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Vegetable Soybean: A Crop with Immense Potential to Improve Human Nutrition and Diversify Cropping Systems In Eastern India- A Review

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ABSTRACT

Vegetable soybean was introduced into Jharkhand state in India to provide local communities with an alternative protein source as well as to diversify the cropping system. The paper covers the introduction of the crop, testing of different lines in farmers' fields, a taste survey, the release of a vegetable soybean cultivar and its popularization, and seed production by the community. The acceptance of the crop by the local community has led to seed production of the cultivar 'Swarna Vasundhara' by farmers. A major challenge is to expand beyond household level consumption and local Jharkhand markets to create awareness among other consumers and establish a larger market throughout India for the crop. Infrastructure such as cold storage facilities will be required to support a viable value chain for vegetable soybean. The good progress made in Jharkhand has given greater hope of expanding vegetable soybean production and consumption across India, particularly in the major grain soybean growing states.

Keywords: Cropping system, legume, nutrition, vegetable soybean

Jharkhand is located in the eastern plateau and hill region of India (agro-climatic zone VII). In its population of 33 million people, about one-quarter (26.3 %) are tribal (http://www.census2011.co.in/census/state/jharkhand.html.). About 76 per cent of the population resides in rural areas (30 % of the tribal population) and more than 80 per cent of the total labor force depends on agriculture (http://rkvy.nic.in/sap/jh.pdf). About 90 per cent of the 795,000 ha of cropped area is used to produce food grains under rain-fed conditions. About 80 per cent of this area remains under mono-cropped rice. Cash crops account for only 4-6 per cent of production. The majority (83 %) of the land holdings belongs to small - scale and marginal farmers and most agriculture is for subsistence. Jharkhand has an average yearly rainfall of 1300-1400 mm and 80 per cent of this is received during the four monsoon months of June to September with dry periods in between. Assured irrigation is available to only 8-9 per cent of the

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cropping area during the *kharif* (monsoon season), 6 per cent during the *rabi* (winter/spring season) and 1-2 per cent during the summer season (Jharkhand Economic Survey, 2012).

According to the National Family Health Survey (NFSH-III, 2006), about half of the children (47.2 %) under three years in Jharkhand are stunted—an indication of undernourishment. One-third (35.8 %) of children are too thin for their height, which may result from inadequate recent food intake or a recent illness (NFHS-III, 2006). Anaemia is found in over 70 per cent of individuals in Jharkhand. About two in five adults (43 % of women and 39 % of men) in Jharkhand are underweight. Under-nutrition is particularly prevalent in rural areas and in the lower wealth quintiles (NFHS- III, 2009). The prevalence of anaemia among adults in Jharkhand is higher than in almost all other states in India. Seventy per cent of women in Jharkhand have anaemia, including 50 per cent with mild anaemia, 19 per cent with moderate anaemia, and 1 per cent with severe anaemia (NFHS-III, 2009).

The crops under cultivation in Jharkhand are dominated by cereals such as paddy rice in lowlands and medium uplands, and vegetable legumes such as green pea (*Pisum sativum)*, chickpea (*Cicer arietinum)*, pigeon pea (*Cajanus cajan)*, cowpea (*Vigna ungiculata),* French bean (*Phaseolus vulgaris*), and Dolichos bean (*Lablab purpureus*). Most of these legumes are available during the *rabi* season only. Diversifying the cropping system with a suitable crop that requires less water due to unexpected dry periods during the *kharif* season under rain-fed conditions would provide economic as well as nutritional benefits. To fulfill this role, vegetable soybean—a special type of soybean for fresh consumption—was introduced into the region. Vegetable soybean is an alternative legume crop that fits into existing cropping systems. Local communities in the target areas (Ranchi and Khunti districts) know about grain soybean, but never have cultivated it. Vegetable soybean production is similar to that of traditional grain soybean, although different planting techniques and equipment are needed to accommodate the larger seed (Ernst, 2001).

Rationale for introduction of vegetable soybean in upland and medium uplands of Jharkhand

The seeds of vegetable soybean are larger (> 30g/100 seeds dry weight), sweeter and more tender than grain soybean (Shanmugasundaram and Yan, 2010). Fresh vegetable soybean is delicious and nutritious, and is an excellent source of protein (35 % to 38 % protein, dry weight basis) which can help alleviate protein malnutrition in Jharkhand, particularly among children. Proximate analysis of seed nutritional composition of vegetable soybean in Colorado, USA (Johnson *et al.,* 1999), and Japan (Masuda, 1991) indicated that the nutritional content of vegetable soybean is superior (Table 1) to that of green peas (Carter and Shanmugasundaram, 1993), which are commonly consumed in Jharkhand. Soybean also has potential for cancer

Table 1. Nutrient composition (values per 100 g) of vegetable soybean compared to other legume crops in Jharkhand

Nutrient composition	Vegetable soybean		Vegetable pigeon pea		Green pea	
	Raw	Cooked	Raw	Cooked	Raw	Cooked
Energy (kcal)	147a	141	136	111	81	84
Moisture (g)	67.5	68.8	65.9	71.8	78.9	77.9
Protein (g)	12.9	12.4	7.2	5.9	5.4	5.4
Fat (g)	6.8	6.4	1.6	1.4	0.4	0.2
Total carbohydrate (g)	11	11	23.9	19.5	14.4	15.6
Crude fiber (g)	4.2	4.2	5.1	6.2	5.1	5.5
Ash (g)	1.7	1.6	1.4	1.4	0.8	0.9
P (mg)	194	158	127	118	108	117
Ca (mg)	197	145	42	41	25	27
Fe (mg)	3.5	2.5	1.6	1.6	1.5	1.5
Vitamin A (mg RAE)	9	8	3	2	38	40
Vitamin B_1 (mg)	0.4	0.2	0.4	0.3	0.2	0.2
Vitamin B_2 (mg)	0.17	0.15	0.17	0.16	0.13	0.15
Vitamin C (mg)	29	17	39	28	40	14
Vitamin E (mg)	(1476)[b]	–	0.39	0.32	0.13	0.14
Folate (mg)	165	111	173	100	65	63
Isoflavones (mg)	20.4[a]	13.8	–	–	–	–

[a]*Value of Isoflavonesobtained from United States Department of Agriculture (USDA)-Iowa State University Database on the Isoflavone Content of Foods (1999); Other value obtained from USDA National Nutrient Database for Standard Reference, Release 24(2011); - data not available in USDA database;* [b]*Value in parenthesis is total tocopherol content (µg/g lipid) at 40 days after flowering (Masuda,1991)*
Source: Shanmugasundaramet al. (2015)

prevention and suppression owing to its high isoflavone content (Kucuk, 2004; Messina, 2004).

Crop diversification utilizing a new crop option such as vegetable soybean is driven by following several factors that motivate famers (Connor, 2001).

Low conventional crop prices: On the uplands and medium uplands, yield of conventional crops such as broadcasted rice, oilseeds, and other pulses is very low; cultivation is only for subsistence farming and not for profit. Therefore, any higher-yielding crop that also can be consumed at home would be an attractive replacement or addition to the cropping system. The overall goal of crop diversification is to increase food availability and farm profitability.

Environmental protection: The inclusion of nitrogen-fixing legumes in cropping systems can reduce the need to apply inorganic fertilizers for vegetable soybean, as well as provide benefits to the succeeding crop on the same land.

Biodiversity: As the number of crops increases, the enhanced biodiversity can reduce pest and diseases problems, as well as create new opportunities for innovative crop management through extended crop rotations.

Development of new production systems: Vegetable soybean fits well into crop rotations or other cropping systems, such as intercropping with cereals. In South and Southeast Asia, legumes are commonly included in cereal-based cropping systems. For example, soybean is cultivated in a rice-based cropping system or on bunds and dikes in lowland rice fields (Shanmugasundaram and Yan, 2010).

Due to its nutritional value, vegetable soybean can contribute to reducing malnutrition. Vegetable soybean can be consumed as a highly nutritious vegetable or grain and is well suited to smallholder production under adverse climatic conditions (Keatinge *et al.,* 2011).

Vegetable soybean is harvested during October, which coincides with festivals in the eastern part of India. During this time vegetable prices are high, and there are few other legume vegetables such as green peas or chickpea available. Farmers are attracted to vegetable soybean because of the potential local market at that time of the year. Because vegetable soybean is harvested when green, growers also can avoid many of the late-season problems that occur with grain soybeans (Ernst, 2001).

Vegetable soybean can yield up to 10 t per ha of high value seed. The crop adds value to the soil by fixing atmospheric nitrogen, boosting the yield of following cereals, and providing up to 30 t per ha of highly nutritious stover or green manure (Shanmugsundaram and Yan, 1999).

Testing vegetable soybean

During the late 1990s vegetable soybean lines were imported from the World Vegetable Center's gene bank by the Research Center of the Indian Council of Agricultural Research (ICAR-RC) at Ranchi. The lines were evaluated for adaptability and time of sowing and it was found that vegetable soybean sown during the *kharif* season provided a good yield with high biomass production similar to grain soybean (Pan *et al.,* 2015). Following this, experiments were conducted during the *kharif* seasons (June to September) in2000, 2001 and 2002 at ICAR-RC, Ranchi. Stability parameters, *viz.* regression coefficient (bi) and mean square deviations (S^2di) from linear regression along with *per-se* performance of 11 lines of vegetable soybean for 11 yield-related characters were studied. Line EC 384907 (15 t/ha) performed the best for graded (2-seeded, 3-seeded) green pod yield and was stable across diverse environmental conditions. EC 384905 was the most stable and suitable for favorable environments for graded green pod yield (14.2 t/ha),

100-green seed weight (49.9 g) and shelling percentage (56.3 %). Also, the line was very promising for early flowering (36 days after sowing) and early maturity (73 days) and responsive in unfavorable environments (Pan *et al.*, 2007). Based on the evaluations, the elite line EC 384907 was recommended for release and cultivation in Jharkhand and Bihar states of India in the *kharif* season and was released in 2008 by the Central Variety Release Committee (CVRC) of the Government of India as "Swarna Vasundhara" (http://smis.dacnet.nic.in/(S(kxrrlhsi3lzvj0xr4011kjy2))/report/ssrsVarietyDetail.aspx?varietycd=A041009).
'Swarna Vasundhara' is distinguished by a bushy growth habit, producing 1-, 2- or 3-seeded bright green pods with grey pubescence and 50-55 per cent recovery of shelled bright green seeds. The variety showed resistance to rust and was least affected by pod borer infestation with an average yield of 15 t per ha.

Taking it to farmers

Although 'Swarna Vasundhara' performed well, as a new crop it was not yet popular with farmers. In 2008, the Sir Ratan Tata Trust sponsored a project; "Improving Vegetable Production and Consumption for Sustainable Rural Livelihoods in Jharkhand" led by World Vegetable Center in Jharkhand and implemented through the trust's non-governmental organization (NGO) CInI (Collectives for Integrated Livelihood Initiatives). The project popularized this new crop across the region, especially in the tribal areas of Ranchi and Khunti districts.

Because these communities already were consuming fresh legumes (green pea, chickpea, cowpea, and French beans) and had developed a taste for these vegetables, it was anticipated that vegetable soybean would not face any difficulty in acceptance. In 2008, the local NGO Indian Grameen Services (IGS) was convinced of the economic and nutritional potential of vegetable soybean. After discussions the seed of 'Swarna Vasundhara' was distributed to the farmers in the Oraontribein villages in the Karra block of Khunti district for sowing in the *kharif* season. Training was provided on a package of practicesWith discussions on yield, income and nutritional potential, and using vegetable soybean as an alternative crop to green pea. The farmers (60) sowed the seeds in ridges to avoid water logging and seedling death during heavy rain in the rain-fed uplands. The crops germinated well, started flowering after 40 days, podded after 60 days and were ready for harvest in 70-75 days. About 80 per cent of the farmers who followed the proper package of practices (particularly ridge sowing, weeding, and earthing-up with a top dressing of fertilizer) were able to get a good crop. The farmers had not yet started harvesting and consuming the cooked fresh pods when a field day was organized in late September at the ICAR Research Center in Ranchi. These 60 farmers along with new farmers were invited to join in discussions about the crop and its benefits. Cooked vegetable soybean was served during lunch and recipes were demonstrated. The farmers appreciated the taste and women farmers in particular compared it to green peas. After this field day, awareness among the farmers increased and they started harvesting green pods and consuming vegetable soybean either boiled or prepared with other vegetables such as potato. The children liked it very much and their mothers were happy to serve it to them for its nutritional benefits. The farmers started saving the mature seeds for sowing in the next *kharif* season. Seed demand was also raised by other stakeholders, NGOs, and farmers after the field day.

In 2009, the demand for seed grew, but the seeds were distributed to only 470 farmers as seed availability was limited at the ICAR research center, which was the only source of seed. The year had dry spells during the monsoon, which was detrimental for most crops, particularly paddy rice, which occupies 80 per cent of the land. Farmers were unable to transplant their paddy rice and vegetables. In this erratic monsoon season, the vegetable soybean crop performed very well with good yields even in marginal soils. Soybean plants gave up to 120 pods with more than 230 seeds.

Due to a price rise in agricultural commodities, especially pulses, farmers were forced to leave their crops to mature to produce dry soybeans. At the same time, due to a lack of other vegetables, farmers harvested 10-20 per cent of the fresh green pods in their crops (Fig. 1). After the season, farmers used the dry grains to prepare *dhal* (a legume stew commonly made with other pulses like black gram and mung bean) and also kept seed for sowing in the following year. Field days were also organized in the villages. This helped to create awareness and promote vegetable soybean in neighboring villages and made it easy to introduce the crop. Farmers accepted this new vegetable soybean variety for growing as a rain- fed *kharif* crop in the uplands of eastern India. The shelled fresh green beans were found to have a good taste when cooked as a vegetable alone or in combination with other vegetables such as potato (Pan *et al.,* 2010). Farmers tried various recipes and integrated it with their normal food preparation habits, such as using oil-fried soybean mixed with vegetables.

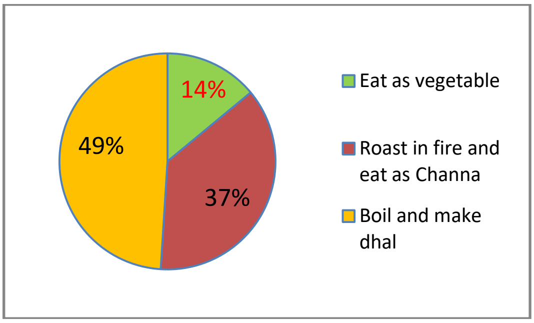

Fig. 1. Method of consumption (in %) of vegetable soybean in Jharkhand (Channa is Chickpea in Hindi)

In 2010, the seed demand from farmers greatly outstripped available supplies. The self-pollinated nature of the crop and the fact that the farmers didn't grow any other grain soybean made seed production easy in farmers' fields.

Training was provided through NGO partners in seed production and storage. Farmers started saving seeds for their sowing, and also shared seed with their fellow farmers and neighboring villages. There was no major pest or disease outbreak observed in this crop apart from a few polyphagous leaf-eating caterpillars and minor viral diseases of pulses. Now the farmers were familiar with the vegetable soybean and they named it "*sabji soya been,*" which means" vegetable soybean". In 2011, more than 20 per cent of the farmers planted their crops using their own seeds.

Sustainability

Farmers started selling the harvested fresh pods in the local market and were able to get INR 20-30 per kg of fresh pods. Although vegetable soybean was well accepted by farmers, seed supply was a major constraint to production. To counter this problem, farmers received training in seed production and saving seeds. Local NGO partner KGVK, which had its own farm, started producing seed and selling it to farmers. To avoid the problem of relying on one released variety, ICAR obtained more lines from the World Vegetable Center and on evaluation found a few promising new lines, some had a basmati flavor.

In the fifth year (2012), after introduction of the crop, a cluster approach was initiated to improve the sustainability of the seed supply. Extension materials and four kilograms of vegetable soybean seed were distributed to each participating farmer to cultivate on 400 m^2 of land. Farmers agreed to follow the package of practices recommended by the World Vegetable Center and to provide back eight kilograms of seed to a farmers' cooperative so that this seed could be used to promote the crop in new areas. Market days were organized in the villages to create awareness among consumers about vegetable soybean, stimulate demand, and test the acceptability of recipes.

Women from the Self Help Group of Iti village prepared a delicious vegetable soybean recipe with tomato, potato and other spices with the aim of promoting it in the market. About 350 consumers tasted the recipe and responses from 39 were taken. All of the respondents accepted the soybean recipe and rated it 4.97 out of a possible 5.00 in terms of taste. More than half of the respondents were excited after tasting the recipe and interested to see the whole crop plants that were on display. The recipe is being used successfully in other villages where vegetable soybean has been promoted. The farmers from Iti village duly deposited their seed with the farmer's cooperative at the end of the season and this seed was then distributed to new villages. Some also sold excess seed to other interested famers, but were still not able to meet the growing demand for the crop.

Opportunities

Vegetable soybean fits in with local farming systems, is liked by consumers, and accepted in local diets. There is great potential for expansion of this crop in Jharkhand as well as entire East Indian plateau with a similar kind of environment and dominated by tribal communities.

Apart from these benefits, the crop residues also improve soil nutritional status. The incorporation of vegetable soybean biomass increased soil nitrogen by 129 kg per ha, potassium by 21 kg per ha and organic carbon by 0.09 per cent (Ravishankar *et al.,* 2015).

There is an opportunity to create value-added products from vegetable soybean similar to the traditional roasted *mung dhal*. The ICAR research center has started working in this area. Dried vegetable soybean is a popular international snack food, and its quality has received considerable attention from processors and consumers (Huang *et al.*, 2014).

Exporting frozen cooked vegetable soybean is possible if production quantities could be substantially increased. Vegetable soybean, or *edamame*, is a popular traditional snack food in Japan, the world's largest importer of the crop. However, good market prices depend on freshness and quality to meet the high standards of the Japanese market (Takahashi and Ohyama, 2011). Owing to its nutritional benefits the crop is also gaining popularity in Europe and the USA.

Challenges

Seed production and supply is a major challenge for the expansion of vegetable soybean. The current seed cost is about INR 150 per kg, which deters new farmers to take up this crop as it is too expensive compared to other pulses. Germination rates rapidly decline as seed ages, so enhancing the germination rate as well as increasing resistance to soil-borne pathogens would help improve crop establishment. Ensuring proper storage of seeds is also critical to maintain good germination rates. Greater awareness is needed among consumers to establish a market for this crop beyond household-level consumption and local Village markets. To ensure a year-round supply, local cold storage facilities must be established to store fresh pods for distribution based on market demand. Consumers should be made aware of the health benefits of consuming vegetable soybean. There is also a need to convince policy makers to promote this crop as part of programs to address malnutrition.

Potential expansion in other states in India

With the suitability of the soils in these regions for soybean cultivation and farmers' familiarity with the crop, there is enormous potential for the expansion of vegetable soybean in India. Field trials of 16 lines of vegetable soybean were conducted in Hyderabad and Jharkhand in 2012. A combined analysis of variance across the two environments was performed to test the significance of environment (E), lines (L) and environment x line (EL) interactions considering environment as random and line as fixed using the SAS MIXED procedure (SAS V9.4; SAS Institute Inc., 2015). Individual environment residuals were modeled into a combined analysis using the REML technique and variance components were estimated. BLUP's (Best Linear Unbiased Predictors) for lines for each environment were estimated using combined analysis. Significant line x environment interaction was observed for all the traits. The data showed the need to develop lines suited to each environment (Table 2).

Table 2. Performance of vegetable soybean lines in Hyderabad and Jharkhand, India during 2012

Line	Days to flowering		Pods (No/ plant)		Pod yield (g/plant)		Seed yield (g/plant)		100 seed weight (g)	
	Hyd	Jhd	Hyd	Jhd	Hyd	Jhd	Hyd	Jhd	Hyd	Jhd
AGS 292	26.0	32.9	10.2	34.0	20.3	77.5	6.9	38.2	33.1	58.1
AGS 329	26.7	32.1	9.0	33.3	15.8	56.3	3.8	29.4	29.4	62.5
AGS 338	30.0	35.6	6.3	42.2	11.3	71.6	2.5	39.8	23.5	49.3
AGS 339	27.0	32.3	10.8	34.2	17.5	72.1	4.5	33.6	32.0	57.1
AGS 406	28.7	35.3	24.4	55.6	47.5	100.4	13.5	50.1	32.3	54.3
AGS 447	27.3	30.1	11.8	36.3	29.7	78.1	7.5	36.9	33.6	61.4
AGS 456	27.0	31.1	12.2	40.6	32.5	102.1	11.8	58.6	34.5	67.9
AGS 457	26.6	30.1	12.9	52.3	31.0	107.9	7.0	51.0	30.9	66.2
AGS 458	27.0	30.7	14.2	60.6	37.3	128.6	12.1	60.4	34.0	73.6
AGS 459	30.3	33.8	19.4	67.7	39.4	125.1	10.0	63.5	33.9	59.4
AGS 460	32.0	35.1	14.8	38.8	31.6	83.5	6.3	40.6	31.9	54.4
AGS 461	29.0	33.1	13.7	39.3	30.9	89.9	10.9	42.5	35.2	76.2
AGS 610	30.3	33.8	22.1	48.5	50.2	92.4	12.9	43.7	29.3	53.0
GC 84501-32-1	35.1	45.5	55.1	148.4	44.4	102.1	15.2	57.6	13.1	22.6
Harit Soya*	34.4	44.1	33.9	70.8	35.7	69.3	17.5	37.3	15.7	28.1
Swarna Vasundhara	36.1	48.4	25.1	78.7	52.9	143.4	12.5	73.6	31.2	46.3

**grain soybean line*

One of the strategies to promote the crop is to create awareness among grain soybean farmers in the major soybean growing states such as Madhya Pradesh, Maharashtra and Rajasthan to grow vegetable soybean as a niche crop. For example, in Maharashtra, the World Vegetable Center has initiated vegetable soybean production in collaboration with a progressive farmer in Latur district. The farmer has now formed a cooperative farmer group to expand vegetable soybean seed production to cover the whole state. The need for creating markets for the crop in India by linking famers to food chain outlets and diversifying food products developed from vegetable soybean will help increase demand. During 2012, a taste test survey was conducted in Hyderabad on the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) campus involving 25 participants. Friedman's non-parametric test (Friedman, 1937) was performed using chi-square statistics to test the significance of the rankings for each line (Table 3). 'Swarna Vasundhara' received the highest overall ranking

Table 3. Sum of ranks of vegetable soybean lines in a taste survey conducted in Hyderabad, India during 2012

Line	Pod appear-ance	Pod colour	Pod texture	Bean appear-ance	Bean colour	Bean aroma	Bean taste	Bean texture	Overall rank
AGS 292	183	200	226	230	290.5	218	187	261.5	233
AGS 329	194.5	251	224	220.5	239.5	216.5	220	216.5	208.5
AGS 338	137.5	214	233	176	192	200.5	195	170.5	162.5
AGS 339	175.5	158.5	189	234	190	196	198.5	198	202.5
AGS 406	292.5	279	210.5	251.5	270.5	157.5	226	219	277
AGS 447	192	140.5	172	100.5	88	121.5	130	111	93
AGS 456	232.5	232.5	205	198.5	218.5	240.5	227.5	249	251
AGS 457	212	225	180.5	173	143.5	182	187.5	204	148
AGS 458	211.5	157.5	178	187.5	172.5	188	207	199	189.5
AGS 459	226.5	208	219.5	192.5	193	203.5	226	195	203.5
AGS 460	191.5	211	209.5	228.5	186.5	195.5	217.5	221	239
AGS 461	199	195.5	203.5	205	185.5	241	218.5	278	220
AGS 610	255.5	261.5	240.5	250.5	271.5	256.5	250	210	244
GC 84501-32-1	171.5	191	212	221	249	232.5	190	175	194.5
Harit Soya	211.5	162	192	232.5	229	245	226.5	216.5	229
Swarna Vasundhara	313.5	313	289	298.5	280.5	305.5	293	276	305
$\chi 2$-Statistic	65.8	77.2	12.9	66.6	106.4	61.1	40.7	55.4	80.4
P	< .0001	<.0001	.604	<.0001	<.0001	<.0001	.0003	<.0001	<.0001

compared to other lines. Further on-farm demonstrations as well as targeted cooking classes would help improve consumer awareness of the crop. In 2015, a survey conducted by ITC Ltd through their hotel chain found that consumers would prefer glabrous pod types to hairy podded-types; the hairiness of pods in Swarna Vasundhara' is thus an undesirable trait. The availability of basmati-flavored vegetable soybean would be an attraction, particularly in the Indian sub-continent. Poornima *et al.* (2014) reported high taste-test scores for the basmati-flavored (World Vegetable Center bred lines)

AGS 447 and AGS 457 in a taste survey conducted in the state of Karnataka. Use of integrated pest management strategies would help position the crop as a healthy nutritious snack produced with fewer or no pesticides, as well as open stringent export markets.

Conclusion

The successful introduction of vegetable soybean in the Indian state of Jharkhand has highlighted the need for community involvement at the outset. Development of varieties suited to consumer needs is paramount for the successful inclusion of the crop in the diet, which would potentially lead to improvement in the nutritional status of the community. Ongoing effort to expand the crop in other states, particularly the major grain soybean growing regions, will help ensure enough volume is produced to encourage private companies to become involved in the vegetable soybean value chain.

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Distributions of Soybean and Corn Plants in Intercropping and Solid Patterns

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ABSTRACT

Ridge width has an important role in spatial arrangement of intercropping system. A two–year study was carried out at Sids Agricultural Experiments and Research Station, A.R.C., Beni–Sweif governorate, Egypt, during 2013 and 2014 seasons to evaluate productivity of two soybean cultivars under different spatial arrangement of intercropping system with the stability of plant densities per unit area for increasing LER, productivity and net returns. Local corn cv. T.W.C. 310 was grown as one plant per hill distanced by 35, 30 and 26 cm in the middle of ridge width of 60, 70 and 80 cm, respectively, meanwhile soybean cvs. *Giza 21 and Giza 35 were drilled in two rows in both sides of corn ridge (two plants/hill spaced at 20, 17 and 15 cm under three ridge widths of 60, 70 and 80 cm, respectively, in addition to solid cultures of both crops. A split-split plot in randomized complete block design with three replications was used. Results indicated that the ridge width 70 cm of intercropping system had the highest value of intercepted light intensity within soybean canopy which reflected positively on soybean seed yield and its attributes compared to the others. Intercropping soybean with corn decreased seed yields per plant by 43.10 per cent and per ha by 45.70 per cent as compared with solid culture. Soybean cv. Giza 35 produced the highest seed yield. The interactions affected significantly soybean traits. LER and LEC ranged from 1.43 to 1.65 and 0.45 to 0.66, respectively. The value of aggressivity of soybean was negative for all combinations indicating that soybean is subordinate component. Intercropping soybean cv. Giza 35 with corn on ridges 70 cm width increased productivity and net returns by about US$ 1000 per ha compared to solid culture of corn.*

Key words: Intercropping, corn, soybean cultivars, ridge width, net returns

In Egypt, soybean [*Glycine max* (L.) Merrill] is a valuable resource for both oil and protein and is used for a wide variety of consumer uses today. Unfortunately, there is decline for soybean acreage where it reached 9,270 ha in 2013 with an average yield of 3.61 ton per ha as a result of higher production costs and lower net returns as compared with the other strategic summer crops such as corn (*Zea ma*ys L.). Therefore, demand for the corn grains in the Egyptian market is intensively increasing where corn cultivated area

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reached to about 81,4435 ha in 2013 with an average yield of 7.64 ton per ha (Anonymous, 2014).

Accordingly, there is need for expanding the scope of soybean cultivation through intercropping system; especially intercropping is the best way to keep the area of soybeans without significant change in crop structure. It is recommended to increase total agriculture products in Egypt (Metwally, 1999). It is known that yield components of any crop can be governed by plant density and distribution of these plants in the unit area. Soybeans have the ability to regulate growth and yield component productivity in response to changes in plant population and competition (Mellendorf, 2011). Yield attributes of intercropped soybean with corn can be governed by plant density of corn and soybean per unit area with regard to soybean cultivar as the competition for environmental resources between them must be less than exists within the same species. Spatial arrangement of intercropping system influenced strongly corn productivity of unit area though maintaining the recommended plant density of both species that integrated strongly with positive effects of soybean plant on soil N availability (El-Shamy *et al*., 2015). Consequently, the same plant density of the intercrops per unit area with different ridge widths could be affected inter- and intra-specific competition between the intercrops for basic growth resources especially solar radiation.

Crop species in intercropping pattern must be carefully chosen to minimize competition and enhance the efficient use of water, light and nutrients (Sayed Galal *et al*., 1983). Abdel-Galil *et al*. (2014a) concluded that soybean *cv*. Giza 22 was most compatible with growing three corn plants per hill under intercropping pattern. So, the objective of this study is to evaluate productivity of two soybean cultivars under different spatial arrangement of intercropping system with the stability of plant densities per unit area for increasing LER, productivity and net returns.

MATERIALS AND METHODS

A two-year study was carried out at Sids Agricultural Experiments and Research Station, Agricultural Research Center (ARC), Beni-Sweif governorate (Lat. 29° 12' N, Long. 31° 01' E, 32 m a.s.l.), Egypt during 2013 and 2014 seasons. The experiment included three ridge widths (60, 70 and 80 cm), two cropping systems (intercropping and solid cultures) and two soybean *cvs*. Giza 21 and Giza 35. The treatments were the combinations among ridge width, cropping system and soybean cultivar (Fig. 1).

I. ***Intercropping patterns***

1. Soybean seeds were sown in both sides of ridge (60 cm width) by growing two plants per hill distanced at 20 cm, meanwhile corn was grown in middle of the ridge with leaving one plant per hill distanced at 35 cm.

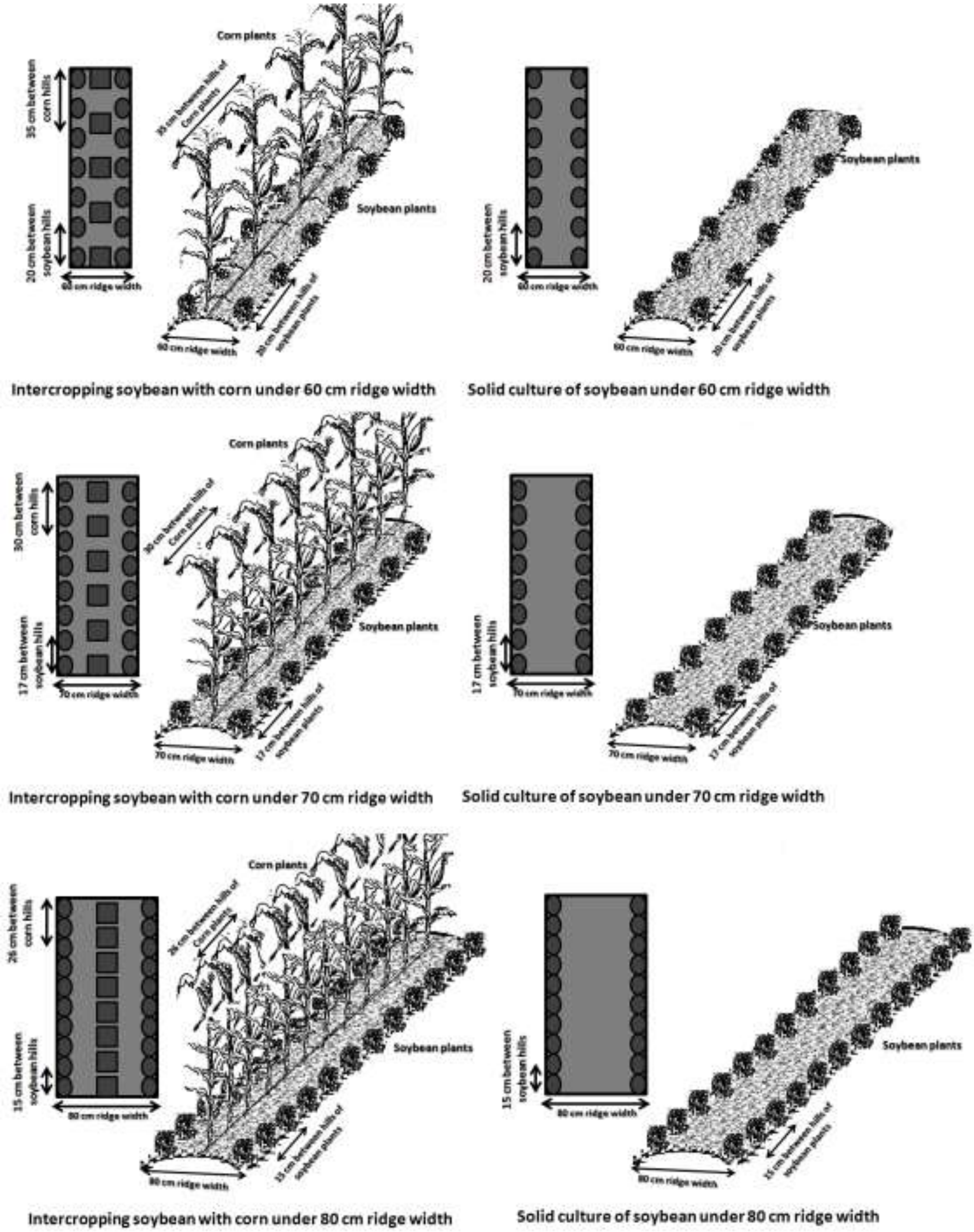

Fig. 1. Soybean and corn plants under intercropping and solid cultures

2. Soybean seeds were sown in both sides of ridge (70 cm width) by growing two plants per hill distanced at 17 cm, meanwhile corn was grown in middle of the ridge with leaving one plant per hill distanced at 30 cm.
3. Soybean seeds were sown in both sides of ridge (80 cm width) by growing two plants per hill distanced at 15 cm, meanwhile corn was grown in middle of the ridge with leaving one plant per hill distanced at 26 cm.

II. ***Solid patterns***

1. Pure stand of soybean ridge (60 cm width) by growing two rows in the ridge, two plants per hill distanced at 20 cm.
2. Pure stand of soybean ridge (70 cm width) by growing two rows in the ridge, two plants per hill distanced at 17 cm.
3. Pure stand of soybean ridge (80 cm width) by growing two rows in the ridge, two plants per hill distanced at 15 cm.
4. Pure stand of corn ridge (60 cm width) by growing one plant per hill distanced at 35 cm.
5. Pure stand of corn ridge (70 cm width) by growing one plant per hill distanced at 30 cm.
6. Pure stand of corn ridge (80 cm width) by growing one plant per hill distanced at 26 cm.

Recommended solid cultures of both crops were used to estimate the competitive relationships.

Soybean seeds were sown on May 26th and June 2nd in 2013 and 2014 seasons, respectively. Corn grains were sown on June 6th and 11th in 2013 and 2014 seasons, respectively. Furrow irrigation was the irrigation system in this study. Other agronomic practices were conducted as recommended. Soybean *cv*. Giza 35 was harvested on September 2nd and 8th in 2013 and 2014 seasons, respectively, meanwhile soybean *cv*. Giza 21 and corn were harvested on October 3rd and 7th in 2013 and 2014 seasons, respectively. The treatments were laid out in split-split plot design with three replications. Ridge width was randomly assigned to the main plots, cropping systems were allocated in sub-plots and soybean cultivars were devoted to sub-sub plots. The area of sub-sub plot differed according to ridge width, each sub-sub plot consisted of 10 ridges and each ridge was 3.0 m in length.

At harvest, the soybean traits recorded on ten plants from each sub-sub plot were light intensity (lux) inside each canopy (at the middle of the plant and at the bottom of the plant at 20 cm from the soil surface) by Lux-meter apparatus at 12 h and expressed as percentage from light intensity measured light intensity measured above the plant, biological yield per ha (ton), straw yield per ha (ton), plant height (cm), number of branches per plant, pod yield per plant(g), seed yield per plant (g), 100 seed weight (g), seed yield per ha(ton) and harvest index (%). The harvest index was calculated by economic yield/biological yield (Clipson *et al*., 1994). In addition to corn grain yield per ha, biological, straw and seed yields of soybean were recorded on the basis of experimental plot and expressed as ton per ha.

The indicators of competitive relationship, namely Land Equivalent ratio (LER) (Mead and Willey, 1980), Land Equivalent Coefficient (LEC) (Adetiloye *et al.,* 1983) and Aggressivity (Agg) (Willey, 1979) were calculated as follows.

LER = $(Y_{ab} / Y_{aa}) + (Y_{ba} / Y_{bb})$, where Y_{aa} - Pure stand yield of crop a (corn), Y_{bb} - Pure stand yield of crop b (soybean), Y_{ab} - Intercrop yield of crop a (corn) and Y_{ba} = Intercrop yield of crop b (soybean).

LEC = $L_a \times L_b$, where La - relative yield of crop a (corn) and L_b - relative yield of crop b (soybean)

Agg = $A_{ab} = [Y_{ab} / (Y_{aa} \times Z_{ab})] - [Y_{ba} / (Y_{bb} \times Z_{ba})]$; $A_{ba} = [Y_{ba} / (Y_{bb} \times Z_{ba})] - [Y_{ab} / (Y_{aa} \times Z_{ab})]$, where, Y_{aa} - Pure stand yield of crop a (corn); Y_{bb} - Pure stand yield of crop b (soybean); Y_{ab} - Intercrop yield of crop a (corn); Y_{ba} - Intercrop yield of crop b (soybean); Z_{ab} - The respective proportion of crop a in the intercropping system (corn); Z_{ba} - The respective proportion of crop b in the intercropping system (soybean)

Economical benefit (US$) was calculated as a difference between total net returns from intercropping and solid crops utilizing the prevailing prices of corn grains and soybean seeds (Anonymous, 2014) Net returns were calculated by subtraction the sum of fixed cost of corn plus variable costs of both crops. Analysis of variance of the obtained results of each season was performed. The homogeneity test was conducted of error mean squares and accordingly, the combined analysis of the two experimental seasons was also carried out. The measured variables were analyzed by ANOVA using MSTATC statistical package (Freed, 1991). Mean comparisons were performed using the east significant differences (L.S.D) test with a significance level of 5% (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Seed yield and its attributes

Ridge width: Intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, biological, straw and seed yields per ha and harvest index, as well as, corn grain yield per ha were influenced significantly by ridge width in the combined data across 2013 and 2014 seasons (Tables 1, 2 and 3). Ridge width of 70 cm increased significantly intercepted light intensity within soybean canopy, within soybean canopy, number of branches per plant, pod and seed yields per plant, 100 seed weight, biological, straw and seed yields per ha compared to the other ridge widths. Clearly, decreasing ridge width from 80 to 70 cm increased biological, straw and seed yields per ha by 7.25, 6.98 and 8.76 per cent, respectively. Also, increasing ridge width from 60 to 70 cm increased biological, straw and seed yields per ha by 10.28, 8.41 and 18.69 per cent, respectively (Tables 1, 2 and 3). It is noticed that there were non-significant

Table 1. Effect of ridge width, cropping systems, soybean cultivars and their interactions on light intensity within soybean plants, plant height and number of branches per plant at harvest, combined data across 2013 and 2014 seasons

Traits		Percentages of light intensity at						Plant height (cm)			Branches/plant (No)		
		Middle of the plant			Bottom of the plant								
		G.21	G.35	Mean	G.21	G.35	Mean	G.21	G.35	Mean	G.21	G.35	Mean
60 cm	Inter	4.12	4.44	**4.28**	1.27	1.48	**1.37**	.109.08	104.13	**106.60**	1.57	2.35	**1.96**
	Solid	8.40	8.72	**8.56**	3.48	3.72	**3.60**	.102.54	96.73	**99.63**	2.96	4.65	**3.80**
Mean		**6.26**	**6.58**	**6.42**	**2.37**	**2.60**	**2.48**	**105.81**	**100.43**	**103.12**	**2.26**	**3.50**	**2.88**
70 cm	Inter	4.88	5.12	**5.00**	1.77	2.02	**1.90**	98.81	97.55	**98.18**	1.82	2.51	**2.16**
	Solid	9.07	9.24	**9.15**	3.91	4.17	**4.04**	93.09	86.16	**89.62**	3.22	4.97	**4.09**
Mean		**6.97**	**7.18**	**7.07**	**2.84**	**3.09**	**2.96**	**95.95**	**91.85**	**93.90**	**2.52**	**3.74**	**3.13**
80 cm	Inter	4.51	4.79	**4.65**	1.43	1.68	**1.55**	102.41	100.67	**101.54**	1.69	2.46	**2.07**
	Solid	8.71	9.02	**8.86**	3.63	3.82	**3.72**	96.44	93.04	**94.74**	3.13	4.81	**3.97**
Mean		**6.61**	**6.90**	**6.75**	**2.53**	**2.75**	**2.63**	**99.41**	**96.85**	**98.13**	**2.41**	**3.63**	**3.02**
Average of cropping systems	Inter	**4.50**	**4.78**	**4.64**	**1.49**	**1.72**	**1.60**	**103.43**	**100.78**	**102.10**	**1.69**	**2.44**	**2.06**
	Solid	**8.72**	**8.99**	**8.85**	**3.67**	**3.90**	**3.78**	**97.35**	**91.97**	**94.66**	**3.10**	**4.81**	**3.95**
Average of soybean cultivars		**6.61**	**6.88**	**6.74**	**2.58**	**2.81**	**2.69**	**100.39**	**96.37**	**98.38**	**2.39**	**3.62**	**3.00**
L.S.D. 0.05 Ridge width (R)				**0.58**			**0.33**			**4.06**			**0.23**
L.S.D. 0.05 Cropping systems (C)				**0.43**			**0.26**			**3.34**			**0.18**
L.S.D. 0.05 Soybean cultivars (S)				**0.22**			**0.19**			**2.92**			**0.11**
L.S.D. 0.05 R x C				**0.62**			**0.35**			**4.69**			**0.26**
L.S.D. 0.05 R x S				**0.66**			**0.37**			**4.83**			**0.28**
L.S.D. 0.05 C x S				**0.47**			**0.28**			**3.76**			**0.22**
L.S.D. 0.05 R x C x S				**0.71**			**0.42**			**4.98**			**0.33**

Table 2. Effect of ridge width, cropping systems, soybean cultivars and their interactions on pod and seed yields per plant, 100 – seed weight and biological yield per ha at harvest, combined data across 2013 and 2014 seasons

Traits		Pod yield (g/plant)			Seed yield (g/plant)			100 seed weight (g)			Biological yield (ton/ha)		
		G.21	G.35	Mean	G.21	G.35	Mean	G.21	G.35	Mean	G.21	G.35	Mean
60 cm	Inter	5.31	5.49	**5.40**	4.77	5.08	**4.92**	12.33	14.71	**13.52**	8.11	9.60	**8.85**
	Solid	9.14	9.31	**9.22**	8.64	8.91	**8.77**	16.78	18.22	**17.50**	15.58	14.97	**15.27**
Mean		**7.22**	**7.40**	**7.31**	**6.70**	**6.99**	**6.84**	**14.55**	**16.46**	**15.50**	**11.84**	**12.28**	**12.06**
70 cm	Inter	6.06	6.21	**6.13**	5.52	5.78	**5.65**	13.14	15.44	**14.29**	9.41	9.46	**9.43**
	Solid	9.91	10.05	**9.98**	9.33	9.61	**9.47**	17.20	18.82	**18.01**	17.72	16.64	**17.18**
Mean		**7.98**	**8.13**	**8.05**	**7.42**	**7.69**	**7.56**	**15.17**	**17.13**	**16.15**	**13.56**	**13.05**	**13.30**
80 cm	Inter	5.62	5.80	**5.71**	5.15	5.42	**5.28**	12.81	15.07	**13.94**	8.79	9.18	**8.98**
	Solid	9.48	9.66	**9.57**	8.92	9.23	**9.07**	16.98	18.57	**17.77**	16.53	15.11	**15.82**
Mean		**7.55**	**7.73**	**7.64**	**7.03**	**7.32**	**7.17**	**14.89**	**16.82**	**15.85**	**12.66**	**12.14**	**12.40**
Average of cropping systems	Inter	**5.66**	**5.83**	**5.74**	**5.14**	**5.42**	**5.28**	**12.76**	**15.07**	**13.91**	**8.77**	**9.41**	**9.09**
	Solid	**9.51**	**9.67**	**9.59**	**8.96**	**9.25**	**9.10**	**16.98**	**18.53**	**17.75**	**16.61**	**15.57**	**16.09**
Average of soybean cultivars		**7.58**	**7.75**	**7.66**	**7.05**	**7.33**	**7.19**	**14.87**	**16.80**	**15.83**	**12.68**	**12.49**	**12.58**
L.S.D. 0.05 Ridge width (R)				**0.52**			**0.47**			**0.52**			**0.96**
L.S.D. 0.05 Cropping systems (C)				**0.36**			**0.35**			**0.43**			**0.78**
L.S.D. 0.05 Soybean cultivars (S)				**0.25**			**0.23**			**0.36**			**N.S.**
L.S.D. 0.05 R x C				**0.54**			**0.51**			**0.55**			**1.02**
L.S.D. 0.05 R x S				**0.59**			**0.57**			**0.57**			**N.S.**
L.S.D. 0.05 C x S				**0.44**			**0.42**			**0.47**			**N.S.**
L.S.D. 0.05 R x C x S				**0.67**			**0.64**			**0.62**			**N.S.**

Table 3. Effect of ridge width, cropping systems, soybean cultivars and their interactions on straw and seed yields per ha, harvest index, as well as, corn grain yield/ha at harvest, combined data across 2013 and 2014 seasons

Traits		Straw yield (ton/ha)			Seed yield (ton/ha)			Harvest index (%)			Corn grain yield (ton/ha)		
		G.21	G.35	Mean	G.21	G.35	Mean	G.21	G.35	Mean	G.21	G.35	Mean
60 cm	Inter	6.72	7.73	**7.22**	1.39	1.87	**1.63**	17.12	19.47	**18.29**	6.78	6.81	**6.79**
	Solid	12.71	11.88	**12.29**	2.87	3.09	**2.98**	18.41	20.64	**19.52**			**6.99**
Mean		**9.71**	**9.80**	**9.75**	**2.13**	**2.48**	**2.30**	**17.76**	**20.05**	**18.90**	**6.88**	**6.90**	**6.89**
70 cm	Inter	7.66	7.39	**7.52**	1.75	2.07	**1.91**	18.58	21.87	**20.22**	7.07	7.12	**7.09**
	Solid	14.32	12.92	**13.62**	3.40	3.72	**3.56**	19.18	22.35	**20.76**			**7.15**
Mean		**10.99**	**10.15**	**10.57**	**2.57**	**2.89**	**2.73**	**18.88**	**22.11**	**20.49**	**7.11**	**7.13**	**7.12**
80 cm	Inter	7.18	7.20	**7.19**	1.61	1.98	**1.79**	18.31	21.56	**19.93**	6.84	6.86	**6.85**
	Solid	13.38	11.77	**12.57**	3.15	3.34	**3.24**	19.05	22.10	**20.57**			**7.01**
Mean		**10.28**	**9.48**	**9.88**	**2.38**	**2.66**	**2.51**	**18.68**	**21.83**	**20.25**	**6.92**	**6.93**	**6.92**
Average of cropping systems	Inter	**7.18**	**7.44**	**7.31**	**1.58**	**1.97**	**1.77**	**18.00**	**20.96**	**19.48**	**6.89**	**6.93**	**6.91**
	Solid	**13.47**	**12.19**	**12.83**	**3.14**	**3.38**	**3.26**	**18.88**	**21.69**	**20.28**			**7.05**
Average of soybean cultivars		**10.32**	**9.81**	**10.06**	**2.36**	**2.67**	**2.51**	**18.44**	**21.33**	**19.88**	**6.97**	**6.99**	**6.98**
L.S.D. 0.05 Ridge width (R)				**0.66**			**0.38**			**1.47**			**0.12**
L.S.D. 0.05 Cropping systems (C)				**0.48**			**0.27**			**0.73**			**N.S.**
L.S.D. 0.05 Soybean cultivars (S)				**0.34**			**0.19**			**0.42**			**N.S.**
L.S.D. 0.05 R x C				**0.73**			**0.44**			**1.54**			**N.S.**
L.S.D. 0.05 R x S				**0.79**			**0.49**			**1.61**			**N.S.**
L.S.D. 0.05 C x S				**0.57**			**0.32**			**0.95**			**N.S.**
L.S.D. 0.05 R x C x S				**0.85**			**0.54**			**1.68**			**N.S.**

differences between 60 and 80 cm ridge width for the studied soybean traits.

Since the ridge width played a major role in intra- and inter-specific competition between the same and two species for solar radiation, respectively, it is expected that there was more shading around soybean plant that grown in 60 or 80 cm ridge width and thereby soybean plant suffered from mutual shading compared to those grown in 70 cm ridge width. Mutual shading is known to increase the proportion of invisible radiation, which has a specific elongating effect upon plants (Chang, 1974). So, the observed response in soybean plant height that grown in 60 or 80 cm ridge width could be primarily attributed to an increase of internodes number and elongation of soybean plant as a result of increasing plant hormones.

On the other hand, soybean seed yield and its attributes were affected severely by the narrowest or widest ridge width that may have cooler canopy temperatures as a result of low light intensity (Table 1) and retain moisture longer which increased the probability of foliar disease problems compared to other ridge widths. Growth and development of some plant species is regulated more by synergism of temperature and light (White and Warrington, 1988). Clearly, number of branches per plant, pod and seed yields per plant and per ha, 100 seed weight and harvest index were increased by increasing ridge width from 60 to 70 cm or by decreasing ridge width from 80 to 70 cm. This might be due to the favourable soil condition created by spatial arrangement of ridge width (70 cm) resulting in better root development thereby enabling soybean plants to uptake more moisture and nutrients meaning bigger assimilatory system and hence more dry matter production leading to higher economic yield.

In this concern, Leuschen *et al*. (1992) reported that yields were 8 to 14 per cent greater for soybean grown in 10-inch rows compared to soybeans grown in 30-inch rows. Also, De Bruin and Pedersen (2008) found a 3.7 bushel per acre yield advantage for soybean grown in intermediate (15 inch) rows compared to wide rows (30 inch), the yield advantage from intermediate row widths was stable across fields and environments suggesting the yield advantage could be achieved by most farmers. Corn plants grown in 70 cm ridge width recorded the highest grain yield (7.12 ton/ha) compared to the others. These results reveal that ridge width of 70 cm formed suitable spatial arrangement of mixed pattern to decrease inter and intra-specific competition between the same and two species, respectively, for above and underground environmental conditions to achieve higher economic yield of both species per unit area compared to the others. Similar results were obtained by Porter *et al*. (1997) who revealed that an average 7.3 per cent yield advantage of corn for 20-inch over 30-inch rows

Cropping systems: Intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, biological, straw and seed yields per ha were affected significantly by cropping systems in the combined data across 2013 and 2014 seasons, meanwhile, corn grain yield per ha was not affected (Tables 1, 2 and 3). Intercropping soybean with corn decreased significantly intercepted light intensity within soybean canopy, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, biological, straw and seed yields per ha as compared to soybean solid culture. As a result of intercropping, percentages of light intensity at middle and bottom of the plant, seed yields per plant and per ha were decreased by 47.57, 57.67, 41.97, and 45.70 per cent, respectively, compared to soybean solid culture. These results may be due to intercropping system that decreased light transmission between soybean plants (Table 1), which affected negatively efficiency of photosynthetic process of soybean during different periods of soybean growth and development. Plant dry matter production often shows a positive correlation with the amount of intercepted radiation by crops in intercropping system (Sivakumar and Virmani, 1980) and sole cropping (Kiniry *et al*., 1989).

These results showed that there had been yield advantage because the growth resources such as light, water, and nutrients were completely absorbed and converted to crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops. Similar results were obtained by Abdel-Galil *et al* (2014a) who observed that intercropping soybean with corn resulted in unfavorable conditions for growth and development of soybean plant which reflected on the little dry matter accumulation in different parts of soybean organs as compared with soybean solid culture.

Soybean cultivars: Soybean cultivars differed significantly for intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha in the combined data across 2013 and 2014 seasons, meanwhile, soybean biological and corn grain yields per ha did not differ (Tables 1, 2 and 3).

Soybean *cv*. Giza 35 recorded higher values of intercepted light intensity within soybean plants, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha than the other cultivar. Soybean *cv.* Giza 35 intercepted more light intensity at middle (6.88 %) and bottom (2.81 %) of the canopy than soybean *cv.* Giza 21. As soybean *cv*. Giza 21 was taller than soybean *cv.* Giza 35, its morphological traits gave higher self-shading intensity than the other one leading to lower light transmission within soybean canopy and thereby resulting in lower dry matter accumulation during soybean plant growth and development. These results are in line with those of Noureldin *et al*., (2002) and Abdel-Galil *et al* (2014a), who reported that soybean *cv.* Giza 21 was the tallest cultivar that reflected negatively on seed yield per unit area and finally harvest index as compared to the other soybean cultivars.

Response of ridge width to cropping systems: Intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, biological, straw and seed yields per ha were affected significantly by ridge width x cropping systems in the combined data across 2013 and 2014 seasons, meanwhile, corn grain yield per ha was not affected (Tables 1, 2 and 3). Solid culture of soybean that grown in 70 cm ridge width increased significantly intercepted light intensity within soybean canopy, number of branches per plant, pod and seed yields per plant, 100 seed weight, biological, straw and seed yields per ha compared to the others.

These results could be due to the narrowest (60 cm) or the widest ridge width (80 cm), which interacted negatively with intercropping system to decrease light penetration within soybean canopy and reflected on dry matter accumulation in the legume component and finally pod and seed yields per plant. Also, growing soybean with corn on the narrowest ridge (60 cm) increased shade intensity (Table 1), which may be increased the probability of foliar disease problems compared to the other treatments as a result of comparatively cooler environment and conservation of moisture for longer period in intercropped soybean.

These data indicated that there was effect *($P \leq 0.05$)* of ridge width x cropping systems on intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, biological, straw and seed yields per ha except corn grain yield per ha.

Response of ridge width to soybean cultivars: Intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha were affected significantly by ridge width x soybean cultivars in the combined data across 2013 and 2014 seasons, meanwhile, soybean biological and corn grain yields per ha were not affected (Tables 1, 2 and 3). Decreasing ridge width from 80 to 70 cm interacted positively with soybean *cv*. Giza 35 and led to the greatest seed yield per ha.

These results could be attributed to soybean *cv*. Giza 35 grows well with 70 cm ridge width than the others. These data showed that each of these two factors act dependently on intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha except soybean biological and corn grain yields per ha. These results are in accordance with those reported by Ablett *et al.* (1991) who concluded that a significant cultivar x row width interaction for yield occurred with soybean *cvs.* Maple Arrow and Harcor showing the greatest seed yield response.

Response of cropping systems to soybean cultivars: Intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha were affected significantly by cropping systems x soybean cultivars in the combined data across 2013 and 2014 seasons, meanwhile, soybean biological and corn grain yields per ha were not affected (Tables 1, 2 and 3).

Obviously, solid culture of soybean could be interacted positively with soybean *cv*. Giza 35 to achieve the highest intercepted light intensity within soybean canopy, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha compared to the others.

These data indicated that there was effect *(P≤0.05)* of cropping systems x soybean cultivars on intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha except soybean biological and corn grain yields per ha.

These results are in accordance with those obtained by Metwally *et al*. (2009) and Abdel-Galil *et al* (2014a) who found that solid culture of soybean *cv.* Giza 22 had the highest soybean seed yield and its attributes compared to the other treatments.

Response of ridge width to cropping systems and soybean cultivars: Intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 – seed weight, harvest index, straw and seed yields per ha were affected significantly by ridge width x cropping systems x soybean cultivars in the combined data across 2013 and 2014 seasons, meanwhile, soybean biological and corn grain yields per ha were not affected (Tables 1, 2 and 3).

Clearly, solid culture of soybean *cv*. Giza 35 could be integrated with 70 cm ridge width recorded the highest values of intercepted light intensity within soybean canopy, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha compared to the others.

These data reveal that there was effect *(P≤0.05)* of ridge width x cropping systems x soybean cultivars on intercepted light intensity within soybean plants, plant height, number of branches per plant, pod and seed yields per plant, 100 seed weight, harvest index, straw and seed yields per ha except soybean biological and corn grain yields per ha.

Competitive relationships

Land equivalent ratio (LER): Intercropping soybean with corn increased LER as compared to solid cultures of both crops in the combined data across 2013 and 2014 seasons (Fig. 2). It ranged from 1.43 (by intercropping soybean *cv*. Giza 21 with corn that grown in 60 cm ridge width) to 1.66 (by intercropping soybean *cv*. Giza 35 with corn that grown in 70 cm ridge width). The results showed that corn was superior in the intercrop system where relative yield increased; meanwhile, soybean was inferior companion crop where the relative yield was decreased in the combined analysis.

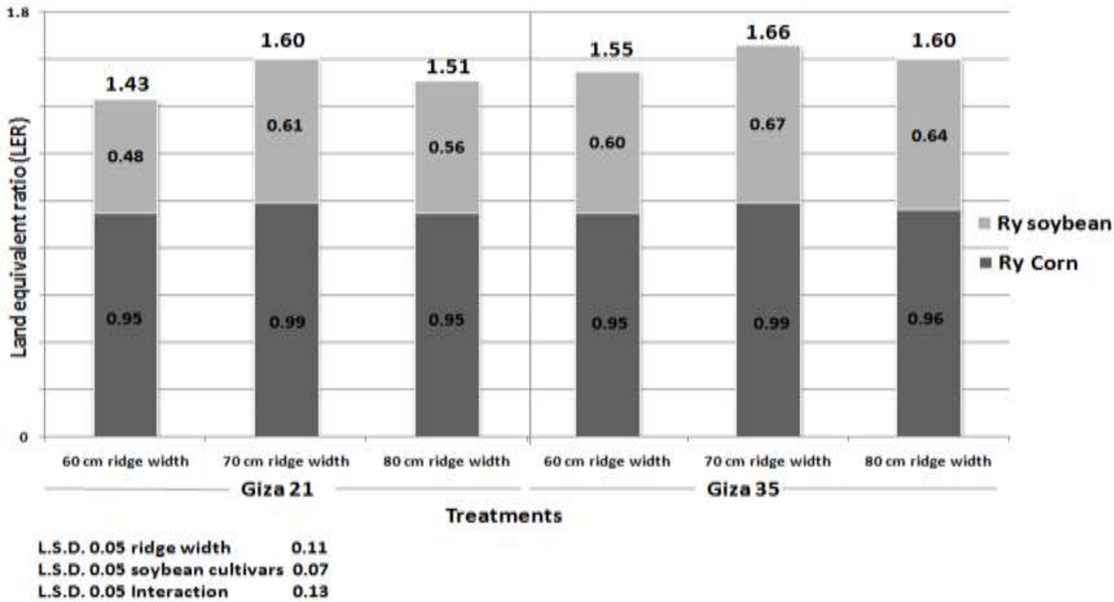

Fig. 2. Land equivalent ratio (LER) as affected by ridge width, soybean cultivars and their interaction, combined data across 2013 and 2014 seasons

LER was affected significantly by ridge width in the combined data across 2013 and 2014 seasons (Fig. 2). The advantage of the highest LER by intercropping soybean with corn on ridges 70 cm width could be due to 70 cm ridge width formed suitable spatial arrangement of intercropping system to decrease inter and intra-specific competition between the same species and the two species for above and underground conditions to achieve higher economic yield of both species per unit area compared to the others. These results are in accordance with those obtained by Metwally *et al.* (2009) who concluded that the actual productivity was higher than expected productivity.

LER was affected significantly by soybean cultivars in the combined data across 2013 and 2014 seasons (Fig. 2). Soybean *cv*. Giza 35 gave higher LER than that obtained by soybean *cv*. Giza 21. These results may be due to canopy structure of soybean *cv*. Giza 35 permit more solar radiation to the other leaves of the plant (Table 1) and increased dry matter accumulation in different organs of this cultivar which reflected on seed yield per ha. Similar results were obtained by Abdel-Galil *et al.* (2014b) who showed that soybean *cv*. Giza 22 gave higher LER than that obtained by the other cultivars.

LER was affected significantly by the interaction between ridge width and soybean cultivars in the combined data across 2013 and 2014 seasons (Fig. 2). These results may be due to 70 cm ridge width integrated with soybean *cv*. Giza 35 to increase dry matter accumulation in the different parts of the plant during soybean growth and development.

Land equivalent coefficient (LEC): LEC was a measure of interaction concerned with the strength of relationship. LEC is used for a two- crop mixture, the minimum expected productivity co-efficient (PC) is 25 per cent, that is, a yield advantage was obtained if LEC value was exceeded 0.25. LEC was affected significantly by ridge width in the combined data across 2013 and 2014 seasons (Fig. 3). The highest advantage of (LEC) intercropping soybean with corn on ridges 70 cm width over the others could be due to decrease inter and intra-specific competition between the same species and the two species for above and underground environmental conditions to achieve higher economic yield of both species per unit area compared to the others.

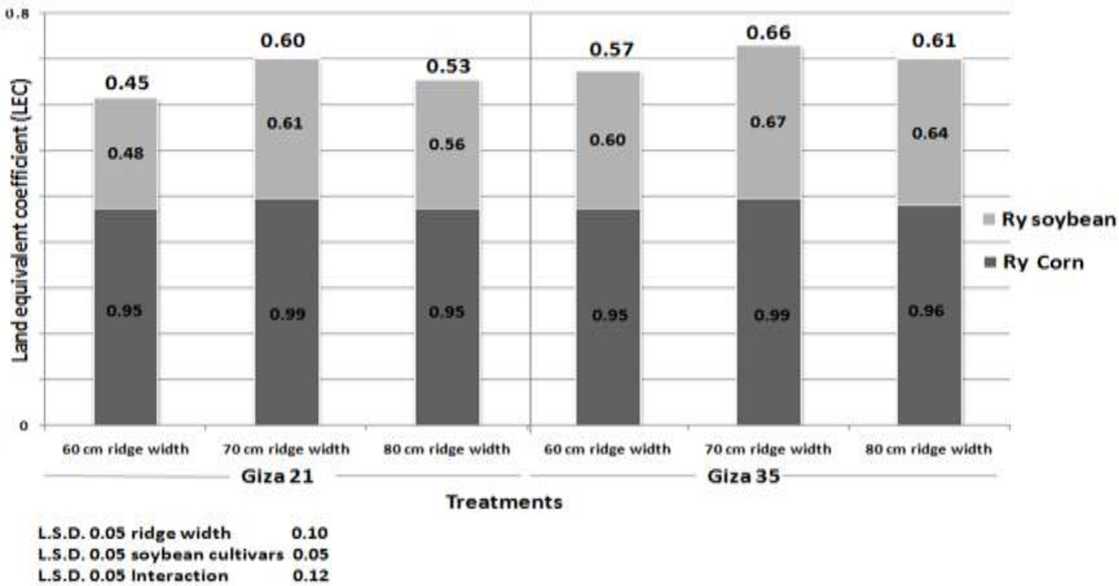

Fig. 3. Land equivalent coefficient (LEC) as affected by ridge width, soybean cultivars and their interaction, combined data across 2013 and 2014 seasons

LEC was affected significantly by soybean cultivar in the combined data across 2013 and 2014 seasons (Fig. 3). Soybean *cv*. Giza 35 gave higher LEC than that obtained by soybean *cv*. Giza 21. These results may be due to canopy structure of soybean *cv*. Giza 35 permit more solar radiation to the other leaves of the plant (Table 1) and increased dry matter accumulation in different organs of this cultivar which reflected on seed yield per ha.

LEC was affected significantly by the interaction between ridge width and soybean cultivars in the combined data across 2013 and 2014 seasons (Fig. 3). These results may be due to 70 cm ridge width integrated with soybean *cv*. Giza 35 to increase dry matter accumulation in the different parts of the plant during soybean growth and development.

Aggressivity (Agg): Aggressivity determines the difference in competitive ability of the component crops in intercropping association. The positive sign indicates the dominant component and the negative sign indicates the dominated component. Higher numerical values of aggressiveness denote greater difference in competitive ability, as well as, bigger difference between actual and expected yield in both crops. The results indicated that the value of aggressivity of corn was positive for all treatments, while, the values of aggressivity was negative for all intercropped soybean with corn plants in the combined data across 2013 and 2014 seasons (Fig. 4). These data show that corn and soybean plants are dominant and dominated components, respectively.

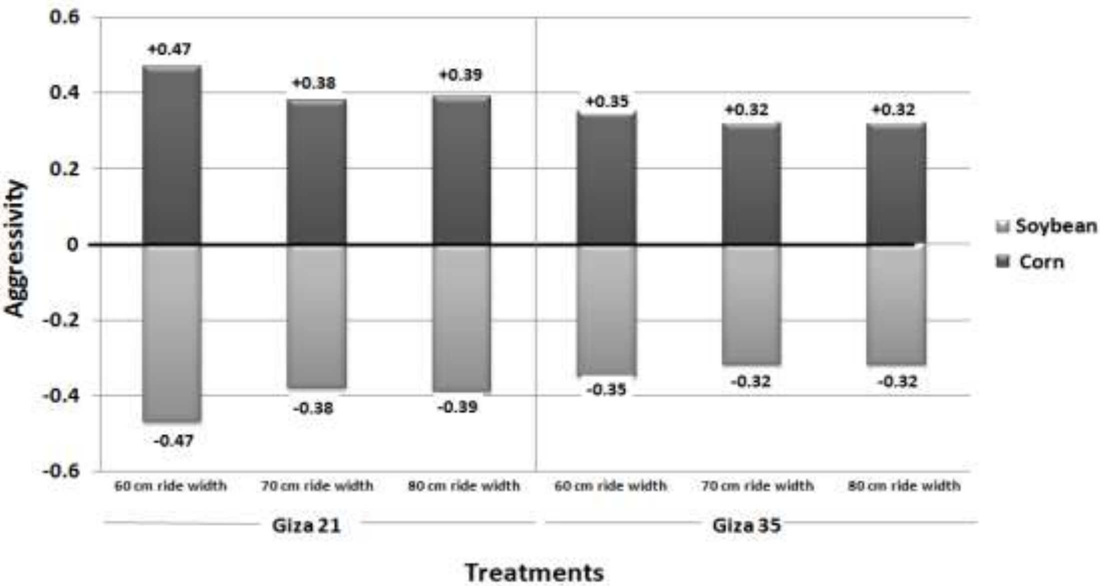

Fig. 4. Aggressivity (Agg) as affected by ridge width, soybean cultivars and their interaction, combined data across 2013 and 2014 seasons

In general, the highest negative values were obtained by growing soybean *cv*. Giza 21 with corn plants in ridges 60 cm width, meanwhile, intercropping soybean *cv*. Giza 35 with corn plants in ridges 70 cm width had the lowest negative values. It is obvious that canopy structure of soybean *cv*. Giza 35 (Table 1) played a major role in coexistence with tall plants when grown together on ridges 70 cm width which decreased aggressivity between the two species.

Economic analysis

The financial returns showed that intercropping soybean with corn increased total and net returns compared to solid culture of corn, combined data across 2013 and 2014 seasons (Table 4). Net returns varied between US$ 1082 and 1596 per ha for intercropped systems as compared to solid culture of corn (US$ 601 per ha). Intercropping soybean *cv.* Giza 35 with corn on ridges 70 cm width achieved farmers benefit by US$ 995 per ha over solid culture of corn. These results are in parallel with those obtained by Oriade *et al*. (1997) who found that net returns for rows (19-inch) superior to wide row (38-inch) spacings for irrigated and non-irrigated soybeans. Also, Abdel-Galil *et al.* (2014a) reported that mixed intercropping pattern increased total and net returns by about 32.0 and 27.3 per cent, respectively, as compared with solid culture of corn. They added that net returns of intercropping soybean with corn was varied between treatments from EUR 434 to 576 per ha as compared with corn solid culture (EUR 395).

Table 4. Total and net returns as affected by ridge width, cropping systems, soybean cultivars and their interactions, combined data across 2013 and 2014 seasons

Cropping systems	Soybean			Corn			Total			Net		
	G. 21	G. 35	Mean	G. 21	G. 35	Mean	G. 21	G. 35	Mean	G. 21	G. 35	Mean
Intercropping												
60 cm ridge width	835	1123	**979**	2095	2104	**2099**	2930	3227	**3078**	1082	1379	**1230**
70 cm ridge width	1051	1244	**1147**	2185	2200	**2192**	3236	3444	**3340**	1388	1596	**1492**
80 cm ridge width	967	1189	**1078**	2114	2120	**2117**	3081	3309	**3195**	1233	1461	**1347**
Mean	**951**	**1185**	**1068**	**2131**	**2141**	**2136**	**3082**	**3326**	**3204**	**1234**	**1478**	**1356**
Solid corn			**---**			**2210**			**2210**			**601**

Prices of main products are that of 2013: US$ 601.0 for ton of soybean; US$ 309.1 for ton of corn; intercropping soybean with corn increased variable costs of intercropping culture from US$ 629 – 891 per ha over those of corn solid culture.

It could be concluded that soybean *cv.* Giza 35 was more compatible with corn on ridges 70 cm width under mixed pattern, in addition to 7.12 ton per ha of corn grains. Egyptian farmers could achieve US$ 1596 per ha when growing soybean *cv.* Giza 35 on both sides of corn ridge (30 x 70 cm).

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Nitrogen Use Efficiency in Soybean

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ABSTRACT

Field experiments were conducted for consecutive three kharif *seasons during 2011 and 2013 to study the effect of land configuration and nitrogen levels on productivity, nitrogen uptake and nitrogen use efficiency by promising soybean (*Glycine max *(L.) Merrill) varieties under semi-arid climate of* Malwa *plateau of Central India. Planting of soybean on broad bed furrow system had superiority over flat bed planting with respect to all the parameters evaluated. Broad bed furrow planting system gave higher yield (5.49 %), nitrogen uptake (5.62 %) and sustainable yield index (0.69) over flat bed planting. Soybean variety JS 97-52 had an edge over JS 95-60 except for seed index and harvest index. Soybean yield increased (8.72 to 15.97 %) as the levels of nitrogen increased up to 40 kg N per ha as basal over control. Basal application of 40 kg N per ha increased the seed yield by 6.68 per cent over recommended basal application of nitrogen (20 kg N/ha). Significantly highest yield, additional yield, net returns, incremental benefit cost ratio, nitrogen uptake and sustainable yield index were recorded with 20 kg N as basal + 40 kg N per ha at R_5 stage. Agronomic efficiency and partial factor productivity decreased as the levels of nitrogen increased while reverse were true with recovery efficiency. All the three nitrogen use efficiencies were maximum with the application of nitrogen @ 10 kg N as basal + 10 kg N per ha at R_5 stage.*

Key words: Nitrogen level, nitrogen use efficiency, sustainable yield index

Increasing soybean yield continues to be an important focus today as input costs and fuel prices are on rise. Producers are progressively facing narrowing of profit margins from soybean and therefore, management decisions are vital for increasing yield and the economic returns. In addition to normal management decisions, producers are exploring the use of fungicides, inoculants, fertilizers and seed treatments to increase yield.

Soybean being highly protein rich crop and concomitantly required high amount of nitrogen for producing the high yield as well as protein. However, the biological fixation of atmospheric nitrogen by the soybean plant makes it one of the unique crops grown in the world. The maximum N fixation was observed at starter dose of 20 to 30 kg N per ha. More conservative estimates suggest that the uptake of fixed nitrogen by soybean can meet its 60-89 per cent of total demand (Abendroth *et al*., 2006 and Rao and Reddy, 2010). The amount of fixed nitrogen used by a plant is often largely dependent on N availability in the soil, with the plants utilizing available soil N prior to fixed N

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(Salvagiotti *et al.*, 2009). Biological N_2 fixation and mineral soil or fertilizer N are the main sources of meeting the N requirement of high-yielding soybean. A negative exponential relationship was observed between N fertilizer rate and N_2 fixation (Salvagiotti *et al.*, 2009). However, antagonism between nitrate concentration in the soil solution and the N_2 fixation process in the nodules is the main constraint the crop faces in terms of increasing N uptake (Streeter, 1988) and any gaps between crop N demand and N supply by N_2 fixation must be met by N uptake from other sources. However, the generally observed reduction in N_2 fixation activity between the R_5 and R_7 stages (Zapata *et al.*, 1987) could lead to a shortage of N during seed-filling in high-yielding environments.

Applying fertilizer-N has been proposed as an aid for increasing available N in the soil. Studies of nodulated soybean showed significant yield response to frequent N additions when the N_2 fixation apparatus could not meet N demand (Thies *et al.*, 1995). However, yield response of soybean to fertilizer N has been inconsistent at economically acceptable levels (Gan *et al.*, 2003; Barker and Sawyer, 2005). An important research question is whether fertilizer N can alleviate N limitations without compromising the N_2 fixation capacity of the crop and doing so in a cost effective manner.

Majority of soybean acreage is on Vertisols and associated soils. Soybean being a rainfed crop in India it experiences the moisture stress in its life cycle. The land configurations may be help under such situation. The yielding ability of soybean varieties was found to differ substantially because of their genetic makeup. The objective of the present research was to evaluate the effects of late-season supplemental N on soybean grain yield and nitrogen use efficiency of soybean varieties under different land configurations.

MATERIALS AND METHODS

A field study was carried out during *kharif* seasons between 2011 and 2013 at research farm of ICAR-Indian Institute of Soybean Research, Indore on Typic Chromusterts. The soil of experimental site analyzed: pH, 7.86; EC, 0.14 dS/m; organic carbon, 0.30 per cent; available P and K 4.80 and 120 kg per ha, respectively. The treatments included two land configurations (Broad bed furrow – BBF and flat bed system), two soybean varieties (JS 95-60 and JS 97-52) and 6 levels of nitrogen, namely, 0, 20, 40, 10 (basal) + 10 (at R_5 stage- pod filling), 20 + 20, and 20 + 40 kg N per ha. The design of the experiment was strip plot with three replications at a fixed site. The plot size was 3.6 m x 6 m. Uniform recommended dose of phosphorus (60 kg/ha) and potassium (20 kg/ha) were applied to all the treatments. The crop was planted on the onset of monsoon and grown as rainfed. The recommended package of practices was adopted for raising the soybean crop during the experimentation. Nitrogen uptake of seed and straw of soybean (kg/ha) was calculated by multiplying grain/straw yield (kg/ha) with nutrient concentration for the particular treatment, while, total N uptake (kg/ha) by the crop was calculated by sum of nutrient uptake in grain and straw.

The nitrogen use efficiencies were calculated in terms of fertilizer N use efficiency (Yield in treatment – yield in control/kg N applied), recovery efficiency (N uptake in treatment - N uptake in control/kg N applied) and partial factor productivity (yield/kg N applied) using standard formulae. The sustainable yield index was calculated as mean yield – standard deviation/ maximum yield.

RESULTS AND DISCUSSION

Land configuration system

The planting of soybean on BBF system improved the soybean yield attributing traits, namely branches per plant, pods per plant and seed index significantly over the flat bed planted soybean (Table 1). Planting of soybean on BBF enhanced the seed and straw yield by 5.49 and 7.79 per cent, respectively and also showed higher value of sustainable yield index as compared to flat bed planting. Harvest index remained unaffected due to land configuration treatments. The planting of soybean on BBF showed their superiority with reference to the total nitrogen uptake, agronomic efficiency, partial factor productivity and recovery efficiency over flat bed planting (Table 2). A similar trend was also observed in economical parameters. The higher soybean yield and nitrogen use efficiencies associated with broad bed planting might be due to the *in-situ* moisture conservation, better acquisition of nutrient including nitrogen, creation of better soil physico-chemical environment in root zone (Ramesh *et al*., 2006) in addition to drainage of excess water during the crop life. The furrow helps in conserving the moisture under scanty rainfall period and also helps in draining out the excess water during heavy rainfall period indicating that under both the conditions they regulate the hydrological event properly which provides congenial environment for soybean growth and ultimately leading to higher yield. The BBF and the nitrogen and phosphorus fertilization package increased grain yield by 90 per cent, grain nitrogen and phosphorus uptakes by 183 and 252 per cent, and stover nitrogen and phosphorus uptakes by 152 and 121 per cent. Similar findings were reported by Mandal *et al.* (2013) and Fahong *et al* (2004).

Soybean varieties

Among the two varieties evaluated, late maturing JS 97-52 showed its superiority over early maturing JS 95-60 with respect to almost all the parameters except for seed index and harvest index (Table 1). Variety JS 97-52 produced higher seed and straw yield by27.46 and 55.82 per cent, respectively over JS 95-60 and also showed higher values of nitrogen uptake, nitrogen use efficiencies and economical parameters (Table 2). The existing differences between the two varieties in yielding ability, nitrogen uptake and nitrogen use efficiencies might be due to differences in their genetic makeup and maturity

Table 1. Effect of land configuration and nitrogen levels on growth, yield and yield attributes of soybean genotypes

Treatment	Plant height (cm)	Branches (No/ plant)	Pods (No/ plant)	Seed yield (g/ plant)	Seed index (g/100 seeds)	Seed yield (kg/ha)	SYI	Straw yield (kg/ha)	HI (%)
Land configuration									
Flat bed	56.97	3.35	30.27	4.13	9.62	2041	0.63	2730	42.74
BBF	55.09	3.69	34.18	4.84	10.41	2153	0.69	2945	42.28
SEm	0.36	0.04	0.36	0.07	0.07	25.19	-	33.53	0.37
CD (P=0.05)	**1.26**	**0.11**	**1.10**	**0.23**	**0.24**	**87.15**	**-**	**116.01**	**NS**
Variety									
JS 95 60	43.46	2.45	16.26	4.25	13.82	1843	0.42	2218	45.06
JS 97 52	68.70	4.58	48.19	4.72	8.41	2349	0.80	3456	40.45
SEm (±)	0.43	0.04	0.36	0.08	0.07	20.64	-	16.96	0.10
CD (P=0.05)	**1.33**	**0.13**	**1.09**	**0.26**	**0.20**	**71.43**	**-**	**52.24**	**0.32**
Nitrogen level (kg/ha)									
0	40.68	3.41	29.03	4.46	9.55	1790	0.57	2524	41.49
20	47.39	3.61	33.09	4.58	9.81	1946	0.61	2638	42.39
40	52.09	3.49	31.26	4.54	9.93	2076	0.66	2916	41.57
10+10	56.29	3.43	32.97	4.65	9.67	2091	0.65	2831	42.42
20+20	56.81	3.65	34.92	4.88	9.67	2224	0.71	2885	43.49
20+40	56.11	3.50	32.02	4.79	9.84	2461	0.78	3229	43.16
SEm (±)	0.81	0.04	0.76	0.14	0.11	24.81	-	40.66	0.42
CD (P=0.05)	**2.25**	**0.12**	**2.14**	**0.40**	**0.32**	**69.49**	**-**	**113.87**	**1.17**

SYI-Sustainable yield index; HI- Harvest index

period. These results are in agreement with the findings of Gurmu *et al.* (2009) and Ngalamu *et al* (2013). Izaguirre-Mayoral and Sinclair (2005) also expressed that the soybean varieties differed substantially among themselves for nutrient accumulation and nutrient use efficiencies.

Nitrogen levels

Application of nitrogen has an advantage over control with reference to soybean growth, development, yield attributes, yield, nitrogen uptake, nitrogen use efficiencies and economical parameters (Table 1). The split application of recommended dose also produced higher yield than one time use. The soybean yield increased as the levels of nitrogen increased. Further yield enhancement was also recorded when nitrogen was applied in two splits (basal and at R_5 stage). The maximum yield was

was noted with 20 kg N per ha as basal + 40 kg N per ha at R_5 stage, which was higher by 34.49 per cent over control, 26.46 per cent over recommended dose, 18.54 per cent over 40 kg N per ha as basal, 17.69 per cent over 10 + 10 kg N per ha and 10.66 per cent over 20 + 20 kg N per ha. A similar trend was also recorded in case of straw yield. Nitrogen uptake was also increased as the levels of nitrogen increases and further enhancement was recorded with split application of nitrogen. Maximum N_2 fixation occurs between the R_3 and R_5 stages of soybean development (Zapata *et al.*, 1987), and any gaps between crop N demand and N supply by N_2 fixation must be met by N uptake from other sources. Studies of nodulated soybeans showed significant yield response to frequent N additions when the N_2 fixation apparatus could not meet N demand (Thies *et al.*, 1995; Wesley *et al.*, 2013).

Agronomic efficiency and partial factor productivity decreased as the levels of nitrogen increased and their highest values were associated with 10 (basal) +10 (at R_5 stage) kg N per ha (Table 2). However, the recovery efficiency increased with increasing

Table 2. Effect of land configuration and nitrogen levels on nitrogen use efficiencies and economics of soybean genotypes

Treatment	AE (kg/kg)	PFP (kg/kg)	RE (%)	Total N uptake (kg/ha)	Additional yield (kg/ha)	Additional returns (Rs/ha)	IBCR
Land configuration							
Flat bed	9.49	56.98	28.18	174.19	339	11605	14.27
BBF	11.29	60.00	30.53	183.98	398	13669	49.88
SEm	-	-	-	-	-	-	-
CD (P=0.05)	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Variety							
JS 95 60	9.67	49.32	17.77	152.38	348	11656	14.54
JS 97 52	11.12	63.86	40.51	206.89	389	13565	16.20
SEm (±)	-	-	-	-	-	-	-
CD (P=0.05)	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Nitrogen level (kg/ha)							
0	-	-	-	151.18	-	-	-
20	7.82	97.30	21.20	163.70	122	5357	11.77
40	7.15	51.90	27.20	180.29	225	9869	13.90
10+10	15.09	104.57	34.06	177.92	302	10205	15.58
20+20	10.86	55.60	33.66	192.54	434	14923	16.40
20+40	11.05	41.02	33.47	213.29	663	22672	19.54
SEm (±)	-	-	-	-	-	-	-
CD (P=0.05)	**-**	**-**	**-**	**-**	**-**	**-**	**-**

AE-Agronomic efficiency, PFP- Partial Factor Productivity, RE- Recovery efficiency; IBCR- Incremental benefit cost ratio increasing levels of nitrogen and the maximum being with 10 (basal) + 10 (at R_5 stage) kg N per ha. Recovery efficiency increased from 0.18 to 0.74 kg per kg when nitrogen was applied late as compared to early (Gan *et al.*, 2002). The application of 20 (basal) + 40 (at R_5 stage) kg N per ha was found to be the most sustainable (0.78) and closely followed by 20 (basal) + 20 (at R_5 stage) kg N per ha (0.71). The application of nitrogen either as basal or in splits produced SYI values more than 0.60 as compared to without nitrogen (control) (0.57).

The additional yield, additional returns and IBCR increased as levels of nitrogen increased and the highest were observed with 20 (basal) + 40 (at R_5 stage) kg N per ha (Table 2). The application of nitrogen in splits has been found to be more sustainable than applied as basal only.

On the basis of three years results, it could be concluded that the planting of soybean variety JS 97-52 on BBF with split application of nitrogen 20 kg N per ha as basal + 40 kg N per ha at R_5 stage found to be most productive, remunerative and nitrogen use efficient.

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Co-inoculation of Resident AM Fungi and Soybean Rhizobia Enhanced Nodulation, Yield, Soil Biological Parameters and Saved Fertilizer Inputs in Vertisols under Microcosm and Field Conditions

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ABSTRACT

Interaction effect of native AMF (arbuscular mycorrhizal fungi) and root nodulating soybean rhizobia was evaluated on soybean growth and associated soil biological parameters under microcosm (sterilized and un-sterilized) and field conditions. Treatments under microcosm experiment consisted of two rhizobial strains [Bradyrhizobium japonicum *(5a) and* Bradyrhizobium liaoningense *(17c)*] *and one AMF (mixed culture of* Glomus intraradices, G. mosseae *and* G. geosporum*) alone and in combination with 50 per cent of recommended dose of NPK fertilizers (20:26.2:16.6 kg N:P:K/ha) and control. For field trial, only* B. japonicum *(5a) was included with AMF and fertilizers. Under both the conditions, bradyrhizobial and AMF inoculation at 50 per cent RDF produced significantly higher nodules, nodule dry weight and grain yield when compared to control plants and was found to be comparable with plants grown with RDF. The two-way ANOVA analysis revealed that interaction effect of soil conditions and inoculation treatment was significant on nodulation and yield. Irrespective of soil conditions, co-inoculation of AMF and* Bradyrhizobium *with or without 50 per cent RDF produced comparatively higher nodulation, N uptake, had higher AM colonization and grain yield than other treatment combinations and was found significantly higher over control plants. It means* Bradyrhizobium *inoculation is favoring AMF colonization. AMF spore density in soil and per cent root length colonized by AMF and the background population enhanced in presence of* Bradyrhizobium *both under microcosm and field evaluation. Soil enzymes activities of AMF and* Bradyrhizobium *inoculated samples had higher alkaline and acid phosphatase activity over other treatments. Inoculation of AMF alone and* Bradyrhizobium *with 50 per cent showed higher activity of acid and alkaline phosphatases indicating the release of P from organic pool. Moreover, inoculation of AMF either used singly or in combination also enhanced ß- glucosidase and fluorescein diacetate (FDA). Overall, higher soil enzymes particularly alkaline phosphatases in AM-mediated rhizosphere of* Bradyrhizobium *and 50 per cent RDF combination was found to be efficient in producing higher yield and N uptake at reduced dose of NPK fertilizers.*

Key words: Indigenous AM fungi, soybean rhizobia, *Glycine max*, field response

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Soybean [(*Glycine max* (L.) Merrill] with its about 40-42 per cent protein and 18-22 per cent oil emerging as one of the fast growing oilseed crop in the world (Masciarelli *et al.,* 2014). In India, Malwa plateau of Central India is the hub for soybean cultivation, the total production during 2014 was about 11.64 m t from 10.02 m ha hectare (Anonymous 2014-15). Although, the spread of soybean in different parts of the country also resulted into parallel growth of oil industry by commissioning solvent extraction plants, which, apart from expelling oil, are also earning foreign exchange through export of deoiled cake (DOC). But for the past few years soybean is facing climatic challenges, with the result the soybean yields are declining.

Otherwise also, when compared to other soybean growing countries, the productivity of soybean is very low in India. The reasons for lower productivity are recurrence of drought, the low nutrient use efficiency of crop, nutrient deficiency in soil and other biotic and abiotic stresses. Since soybean is a legume crop, mainly draw nutrients from native pool of soil, the incremental applications of fertilizers are not likely to help in increasing the productivity of this crop. Soybean depends on their symbionts for a large part of their nitrogen requirements for growth and increased dry matter production. Therefore, the approach of using rhizosphere microorganisms is viable that can fix atmospheric nitrogen and solubilize and mobilize phosphorus and other soil nutrients to stimulate plant growth and improve soil health. Amongst such microbes, soybean root nodule forming rhizobia and mycorrhizal fungi are the important symbionts associated with plant roots and known to improve the plant growth, nodulation and plant nutrition. Since, both mycorrhizal fungi as well as rhizobial are commonly found inhabiting the common rhizosphere and colonizing the roots of crop plants including soybean. These arbuscular mycorrhizal fungi (AMF) forms symbiotic association and enhances water and nutrient transport particularly phosphorus (Xiao *et al*., 2010; Tajini *et al*., 2012), Zn (Chen *et al*., 2003), N and also increases growth and yield of many crop plants (Raverkar and Tilak, 2002). In recent years, the effect of combined inoculation with AMF and rhizobia have been reported to further increase the growth and yield of some crops including soybean (Aryal *et al.,* 2006; Meghavansi *et al*., 2008; Abd-Alla *et al*., 2014; Antunes *et al*., 2006). The association of bradyrhizobial strains with the roots of soybean plants also improves soil health and nitrogen fixation, thus further increasing crop production (Van Jaarsveld *et al.,* 2002). The tripartite association of symbiotic AMF, root nodule bacteria *Bradyrhizobium japonicum* and soybean host was investigated to find its effect on the promotion of growth and yield of soybean (Meng *et al*., 2015). These two groups of microbes exert positive effects on plant growth by improving P and N availability. Very recently studies have corroborated a positive effect of the interactions between AMF and rhizobial under drought conditions (Ruiz-Lozano *et al*., 2001) and it was found that inoculation with AMF protected soybean plants against the detrimental effects of drought and helped them cope with the premature nodule senescence induced by drought stress (Porcel *et al.,* 2003). Besides drought tolerance, the association of rhizobia with roots of AM soybean plants improves growth, yield, nitrogen fixation thus increasing crop production (Meng *et al*., 2015). These AMF-rhizobia interactions may be of crucial importance within sustainable, low-input agricultural cropping systems that rely on biological processes rather than agro-chemicals to maintain soil fertility and plant health. It has been already known that native strains are more efficient and ecological stable than introduced strains. Synergistic effects of native AMF and *Bradyrhizobium* have a high potential to improve growth, nutrient supply of soybean grown as sole crop or intercropped with maize (Men *et al*., 2015). Therefore, the current research was carried out to investigate the interaction effects of native *Bradyrhizobium* and AMF for the improvement in the growth, yield, nutrition and soil biological health of soybean grown in sterilized and un-sterilized microcosm and field conditions along with recommended doses of NPK fertilizers.

MATERIAL AND METHODS

Bradyrhizobium *cultures*

The soybean root nodulating rhizobial cultures [(*Bradyrhizobium japonicum,* 5a and *B. liaoningense,* 17c (Sharma *et al*., 2010)] isolated from Malwa region, obtained from Microbiology Section, ICAR-IISR, Indore, India. Pure white creamy colonies were picked up and streaked on yeast extract mannitol agar medium-congo red (Hi-Media) and incubated at 25 ± 3°C for 2-3 days or until pure colony appeared.

AM inoculum and assessment of AMF propagules

For both the trials (microcosm and field), mixed native arbuscular mycorrhizal (AM) fungi culture (*Glomus intraradices; G. mosseae and G. geosporum*) isolated from a long-term soybean based cropping system (Sharma *et al*., 2012) was procured from Microbiology Section, ICAR-IISR, Indore and used for these trials. Infectious propagules (IP) number in the inoculum was also determined using bioassay method (Sharma *et al*., 1996) and expressed as IP number per g soil inoculum.

Experimental details

Microcosm trial

Microcosm trial was conducted in Vertisols [pH 7.6 (1:2.5, soil water ratio)]; organic carbon 0.54 per cent; Olsen P 6.12 mg per kg; mineral N 6.24 mg per kg; DTPA extractable Zn 2.12 mg per kg using sterilized and unsterilized soil and consisted of ten treatments comprising of two native rhizobia [*B. japonicum*, 5a; MTCC 10751; *B. liaoningense*, 17c; MTCC 10753), one AM fungus singly and in combination with and without 50 per cent recommended doses of fertilizers (RDF); uninoculated control and a treatment with 100 per cent RDF (20:26.2:16.6 kg NPK/ha) was also taken (given below). Experiment was conducted in UV protectant black polythene bags (8 kg capacity, 20 cm wide and 30 cm high, 1 cm deep gusseted type) on soybean (cultivar, JS 93-05) using factorial completely randomized design (2×10) in three replications.

T1 = Absolute control
T2 = AMF @ 1000 IP per pot through mixing
T3 = *Bradyrhizobium japonicum,* 5a @ 5 g per kg seed as seed treatment
T4 = *Bradyrhizobium liaoningense, 17c* @ 5 g per kg seed as seed treatment
T5 = Recommended dose of fertilizers (RDF) @ 20:26.2:16.6 kg NPK per ha
T6 = T2 + T3 + T4
T7 = 50 per cent of RDF + T2
T8 = 50 per cent of RDF + T3
T9 = 50 per cent of RDF + T4
T10 = 50 per cent of RDF + T2 + T3 + T4

AM inoculation @ 50 g crude soil mixed AM inoculum consisting of 1000 IP (mixed native AMF culture, *G. intraradices*; *G. mosseae; G. geosporum*) containing roots bits, and hyphal and mycelial mass per pot was inoculated by layering method just below the seeds. Bradyrhizobial cultures were grown in YEM broth and mixed with sterilized charcoal power (CFU 10^9/g) and inoculated as seed treatment @ 5 g per kg seed of soybean cultivar JS 93-05 in shade just before sowing.

Field trial

Field trial on soybean (cultivar JS 93-05) was conducted at Experimental Research Farm, ICAR-IISR, Indore using eight treatments comprised of one native bradyrhizobia (*B. japonicum,* 5a), AMF singly and in combination with and without 50 per cent recommended doses of fertilizers (RDF); uninoculated control and a treatment with 100 per cent RDF (@ 20:26.2:16.6 kg NPK per ha was also taken. Each treatment plot measuring 3.6 m × 6 m (21.6 m^2) was randomly allocated in completely randomized block in three blocks per replications on soybean (cultivar, JS 93-05) as follows.

T1 = Absolute control
T2 = AMF @ 2000 propagules per sq. meter applied in furrows during sowing
T3 = *Bradyrhizobium* strain (5a) @ 5 g per kg seed as seed treatment
T4 = Recommended dose of fertilizers (RDF) @ 20:26.2:16.6 kg NPK per ha
T5 = T2 + T3
T6 = 50 % of RDF + T2
T7 = 50 per cent of RDF + T3
T8 = 50 per cent of RDF + T2 + T3

AM inoculation @ 100 g crude inoculum consisting of 2000 IP (mixed native AMF culture, (*Glomus intraradices*; *G. mosseae; G. geosporum*) containing roots bits and hyphal and mycelial mass per m^2 was inoculated in furrows at the time of sowing just below the seeds. Rhizobial inoculation was done as described in microcosm trial.

Growing conditions and measurements

Plants of both the trials were grown under ambient atmosphere conditions(monsoon season) for 90 days after germination with a mean temperature of 34^0 C and relative humidity 80 per cent. Plants were watered regularly as and when required. Nodulation parameters (nodules/–plant, nodule dry weight and total N content) were recorded and analyzed at 50 per cent flowering stage. The plants were harvested at maturity (90 days after germination) and rhizosphere soil and root samples were subjected to AM spore density, soil enzymes, mycorrhizal root colonization and grain yield per plant.

The nodules were dried at 70°C for 96 h until constant weight attained. Dried nodules were used for N analysis by the method of Micro-Kjeldahl's apparatus method. Available phosphorus in soil was determined by sodium bicarbonate extraction method (Olsen *et al*., 1954). Organic carbon in soil was determined according to modified (1934) and Black method as described by Jackson (1967). Acid and alkaline phosphatases activity in soil was determined colorimetrically using Acetate buffer (for acid phosphatase) and Borax-NaOH buffer (for alkaline phosphatase) by the method of (Tabatabai and Bremner, 1969). Fluorescein diacetate (FDA) activity was determined by the method of Aseri and Tarafdar (2006). The soil dehydrogenase activity was determined by the method of Cassida (1977). The mycorrhizal colonization in roots was determined after digesting and clearing the roots in acid (0.05 %) fuschin in lactoglycerol (Philips and Hayman, 1970) and extent of colonization in stained roots was determined by the frequency distribution method of Baermann and Linderman (1981). The grain yield, nodulation and nodule dry mass data of soybean from different treatments of both the trials were also recorded

Statistical analyses

The data of other parameters were analyzed using the analysis of variance (ANOVA) (SAS Institute Inc., 1991). Data from microcosm trial was analysed using one factor (treatments of sterilized/unsterilized) and two factor (treatments and soil conditions) ANOVA. The least significant difference (LSD) of Duncan's Multiple Range Test (DMRT) was used to separate the treatment means using Costat statistical software (Cohort Berkeley, Calif.).

RESULTS AND DISCUSSION

Effect on nodulation, yield and nutrient uptake

The inoculation of *Bradyrhizobium* (both the isolates) and AMF at 50 per cent fertilizers produced significantly higher nodules, nodule dry weight and grain yield as compared to control plants (Fig. 1). In general, nodulation and grain yield observed in inoculated plants was found to be comparable with plants grown with 100 per cent of recommended dose of fertilizers (RDF). The two-way ANOVA analysis carried out using two factors (soil conditions-sterilized/un-sterilized and treatments) revealed that interaction effect of soil conditions and inoculation treatment was significant for nodulation and yield. Irrespective of treatment combinations, significantly higher nodules number was recorded in plants grown in sterilized soil, whereas the nodule dry mass and grain yield did not differ significantly. On the other hand, irrespective of soil conditions, plants inoculated with AMF alone or with *Bradyrhizobium* at 50 per cent RDF produced comparatively higher nodulation and grain yield than other treatment combinations and was found significantly higher over control plants. However, these plants produced statistically similar response to RDF plants. This indicated that both the strains of rhizobia are compatible with AMF for producing higher nodulation and yield response.

Under field conditions, dual inoculation of AMF and *Bradyrhizobium* with and without 50 per cent RDF had significantly higher nodule dry mass as compared to other treatments. However, the nodule number was not influenced by inoculation treatments (Fig. 3). Significantly higher grain yield was recorded in treatment comprising of 50 per cent RDF with dual inoculation over control and did not significantly vary with treatments comprising of AMF application alone or with 50 per cent RDF (Fig. 3).

The present findings of higher response of AMF and *Bradyrhizobium* as dual inoculation is corroborated (Meghvansi *et al.*, 2008), wherein they found that dual inoculation with AMF (*G. intraradices)* and *Bradyrhizium japonicum* improved nodulation, growth parameters demonstrating synergism between the two microsymbionts. Among the dual treatments, *G. intraradices* and *B. japonicum* brought about significant increases in the studied characteristics particularly in seed weight per plant, which increased up to 115.19 per cent, suggesting a strong selective synergistic relationship existed between AMF and *B. japonicum.* It is attributed that soybean-bradyrhizobia association in the study benefited from AM fungi due development of extended root and hyphal network which not only met P demand but also helped plants to ameliorate any other nutrient deficiencies might be limiting to bradyrhobia (Smith, 2002). For example Wang *et al*. (2011) demonstrated the co-inoculation responses in deep rooted soybean genotypes for higher uptakes of N and P. Increased mineral nutrient levels in the plants would not only benefit rhizobia directly, but would also lead to increased photosynthesis, making a greater proportion of photosynthates available to the *Rhizobium* nodules (Mortimer *et al*., 2008). Very recently Meng *et al*. (2015) demonstrated the inoculation of both AMF and rhizobium in the soybean + maize intercropping system which improved the N-fixation efficiency in soybean and promoted N transfer from soybean to maize, resulting in the improvement of yield advantages of legume + non-legume intercropping. In our study, inoculated plants had significantly higher nitrogen uptake in roots and nodules as compared to uninoculated plants (Fig. 1). However, comparatively higher N-uptake was observed in plants inoculated with AMF and *Bradyrhizobium* alone or with 50 per cent RDF. Besides enhancing N-uptake and yield, the treatments consisting of dual inoculation of AMF and rhizobia alone and with 50 per cent RDF did

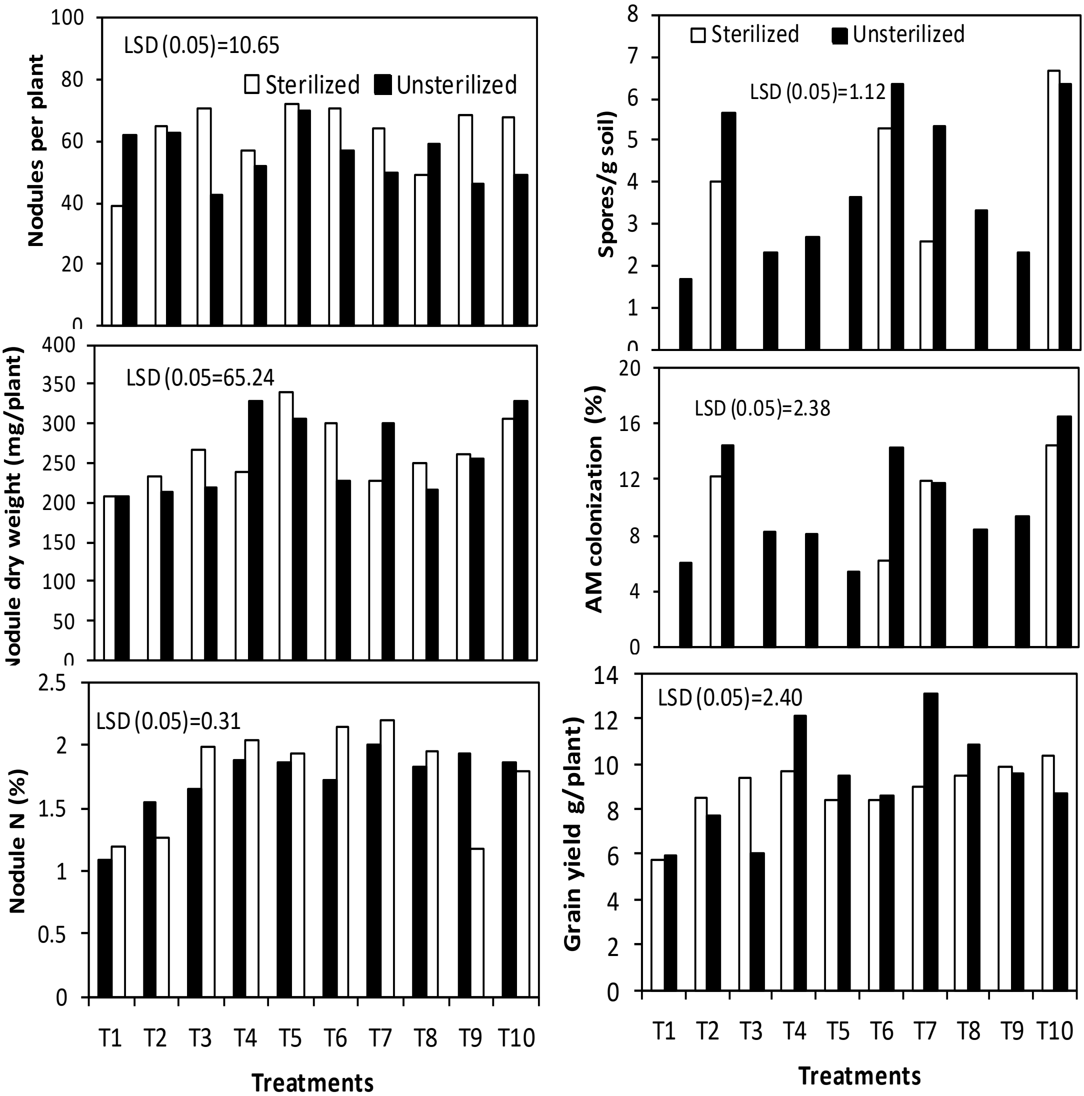

Fig. 1. Influence of indigenous AMF and root nodulating rhizobia on nodulation, mycorrhizal symbiosis and grain yield of soybean grown under sterilized and un-sterilized microcosm conditions; Data are mean of three replications; LSD, least significant difference (P = 0.05) by DMRT of ANOVA; Treatments T1, Absolute control; T2, AMF; T3, *Bradyrhizobium japonicum,* 5a; T4, *Bradyrhizobium liaoningense,* 17c; T5, Recommended dose of fertilizers (RDF); T6, T2 + T3 + T4; T7, 50 % of RDF + T 2; T8, 50 % of RDF + T3; T9, 50 % of RDF + T4; T10, 50 % of RDF + T2 + T3 + T4

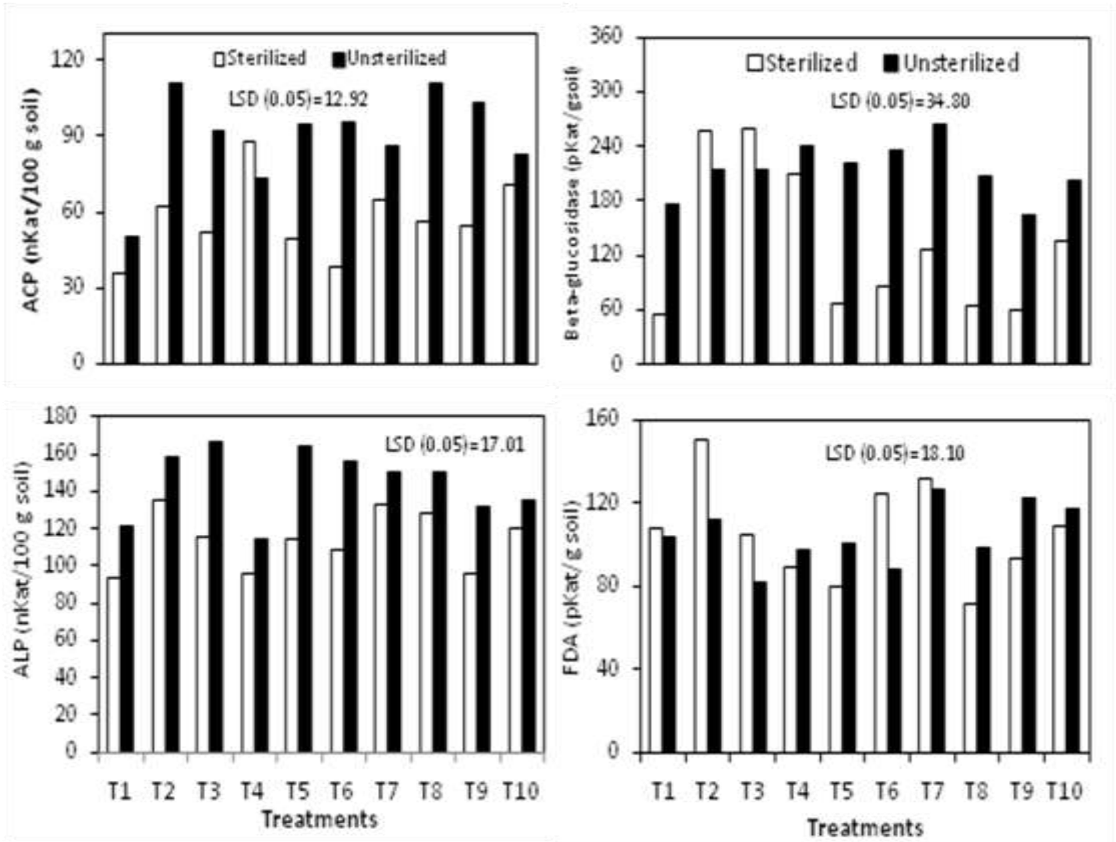

Fig. 2. Influence of indigenous AMF and root nodulating rhizobia on soil enzyme activities assessed in the rhizosphere of soybean grown under sterilized and un-sterilized microcosm conditions; Data are mean of three replications; LSD, least significant difference (P = 0.05) by DMRT of ANOVA; ACP, Acid phosphatases; ALP, Alkaline phosphatases; FDA, fluroscein diacetate; Treatments T1, Absolute control; T2, AMF; T3, *Bradyrhizobium japonicum*, 5a; T4, *Bradyrhizobium liaoningense*, 17c; T5, Recommended dose of fertilizers (RDF); T6, T2 + T3 + T4; T7, 50 % of RDF + T2; T8, 50 % of RDF + T3; T9, 50 % of RDF + T4; T10, 50 % of RDF + T2 + T3 + T4

maintain higher available phosphorus in the soil. This meant that inoculation of AMF with *Bradyrhizobium* with and without 50 per cent RDF showed increase mineralization of unavailable P from native pool for P uptake to produce higher yield and N uptake in roots and also increasing available P content in soil. The two factor analysis revealed that irrespective of treatments, the effect of soil conditions did not influence N–uptake, whereas soil available P was influenced significantly. There was significantly higher available P in the

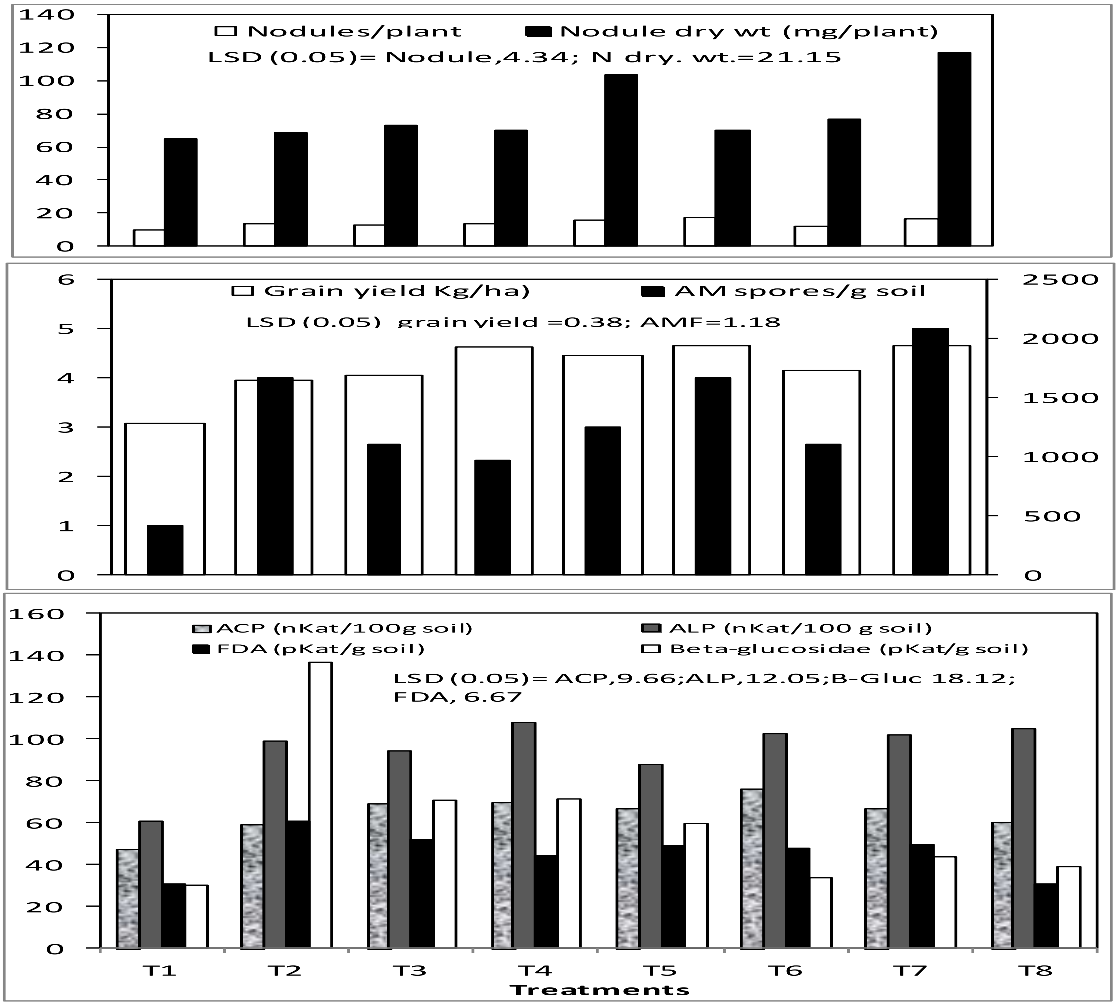

Fig. 3. Influence of indigenous AMF and root nodulating rhizobia on nodulation, AM formation, grain yield and soil enzyme activities assessed in soybean grown in Vertisols under field; Data are mean of three replications; LSD, least significant difference (P=0.05) by DMRT of ANOVA; ACP, Acid phosphatases; ALP, Alkaline phosphatases; FDA, fluroscein diacetate; Treatments T1, Uninoculated control;T2, AMF; T3, *Bradyrhizobium japonicum*, 5a; T4, Recommended dose of fertilizers (RDF); T5, T2 + T3; T6, 50 % of RDF + T2; T7, 50 % of RDF + T3; T8, 50 % of RDF + T2 + T3

unsterilized soil. Irrespective of soil conditions, combination of *Bradyrhizobium* and AMF with 50 per cent RDF showed higher N-uptake as compared to RDF plants. The effect on available P status showed that combined inoculation of AMF and *Bradyrhizobium* with and without 50 per cent RDF plants maintained higher P in soil and did not significantly vary with 100 per cent RDF.

The roles of AM in the stimulation of growth and nutrient uptake of many host plants have been well documented (Smith and Read, 1997; Jeffries *et al*., 2003). The higher response due to AMF can be explained that it has been known that AMF are beneficial, symbiotic fungal associations with plant roots which increase the effective absorbing zone of the root through the hyphae which explore the soil away from the root surface. AM are renowned for their ability to improve the P nutrition of plants. One estimate suggested that up to 80 per cent of the P taken by mycorrhizal plant was supplied by the fungus (Marschner and Dell, 1994). Ilbas and Sahin (2005) reported that both mycorrhiza inoculation and P treatments affected P and N concentrations of grain and roots of soybean. In their study mycorrhizal inoculation decreased the need of P addition in growth medium by contributing to the demand of optimum phosphorus for growth of soybean. The higher N-uptake in AM-plants could be due to increased nitrogenase enzyme of rhizobia that enables to fix atmospheric nitrogen in the nodules (Thorneley, 1992), and fungal hyphae facilitate the uptake of ions, mainly phosphate, in mycorrhizal roots. In most cases investigated, especially when both nitrogen and phosphate are limiting factors, AMF and rhizobia appear to act synergistically since combined inoculation with mycorrhiza and rhizobia enhances plant growth and reproduction more than inoculation with either microsymbiont alone and also leads to a higher degree of host colonization by the two symbionts (Kawai and Yamamoto, 1986; Chaturvedi and Singh, 1989). Nevertheless, AMF and rhizobia in established nodules may compete for photosynthate (Harris *et al*., 1985). Moreover, antagonistic effects in the establishment of the symbiosis between the mycorrhizal fungus *Glomus* and *Bradyrhizobium* were reported for soybeans when one of the microsymbionts had colonized the root system prior to the other (Bethlenfalvay *et al*., 1985).

Effect on mycorrhizal symbiosis and soil enzymes

Mycorrhizal spore density in soil and per cent root length colonized by inoculated AMF and back ground population (Fig. 2 and 3) revealed that plants inoculated with *Bradyrhizobium* (either of strain) enhanced the mycorrhizal spore population in AM inoculated and non-inoculated plants. The spore population in the AMF-inoculated plants was significantly higher over non-AM inoculated plants. In general, AMF colonization was higher in plants inoculated with AMF + *Bradyrhizobium*. The two way ANOVA interaction results showed that irrespective of soil conditions, higher colonization was observed in plants inoculated both with AMF and *Bradyrhizobium*. It meant *Bradyrhizobium* inoculation is favoring AMF colonization (Fig. 1).

Joner and Leyval (2001) suggested that AMF coexist and interact with Plant Growth Promoting Rhizobacteria (PGPR) in soils; changes in microbial community structure may also affect the function of AMF, which necessitates experiments with unsterilized soils. The interaction effect of soil conditions and inoculation treatments was found to be significant. Irrespective of soil conditions, dual inoculation of AMF and *Bradyrhizobium* (either of strain) with and without 50 per cent RDF had higher AMF spores in the rhizosphere as compared to non-inoculated and single inoculated treatments (Fig. 1). This indicated that indigenous AM (Gi) and *Bradyrhizobium* 5a or 17c is compatible and can be used as consortia for application in soybean. Under field conditions, the plots that received either AMF alone or with *Bradyrhizobium* (with and without 50 % RDF) maintained higher spore density which is corroborated with higher grain yield.

Aryal *et al*. (2006) suggested that inoculated rhizobial strains interact positively with the native AMF, yet the mechanisms of such interactions are still mostly unclear (Bethlenfalvay and Linderman, 1992). Various mechanisms, off course account for the positive interactions between rhizobia, AMF and the host plant, and further studies, especially in the molecular mechanisms of such interactions, would be an important tool to enhance the present understanding, and their potential application in sustainable and/or organic farming systems. Recently in a field study the effect and interaction of rhizobium, mycorrhiza and diammonium phosphate and rhizobium significantly increased nodulation number per plant, relative growth rate and yield of soybean over control (Salih *et al*., 2015).

Soil enzymes data (Fig. 2 and 3) revealed that plants inoculated with AMF and *Bradyrhizobium* single or dual inoculation had higher alkaline and acid phosphatase activity over other treatments. Inoculation of AMF alone and *Bradyrhizobium* with 50 per cent RDF showed higher activity of acid and alkaline phosphatases indicating the release of P from organic pool. Inoculation of AMF alone and with 50 per cent RDF showed higher activity of ß-glucosidase and fluorescein diacetate (FDA). The two way ANOVA indicates that except FDA, irrespective of inoculation and fertilizer treatments, significantly higher soil enzyme activities (ACP, ALP and ß-glucosidase) was observed in un-sterilized soil. Irrespective of soil conditions, plants inoculated with AMF alone or with 50 per cent RDF or with *Bradyrhizobium* showed comparatively higher activity of all the four soil enzymes. Under field conditions, significantly higher ALP activity was observed in treated/inoculated plants over control and maximum activity was observed in AMF inoculated plots. The ACP activity was not influenced by inoculation treatments. However, in general, ACP was higher as compared to control plots. Soil phosphatase plays an important role in the P nutrition of plants because it mediates the release of inorganic phosphorus from organically bound phosphorus (Wang *et al*., 2006). The ß-glucosidase and FDA activity was found be higher in AMF-inoculated plots as compared other treatments (Fig. 2 and 3). The higher activity of soil enzymes in

AM-mediated plants has also been observed by many workers wherein they reported that AMF can increase soil enzyme activities, such as phosphatase (Kothari *et al*., 1990; MarVa´zquez *et al*., 2000), dehydrogenase, acid phosphatase and ß-glucosidase (Caravaca *et al*. 2004).

The present study concluded that the co-inoculation of soybean plants with native mixed AM fungi and soybean rhizobia (*Bradyrhizobium strains-liaoningense and japonicum)* evaluated under microcosms (sterilized or unsterilized) and field conditions has increased growth, nutrition, yield and biochemical parameters. Therefore, the use of both AM fungi and soybean rhizobia is required to be promoted for large scale application in other soybean cultivars which are in seed chain for enhanced productivity of soybean.

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Impact of Inorganic and Organic Manures on Yield of Soybean and Soil Properties

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ABSTRACT

The present investigation dealing with the effects of enriched manures, such as phospho-compost, FYM with and without chemical fertilizers on sustainable soybean production and its economics was conducted on Inceptisols for consecutive kharif *seasons of 2012 to 2014 at Research Farm of Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Results revealed that the application of 100 per cent RDF + FYM @ 5 t per ha recorded significantly highest uptake of N, P and K. The application of 100 per cent recommended dose of fertilizers + FYM @ 5 t per ha for soybean significantly improved the seed yield (2,164 kg/ha), gave highest net returns (Rs 85, 646 and highest returns per rupee invested (4.05). The organic carbon status at harvest of soybean ranged between (4.43 to 5.91 g/ kg). Thus, it shows the positive impact of organic manure application on reduction of chemical fertilizer.*

Key words: Cotton stock, Inceptisol, economics, FYM, organic matter, phospho-compost, soybean

Soybean being a high protein and energy rich crop, its productivity is often limited by the low availability of essential nutrients or imbalanced nutrition. The maintenance of soil organic matter in agricultural soil is primarily governed by climate particularly, temperature, annual precipitation and cropping practices. Crop residues, roots, root exudates, and green manure contribute significantly towards buildup of soil organic matter. The integrated use of manures and fertilizers with greater frequency of leguminous crops in the cropping sequence is the most effective way to monitor soil organic matter under given climate. Babhulkar *et al*. (2000), while studying the residual effect of long-term application of FYM (Farmyard manure) and fertilizers on soil properties of Vertisols and yield of soybean, reported that the highest yield soybean seed and straw yields were obtained due to residual effect of application of 7.5 Mg FYM per ha + 50 per cent N and P fertilizer treatment. A field experiment conducted on integrated nutrient management at Akola during 1999 also revealed maximum increase in grain and straw yield of soybean with an application of 10 t FYM with recommended dose of 30:75:00 kg

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$N:P_2O_5:K$ per ha (Patil and Puranik, 2002). Intensive cropping without proper soil management practices particularly in arid and semi-arid conditions leads to decline in soil fertility and subsequently soil quality (Caracava *et al*., 2002). Since, limited information is available on the effects of enriched manures such as phospho-compost, FYM with and without chemical fertilizers on sustainable crop production and changes in soil mineral N and organic carbon pools under intensive cropping system where the dynamics of active pools and mineral N keeps on changing and the differences in the active pools are expected to be more pronounced, the present investigation was undertaken.

MATERIAL AND METHODS

Field experiments at a fixed site were conducted at Research Farm, Integrated Farming System Research, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during two consecutive *kharif* seasons of 2012-2013 to evaluate the effect of integrated nutrient management and economics thereof. Akola is situated in sub-tropical zone about 307.42 m above MSL and geographically situated on 22^{0}42′ N latitude and 77^{0}02′ E longitude. The rainfall distribution is erratic. The rainfall received in 2012 and 2013 was 592.8 mm and 636.2 mm, respectively with number of rainy days of 34.2 and 44. The soil of the experimental site analyzed: pH - 7.8, organic carbon 4.8 g per kg, available nitrogen 158.0 kg N per ha, available phosphorus 9.5 kg P_2O_5 per ha and available potash 320.0 kg K_2O per ha.

The experiments were laid out under randomized block design with three replications comprising of eight treatment encompassing control, 100 per recommended dose of fertilizers (RDF-30:75:00 of $N:P_2O_5:K_20$), 100 per cent RDF + FYM @ 5 t per ha, 75 per cent RDF + 25 per cent P_2O_5 through phospho-compost (1,135 kg/ha), 50 per cent RDF + 50 per cent P_2O_5 through phospho-compost (2,270 kg/ha), 25 per cent RDF + 75 per cent P_2O_5 through phospho-compost (3,450 kg/ha), 75 per cent RDF + 25 per cent N through cotton stalk (1,728 kg/ha), 100 per cent RD-N through FYM (5,357 kg/ha) + remaining P through phospho-compost (4,545 kg/ha). Nutrient content (oven dry basis) of added FYM (0.56 % N, 0.19 % P and 0.58 % K), phospho-compost (0.76 % N, 1.65 % P and 0.61 % K) and cotton stalk (0.44 % N, 0.26% P and 0.71 % K) were analyzed.
Soybean variety 'JS 335' was grown during mid-June keeping seed rate of 75 kg per ha. The total contents of NPK in seed and plant were estimated using standard methods (Piper, 1966) and the uptake by the crop was worked out. Surface soil samples (0 - 20 cm) drawn before the start of the experiment and after the harvest of soybean after two season and analyzed as described by Jackson (1973) for organic carbon and N, P, K, S to visualize treatment effect. The land was kept fallow during *rabi* season and mono-cropping system was followed at the experimental site.

RESULTS AND DISCUSSIONS

Nutrient uptake

The total uptake of nitrogen,

phosphorus and potash was recorded to be maximum in treatment 100 per cent RDF + FYM @ 5 t per ha (180.33 kg N, 20.26 kg P and 65.41 kg K /ha, respectively), whereas it was minimum with control (112.42 kg N, 20.26 kg P and 65.41 kg K/ha, respectively). The N, P and K uptake increased with the combination of inorganic fertilizers with organic manures. The RDF and all the integrated nutrient management treatments recorded significant increase in uptake of nutrients over control. Application of 100 per cent RDF + FYM @ 5 t per ha also proved to be significantly superior in NPK uptake over RDF. In case of P uptake, application of integrated management treatments gave numerically higher values than RDF; the significant level was achieved only in case of 25 per cent RDF + 75 per cent P through phospho-compost and 75 per cent RDF + 25 per cent N through cotton stalk. K uptake was significantly higher in 75 per cent RDF + 25 per cent P through phospho-compost over RDF only. These changes in NPK uptake may be accounted for the incorporation of organic resources as well as chemical fertilizers. These findings are in conformity with the results reported by Chaturvedi and Chandel (2005), Patil (2008) and Santhy *et al*. (1998). Verma *et al*. (2006) also found a significantly higher NPK uptake by maize –wheat cropping system by the application of 100 % NPK + FYM 10 t per ha.

Table 1. Effect of various treatments on total uptake of NPK by soybean (Pooled over 2 years)

Treatments	Total uptake (kg/ha)		
	N	P	K
Control	112.42	10.73	33.46
100 % RDF	163.01	14.89	54.48
100 % RDF+FYM @ 5t/ha	180.33	20.26	65.41
75 % RDF+25 % P through phospho-compost	146.97	16.85	63.34
50 % RDF+50 % P through phospho-compost	154.92	16.73	55.21
25 % RDF+75 % P through phospho-compost	134.59	17.95	56.40
75 % RDF+25 % N through cotton stalk	143.88	18.11	53.10
100 % RD-N-through FYM + remaining P through phospho-compost	134.53	16.77	45.23
SEm (±)	3.23	0.77	0.93
CD (P = 5 %)	**9.77**	**2.34**	**2.8**

Status of organic carbon and available nutrient status of soil before sowing of soybean

The available nitrogen content of the soil ranged from 152 to 218 kg per ha. The highest available nitrogen was in the treatment 100 per cent RDF + FYM @ 5 t per ha and 75 per cent RDF +25 per cent P through phospho-compost (219.43 and 210.41 kg/ha). The significantly lower available nitrogen content was recorded in control (152.29 kg/ha). The available phosphorous content in treatments ranged from 21.20 to 27.26 kg per ha; the highest content of P_2O_5 was recorded on application of 100 per cent RDF + FYM 5 t per ha. Similar trend in case of available potassium was observed in 75 per cent RDF + 25 per cent P through phospho-compost. The K value ranged between 374 to 470.05 kg per ha. The available status of sulphur ranged from 10.93 to 16.28 mg per kg. The significantly highest value available sulphur content was noted in the treatment 75 per cent RDF + 25 per cent P through phospho-compost and 100 per cent RDF + FYM @ 5t per ha followed by the treatment 100 per cent RD-N- through FYM + remaining P through 13.44 mg per kg. The available sulphur content in the treatment of application of phospho-compost, cotton stalk were statically at par. The lowest sulphur content was observed in control treatment (Table 2).

Effect of various treatments on available nutrient status of soil after sowing of soybean

The available nitrogen content of the soil ranged from 154.31 to 223.21 kg per ha. The highest available nitrogen was in the treatment 100 per cent RDF + FYM @ 5 t per ha and 75 per cent RDF + 25 per cent P through phospho-compost (223.21 and 221.01 kg/ha). Comparatively lower (209.22 kg/ ha) was in application of 100 per cent RDF. The significantly lower available nitrogen content of 154.31 kg per ha was recorded in control (Table 2). This results are in line with Yadav (1998) reported that significant improvement in available N in swell-shrink soil in combination with RDF + FYM in soybean. The increment was due to slow release of nutrients through organic manures and enriching the available pool of nitrogen (Bharadwaj, 1994). The increase in available nitrogen status under integrated treatment might also be attributed to a greater multiplication of soil microbes as a result of which organically bound nitrogen was converted to inorganic form of nitrogen (Bharadwaj, 1994).The lower values for available nitrogen with 100 per cent RDF was attributed to maximum utilization of applied nutrients by the crop which are in readily available form (Uma, 1999). The available P_2O_5 content of soil ranged from 25.18 to 29.50 kg per ha. The highest value of P_2O_5 was recorded in the treatment 100 per cent RDF + FYM 5 t per ha. The results are in line with Bajpai *et al.* (2006) and Singh *et al.* (2008). The available phosphorus in the soil after the harvest of soybean was significantly lower in the treatments received inorganic alone compared to the integration of inorganic with organic fertilizers. It may be due to lack of addition of organic matter and thereby depletion of native pool which was mineralized by the build of microflora. In addition, the organic anions compete with phosphate ions for the binding sites on the soil colloids. The organic anions chelate Al^{+3}, Fe $^{+3}$ and Ca $^{+2}$ and thus decrease the phosphate precipitating power of these cations and thereby increase in the phosphorus availability. The K value ranged between 374.83 to 490.02 kg per ha while significantly

Table 2. Effect of various treatments on organic carbon and available nutrient status of soil before sowing and after harvest of soybean (Pooled over 2 years)

Treatments	Before sowing of soybean					After harvest of soybean				
	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	S (mg/kg)	OC (g/kg)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	S (m/kg)	OC (g/kg)
Control	152.29	21.20	374.56	10.93	4.28	154.31	25.18	374.33	12.34	4.43
100 % RDF	185.15	24.08	452.89	13.60	5.16	209.22	29.26	452.77	15.49	5.42
100 % RDF+FYM @ 5t/ha	219.43	27.26	470.05	16.28	5.39	223.21	29.50	490.02	17.08	5.91
75 % RDF+25 % P through phospho-compost	210.41	27.12	463.19	15.49	5.35	221.01	29.33	465.74	16.55	5.36
50 % RDF+50 % P through phospho-compost	184.41	24.03	421.27	14.23	5.32	193.03	26.56	424.35	15.47	5.44
25 % RDF+75 % P through phospho-compost	173.44	25.07	414.70	14.17	4.95	186.75	25.44	417.25	13.38	5.10
75 % RDF+25 % N through cotton stalk	193.11	24.60	442.00	16.26	5.28	192.45	27.24	421.03	14.45	5.23
100 % RD-N- through FYM + remaining P through phospho-compost	174.13	21.16	413.74	13.44	5.36	188.47	25.26	420.28	14.39	5.64
SEm (±)	1.53	0.36	0.97	0.15	0.05	0.84	0.12	1.26	0.18	0.02
CD (P = 5 %)	**4.61**	**1.09**	**2.92**	**0.45**	**0.16**	**2.55**	**0.35**	**3.81**	**0.53**	**0.05**

lowest value in control (Table 2). The similar results were recorded by Singh *et al* (2008). The organic manure either alone or in combination of chemical fertilizer caused significant increase in available K. Yadav (1998) stated that beneficial effect of FYM on available potassium may be ascribed to the reduction in the potassium fixation, solublization and release of K due to interaction of organic matter with clay. It may be due to the beneficial effects of organic manures affecting clay-organo interaction and direct K_2O additions widening available K pool of soil.

The organic carbon status at harvest of soybean ranged between 4.43 and 5.91 g per kg. The treatment 100 per cent RDF + FYM 5 t per ha showed the highest value in organic carbon. The lowest organic carbon content was observed in control (Table 2). The organic carbon in soil after harvest of soybean crop was significantly increased in all treatments, particularly in integrated nutrient management treatments. Several researchers (Sarkar *et al*., 2000; More (1994), Ravankar *et al*., 2003, Kundu *et al*., 2008; Muneshwar *et al*., 2008) have observed increase in organic carbon content with integrated nutrient management. The organic carbon is integral part of soil fertility indicator. The fertility of soil is depending on the amount of organic carbon added to soil; hence this function is carried by addition of organic matter to soil. Improvement in organic carbon due to FYM application along with chemical fertilizer is in line with the reports of Kundu *et al*. (2008) and Singh *et al.* (2008). Singh *et al.* (1999) reported a drastic reduction in organic carbon concentration on a continuous application of chemical fertilizer whereas addition of 5 t FYM per ha along with fertilizer N helped in maintaining the original organic matter status in soil.

Effect of treatment on yield and economic evaluation

The performance of the crop and economic evaluation revealed that the seed yield significantly increased by the application of 100 per cent RDF + FYM @ 5t per ha over rest of the treatments. This treatment yielded 2,164 kg per ha with net returns of Rs 85,645 per ha and return per rupee of 4.05 followed by the application of 75 per cent RDF + 25 per cent P through phospho-compost (2,054 kg/ha, Rs 78,137/ha and 3.74 respectively). The corresponding cost of cultivation for the above two treatments were Rs 21142 and Rs 20881, respectively (Table 3). These results are confirmed with the findings of Chaturvedi and Chandel (2005). Babhulkar *et al*. (2000) reported that with the application of 100 per cent RDF and FYM soybean gave a higher grain yield elevating both net returns and benefit-cost ratio. The findings revealed that the application through phospho-compost was highly significant as compare to cotton stalk treatments. The result showed that grain yields in 75 per cent RDF + 25 per cent N through cotton stalk treatment was 1367 kg per ha and with per day return of Rs 408.97 followed by 100 per cent RDF (1030 kg/ha) and control (1022 kg/ha) with per day return of Rs 269.02

Table 3. Effect of different treatment on economics of soybean (Pooled over 2 years)

Treatment	Seed yield (kg/ha)	Stalk yield (kg/ha)	Value of seed (Rs)	Value of stalk (Rs)	Total cost (Rs)	Net returns (Rs)	Return (Rs/day)	B:C Ratio
Control	1022	1753	44058	6102	19574	31893	271.93	1.63
100 % RDF	1030	1763	44424	6137	18821	31552	269.02	1.68
100 % RDF+FYM @ 5t/ha	2164	3595	93265	12515	21142	85646	730.24	4.05
75 % RDF+25 % P through phospho-compost	2054	2737	88482	9528	20881	78137	666.23	3.74
50 % RDF+50 % P through phospho-compost	1655	2131	71337	7421	20076	59530	507.58	2.97
25 % RDF+75 % P through phospho-compost	1457	2396	62746	8344	20358	51468	438.84	2.53
75 % RDF+25 % N through cotton stalk	1367	2296	58884	7995	19605	47965	408.97	2.45
100 % RD-N- through FYM + remaining P through phospho-compost	1698	2782	73148	9684	20389	63271	539.48	3.10
SEm (±)	51.65	35.68	194.70	41.57	23.38	120.19	9.99	0.08
CD (P =5 %)	**110.28**	**107.74**	**587.85**	**125.51**	**70.61**	**362.89**	**30.18**	**0.24**

and Rs 271.93, respectively. The latter two treatments produced lower yields as compared to treatments with integration of inorganics and organics. This might be due to the lesser availability of nutrients, especially nitrogen to the crop at the letter stages of crop growth when the root nodules degenerated and the nitrogen supply falls short of crop requirements during the pod development phase of the crop. These results corroborated the findings of Kundu *et al*. (2008) and Singh and Rai (2004).

From the above study it can be concluded that integration of inorganic fertilizers with organic manures that is the application of 100 % RDF + FYM @ 5 t per ha recorded significantly highest uptake of N, P and K. Highest values were obtained in all treatment over control. The available nitrogen content of the soil ranged from 154.31 to 223.21 kg per ha. In case of available phosphorous content of soil after harvest of crop it was observed that P_2O_5 content of soil ranged from 25.18 to 29.50 kg per ha. The K value ranged between 374.83 to 490.02 kg per ha. Organic carbon after the harvest of soybean was also increased with the combined application of inorganic fertilizers with organic manure. The application of 100 per cent RDF + FYM @ 5 t ha per ha for soybean significantly improved the grain yield and highest net returns with the highest return per rupee. Thus it is suggested that for maximizing yields as well as maintaining soil health and productivity can be furnished by a balanced use of inorganic fertilizers conjunctively with organic manure.

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Present Status of Registration of Soybean Varieties under PPV&FR Act and Future Perspective

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ABSTRACT

In compliance to the international agreement on TRIPS, a sui-generous *system on protection of plant varieties and farmers' rights came into force by enacting PPV&FR Act in 2001 by Government of India. Soybean is one of the 110 crops, which became eligible for protection after gazette notification on April, 2010. Several soybean varieties from public sector institutions, private seed companies and farmers have either been protected or in the process of protection. The soybean cultivation in India is mostly dominated by the public sector protected varieties. These protected soybean varieties are being marketed by public as well as private sector seed producing agencies without obtaining any legal license or paying any royalty or license fees to the legal right holder of these varieties (ICAR) at present. Though the Council had been conferred with the legal right of marketing and licensing others for marketing these varieties, provision of researchers' right for use of protected varieties for further research and unique farmers' right to produce, market without branding and resow own saved seeds by farmers are adequately framed in the said act. Setting of appropriate guidelines to fetch the benefits of this act by legally conferring license to commercialize protected varieties, strengthen the varietal development programme by paying royalty to breeders and prevent unauthorized commercialization of protected varieties by the legal right holder (ICAR) remains to be done.*

Key words: Future perspectives, PPV&FR Act, soybean varieties

The natural diversity is the source of genes for manipulation of genetic background of newly developed plant varieties to fulfill emerging nutritional need of mankind and livestock. The natural plant and animal resources differ in different regions of the world. With the emerging ideas of utilization and benefit sharing out of the product or plant types evolved from these biological diversities, documentation and protection of biological diversity of every country is basic necessity. Several regulatory systems, like CBD (Convention on Bio Diversity), TRIPS (Trade-Related Aspects of Intellectual Property Rights) Agreement and UPOUV (International Union for Protection of New plant Varieties) came into force in order to protect biological resources. India is signatory to CBD and TRIPS Agreement with obligation to develop *sui generis* system of plant variety protection. To meet the obligation, the Protection of Plant Varieties and Farmers' Right Act (PPV&FR Act-2001) was enacted in

[1,3]*Principal Scientist;* [2]*Scientist (Senior Scale);* [4]*Ex-Principal Scientist*

2001. Subsequently, crop-wise guidelines for protection of different crop varieties were developed. Presently, 110 crop species are eligible for protection under this act. The objectives of adopting and implementing PPV&FR Act-2001 are as follows.

- To provide establishment of an effective system for protection of plant varieties,
- To provide rights to the farmers and plant breeders,
- To stimulate investment for research and development and facilitate growth of the seed industry, and
- To ensure availability of high quality seeds and planting materials of improved varieties to the farmers and seed producing agencies.

Salient features of PPV&FR Act-2001

Eligibility for protection: For a variety to be eligible for registration, it must conform to the criteria of novelty, distinctiveness, uniformity and stability (NDUS), as described below [Section 15 (1)–(3)]. For the purposes of the Act, a new variety shall be deemed to be: (a) *Novel*, if, at the date of filing of the application for registration for protection, the propagating or harvested material of such a variety has not been sold or otherwise disposed of by or with the consent of its breeder or his successor for the purposes of exploitation of such variety (i) in India, earlier than one year, (ii) or outside India, in the case of trees or vines earlier than six years, or, in any other case, earlier than four years, before the date of filing such applications. Provided that a trial of a new variety which has not been sold or otherwise disposed off shall not affect the right to protection. Provided further that the fact that on the date of filing the application for registration, the propagating or harvested material of such variety has become a matter of common knowledge other than through the aforesaid manner shall not affect the criteria of novelty for such variety, (b) *Distinct*, if it is clearly distinguishable by at least one essential characteristic from any other variety whose existence is a matter of common knowledge in any country at the time of filing of the application, (c) *Uniform*, if subject to the variation that may be expected from the particular features of its propagation, it is sufficiently uniform in its essential characteristics, and (d) *Stable*, if it's essential characteristics remain unchanged after repeated propagation or, in the case of a particular cycle of propagation, at the end of each such cycle. The variety will be subjected to such distinctiveness, uniformity and stability tests as shall be prescribed.

Breeders' rights: The certificate of registration for a variety issued under this Act shall confer an exclusive right on the breeder or his successor or his agent or licensee, to produce, sell, market, distribute, import or export of the variety [Section 28 (1)]. ***Researchers' right:*** The researchers have been provided access to protected varieties for bona fide research purposes [Section 30]. This Section states, 'Nothing contained in this Act shall prevent (a) the use of any variety registered under this Act by any person using such variety for conducting experiments or research; and (b) the use of a variety by any person as an initial source of a variety for the purpose of creating other varieties provided that the authorization of the breeder of a registered variety is required where the repeated use of such variety as a parental line is necessary for commercial production of such other newly developed variety.

Farmers' rights: The farmers' rights of the Act define the privilege of farmers and their right to protect varieties developed or conserved by them [Chapter VI]. Farmers can save, use, sow, resow, exchange, share and sell farm produce of a protected variety except sale under a commercial marketing arrangement (branded seeds) [Section 39 (1), (i)–(iv)]. Further, the farmers have also been provided protection of innocent infringement when, at the time of infringement, a farmer is not aware of the existence of breeder rights [Section 42 (1)]. A farmer who is engaged in the conservation of genetic resources of landraces and wild relatives of economic plants and their improvement through selection and preservation, shall be entitled in the prescribed manner for recognition and reward from the Gene Fund, provided the material so selected and preserved has been used as donor of genes in varieties registrable under the Act. The expected performance of a variety is to be disclosed to the farmers at the time of sale of seed/propagating material. A farmer or a group of farmers or an organization of farmers can claim compensation according to the Act, if a variety or the propagating material fails to give the expected performance under given conditions, as claimed by the breeder of the variety.

Communities' rights: The rights of the communities as defined provide for compensation for the contribution of communities in the evolution of new varieties in quantum to be determined by the PPVFR Authority [Section 41 (1)].

Special provision of protection of notified varieties under Extant notified varieties category

Varieties are released and notified in India under Seed Act 1966. The plant varieties are developed by breeding and evaluated in developing station for their yield potential and other useful characteristics. The superior lines or genotypes are then tested in the national trials for three years in three stages of Initial Varietal Trial (IVT), Advanced Varietal Trial I (AVT I) and Advanced Varietal Trial II (AVT II). The qualifying varieties against the national checks are only tested in the subsequent advanced varietal trials. The qualifying most promising varieties are identified in Annual Group Meeting of All India Co-ordinated Research Project on Soybean (AICRPS), thereafter released and notified by Central Variety release Committee. During these three years, resistance to diseases and insect-pest, quality parameters, plant variety characters are also tested and well documented along with yield of the variety. The varieties which are not older than 15 years can be protected under this Extant Notified Varieties category. The date of notification is considered as the initial date of commencement of protection of plant varieties and protection is granted for the period of 15 years from the date of notification provided other formalities are duly abided by the breeder or holder of the right of protection.

Brief procedure of protecting plant varieties under Extant Notified Varieties category

The protection of plant varieties and farmers' right authority was formed under the provision of PPV& FR Act-2001 to facilitate all the procedure of protection of plant varieties. The protection of varieties is conferred as per Distinctiveness, Uniformity and Stability (DUS) Test guidelines of that crop species. Applications of protection of varieties are accepted only after publication of DUS Testing guidelines and gazette notification of crops eligible for protection. The DUS Testing guideline of soybean (*Glycine max* (L.) Merrill.) was published on Oct, 2009 and Indian Gazette notification of eligibility of soybean varieties for protection came on April, 2010 (gazette notification number S.O 993(E) dated 30.04.2010). Afterward, process of granting of protection to soybean varieties was started. The application of plant variety protection (Form 1 duly filled) along with all other relevant documents and application (presently Rs. 200.00) and registration fees (presently Rs 2000). Every application for registration will have to be accompanied with the following information [Section 18 (a–h)]:

(a) Denomination assigned to such variety by the applicant;
(b) An affidavit sworn by the applicant that such variety does not contain any gene or gene sequence involving terminator technology;
(c) The application should be in such form as specified by regulations;
(d) A complete passport data of the parental lines from which the variety has been derived along with the geographical location in India from where the genetic material has been taken and all such information relating to the contribution, if any, of any farmer, village community, institution or organization in breeding, evolving or developing the variety;
(e) A statement containing a brief description of the variety, bringing out its characteristics of novelty, distinctiveness, uniformity and stability as required for registration;
(f) Such fees as prescribed;
(g) Contain a declaration that the genetic material or parental material acquired for breeding, evolving or developing the variety has been lawfully acquired; and
(h) Such other particulars as prescribed.
(i) Requisite quantity of seeds (on date two packets of 300 g each).

The application of each variety is scrutinized by the PPV&FR Authority and the variety along with the essential distinct characters is published in the Plant Variety Journal. Six month time is given to invite objection against the ownership of the variety or any other benefit sharing. After this period if no objection is received, the variety is protected under PPV&FR Act-2001 and registered in the National Plant Variety Register.

Status of protection of notified soybean varieties under Extant notified varieties category

The provision of protection of notified soybean varieties was started with the Indian Gazette publication of Soybean DUS testing guidelines in Oct, 2009. Presently 21 soybean notified soybean varieties are protected and process of protection under way for left out varieties. These protected soybean varieties (Table 1 and 2) are most important in terms of popularity and acreage.

Registration to Confer Right

As per the PPV&FRAct-2001 clause 28.- (1) Subject to the other provisions of this Act, a certificate of registration for a variety issued under this Act shall confer an exclusive right on the breeder or his successor, his agent or licensee, to produce, sell, market, distribute, import or export the variety. In the case of these varieties the exclusive right is vested to ICAR, New Delhi.

Benefit of farmers to grow the protected varieties

Where any propagating material of a variety registered under this Act has been sold to a farmer or a group of farmers or any organisation of farmers, the breeder of such variety shall disclose to the farmer or the group of farmers or the organisation of farmers, as the case maybe, the expected performance under given conditions, and if such propagating material fails to provide such performance under such given conditions, the farmer or the group of farmers or the organisation of farmers, as the case may be, may claim compensation in the prescribed manner before the Authority and the Authority, after giving notice to the breeder of the variety and after providing him an opportunity to file opposition in the prescribed manner and after hearing the parties, may direct the breeder of the variety to pay such compensation as it deems fit, to the farmer or the group of farmers or the organisation of farmers, as the case may be.

The future perspective of variety protection under PPV&FR Act 2001

The objective of this act is to protect plant varieties and give reward for the intellectual output of plant breeders, *i.e.* plant varieties which are otherwise not covered under the patent act. The act came into force in 2001 and after that several varieties from both public sector institutes and private organisations involved in development of plant varieties and their marketing had been protected. The seed companies in India are growing rapidly and have significant share in varietal diversity. The act renders the full commercial right to the breeder of the variety and legally prevents others from commercial exploitation of such protected variety which was not possible earlier. The public sector institutes are working for the betterment of Indian agriculture and in due course had developed several varieties which are being cultivated in different parts of the country

Table 1. Details of registered soybean varieties by ICAR-SAU system under PPV&FR Act-2001

S.. No.	Name of variety	Notification number and date	Centre of development	Area of adaptation	Name of breeders and associates	PPV&FRA Registration number
1	Jawahar Soybean 97-52 (JS 97-52)	S.O. 2458(E)/ 16.10.08	JNKVV, Jabalpur, M P	Central zone and North Eastern zones	Dr A N Shrivastava, Dr M K Shrivastava, Dr S K Rao	241/2013
2	Jawahar Soybean 95-60 (JS 95-60)	S.O. 1178(E)/ 20.07.2007	JNKVV, Jabalpur, M P	Madhya Pradesh	Dr A N Shrivastava, Dr M K Shrivastava, Dr R K Verma	246/2013
3	JS 93-05 (Jawahar Soybean 93-05)	S.O. 937(E)/ 04.09.2002	JNKVV, Jabalpur, M P	Central zone	Dr A N Shrivastava, Dr M K Shrivastava, Dr R K Verma	244/2013
4	Samrudhi (MAUS 71)	S.O. 937(E)/ 04.09. 2002	VNMKV, Parbhani, M S	North Eastern zone and Maharashtra	Dr A R Singh, Shri D G Dalvi	242/2013
5	Ahilya-4 (NRC 37)	S.O. 92(E)/ 22.02.2001	ICAR-DSR, Indore, M P	Central zone	Dr P G Karmakar, Shri Upendra Singh, Dr S P Tiwari	156/2012
6	TAMS 38	S.O. 122(E)/ 02.02.2005	RRC, Dr PDKV, Amravati, M S and BARC, Mumbai, M S	Vidarbha region of Maharashtra	Dr S E Pawar, Dr J G Manjaya Dr R S Nandanwar, Shri R B Dhale, Shri P Y Sontake	26/2014
7	TAMS 98-21	S.O. 122(E)/ 06.02.2007	RRC, Dr PD KV, Amravati and BARC, Mumbai, M S	Maharashtra	Dr S E Pawar, Dr J G Manjaya Dr R S Nandanwar, Shri R B Dhale, Shri P Y Sontake	35/2014
8	Pant Soybean-1347 (PS 1347)	S.O. 2458(E)/ 16.10.2008	GBPUA&T, Pant Nagar, Uttarakhand	North Plain Zone	Dr B V Singh, Dr Pushpendra, Dr Kamendra Singh	361/2014

Table 1 contd.

S. No.	Name of variety	Notification number and date	Centre of development	Area of adaptation	Name of breeders and associates	PPV&FRA Registration number
9	Pant Soybean -1225 (PS 1225)	S.O. 449(E)/ 11.2.2009	GBPUA&T, Pant Nagar, Uttarakhand	Tarai and Bhabar Region of U P and Uttarakhand	Dr B V Singh, Dr Pushpendra, Dr Kamendra Singh	360/2014
10	Pant Soya- 1092	S.O. 821 (E)/ 13.9.2000	GBPUA&T, Pant Nagar, Uttarakhand	Tarai and Babar region of Uttar Pradesh, Uttarakhand	Dr Pushpendra, Dr Kamendra Singh, Dr Hari Har Ram	359/2014
11	MAUS 81	S.O. 161(E)/ 04.02.2004	VNMKV, Parbhani, M S	Central zone	Dr A R. Singh, Shri D G Dalvi,	15/2015
12	Pratikar (MAUS 61)	S.O. 937(E)/ 4.9.2002	VNMKV, Parbhani, M S	Southern zone	Dr A R Singh, Shri D G Dalvi,	10/2015
13	MAUS 158	SO. 2137(E)/ 31.08.2010	VNMKV, Parbhani, M S	Marathwada region of Maharashtra	Dr A R Singh, Dr P R Khapre, Dr K S Baig, Dr I A Madrap	09/2015
14	PUSA 9712 (DS 9712)	SO. 1566 (E)/ 5/11/05	IARI, New Delhi	North Plain zone	Dr V K S Rana, Dr S K Lal, Dr R L Sapra, Dr B B Singh,	12/2015
15	JS 20-29	S.O 1146(E)/ 24.04.2014	JNKVV, Jabalpur, M P	Central zone	Dr A N Shrivastava, Dr M K Shrivastava, Dr R K Verma, Dr D K Mishra	246/2015
16	JS 20-34	S.O 1146(E)/ 24.04.2014	JNKVV, Jabalpur, M P	Central zone	Dr A N Shrivastava, Dr M K Shrivastava, Dr R K Verma, Dr D K Mishra	247/2015

Table 1 contd.

S. No.	Name of variety	Notification number and date	Centre of development	Area of adaptation	Name of breeders and associates	PPV&FRA Registration number
17	MAUS 162	S. O. 1919(E)/ 30.07.2014	VNMKV, Parbhani, M S	Marathwada region of Maharashtra	Dr K S Baig, Dr P R Khapre, Dr I A Madrap, Dr A R Singh	244/2015
18	MACS 1188	S. O. 2817(E) 19.09.2013	MACS (ARI), Pune, M S	Southern zone	Dr Philips Varghese, Dr S P Taware, Dr G B Halvankar,	245/2015
19	RKS 45	S.O. 2815(E) 19.09.2013	Agriculture University Kota, Rajasthan	Rajasthan	Dr Mashiat Ali, Dr Rajesh Mahawar	248/2015
20	RKS 18	S.O. 122(E) 06.02.2007	Agriculture University Kota, Rajasthan	Southern and North Eastern zones	Dr Mashiat Ali , Dr Pratap Singh, Dr V P Gupta,	249/2015
21	RAUS 5	S.O. 1703(E)/ 5.10.07	Agriculture University Kota, Rajasthan	North Eastern zone	Dr Mashiat Ali	250/2015

Details of soybean growing zones

Name of Zone	Respective states
Central Zone	Madhya Pradesh, Rajasthan, Gujarat, Bundelkhand region of UP and, Marathwada and Vidarbha Region of Maharashtra
Southern Zone	Southern Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu
Northern Plain Zone	Delhi, Haryana, Punjab, Uttar Pradesh (Except Bundelkhand Region), Bihar
Northern Hill Zone	Himachal Pradesh and Uttarakhand
North Eastern Zone	Chhattisgarh, Jharkhand, Orissa, West Bengal, North Eastern States

Table 2. DUS Characteristics of protected extant notified soybean varieties

S. No.	Varieties	DUS characteristics				
		DUS 1 Hypocotyl anthocyanin pigmentation	**DUS 2 Plant growth type**	**DUS 3 Days to 50 % flowering**	**DUS 4 Leaf : Shape**	**DUS 5 Leaf : Color**
1.	Jawahar Soybean 97-52 (JS 97-52)	Absent	Semi determinate	Medium	Pointed ovate	Green
2.	Jawahar Soybean 95-60 (JS 95-60)	Present	Determinate	Early	Lanceolate	Dark Green
3.	JS 93-05 (Jawahar Soybean 93-05)	Present	Semi determinate	Medium	Lanceolate	Dark Green
4.	Samrudhi (MAUS 71)	Present	Semi determinate	Medium	Pointed ovate	Dark green
5.	Ahilya-4 (NRC 37)	Absent	Determinate	Medium	Pointed ovate	Green
6.	TAMS 38	Absent	Determinate	Medium	Pointed ovate	Dark Green
7.	TAMS 98-21	Present	Determinate	Medium	Pointed ovate	Green
8.	Pant Soybean-1347 (PS 1347)	Absent	Determinate	Late	Lanceolate	Dark Green
9.	Pant Soybean -1225 (PS-1225)	Absent	Determinate	Late	Pointed ovate	Green
10.	Pant Soya- 1092	Present	Determinate	Late	Pointed ovate	Dark Green
11.	MAUS-81	Present	Semi determinate	Medium	Pointed ovate	Dark Green
12.	Pratikar (MAUS 61)	Present	Semi determinate	Medium	Pointed ovate	Green
13.	MAUS 158	Present	Semi determinate	Medium	Pointed ovate	Dark Green
14.	PUSA 9712 (DS 9712)	Absent	Determinate	Late	Pointed ovate	Green
15.	JS 20-29	Absent	Semi determinate	Medium	Pointed ovate	Green
16.	JS 20-34	Absent	Determinate	Early	Rounded ovate	Dark Green
17.	MAUS 162	Present	Semi determinate	Medium	Pointed ovate	Dark Green
18.	MACS 1188	Absent	Determinate	Medium	Rounded ovate	Green
19.	RKS 45	Absent	Determinate	Medium	Pointed ovate	Dark Green
20.	RKS 18	Present	Determinate	Medium	Pointed ovate	Dark Green
21.	RAUS 5	Present	Determinate	Medium	Pointed ovate	Dark Green

Table 2. Contd

S. No.	Varieties	DUS characteristics				
		DUS 7	DUS 8	DUS 9	DUS 10	DUS 11
		Flower Color	Plant Height	Pod pubescence	Pod pubescence color	Pod color
1.	Jawahar Soybean 97-52 (JS 97-52)	White	Medium	Present	Tawny	Brown
2.	Jawahar Soybean 95-60 (JS 95-60)	Violet	Medium	Absent	NA	Black
3.	JS 93-05 (Jawahar Soybean 93-05)	Violet	Medium	Absent	NA	Black
4.	Samrudhi (MAUS 71)	Violet	Medium	Absent	NA	Brown
5.	Ahilya-4 (NRC 37)	White	Medium	Present	Tawny	Brown
6.	TAMS 38	White	Medium	Present	Grey	Brown
7.	TAMS 98-21	Violet	Tall	Present	Tawny	Brown
8.	Pant Soybean-1347 (PS 1347)	White	Medium	Present	Tawny	Brown
9.	Pant Soybean -1225 (PS-1225)	White	Tall	Present	Grey	Brown
10.	Pant Soya- 1092	Violet	Tall	Present	Tawny	Brown
11.	MAUS-81	Violet	Medium	Absent	NA	Brown
12.	Pratikar (MAUS 61)	Violet	Tall	Present	Grey	Brown
13.	MAUS 158	Violet	Medium	Absent	NA	Brown
14.	PUSA 9712 (DS 9712)	White	Tall	Present	Tawny	Brown
15.	JS 20-29	White	Medium	Present	Tawny	Brown
16.	JS 20-34	White	Medium	Absent	NA	Yellow
17.	MAUS 162	Violet	Tall	Absent	NA	Brown
18.	MACS 1188	White	Medium	Absent	NA	Brown
19.	RKS 45	White	Medium	Present	Tawny	Brown
20.	RKS 18	Violet	Medium	Absent	NA	Brown
21.	RAUS 5	Violet	Tall	Absent	NA	Brown

Table 2. Contd

S. No.	Varieties	DUS characteristics				
		DUS 13	DUS 14	DUS 15	DUS 16	DUS 17
		Days to maturity	Seed size	Seed shape	Seed color	Seed luster
1.	Jawahar Soybean 97-52(JS 97-52)	Medium	Small	Spherical	Yellow	Dull
2.	Jawahar Soybean 95-60(JS 95-60)	Early	Large	Spherical	Yellow	Dull
3.	JS 93-05 (Jawahar Soybean 93-05)	Early	Medium	Spherical	Yellow	Shiny
4.	Samrudhi (MAUS 71)	Medium	Medium	Spherical	Yellow	Dull
5.	Ahilya-4 (NRC 37)	Medium	Medium	Spherical	Yellow	Shiny
6.	TAMS 38	Early	Medium	Elliptical	Yellow	Shiny
7.	TAMS 98-21	Medium	Medium	Elliptical	Yellow	Dull
8.	Pant Soybean-1347 (PS 1347)	Late	Medium	Spherical	Yellow	Shiny
9.	Pant Soybean -1225 (PS-1225)	Late	Small	Spherical	Yellow	Shiny
10.	Pant Soya- 1092	Late	Large	Spherical	Yellow	Dull
11.	MAUS-81	Medium	Medium	Spherical	Yellow	Dull
12.	Pratikar (MAUS 61)	Medium	Medium	Spherical	Yellow	Dull
13.	MAUS 158	Medium	Medium	Spherical	Yellow	Dull
14.	PUSA 9712 (DS 9712)	Late	Medium	Spherical	Yellow	Dull
15.	JS 20-29	Medium	Large	Spherical	Yellow	Dull
16.	JS 20-34	Early	Medium	Spherical	Yellow	Shiny
17.	MAUS 162	Medium	Medium	Spherical	Yellow	Shiny
18.	MACS 1188	Medium	Large	Spherical	Yellow	Shiny
19.	RKS 45	Medium	Medium	Spherical	Yellow	Dull
20.	RKS 18	Early	Medium	Spherical	Yellow	Dull
21.	RAUS 5	Medium	Medium	Spherical	Yellow	Dull

Table 2. Contd

S. No.	Varieties	DUS characteristics				
		DUS 18	DUS 19	DUS 20	DUS 21	DUS 22
		Coloration due to peroxidase activity in seed coat	Seed hilum colour	Seed cotyledon colour	Seed oil content (%)	Seed protein content (%)
1.	Jawahar Soybean 97-52(JS 97-52)	Present	Black	Yellow	High	Medium
2.	Jawahar Soybean 95-60(JS 95-60)	Absent	Grey	Yellow	Medium	Medium
3.	JS 93-05 (Jawahar Soybean 93-05)	Absent	Black	Yellow	Medium	High
4.	Samrudhi (MAUS 71)	Absent	Black	Yellow	High	High
5.	Ahilya-4 (NRC 37)	Absent	Brown	Yellow	Average	Low
6.	TAMS 38	Present	Brown	Yellow	Medium	Medium
7.	TAMS 98-21	Absent	Brown	Yellow	Medium	High
8.	Pant Soybean-1347 (PS 1347)	Present	Brown	Yellow	Medium	Medium
9.	Pant Soybean -1225 (PS-1225)	Absent	Brown	Yellow	Average	High
10.	Pant Soya- 1092	Present	Black	Yellow	Medium	High
11.	MAUS-81	Absent	Black	Yellow	High	High
12.	Pratikar (MAUS 61)	Absent	Brown	Yellow	High	High
13.	MAUS 158	Absent	Black	Yellow	Medium	High
14.	PUSA 9712 (DS 9712)	Present	Black	Yellow	Average	Medium
15.	JS 20-29	Present	Black	Yellow	High	High
16.	JS 20-34	Present	Black	Yellow	High	High
17.	MAUS 162	Absent	Black	Yellow	High	High
18.	MACS 1188	Absent	Black	Yellow	Medium	High
19.	RKS 45	Absent	Brown	Yellow	High	High
20.	RKS 18	Absent	Black	Yellow	Medium	High
21.	RAUS 5	Absent	Brown	Yellow	Medium	High

and are easily available. The varietal development programmes are long-term intellectual labour and capital intensive. The act encourages the private stakeholders to market such improved varieties by taking the licence to produce and sell after payment of licence fees as agreed up on between the plant breeder right holders and the private partners.

As per Clause 64 of the act the right of the breeder or registered agent or licensee is infringed if any unauthorized person sells, exports, imports or produces such variety without the permission of its breeder or registered licensee. Private sectors are mostly involved in development of hybrids and high value low volume crops like vegetables. Soybean is high volume low valued crop and most of the varieties are developed by public sectors institutions and universities. Private seed companies are making profit by marketing these popular and high yielding soybean varieties which are already protected under the act, without paying any licence fees or royalties to the breeders or breeding institutions at present.

ICAR should frame guidelines as per the PPV&FR Act-2001 to collect licence fees from private parties for marketing such varieties and pay royalty to the breeders for their intellectual properties, *i.e.* popular soybean varieties. Presently institutes and universities are producing the breeder seeds as per the requirements of private companies and public sector seed producing agencies. Subsequent stages of seed chain are produced by the seed producing parties and sold in the market. The following strategies may be opted for formulating the guideline to give licence of marketing the public sector bred soybean or other crop varieties.

Option 1: The private parties may be given non-exclusive rights to produce and market of such protected soybean varieties on payment of lump-sum amount of licence fees as decided by council or universities or institutions. The private parties may be given authority to produce Breeder Seed and subsequent stages of seed chain or breeder seed may be produced at originating centres and premium price may be charged for breeder seeds.

Option 2: The private parties may be given non-exclusive rights to produce and market certified seeds of such protected soybean varieties on payment of licence fees and royalty may be collected as certain percentage of value of certified seed marketed. Breeder seed may be supplied by the originating institutions on a premium price or authority of production of Breeder seed may be given to the private parties.

In all such cases where authority to produce breeder seed is given to private parties the monitoring of breeder seed production should be followed by the monitoring team comprising the breeder or representative of the originating institute/university, representative of certification agencies and other members.

To fetch the fruit of this new law, guidelines should be framed by the Council and the universities soon to strengthen the varietal developmental programme and prevent unauthorized marketing of protected soybean varieties.

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Protection of Plant Varieties and Farmers' Right Act-2001 (http://www.plantauthority.gov.in)

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Genetic Variability and Association Studies in New Soybean Germplasm Accessions

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Yield is the principal factor for determining improvement of a crop. Like other legumes, seed yield in soybean is a quantitative character and influenced by a number of yield contributing traits. The selection of desirable types should, therefore, be based on yield as well as on other yield components. Information on mutual association between yield and yield components is necessary for efficient utilization of the genetic stock in crop improvement program of this crop. Although, correlation coefficient is useful in quantifying the size and direction of trait associations, it can be misleading due to the indirect effect of other traits (Dewey and Lu, 1959). Wright (1934) proposed a method called path analysis, which partitions the estimated correlations into direct and indirect effects for better understanding of the association among traits. However, the crop has a narrow genetic base which is a major constraint in breeding programs. Low genetic variability reduces the fitness of a population making it susceptible to diseases, pests and environmental challenges. Use of germplasm in breeding program can help in broadening the genetic base by increasing the possibility of new recombinations. The ICAR-Indian Institute of Soybean Research is a National Active Germplasm Site (NAGS) which collects conserve, characterize and evaluate the soybean germplasm.

A total of 47 new soybean accessions collected were sown during *kharif* 2014 to evaluate and conserve in the NAGS. All the 47 new accessions were evaluated in 3 m row length with 45 cm x 10 cm row to row and plant to plant spacing. The observations were recorded on ten quantitative traits namely, days to flower, days to pod initiation, days to maturity, plant height, number of primary branches, pods per plant, seeds per pod, nodes per plant, hundred seed weight and seed yield per plant (Table 1). The genotypic and phenotypic coefficient

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of variation, heritability and genetic advance for each character was computed as per standard formulae (Burton and Devane 1953; Johnson *et al*., 1955; Allard, 1960) and correlation and path values were worked out according to the methods described by Webber and Murthy (1952) and Dewey and Lu (1959) respectively.

Table 1. Details of the 47 new soybean accessions used in the present study

S. No.	Name of the Collection	Location of collection
1	VL Bhatt 65, VLB 201, VLB 202, VS 2010-108, VS 2010-103, VS 2007-221, VS 2010-105, VRPH 1961, VS 2008-50, VS 2010-115, VS 2007-207, VS 2011-112, VS 2011-121, VS 2011-101, VS 2011-118, VS 2011-119, VS 2011-122, VS 2011-116, VS 2011-107, VS 2011-105, VS 2011-109, VS 2011-113, VS 2011-117, VS 2011-114, VS 2011-106 (**25 accessions**)	Almora
2	SL 1123 (**1 accession**)	Ludhiana
3	EC 785505, EC 785506 (**2 accessions**)	Nigeria
4	EC 784252, EC 784253, EC 784254 (**3 accessions**)	USA
6	CAT 3476, CAT 3480, CAT 3483, CAT 3484, CAT 3485, CAT 3489 (**6 accessions**)	Manipur
7	KP/SC-1456, CAT 3493, CAT 3495, CAT 3496, CAT 3497, CAT 3498, CAT 3499, CAT 3501, CAT 3506, CAT 3507 (**10 accessions**)	Nagaland

In the present study 47 new soybean accessions were evaluated to multiply, conserve, distribute and utilize promising accessions for soybean improvement programme. The ANOVA indicated significant and wide variability for the traits studied except for the primary branches and seeds per pod. To examine breeding utilities, few genetic parameters were studied for the new accessions. The estimates depicting the genetic variability including mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (h^2) and genetic advance (GA) are presented in table 2. Except, few traits like number of seeds per pod all other traits exhibited wide range of variations. This was substantiated by the fact that seed yield per plant, number of nodes per plant, pods per plant, days to flowering and hundred seed weight showed highest PCV and GCV indicating presence of extensive variability rendering selection effective. Moderate to low estimates of PCV and GCV were recorded for branches per plant, seeds per pod and days to maturity, while it was rather low for seeds per pod and days to flowering. As it has been seen here, these traits exhibited moderate to low PCV and GCV in a number of similar other studies (Bangar *et al*., 2003; Rajkumar *et al*., 2010). The narrow

Table 2. Estimates of variability parameters for ten quantitative traits in forty seven new germplasm accessions

Characters	Mean	Range	GCV (%)	PCV (%)	h_b^2	GA
Days to flowering	42.61	34-93	25.36	27.66	0.840	20.41
Days to pod initiation	53.51	45-98	22.65	23.78	0.907	23.77
Days to maturity	106.14	97-137	8.84	9.44	0.877	18.12
Plant height	51.43	23-90	26.28	29.64	0.786	24.69
Primary branches (No/plant)	4.94	2.4-9.4	9.59	44.78	0.045	0.209
Pods (No/plant)	36.41	13.8-83.2	35.92	54.31	0.437	17.82
Seeds (No/pod)	2.39	1.4-4.1	8.47	30.75	0.075	0.115
Nodes (No/plant)	12.48	8.2-19.6	21.18	22.16	0.913	5.21
100- seed weight	11.23	3.3-17.2	28.34	34.42	0.678	5.40
Seed yield (g/plant)	6.33	1.2-17.8	53.03	57.54	0.849	6.37

differences between PCV and GCV observed for the traits namely, days to flowering, days to pod initiation and number of nodes per plant indicated the lesser influence of environment in expression of these traits. This is the other indication of genetic improvement for these traits to be effective through selection. Lower difference between PCV and GCV was observed in other experiment also (Shivakumar *et al.*, 2011).

Genetic contribution to phenotypic expression of a trait is better reflected by the estimates of heritability. A higher estimate of heritability indicates presence of more fixable variability. Prediction of successful selection becomes more accurate if it is based on estimates of heritability coupled with genetic advance, because it gives estimates not only of genetic contribution but of expected genetic gain out of selection as well. In this study, high heritability coupled with high genetic advance was recorded for days to flowering, days to pod initiation, days to maturity, plant height, number of nodes per plant, seed yield per plant (Table 2). It, thus, indicated that better expressions of these traits are primarily due to the genetic factors and hence fixable. Depending upon the positive or negative effect of each interacting traits, the yield may either be high or low. Hence it is imperative to study the correlation among the yield attributing traits. In the present study, it was found that number of primary branches, pods per plant, seeds per pod and hundred seed weight showed positive and significant correlation with yield (Table 3). Thus, selection based on these traits is expected to contribute towards yield enhancement. However, the seed yield is negatively associated with days to flower, days to pod initiation, days to maturity, plant height and number of nodes per plant. Similar results were also reported earlier (Nutan and Gabrial, 2016; Sudhanshu *et al.*, 2015).

Table 3. Correlation coefficients for seed yield and yield component traits in new 47 germplasm accessions

Characters	Days to flower	Days to pod initiation	Days to maturity	Plant height (cm)	Primary branches (No/ plant)	Pods (No/ plant)	Seeds (No / pod)	Nodes (No/ plant)	Hundred seed weight (g)	Seed yield (g/ plant)
Days to flower	**1.000**									
Days to pod initiation	0.966	**1.000**								
Days to maturity	0.686	0.690	**1.000**							
Plant height	0.393	0.400	-0.008	**1.000**						
Primary branches (No/plant)	0.142	0.144	0.232	-0.208	**1.000**					
Pods (No/plant)	-0.040	0.041	-0.235	0.027	0.455	**1.000**				
Seeds (No/ pod)	-0.471	-0.456	-0.313	-0.036	-0.038	-0.072	**1.000**			
Nodes (No/plant)	0.603	0.624	0.201	0.742	0.072	0.188	-0.256	**1.000**		
Hundred seed weight (g)	-0.628	-0.630	-0.329	-0.661	0.226	0.026	0.424	-0.750	**1.000**	
Seed yield (g/ plant)	-0.316	-0.281	-0.328	-0.339	0.468	0.677	0.263	-0.244	0.548	**1.000**

Table 4. Phenotypic path coefficient analysis for ten yield component traits in new germplasm accession

Characters	Days to flower	Days to pod initia-tion	Days to maturity	Plant height (cm)	Primary branches (No/ plant)	Pods (No/ plant)	Seeds (No/ pod)	Nodes (No/ plant)	Hundred seed weight (g)	Seed yield (g/ plant)
Days to flower	0.3772	-0.2132	-0.0641	-0.0529	0.0054	-0.0265	-0.0804	0.0320	-0.2941	-0.3167
Days to pod initiation	0.3646	-0.2205	-0.0644	-0.0538	0.0054	0.0270	-0.0779	0.0331	-0.2955	-0.2819
Days to maturity	0.2591	-0.1522	-0.0933	0.0011	0.0088	-0.1547	-0.0534	0.0107	-0.1545	-0.3285
Plant height	0.1484	-0.0882	0.0008	-0.1344	-0.0079	0.0181	-0.0062	0.0393	-0.3098	-0.3399
Primary branches (No/plant)	0.0537	-0.0318	-0.0217	0.0280	0.0377	0.2992	-0.0066	0.0038	0.1058	0.4681
Pods (No/plant)	-0.0153	-0.0091	0.0220	-0.0037	0.0172	0.6563	-0.0123	0.0100	0.0123	0.6774
Seeds (No/ pod)	-0.1779	0.1008	0.0292	0.0049	-0.0015	-0.0475	0.1705	-0.0136	0.1986	0.2637
Nodes (No/plant)	0.2275	-0.1378	-0.0188	-0.0998	0.0027	0.1238	-0.0437	0.0530	-0.3516	-0.2445
Hundred seed weight (g)	-0.2369	0.1391	0.0308	0.0889	0.0085	0.0172	0.0723	-0.0398	0.4683	0.5485

RESIDUE= 0.4795

In order to obtain a clear picture of the contribution of each componential character in the total genetic architecture of yield in soybean path analysis was employed in the present study. The direct effect on seed yield of traits days to flowering, primary branches per plant, pods per plant, seeds per pod, number of pods per plant, nodes per plant and hundred seed weight was positive and high where as rest of the traits found have direct negative effect on seed yield (Table 4). Sudhanshu *et al*. (2015) reported high direct effect of biological yield, number of pods per plant and 100 seed weight on seed yield. Whereas Mukesh and Kamendra (2009) reported pods per plant, total dry matter weight per plant and primary branches per plant were found to have high direct effect on seed yield. The characters with high positive correlation and high direct effects are amenable for selection. Hence, path analysis studies of present investigation revealed that pods per plant and 100 seed weight were important yield components with high direct effects on improvement for seed yield.

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Effect of Weed Management and Fertility Levels on Productivity and Economics of Soybean [*Glycine max* (L.) Merr.] in South-Eastern Rajasthan

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Soybean [*Glycine max* (L.) Merr.] ranks first amongst oilseed crops in the world and it contributes nearly 25 per cent of worlds total oil and fat production. In India, soybean is topmost oilseed crop currently covering 11.23 m ha area with expected production of 14.22 million tones and productivity of 1,266 kg per ha (http://eands.dacnet.nic.in/ Advance_ Estimates.htm). Rajasthan is one of the major soybean growing states having an area of 0.92 m ha next to Madhya Pradesh and Maharashtra. In rainy season, about 85 per cent area of South-Eastern Rajasthan is covered by soybean crop. Among the various factors of low productivity of soybean, competition by weeds is the major one. In order to achieve enhanced crop production and higher benefits from applied inputs, weeds must be managed using any of the safe and effective weed control measures. Presently recommended pre–emergence herbicides are either having narrow spectrum of weed control or less effective against different flushes of broad leaved weeds.

Next to weed management in soybean, nutrient management is another important aspect, which can significantly augment the productivity of soybean. It becomes immediate necessity to restore the soil productivity by improving the overall fertility and health of the arable land through nutrient management. Hence, to evaluate the productivity and economical viability of soybean, the present investigation was under taken.

A field experiment was conducted at Agricultural Research Station, Ummedganj, Kota (Rajasthan) during *kharif* 2013 and 2014 to evaluate the productivity and economical viability of soybean as influenced by weed management and fertility levels. The soil of the experimental field was clay loam in texture, alkaline in reaction (pH 7.97 and 7.99), medium in organic carbon (0.55 and 0.53 %), medium in available nitrogen (347 and 336 kg/ha), medium in

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available phosphorus (24.89 and 23.92 kg/ha) and high in available potash (336 and 318 kg/ha) and low in available S (9.1 and 9.3 ppm) during the year 2013 and 2014, respectively.

The experiment was laid out in split plot design comprising of seven weed management practices in main plot [weedy check, two hand weeding (HW) at 20 and 40 days after sowing (DAS), Pendimethalin @ 1.0 kg per ha as pre-emergence (PE) + one hand weeding at 30 DAS, Imazethapyr @ 100 g per ha at 15 DAS as post-emergence (PoE), Imazamox + Imazethapyr @ 75 g per ha as PoE at 15 DAS (ready-mix), Clodinafop-propargyl @ 60 g per ha as PoE at 15 DAS and Quizalofop-ethyl @ 50 g per ha at 15 DAS (PoE)] and four fertility levels (100 % NPK without sulphur, 100 % NPK with sulphur, 125 % NPK without sulphur and 125 % NPK with sulphur) in sub-plots with three replications. Sowing of soybean *cv.* RKS 45 was done on July, 2013 and 2014 by drilling 80 kg seeds per ha in rows 30 cm apart. Nitrogen, phosphorus, potash and sulphur were applied as per treatment at sowing as basal. Full quantity of nitrogen and phosphorus were applied through urea (after adjusting N available through DAP) and DAP, respectively, whereas potash was applied through muriate of potash, and sulphur through gypsum. The recommended dose of fertilizers for soybean in the zone is 40 kg nitrogen, 40 kg phosphorus, 40 kg potash and 30 kg sulphur per ha, respectively. Observation on yield attributes and yields were recorded at harvest. Treatment-wise monetary returns were worked out taking into consideration the prevailing market price of crop produce and input used. Statistical methods based on analysis of variance technique as described by Gomez and Gomez (1984) were employed and the critical difference for the comparison of treatment mean was worked out, whereas the 'F' test was significant at 5 per cent level of significance.

Effect on yield attributes: Pooled data revealed that two hand weeding at 20 and 40 DAS and ready mix of Imazamox + Imazethapyr @ 75 g per ha at 15 DAS recorded highest values of growth characters as well as yield attributes and were statistically superior over rest of the herbicides and weedy check except Imazethapyr @ 100 g per ha which was on par with ready mix treatment (Table 1). Among the herbicidal treatments, application of ready mix of Imazamox + Imazethapyr @ 75 g per ha recorded maximum dry matter accumulation of plants at harvest (17.94 g/plant), number of branches (2.43/plant), pods (47.23/plant) and seed index (9.08 g/100 seeds), which was significantly higher over weedy check.

Among the fertility levels, application of 100 and 125 per cent NPK along with sulphur were significantly superior over 100 per cent NPK without sulphur with respect to yield attributes namely, dry matter accumulation at harvest (17.49 and 16.95 g/plant), number of branches (2.41 and 2.32/plant), number of pods (43.72 and 41.18/plant) and seed index (9.04 and 9.00 g/100 seeds), respectively. The overall increase in these yield

Table 1. Effect of weed management and fertility levels on yield attributes, yield and economics of soybean (pooled data of 2 years)

Treatment	Dry matter accumulation (g/ plant)	Branches (No/ plant)	Pods (No/ plant)	Seed index (g/100 seeds)	Seed yield (kg/ ha)	Haulm yield (kg/ ha)	Harvest index (%)	Net returns (INR/ ha)	B:C ratio
Weed management practices									
Weedy check	15.01	2.05	27.39	8.84	893	1372	39.42	12940	0.66
Hand weeding (HW) (20 and 40 DAS)	18.32	2.57	53.27	9.16	2204	3338	39.71	52534	1.85
Pendimethalin @ 1.0 kg/ ha + HW (30 DAS)	16.98	2.37	43.43	9.04	1900	2893	39.55	43686	1.66
Imazethapyr @ 100 g/ha (15 DAS)	17.23	2.39	45.80	9.04	1944	2959	39.57	49127	2.20
Imazamox + Imazethapyr @ 75 g/ha (15 DAS) (ready mix)	17.94	2.43	47.23	9.08	2014	3058	39.63	52662	2.47
Clodinafop-propargyl @ 60 g/ha (15 DAS)	16.61	2.21	34.77	8.95	1529	2343	39.42	35022	1.65
Quizalofop-ethyl @ 50 g/ ha (15 DAS)	16.91	2.26	36.89	8.97	1651	2520	39.49	38465	1.72
SEm (±)	0.31	0.04	1.04	0.04	34.88	52.31	0.10	1275	0.06
C D (P = 0.05)	**0.91**	**0.12**	**3.04**	**0.11**	101.80	152.65	NS	3721	0.17
Fertility levels									
100 % NPK without S	16.39	2.20	37.43	8.99	1594	2447	39.39	36059	1.59
100 % NPK with S	16.95	2.32	41.18	9.00	1737	2643	39.55	41063	1.79
125 % NPK without S	17.18	2.37	42.69	9.02	1787	2717	39.58	42278	1.79
125 % NPK with S	17.49	2.41	43.72	9.04	1816	2756	39.63	43135	1.81
SEm (±)	0.19	0.03	0.64	0.01	21.18	31.57	0.09	771	0.03
C D (P= 0.05)	**0.54**	**0.09**	**1.80**	**0.04**	59.57	88.79	NS	2168	0.10

attributes may be the result of reduction in weed flora due to herbicide application and balanced nutrition to the crop plants. Malik *et al.* (2006) and Habimana *et al.* (2013) also observed significant effect of weed control and/or fertility levels in increasing yield attributes of soybean and by Bairwa *et al.* (2012) in case of mung bean.

Effect on yield: All the weed management practices significantly enhanced seed and straw yields of soybean over weedy check during the study period (Table 1). On pooled basis, increase in seed yield by two hand weeding, ready mix of Imazamox + Imazethapyr @ 75 g per ha, Imazethapyr @ 100 g per ha at 15 DAS, Pendimethalin @ 1.0 kg per ha as PE + 1 HW (30 DAS), Quizalofop-ethyl @ 50 g per ha and Clodinafop-propargyl 60 @ g per ha was 1,312, 1,121, 1,052, 1,007, 758 and 636 kg per ha higher, respectively over weedy check. Likewise all the weed management practices also produced significantly higher straw yield of soybean as compared to weedy check. Two hand weeding registered highest soybean straw yield (3,338 kg/ha) followed by ready mix of Imazamox + Imazethapyr @ 75 g per ha (3,058 kg/ha), which were significantly superior over weedy check. Weed control treatments might have facilitated higher photosynthate production and translocation from source to sink, resulting in overall improvement yields as compared to weedy check. The results so obtained corroborate with the findings of Goud *et al*. (2013) in case of chickpea crop.

Among the fertility levels, application of 100 and 125 per cent NPK along with sulphur significantly influenced yields of soybean over 100 per cent NPK without sulphur, both of these maximized the seed (1,737 and 1,816 kg/ha) and straw yield (2,643 and 2,756 kg/ha) over 100 per cent NPK without sulphur. Neither weed management practices nor fertility levels could significantly influence harvest index of soybean crop. The results corroborate the findings of Singh (2005).

Effect on economics: As far as the weed management practices are concerned, maximum net returns (INR 52,662/ha) and B:C ratio (2.47) were recorded by ready mix of Imazamox + Imazethapyr @ 75 g per ha at 15 DAS followed by two hand weeding in terms of net returns (INR 52,534/ha) and Imazethapyr @ 100 g per ha in B:C ratio (2.20). Among the fertility levels, maximum net returns (INR 43,135/ha) and B:C ratio (1.81) were obtained with application of 125 per cent NPK with sulphur and it was almost equal to 100 per cent NPK with sulphur in terms of B:C ratio (1.79).

From the study, it could be concluded that among the herbicidal treatments, application of ready mix of Imazamox + Imazethapyr @ 75 g per ha at 15 DAS as PoE produced highest seed yield (2,014 kg/ha) with B:C ratio of 2.47, while among the fertility levels application sulphur produced higherseed yield (1,737 kg/ha) with B:C ratio of 1.79.

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Analysis of Growth Trends and Variability of Soybean Production in Different Districts of Madhya Pradesh

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Madhya Pradesh is popularly known as 'Soya State' as it has remarkable 6.03 million hectare area under soybean producing about 7.80 million tonnes, accounting for about 55.64 per cent and 53.18 per cent, respectively to total area and production of soybean in India. Madhya Pradesh is the leading producer of soybean in India followed by Maharashtra (31.85 %) and Rajasthan (10.01 %) (GOI 2012-13) (Table 1). The inclusion of crop in the cropping pattern has resulted in economic and industrial revolution in the Madhya Pradesh state and has dramatically improved the living standard of farming community that was the worst sufferer of poverty. The major concern is stagnant/declining trend in productivity of soybean in the country, in general, and in Madhya Pradesh in particular (Nahatkar *et al.,* 2005).

The stagnation in soybean yield may be accounted for poor resource base of the farmers, inefficient use of available resources and non-adoption of improved production techniques for soybean

Table 1. Scenario of soybean crop in India (2012-13)

States	Area (m ha)	% to India	Production (m t)	% to India	Productivity (kg/ha)
Madhya Pradesh	6.03	55.64	7.80	53.18	1293
Maharastra	3.22	29.69	4.67	31.85	1451
Rajasthan	1.04	9.59	1.47	10.01	1412
Andhra Pradesh	0.16	1.47	0.29	1.97	1818
Karnataka	0.17	1.57	0.18	1.21	1047
Others	0.22	2.04	0.26	1.77	1182
India	**10.84**	**100**	**14.67**	**100**	**1353**

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation

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cultivation. In this study, an effort have been made to examine the relative change, variability, growth trends in area, production and productivity of soybean in selected districts of Madhya Pradesh.

The major soybean producing districts were selected purposively for the study, which covered 88.51 per cent area of the soybean area in the Madhya Pradesh. The present study is based on time series secondary data on acreage, production and productivity of soybean for last 15 years (1998-99 to 2012-13), which were collected from Department of Farmer Welfare and Agriculture Development, Madhya Pradesh, Bhopal. The relative change was estimated as percentage change in area, production and productivity during triennium average ending (TE) 2012-13 over TE 2000-01. The growth trend and variability in area, production and productivity of soybean were estimated with the help of various statistical tools.

Coefficient of variation = (Standard Deviation/Mean) x 100…………………(1)

Compound growth rates (CGR) were estimated using following equations:

$Y= ab^t$……………………………………………………………(2)

Log Y= Log a+ t log b…………………..(3)
Where, Y = Area/Production/ Productivity; a = Constant/intercept; b = Regression coefficient

CGR (%) = [Antilog (b)-1] x 100

RESULTS AND DISCUSSION

Present status

Soybean is being cultivated in more than 35 districts of Madhya Pradesh, out of which selected 22 districts accounted for 88.5 per cent of the total area under soybean and contributing to 90 per cent of the total soybean production in the state during TE 2012-13. Top ten districts makes up to more than 53 per cent of total soybean area and produces about 55 per cent of total soybean in Madhya Pradesh. The districts accounting for more than 5 per cent of total soybean area in the state were Ujjain, Shajapur, Dewas, Sagar, Rajgarh, Sehore; whereas the districts such as Dhar, Mandsaur and Vidisha accounted for 3 to 5 per cent of total area under soybean in the state (Table 2). The districts which contributes more than 5 per cent of the state's soybean production are Ujjain, Shajapur, Dewas, Sagar, Sehore, Dhar and Mandsaur; while districts like Rajgarh, Vidisha, Betul, Chhindwara contributed in the range of 4 to 5 per cent of total soybean production in the state.

Among the selected districts, Chhindwara district was highest productive one with 2,028 kg per ha. There were nine districts (Harda, Betul, Sehore, Dhar, Mandsaur, Bhopal, Dewas, Ujjain and Vidisha) with average soybean productivity of1,250 to 1,500 kg per ha during TE 2012-13. The districts with significant area under soybean but having low productivity of soybean were Rajgarh, Indore, Hosangabad, Khandwa, Raisen and Shivpuri, requiring attention and efforts of extension personnel and policy makers towards increasing productivity. This will help increase of total soybean production in the state.

Table 2. Soybean producing districts of Madhya Pradesh (TE 2012-13)

District	Area (000′ ha)	% to total	Production (000′ tons)	% to total	Productivity (kg/ha)
Ujjain	455.73	7.82	599.93	8.31	1315.46
Shajapur	358.37	6.15	445.63	6.17	1242.24
Dewas	328.80	5.64	435.23	6.03	1318.42
Sagar	318.93	5.47	387.17	5.36	1214.12
Rajgarh	312.77	5.37	327.70	4.54	1045.29
Sehore	294.13	5.05	425.27	5.89	1453.40
Dhar	274.40	4.71	381.93	5.29	1390.41
Mandsaur	269.93	4.63	374.10	5.18	1377.81
Vidisha	260.40	4.47	328.20	4.55	1267.92
Indore	225.90	3.88	262.33	3.63	1159.05
Betul	223.97	3.84	331.63	4.59	1470.14
Hoshangabad	220.37	3.78	218.67	3.03	995.85
Guna	219.83	3.77	275.87	3.82	1253.9
Ratlam	217.37	3.73	266.23	3.69	1218.45
Harda	176.83	3.03	263.17	3.65	1493.08
Khandwa	172.37	2.96	123.67	1.71	713.52
Raisen	171.77	2.95	155.40	2.15	915.05
Chhindwara	154.00	2.64	312.20	4.32	2027.99
Shivpuri	150.30	2.58	148.47	2.06	992.62
Neemuch	123.00	2.11	150.13	2.08	1217.8
Seoni	120.43	2.07	135.47	1.88	1125.87
Bhopal	108.33	1.86	146.63	2.03	1352.84
Other districts	669.90	11.49	723.54	10.02	1080.07
M P	**5827.83**	**100**	**7218.57**	**100**	**1235.56**

Relative change

The analysis on relative change of area, production and productivity (Table 3) revealed that the highest relative change in case of area has been recorded in Vidisha (158.68 %) followed by Shivpuri, Sagar, Harda, Guna, Chhindwara, Seoni, Bhopal, Raisen, and Betul and lowest in Indore whereas, area has declined in Hoshangabad by 13.21 per cent during the entire period. The maximum relative change in production of soybean has been recorded in Chhindwara followed by Sagar, Betul, Vidisha, Shivpuri, Seoni, Harda, Guna, Bhopal, Khandwa, Sehore, Rajgarh, and Dhar whereas, less than 50 per cent relative change in production was recorded in Ujjain, Shajapur, Dewas, Mandsaur, Hoshangabad, Ratlam, Raisenand Neemach. The Indore district has negative relative change in production during this period. The highest relative change of soybean Seoni whereas, in the districts such as Ujjain, Shajapur, Dewas, Rajgarh, Sehore, Dhar, Mandsaur, Vidisha, Hoshangabad, Guna, Khandwa, Shivpuri, Neemach and Bhopal, less than 50 per cent relative change in productivity was observed during this period. Three districts namely productivity was observed in Betul followed by Chhindwara, Sagar, Harda, Indore, Ratlam and Raisen districts witnessed negative relative change in productivity. In state as a whole, relative change in area, production and productivity was 33.65, 75.41 and 30.66 per cent, respectively.

Table 3. Relative change (%) in area, production and productivity of soybean in different districts of Madhya Pradesh (1998-99 to 2012-13)

District	Area	Production	Productivity
Ujjain	9.73	30.01	18.00
Shajapur	14.12	32.04	15.37
Dewas	27.06	48.44	15.71
Sagar	109.87	280.82	80.76
Rajgarh	28.41	61.67	24.79
Sehore	20.14	73.6	45.15
Dhar	8.54	54.03	41.83
Mandsaur	12.94	27.17	13.00
Vidisha	158.68	246.2	36.60
Indore	7.28	-1.28	-8.02
Betul	28.77	257.36	175.11
Hoshangabad	-13.21	0.44	17.17
Guna	75.91	156.62	47.29
Ratlam	19.02	9.22	-8.59
Harda	81.49	171.31	79.80
Khandwa	22.71	89.48	47.81
Raisen	35.89	21.72	-7.54
Chhindwara	59.7	328.65	158.26
Shivpuri	131.11	205.91	35.68
Neemuch	14.28	42.58	24.91
Seoni	56.81	180.47	76.67
Bhopal	37.36	92.85	41.7
Other districts	65.56	75.41	78.97
MP	33.65	75.41	30.66

Growth rate

The analysis on growth rate of area, production and productivity of soybean in different districts (Table 4) revealed that the highest positive and highly significant growth in term of acreage was registered in Harda followed by Vidisha, Shivpuri, Sagar, Seoni, Chhindwara, Guna, Bhopal, Indore, Dewas, Rajgarh, Ratlam, Shajapur, Neemach, Sehore, Ujjain, Dhar and Indore. Mandsaur showed positive and significant growth with the rate of 1.44 per cent per annum. Two districts namely Khandwa and Raisen showed positive but non-significant growth in area. Only Hoshangabad showed negative growth in term of area. Further, the Harda showed highest positive and highly significant growth rate in case of production followed by Chhindwara,

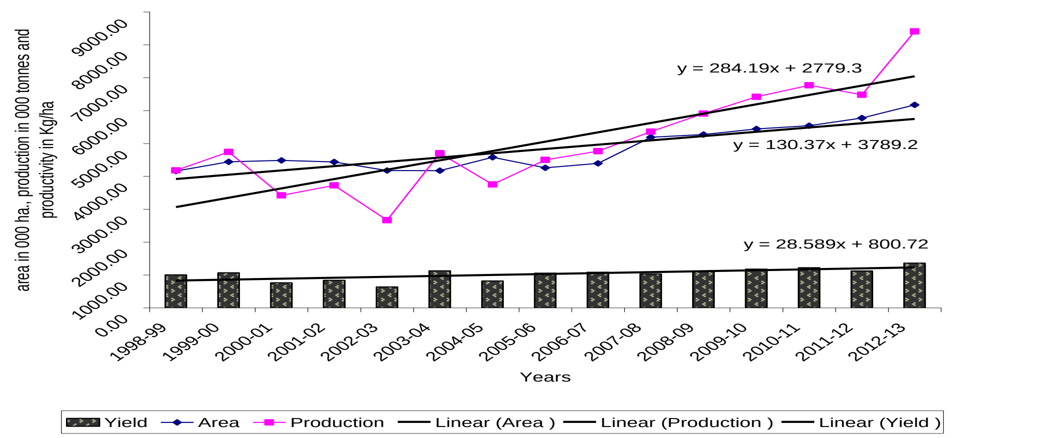
Table 4. Compound growth rate in area, production and productivity (%) of soybean in major districts of Madhya Pradesh (1998-99 to 2012-13)

District	Area	Production	Productivity
Ujjain	0.95**	4.73*	3.75*
Shajapur	1.16**	3.36*	2.17
Dewas	2.12**	3.39**	1.24
Sagar	6.93**	12.08**	4.82**
Rajgarh	2.01**	5.36**	3.28
Sehore	1.51*	4.82**	3.26*
Dhar	0.93**	4.93**	3.96**
Mandsaur	1.44*	2.83	1.37
Vidisha	8.40**	11.23**	2.61**
Indore	0.52**	1.89	1.36
Betul	2.45**	10.93**	8.28**
Hoshangabad	-0.86	0.63	1.5
Guna	4.42**	8.98**	4.36**
Ratlam	1.65**	3.13	1.45
Harda	19.95**	26.79**	5.71**
Khandwa	1.46	5.18**	3.67**
Raisen	3.54	4.19	0.63
Chhindwara	4.42**	13.25**	8.46**
Shivpuri	7.33**	10.70**	3.14
Nimach	1.52**	3.49	1.94
Seoni	4.50**	9.05**	4.35**
Bhopal	2.88**	6.63**	3.65**
Other districts	5.76	5.59	4.69
MP	2.64**	5.59**	2.87**

*** Highly significant at 1% probability level; * Significant at 5% probability level*

Sagar, Vidisha, Betul, Shivpuri, Seoni, Guna, Bhopal, Rajgarh, Khandwa, Dhar, Sehore and Dewas. Ujjain and Shajapur districts showed positive and significant growth rate in production of soybean which were 4.73 and 3.36 per cent per annum, respectively. The positive and non-significant growth rate in production was registered in Mandsaur, Indore, Hoshangabad, Ratlam, Raisen and Neemach districts. Among the different districts of Madhya Pradesh, highest growth rate in productivity was registered in Chhindwara district followed by Betul, Harda, Sagar, Guna, Seoni, Dhar, Khandwa, Bhopal and Vidisha. The Ujjain and Sehore districts were showed positive and significant growth rate in case of productivity at the rate of 3.75 and 3.26 per cent per annum. The positive and non – significant growth in soybean productivity was observed in Dewas, Sagar, Rajgarh, Mandsaur, Indore, Hoshangabad, Ratlam, Raisen, Shivpuri and Neemach districts. The positive and highly significant growth rate in area, production and productivity were recorded in the state as a whole during this period. Similar study has been conducted by Jain *et al.* (1988), Ahirwar *et al.* (2006, 2007) and Meena *et al.* (2014).

Figure 1 Growth rates in area, production and productivity of soybean in M. P. during 1998-99 to 2012-13



Variability

The variability in area, production and productivity of soybean are presented in table 5. The growth rates explains only rate of growth over the period whereas, instability analysis helps in judging, whether the growth performance is stable or unstable for the pertinent variable (Rama Rao and Raju, 2005). The highest variability in area was noticed in Dewas district followed by Mandsaur, Raisen, Shivpuri,Ratlam, Chhindwara, Seoni, Guna, Hoshangabad, Bhopal, Betul, Khandwa, Sehore, Mandsaur and Dewas whereas, the Ujjain, Shajapur, Rajgarh, Dhar, Indore, Ratlam, and Neemach were showed less than 10 per cent variation in area of soybean during the entire period.

The variability in area, production

Table 5. Estimates of variability in area, production and productivity (%) of soybean in different districts of Madhya Pradesh (1998-99 to 2012-13)

Districts	Area	Production	Productivity
Ujjain	05.78	34.00	31.30
Shajapur	05.92	27.29	24.04
Dewas	10.63	19.82	13.29
Sagar	41.30	64.03	29.97
Rajgarh	09.43	31.63	28.00
Sehore	12.18	27.21	26.42
Dhar	06.26	26.25	21.77
Mandsaur	11.50	46.49	40.42
Vidisha	41.54	56.38	17.64
Indore	03.29	23.31	22.21
Betul	13.60	50.91	37.22
Hoshangabad	18.50	31.63	27.37
Guna	23.26	43.87	25.72
Ratlam	09.73	38.24	35.00
Harda	28.81	45.24	35.54
Khandwa	12.42	28.26	23.26
Raisen	35.12	38.22	21.27
Chhindwara	24.31	62.08	43.03
Shivpuri	33.93	49.44	27.84
Nimach	08.82	36.01	32.66
Seoni	23.81	38.42	24.97
Bhopal	14.13	29.91	17.97
Other districts	30.80	29.97	25.28
M P	13.78	29.97	18.49

and productivity was recorded 13.78, 29.97 and 18.49 per cent respectively in the state as a whole. The production fluctuation was more then that the area and productivity in the state. The Sagar district showed highest variability in production of soybean which accounted for 64.03 per cent followed by the Chhindwara, Vidisha, Betul, Shivpuri, Mandsaur, Harda, Guna, Seoni, Ratlam, Raisen, Neemach, Ujjain, Rajgarh, Hoshangabad, Bhopal, Khandwa, Shajapur, Sehore, Dhar, Indore and Dewas. The highest fluctuation in productivity was recorded in Chhindwara district as compared to other district namely Mandsaur, Betul, Harda, Ratlam, Neemach, Ujjain, Sagar, Rajgarh, Shivpuri, Hoshangabad, Sehore, Guna, Seoni, Shajapur, Khandwa, Indore, Dhar, Raisen, Bhopal, Vidisha and Dewas during entire period. Similar study of oilseed has been conducted by Rama Rao and Raju (2005).

It is concluded from the data that the highest area and production were observed in Ujjain, and highest productivity in Chhindwara. The relative change in area was highest in Vidisha while, relative change in case of production was highest in Chhindwara. In case of productivity, Betul showed highest relative change. The positive and highly significant growth rate in area and production was recorded in Harda and Chhindwara showed highest and significant growth rate in case of productivity.

Policy implication

Almost all the districts of Vindhyan plateau showed slow down growth rate in area, production and productivity of soybean due to unfavorable condition of mansoon, slow adoption level of recommended package of practices, slow seed replacement, *etc*. In slow growth rate districts, training arrangement under water management for enhancement of productivity of soybean crops, and improved package of practices. The yield gap analysis should be conducted by various research stations. The various inputs should be applied after soil testing recommendation.

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SOYBEAN RESEARCH

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Ansari M M and Sharma A N. 2000. Compatibility of *Bacillus thuringiensis* with chemical insecticides used for insect control in soybean (*Glycine max*). *Indian Journal of Agricultural Sciences* **70**: 48-9. **(Journal)**

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Pansae V G and Sukhatme P V. 1978. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi. pp.186. **(Book)**

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