
6	Midilli *et al.*	$MR = a.exp(-k.t^n) + b.t$	Midilli *et al.* (2002)

Note: k, n, a, b and c are model constants

Moisture loss with time

Okara obtained as a by-product of soymilk extraction contained 76.45 per cent moisture (*w.b.*). This in turn results in rapid heating of the sample by microwave energy (Pereira *et al.*, 2007). Further, on contact with microwave energy, the pore size is reported to increase; with higher driving forces; thereby resulting in increased mass transfer rate (Mudgett, 1989). During microwave drying process, the moisture content of okara was found to decrease with increase in power input and drying time (Fig. 1). Similar decrease in drying time was reported during microwave drying of peeled longan (Varith *et al.*, 2007) and wild cabbage (Yanyang *et al.*, 2004). In all cases, drying process terminated when product moisture was between 17-18 per cent (being the equilibrium moisture content). Drying time varied from 23 min at 900 W power levels to around 80 min at 180 W. Shorter drying times offered would ensure that the product undergoes minimal quality losses (Mousa and Farid, 2002).

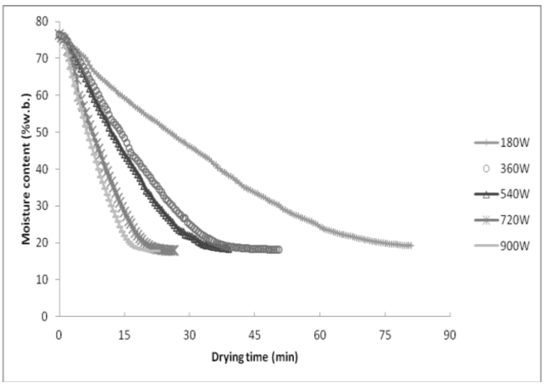

Fig. 1. Change in moisture content during microwave drying of okara

The drying rate was also found to decrease continuously asdrying proceeded (Fig. 2) and its values were comparatively higher at 900 W than 180 W, especially in the initial stages of drying. Persistent fluctuations in the drying rates observed during drying of okara (Fig 2) may be attributed to the non-uniform heating mechanism of microwave energy and the dielectric properties of okara. This has been explained by the differences seen when spouted bed drying was employed during drying of okara (Coronel and Tobinaga, 2004).

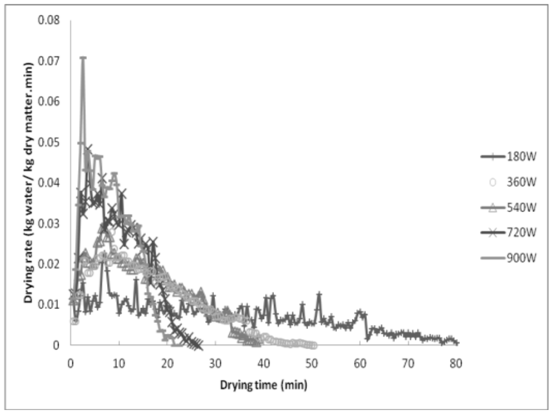

Fig. 2. Change in drying rate during microwave drying of okara

Absence of a prolonged constant rate period can be because of the inability of the product to provide a constant supply of water for a significant period of time because of quick thin layer drying of the product at early phase of drying (Lahsasni *et al.*, 2004).

Modeling of drying curves

Significant decrease in moisture ratio was observed in all the levels with increasing drying time (Fig. 3).

Table 3. Model parameters and statistical parameters of various drying models studied

Model	Power (W)	Model parameters				Statistical parameters			
		a	*b*	*k*	*n*	R^2	*RMSE*	χ^2	*RSS*
Wang and Singh (1978)	180	- 0.02141	0.000108	-	-				
	360	- 0.03999	0.000388	-	-	0.9889	0.03484	0.0030021	0.098410
	540	- 0.04458	0.000459	-	-	0.9919	0.02932	0.0018143	0.052286
	720	- 0.07184	0.001232	-	-	0.9907	0.03230	0.0028765	0.052694
	900	- 0.08544	0.001744	-	-	0.9896	0.03428	0.0029996	0.046413
Midilli *et al.* (2002)	180	0.9788	- 0.001606	0.01006	1.234	0.9976	0.01494	0.0004481	0.027109
	360	0.9842	- 0.000656	0.00891	1.580	0.9964	0.01982	0.0004420	0.014899
	540	0.9888	- 0.001577	0.01421	1.476	0.9974	0.01682	0.0002316	0.006802
	720	1.0010	- 0.001897	0.02854	1.484	0.9974	0.01719	0.0006724	0.012649
	900	0.9926	- 0.001987	0.03269	1.537	0.9968	0.01913	0.0005969	0.009482

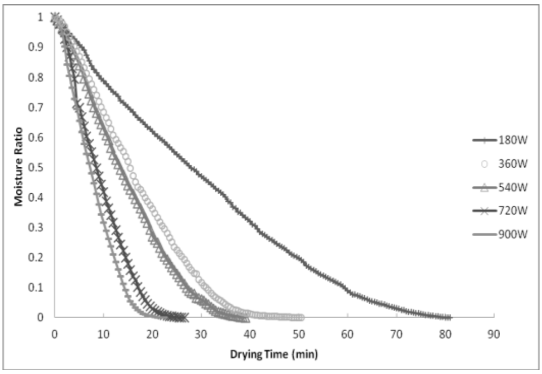

Fig. 3. Change in moisture ratio with respect to time during microwave drying of okara

There was a significant increase in drying rate constant with an increase in power level. Similar trends were reported in other studies involving micro-wave drying of carrots (Prakash *et al*., 2004) and okra (Dadali *et al*, 2008). Six different models were employed to describe the drying data (Table 2). Table 3 shows the statistical analysis parameters of Midilli *et al.* (2002) and Wang and Singh (1978) models, the ones that showed good agreement to the experimental values and fitted best to the drying curves with high regression coefficient (R^2 > 0.99 and 0.98 respectively) and low root mean square error values (*RMSE* < 0.01 and 0.03 respectively) compared to other models. Thus, the Midilli *et al.* model can be considered to represent the microwave drying kinetics of okara.

Results indicate that with an increase in microwave power from 180 W to 900 W, the drying time for okara reduced from 80 to 23 minutes. Among the models evaluated, the Midilli model followed by Wang and Singh were found to best represent the microwave drying kinetics of soybean okara.

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Ansari M M and Gupta G K. 1999. Epidemiological studies of foliar diseases of soybean in Malwa plateau of India. Proceedings, World Soybean Research Conference VI, Aug 4-7, 1999, Chicago, Illinois, USA, 611p. **(Symposium/ Conf./Workshop)**

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