ISSN 0973-1830
Volume 18, Number 1: 2020

SOYBEAN RESEARCH

Society for Soybean Research and Development
ICAR-Indian Institute of Soybean Research
Khandwa Road, Indore 452 001
Madhya Pradesh, India

Society for Soybean Research and Development

(Founded in 2003)

(Registration No. 03/27/03/07918/04)

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NAAS RATING 3.36 (w.e.f. 01.01.2020)

SOYBEAN RESEARCH

ISSN 0973-1830 **Volume 18(1): 2020**

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Research papers

An official publication of Society for Soybean Research and Development, Indore

The 'Soybean Research' is indexed in Soybean Abstract of CAB International, UK and Indian Science Abstracts of NISCAIR, India and are linked to Google Scholar.

Soybean Research 18(1): 01-30 (2020)

Water Consumptive Use and Insects Incidence in Three Soybean Cultivars under Different Intercropping Systems with Maize

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Received: 31.02.2020: Accepted: 16.03.2020.

ABSTRACT

A two–year study was carried out at Giza Agricultural Experiments and Research Station, Agricultural Research Center, Egypt during the two summer seasons 2016 and 2017 to evaluate water consumption and insect infestation of three soybean cultivars under different intercropping systems with maize in order to increase land usage and economic returns. The treatments were the combinations between three intercropping systems (alternating ridges "2 maize: 2 soybean and 2 maize: 4 soybean" and mixed intercropping systems) and three soybean cultivars (Giza 22, Giza 35 and Crawford) in addition to solid cultures of both the crops. A split plot design with three replications was used. Intercropping systems were randomly assigned to the main plots and soybean cultivars were allocated to sub-plots. The results indicated that intercropping soybean cv. *Giza 22 with maize under mixed intercropping system had the highest water consumptive use as compared with the others. Conversely, intercropping soybean* cv. *Crawford with maize under intercropping system 2 maize: 4 soybean recorded the lowest water consumptive use. With respect to soybean insects, lower infestation rate of aphids on leaves of soybean* cv. *Giza 22 was observed in mixed intercropping system than the others. Also, lower whitefly infestation rate on leaves of soybean* cv. *Giza 35 was recorded under intercropping system 2 maize: 4 soybean. Also, lower leaf miner fly infestation on soybean leaves was obtained by intercropping soybean* cv. *Giza 22 with maize under intercropping system 2 maize: 4 soybean than the others. Moreover, lower thrips infestation rate on soybean leaves was obtained by intercropping soybean* cv. *Giza 35 with maize under intercropping system 2 maize: 2 soybean than the others. With respect to maize crop, mixed intercropping system had the highest values of most the studied maize traits. Maize grain yield and its attributes were not affected by soybean cultivars or the interaction between intercropping systems and soybean cultivars. With respect to soybean crop, intercropping system 2 maize : 4 soybean had the highest values of*

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studied soybean traits. Soybean cv. *Giza 22 gave the highest plant height, seed yields per plant and per ha, as well as harvest index as compared with the others. Growing soybean* cv. *Giza 22 in intercropping system 2 maize: 4 soybean recorded the highest seed yields per plant and per ha as compared with the others. The highest LER and economic returns per ha were obtained by intercropping soybean* cv. *Giza 22 with maize under mixed intercropping system as compared with those of solid culture of maize. The best treatment was obtained by growing two rows of soybean* cv. *Giza 22 in middle of maize beds which recorded soybean productivity (1.11 and 1.21 ton/ha), water consumptive use (893 and 897 mm), aphids infestation rate (4.2 and 5.2), land usage (1.26 and 1.26) and net returns (USD 1,234 and 1,391/ha) in the first and second seasons, respectively.*

***Key words**:* Intercropping systems, maize, soybean cultivars, water consumptive use, soybean insects, LER, economic returns

Studies on soybean [*Glycine max* (L.) Merrill] production in relation to crop water use and deep drainage losses are needed to demonstrate that the applied irrigation water was used as efficiently as conventional methods (Wright *et al*., 1988). In this concern, Pietrzak *et al*. (2002) found that water in soybean seeds plays an important role not only in physiological but also in chemical processes. Photosynthetic rates, stomatal conductance, and yield of soybean were higher when ground water was at 60 cm depth below the surface (Sarwar, 2002). Accordingly, the water applied at each irrigation needs to be carefully controlled. However, soybean suffers severe damage from insects. According to Viraktamath *et al*. (1993), the leaf miner (*Liriomyza trifolii*)) was found to cause serpentine like mines with a hood on leaves of soybean. Particularly, Higley and Boethel (1994) mentioned that soybean have been traditionally attacked by soybean leaf miner. On the other hand, aphids (*Aphis gossypii*) and whiteflies (*Bemisia tabaci*) were reported as severe pests in tropics and sub-tropics on several crops including soybean (Hammad, 1997 and Chaturvedi *et al*., 1998). The soybean aphid can cause severe economic loss and degrade seed quality through its feeding (Beckendorf *et al*., 2008). They added that soybean aphids have very high reproductive potential, a single soybean aphid introduced on soybean at V5 (plant is about 20 to 30 cm with five nodes of fully expanded leaflets) can multiply to about 4,000 aphids per plant. Thus, soybean aphids are capable to reduce total nodule volume per plant by 34 per cent, nodule leghemoglobin content by 31 per cent, plant nitrogen (N) fixation rate by 80 per cent, and shoot ureide-N concentration by 20 per cent (Riedell *et al*., 2009). Meanwhile, the direct damage of whitefly adults and nymphs leads to high yield losses in soybean production in the Mediterranean region (Gulluoglu *et al*., 2010). In this concern, Murgianto and Hidaya (2017) revealed that whitefly attack can reduce soybean production up to 80 per cent. Although, thrips (*Thrips s*p.) is reportedly not an economic pest in soybean (Gouge *et al*., 1999), but it is important pest in many soybean production areas due to the feeding injury caused by larvae and adults and the indirect damage caused by transmission of tospoviruses (Gent *et al*., 2004). Hence, pest control in soybean crop is mostly performed by application of chemical insecticides. This approach carries risks to the environment and the natural enemies of pests, and favors the selection of insecticide-resistant individuals (Sosa-Gomez and Silva, 2010). When a pesticide is first used, a small proportion of the pest population may survive exposure to the material due to their distinct genetic makeup. These individuals pass along the genes for resistance to the next generation. Consequently, insecticides uses cause insect tolerance that has been shown to be generally quantitative and polygenic (Ojwang *et al*., 2011).

Accordingly, some morphological and physiological traits of soybean leaves could play an important role to reduce adverse effects of insecticidal use. It is known that pubescence traits can mediate various aspects of the plant-herbivore interaction, including, insect movement (Zvereva *et al*., 1998), insect survival (Haddad and Hicks, 2000), insect growth and pupal mass (Malakar and Tingey, 2000). No doubt that the plants produce an efficient enzymatic antioxidant defense system such as peroxidase (POD) that plays an important role in plant stress caused by insect feeding (He *et al*., 2010). In another study, Bellaloui (2012) indicated that secondary metabolites such as phenols are associated with plant defense against pests and survival mechanisms under abiotic and biotic stress. Moreover, jasmonic acid (JA) belongs to class of polyunsaturated fatty acids derived phytohormones and is available ubiquitously in plants. In the downstream of defense signaling pathway, JA lead to the production of defensive allelochemicals that are deterrent or lethal to the insect (Bansal *et al*., 2013). Particularly, Coppola *et al*. (2018) revealed that JA and salicylic acid are known to be the two hormones primarily involved in plant defense responses against aphids.

However, some soybean cultivars are different in their productivity due to their genetic potential that translated into different canopies architectures (El-Habbak, 1985; El-Douby *et al*., 2002). Meanwhile, Noureldin *et al*. (2002) revealed that soybean genotypes differed in their response to applied irrigation water. Moreover, Metwally *et al*. (2003) concluded that soybean *cvs.* Giza 22, Holladay, Giza 21 and Giza 111 under 2:2 gave higher productivity than the others. Consequently, the use of such cultivars resistant to insects and diseases could reduce the application of pesticides, decrease production costs and promote a sustainable agriculture as reported by Lourenção *et al.* (2004). Plant structure is the first line of defense against insects. Morphological and anatomical traits allow a fitness advantage to the plant by directly deterring the herbivores from feeding (Agrawal *et al*., 2009). Induced response in plants is one of the important components of pest control in agriculture, and has been exploited for regulation of insect herbivore population (Agrawal, 2011). Accordingly, soybean cultivars that differ in their pubescence, leaf N content, JA, POD and phenols may be considered as efficient indicator for dynamic defence system against aphids, whiteflies, leaf miner and thrips. Thus, host plant resistance to insects is important for integrated pest management (Souza *et al*., 2014). Hence, choice of soybean cultivar with optimum intercropping system could enhance the management of water consumption and insect infestation in soybean crop.

With respect to intercropping, a little knowledge is yet available about insects associated with intercropped soybean under different intercropping systems. According to Vandermeer (1989), intercropping could be one of the potential ways to address some of the associated obstacles with modern agriculture, including low yield, pest and pathogen infection, soil degradation and environmental deterioration. Particularly, intercropping soybean with maize (*Zea mays* L.) is the best way to increase soybean production without significant change in the cropping structure under Egyptian conditions (El-Douby *et al*., 1996; Metwally *et al*., 2003 and 2005). It is known that soybean requires less irrigation compared with other irrigated crops such as corn and water saving irrigation strategies can be useful in maintaining soybean yields (Lamm *et al*., 2007). In this concern, Ouda *et al.* (2007) showed that increasing productivity of intercropped soybean with maize (one ridge alternating with two ridges "1:2", respectively), over the sole crop has been attributed to better use of water, especially competition for soil nutrients was more important than competition for sunlight, confirming the importance of belowground competition under intercropping conditions (Lv *et al*., 2014). Intercropping soybean with maize under alternating ridges 2:2 achieved water saving and increased land equivalent ratio (LER) and total economic return than sole maize (Metwally *et al*., 2017) and reduced insect-pests infestation (Bapatla *et al*., 2018).

Therefore, the objectives of this investigation were to evaluate water consumption and insect infestation of three soybean cultivars under different intercropping systems with maize in order to increase land usage and economic returns.

MATERIAL AND METHODS

A-two year study was carried out at Giza Agricultural Experiments and Research Station (Lat. 30°00′30″ N, Long. 31°12′43″ E, 26 m a.s.l), Agricultural Research Center, Egypt during two summer seasons (2016 and 2017) to evaluate water consumption and insect infestation of three soybean cultivars under different intercropping systems with maize in order to increase land usage and economic returns. This study included nine treatments which were the combination between three intercropping systems (two maize ridges alternating with two soybean ridges was expressed as 2 maize: 2 soybean, two maize ridges alternating with four soybean ridges wasexpressed as 2 maize: 4 soybean and mixed intercropping) and three soybean cultivars (Giza 22, Giza 35 and Crawford) in addition to solid cultures of both the crops. Maize variety T.W.C. 321 was used in this study. Origin, pedigree and maturity group of the tested soybean cultivars are shown in table 1. Mechanical and chemical properties of the soil (0–15 and 15–30 cm) were analysed by Water, Soil and Environment Research Institute, Agricultural Research Center (Table 2). Mechanical and chemical analyses of the soil were determined using the methods described by Chapman and Pratt (1961**)** and Jackson (1965).

Table 1. Origin, pedigree and maturity group of the tested soybean cultivars

Cultivar	Origin	Pedigree	Maturity group
Giza 22	Egypt	Giza 21 x 186 k – 73	IV
Giza 35	Egypt	Crawford x Celest (early)	III
Crawford	USA	Williams x Columbus	IV

The soil texture was clay loam and the preceding winter crop was wheat in both the seasons. Calcium super phosphate (15.5 % P_2O_5) at rate of 476 kg per ha was applied during soil preparation in the two summer seasons. Soybean seeds were inoculated with *Bradyrhizobium japonicum* and gum Arabic was used as a sticking agent. Soybean seeds were sown on 23rd and 28th May in 2016 and 2017 seasons, respectively, whereas maize variety T.W.C. 321 was sown 15 days later. Mineral N fertilizer was added for maize at a rate of 285.6 kg N per ha as ammonium nitrate (33.5 % N) in two equal doses applied before the first and the second irrigation, respectively, under intercropping and sole plantings. Also, mineral N fertilizer was added for soybean at a rate of 35.7 kg N per ha as ammonium nitrate (33.5 % N) before the first irrigation under intercropping and sole plantings.

Alternating ridges (70 cm width) were conducted by growing two maize ridges alternating with two soybean ridges and growing two maize ridges alternating with four soybean ridges. Mixed intercropping system was conducted by growing maize plants in both sides of raised beds (140 cm width) and soybean seeds were drilled on two rows in middle of the raised beds. With respect to sole plantings of both crops, solid culture of maize was conducted by growing maize plants in one side of ridges (70 cm width), and solid culture of soybean was conducted by drilling two rows of soybean on ridges 70 cm width. Solid cultures of both crops were used to estimate the competitive relationships. Maize was grown in hills distanced at25 cm between hills with one plant per hill under intercropping and solid cultures, meanwhile soybean was thinned to 20 plants per one meter length under intercropping and solid cultures. All normal agricultural practices were performed for raising crops. Furrow irrigation was followed in this study where the amounts of applied irrigation water were 922 and 927 mm in 2016 and

Table 2. Mechanical and chemical properties of the soil at the experimental site

Properties	Soil depth (cm)	
	0-15	15-30
Particle size distribution		
- Coarse sand (%)	2.98	2.95
- Fine sand (%)	12.97	13.00
- Silt (%)	30.10	29.95
- Clay (%)	53.95	54.10
Texture class	clay	clay
Bulk density (Mg m^{-3})	1.16	1.25
Field capacity (% w/w)	42.10	34.60
Permanent wilting point (% w/w)	18.70	16.60
Available water (%)	23.40	18.00
pH (1:2.5)	7.15	7.36
ECe, soil paste extract (dS m^{-1})	0.95	
Soluble cations(meq L^{-1})		
Ca^{2+}	3.54	3.42
Mg^{2+}	1.15	1.3
Na^{+}	2.36	2.44
K^{+}	0.38	0.44
Soluble anions (meq L^{-1})		
CO_3^{2-}	nd*	nd
HCO_3^{-}	2.10	2.25
Cl^{-}	2.22	2.35
SO_4^{2-}	2.40	3.70
Available N (ppm)	38.00	42
Available P (ppm)	16.5	17.88

2017 seasons, respectively. Soybean, *cvs.* Giza 22 and Crawford were harvested on 2nd and 4th October in 2016 and 2017, respectively, whereas *cv.* Giza 35 was harvested on 29th and 31st August in 2016 and 2017 seasons, respectively. Maize plants were harvested on 25th and 28th September in 2016 and 2017 seasons, respectively.

A split plot distribution in randomized complete blocks design with three replications was used. Intercropping systems were randomly assigned to the main plots and soybean cultivars were allocated in sub-plots. Plot area was 25.2 m^2. Each plot included twelve ridges, 3.0 m long and 0.7 m wide for intercropping system 2 maize: 2 soybean and 2 maize: 4 soybean. In case of mixed intercropping systems, each plot consisted of six raised beds, 3.0 m long and 1.4 m wide.

Data recorded

Jasmonic acid (JA), peroxidase (POD) and total phenols contents of soybean leaves: JA, POD and total phenols contents in soybean leaves of the three soybean cultivars were analysed after 60 days from sowing. These analyses were done by Food Technology Research Institute, Agricultural Research Center, Giza, Egypt and Cairo University Research Park, Faculty of Agriculture, Cairo University, Giza, Egypt.

Pubescence traits of soybean leaves: Observations on pubescence traits were taken after 60 days from soybean sowing on three soybean cultivars exhibiting a range of insect infestation levels and pubescence ratings. Pubescence density was divided into two phenotypes: dense and normal (Singh, 2010). Pubescence traits were estimated by pubescence length (µm), number of pubescence per 500 µm and pubescence density. Pubescence traits were estimated as an indication of direct defence for insect infestation by using SEM Model Quanta 250 FEG (Field Emission Gun) in the Egyptian Mineral Resources Authority Central Laboratories Sector.

***Leaf N content**:* The leaves (blade only) from three plants were separated after 60 days of sowing soybean and oven-dried at 75 ^{o}C till constant mass (approximately 48 h), finally ground, thoroughly mixed and stored in closed containers were used for analysis of leaf N content using Kjeldahal digestion (Jackson, 1965) by the General Organization for Agricultural Equalization Fund, ARC, Giza, Egypt.

Water relation measurements: The amounts of applied irrigation water were calculated according to Vermeiren and Jopling (1984). Crop water use was estimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

$$\mathrm{WCU} = \sum_{i=1}^{i-4} \frac{\theta 2 - \theta 1}{100} \times \mathrm{Bdxd}$$

Where: WCU = water consumptive use or actual evapotranspiration, ETa (mm), I = number of soil layer, θ2 = soil moisture content after irrigation, (%, by mass), θ1 = soil moisture contents just before irrigation, (%, by mass), Bd= soil bulk density (g/cm^{3}), d= depth of soil layer (mm).

Insect assemblages: The susceptibility of soybean cultivars to the infestation of aphids, whitefly, leaf miner fly and thrips were investigated after 60 days from soybean sowing in the both seasons. Five soybean plants, represented the sample, were randomly collected from the diagonals of each plot and examined to record the population density of four insects; aphids, whiteflies, the leaf miner and thrips. Since very few other insects such as cotton leaf worm and lima bean pod borer were observed in some experimental plots, they were excluded from the results and discussion in the both seasons.

Maize traits: Ten guarded plants were randomly taken from each sub-plot at harvest to record plant height (cm), number of green leaves per plant, number of ears per plant, ear weight (g), grain yield per plant (g) and 100 – kernel weight. Grain yield per ha (ton) was determined from weight of each sub-plot and converted to ton per ha.

Soybean traits: Light intensity (lux), inside the soybean canopy at the middle and bottom of the plant after 85 days from soybean sowing was recorded by a Lux-meter apparatus at mid-day on ten plants for each sub-plot and expressed as the percentage from full sunlight intensity (100 %) measured above the plants. At harvest, the observations on traits; plant height (cm), numbers of branches and pods per plant, seed yield per plant and 100-seed weight were recorded on 10 guarded plants from each sub-plot. The yield data were utilized to work out the harvest index (HI) according to Donald (1962): Seed yield per plot (kg) was recorded on basis of experimental plot and expressed as ton per ha.

Land equivalent ratio (LER): LER defines the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield (Mead and Willey, 1980). It is calculated as follows: LER = $(Y_{ab} / Y_{aa}) + (Y_{ba} / Y_{bb})$, Where: Y_{aa} = Pure stand yield of crop a (maize), Y_{bb} = Pure stand yield of crop b (soybean), Y_{ab} = Intercrop yield of crop a (maize) and Y_{ba} = Intercrop yield of crop b (soybean).

Economic returns (USD/ha): Farmer's benefit was calculated by determining each of total returns, costs and net returns of intercropping and solid cultures. Total returns per ha (USD) = maize grain yield × price of maize grains + soybean seed yield × price of soybean seeds. The prices were presented by market prices (2018) where one ton of maize grains and soybean seeds are USD 200 and USD 450, respectively. Net returns per ha (USD) = total returns-variable costs for the crops in intercropping and solid cultures. Financial costs were presented by Bulletin of Statistical Cost Production and Net Return (2018).

Statistical analysis: All obtained data were subjected to statistical analysis of variance according to Snedecor and Cochran (1980) and the least significant differences (LSD) at 5 per cent level of significance, tests were done according to Freed (1991) to compare the means of studied traits.

RESULTS AND DISCUSSION

Jasmonic acid (JA), peroxidase (POD) and total phenols contents of soybean leaves

JA (ranged from 344 µg/100 g FW to 430 g/100 g FW) and POD (ranged from 0.70 U/µg FW to 6.85 U/g) contents of soybean leaves of the three soybean cultivars after 60 days from sowing were recorded by intercropping soybean *cv.* Crawford with maize under mixed intercropping system and intercropping *cv.* Giza 35 with maize under intercropping system 2 maize: 4 soybean, respectively. Moreover, total phenols ranged from 21.74 mg per g FW by intercropping soybean *cv.* Crawford with maize under intercropping system 2 maize: 4 soybean to 33.93 mg per g FW by intercropping soybean cv. Giza 35 with maize under mixed intercropping system.

Table 3. JA, POD and total phenols contents in leaves of the tested soybean cultivars under different intercropping systems after 60 days from soybean sowing

Intercropping system		JA (µg/100 g FW)	POD (U/g FW)	Total phenols (mg/g FW)
2 maize : 2 soybean	Giza 22	396	2.15	26.81
	Giza 35	401	4.54	30.72
	Crawford	368	1.84	24.94
2 maize : 4 soybean	Giza 22	414	3.08	24.26
	Giza 35	430	6.85	28.63
	Crawford	387	3.83	21.74
Mixed intercropping	Giza 22	365	1.08	29.38
	Giza 35	382	3.07	33.93
	Crawford	344	0.70	27.40

Pubescence density

Soybean cultivars significantly differed in their leaf pubescence length and number (Fig. 1; Table 4). Soybean *cv.* Giza 22 had higher leaf pubescence length (504.46 µm) and lower number of leaf pubescence (24.00/500 µm) than soybean *cv*. Giza 35 or Crawford, while soybean *cv.* Giza 35 had the opposite trend. There were no significant differences between soybean cultivars Giza 35 and Crawford in leaf pubescence length, while soybean *cv.* Giza 22 was similar to Crawford for number of leaf pubescence. These results may be due to the genetic makeup of the studied soybean cultivars translated into differences in leaf morphology and structure.

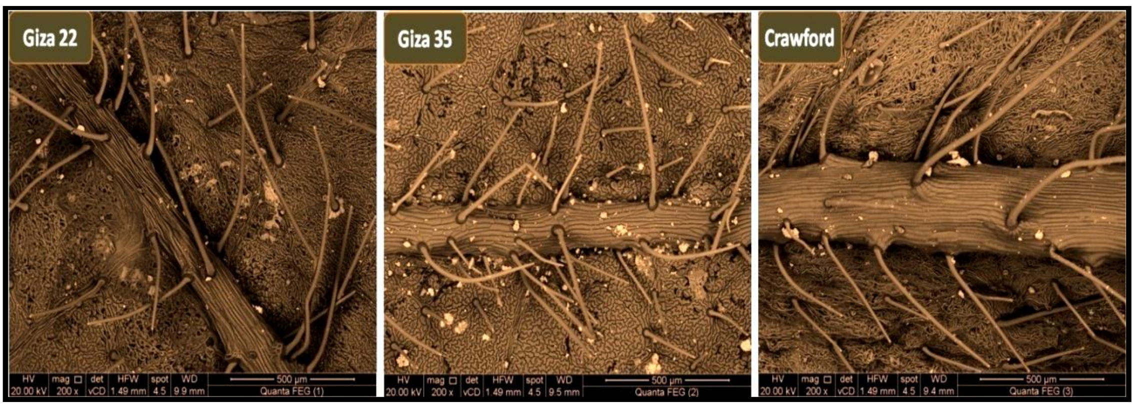

Fig. 1. Scanning of leaf pubescence density of the studied cultivars by electronic microscope

Table 4. Means of leaf pubescence length, number of leaf pubescence per 500 μm and leaf pubescence density of the studied soybean cultivars after 60 days from soybean sowing

Cultivar	Leaf pubescence length (μm)	Number of leaf pubescence (500 μm)	Leaf pubescence density
Giza 22	504.46	24.00	Normal
Giza 35	323.95	47.50	Dense
Crawford	338.67	29.50	Normal
L.S.D. (P = 0.05)	**121.39**	**7.63**	**---**

Leaf N content of soybean

Intercropping systems: Leaf N content was significantly affected by intercropping systems (Table 5). Intercropping system 2 maize: 4 soybean had higher leaf N content, meanwhile mixed intercropping system had lower content. These results could be due to intercropping system 2 maize: 4 soybean furnished suitable environmental condition for soybean growth and development due to the less shading effect of maize plants in this system.

Table 5. Effect of intercropping systems, soybean cultivars and their interaction on leaf N content of soybean after 60 days from soybean sowing

Intercropping system	Leaf N content (mg/g)			
	Giza 22	**Giza 35**	**Crawford**	**Mean**
2 maize : 2 soybean	24.76	23.29	26.76	**24.93**
2 maize : 4 soybean	26.92	25.69	28.16	**26.92**
Mixed intercropping	23.40	22.53	25.88	**23.93**
Mean	**25.02**	**23.83**	**26.93**	**25.26**
	L S D (P = 0.05			
	Intercropping systems	**Soybean cultivars**	**Interaction**	
	0.96	**0.75**	**1.13**	

Soybean cultivars: Soybean cultivars significantly differed for leaf N content (Table 5). Soybean *cv.* Crawford had the highest whereas soybean *cv.* Giza 35 had the lowest leaf N content. These results could be due to genetic makeup of the studied soybean cultivars translated into different canopies architectures for benefiting from the surrounding environmental conditions with this canopy adequately during growth and development stages.

The interaction between intercropping systems and soybean cultivars: The interaction between intercropping systems and soybean cultivars significantly affected leaf N content (Table 5). Growing soybean *cv.* Crawford in intercropping system 2 maize: 4 soybean recorded the highest leaf N content whereas *cv.* Giza 35 in mixed intercropping system had the lowest value of this trait as compared with the others. These results probably due to spatial arrangements of intercropping system 2 maize: 4 soybean interacted positively with genetic makeup of soybean *cv.* Crawford for benefiting from available solar radiation that reflected on leaf N content as compared with the others. Greater rates of leaf photosynthesis on an absorbed photon basis were evident in light-green soybean leaves, and the increase in leaf photosynthesis correlated with a more even light distribution among chloroplasts within leaves (Slattery *et al.*, 2016).

Water consumptive use of three soybean cultivars under different intercropping systems with maize

Intercropping systems: Water consumptive use was significantly affected by intercropping systems in both the seasons (Table 6). Mixed intercropping system had the highest water consumptive use as compared with those of intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean, meanwhile the reverse was true for intercropping system 2 maize: 4 soybean in both the seasons. These results could be due to maize plant density, which reached 100 per cent of solid culture of maize under mixed intercropping system, which increased intra-specific competition between plants of the same species (soybean) and inter-specific competition between the two species (soybean + maize) for basic growth resources mainly irrigation water compared with intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean.

Soybean cultivars: Water consumptive use was not significantly affected by soybean cultivars in both the seasons (Table 6).

The interaction between intercropping systems and soybean cultivars: The interaction between intercropping systems and soybean cultivars significantly affected water consumptive use in both the seasons (Table 6). In general, intercropping soybean *cv.* Giza 22 with maize under mixed intercropping system recorded the highest water consumptive use as compared with the other treatments. Conversely, intercropping soybean *cv.* Crawford with maize under intercropping system 2 maize: 4 soybean recorded the lowest water consumptive use compared with the others. These results can be attributed to maize plant density, which reached 33 per cent of solid culture of maize under intercropping system 2 maize: 4 soybean. Generally, water needs of all the studied soybean cultivars were not increased under intercropping system 2 maize: 4 soybean due to the decrease of intra-specific competition between plants of the same species (soybean) and inter-specific competition between the two species (soybean + maize) for basic growth resources. On the other hand, water needs of all the studied soybean cultivars were increased in mixed intercropping system than the other intercropping systems in both the seasons. It is expected that canopy architecture of soybean *cv.* Giza 22, that is late maturing cultivar (Table 1), was more compatible with spatial

Table 6. Effect of intercropping systems, soybean cultivars and their interaction on water consumptive use in both seasons

Intercropping system	Soybean cultivar	Applied irrigation water (mm)		Water consumptive use (mm)	
		First season	Second season	First season	Second season
	Giza 22	922	927	752	824
2 maize : 2	Giza 35	922	927	738	816
soybean	Crawford	922	927	756	812
	Mean	**922**	**927**	**748**	**817**
	Giza 22	922	927	570	669
2 maize : 4	Giza 35	922	927	548	658
soybean	Crawford	922	927	556	656
	Mean	**922**	**927**	**558**	**661**
	Giza 22	922	927	893	897
Mixed	Giza 35	922	927	900	902
intercropping	Crawford	922	927	897	894
	Mean	**922**	**927**	**896**	**897**
Average of	**Giza 22**	**922**	**927**	**738**	**796**
soybean	**Giza 35**	**922**	**927**	**728**	**792**
cultivars	**Crawford**	**922**	**927**	**736**	**787**
				L S D (P= 0.05)	
Intercropping systems				**96.72**	**65. 61**
Soybean cultivars				**N.S.**	**N.S.**
Interaction				**114.53**	**82.34**

arrangement of mixed intercropping system by furnishing a good rooting system that reflected on more absorption of water from the soil. Densely pubescence lines have a greater root density and a deeper root extension (Garay and Wilhelm, 1983).

Insect incidence

Intercropping systems: Susceptibility of soybean plants to the infestation by aphids statistically varied according to intercropping systems (Tables 7). Higher aphids assemble on soybean leaves were recorded in intercropping system 2 maize: 4 soybean than those of the other intercropping systems in both the seasons. These results indicated that soybean leaves of intercropping system 2 maize: 4 soybean were susceptible to aphid's infestation than those of the other intercropping systems due to higher N content (Table 5) and lower water consumptive use (Table 6). In general, maize plants seem to be used as a trap crop in mixed intercropping system for decreasing aphids attack on soybean leaves by increasing maize plant density from 50 to 100 per cent of solid culture of maize.

Table 7. Effect of intercropping systems, soybean cultivars and their interaction on insect assemblages on soybean leaves after 60 days from soybean sowing in the first and second seasons

Intercropping system	Soybean cultivar	Mean number of aphids/ leaf	Mean number of whitefly/ leaf	Mean number of leaf minor/ leaf	Mean number of thrips/ leaf	Mean number of aphids/ leaf	Mean number of whitefly/ eaf	Mean number of leaf minor/ leaf	Mean number of thrips/ leaf
		First season (2016)				Second season (2017)			
2 maize : 2 soybean	Giza 22	4.40	2.20	8.00	2.00	5.60	1.20	6.00	1.20
	Giza 35	6.20	2.00	12.00	1.00	6.40	1.00	10.60	1.00
	Crawford	8.20	2.60	14.00	2.00	7.20	2.20	14.20	2.20
	Mean	**6.26**	**2.26**	**11.33**	**1.66**	**6.40**	**1.46**	**10.26**	**1.46**
2 maize : 4 soybean	Giza 22	4.80	2.00	8.00	2.20	6.80	1.20	8.00	1.20
	Giza 35	6.60	2.00	10.80	2.40	6.40	1.00	10.00	2.20
	Crawford	6.40	2.40	14.00	2.40	8.10	2.20	14.40	2.40
	Mean	**5.93**	**2.13**	**10.93**	**2.33**	**7.10**	**1.46**	**10.80**	**1.93**
Mixed intercropping system	Giza 22	4.20	4.00	10.00	2.00	5.20	3.10	10.00	2.20
	Giza 35	6.00	4.80	12.60	2.40	5.80	3.00	12.00	3.00
	Crawford	6.40	4.60	15.00	2.80	6.20	5.00	14.00	4.00
	Mean	**5.53**	**4.46**	**12.53**	**2.40**	**5.73**	**3.70**	**12.00**	**3.06**
Average of soybean cultivars	**Giza 22**	**4.46**	**2.73**	**8.66**	**2.06**	**5.86**	**1.83**	**8.00**	**1.53**
	Giza 35	**6.26**	**2.93**	**11.80**	**1.93**	**6.20**	**1.66**	**10.86**	**2.06**
	Crawford	**7.00**	**3.20**	**14.33**	**2.40**	**7.16**	**3.13**	**14.20**	**2.86**
					L S D (P=0.05)				
Intercropping systems		**0.64**	**0.69**	**1.48**	**0.63**	**1.29**	**1.41**	**1.53**	**1.36**
Soybean cultivars		**0.49**	**0.43**	**1.32**	**0.41**	**1.14**	**1.28**	**1.31**	**1.18**
Interaction		**0.72**	**0.77**	**1.56**	**0.71**	**1.42**	**1.54**	**1.66**	**1.57**

These results are in agreement with those of Gad El-Rab (1997), who showed that aphid density was higher on solid culture of soybean and lower on intercropping system (one maize : one soybean). Aphids feed on carbohydrates and amino acids from the leaf tissue with alternating between sexual and asexual generations, which allows them to proliferate rapidly (Guerrieri and Digilio, 2008).

In other words, increasing maize plant density from 33 to 100 per cent of solid culture of maize is biological tool for obstructing aphids' movement on soybean leaves under intercropping condition. On the other hand, susceptibility of soybean plants to the infestation with whitefly, leaf miner fly and thrips varied statistically according to intercropping systems (Tables 7). The whitefly, leaf miner flies and thrips assembles on soybean leaves of mixed intercropping system were higher than those of intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean in both the seasons. According to Montagnini and Jordan (1983), whitefly attack was increased with increasing soil water through rainfall rate. Moreover, increasing maize plant density from 50 to 100 per cent of solid culture increased whitefly infestation on soybean leaves under intercropping conditions. Soybean leaves of mixed intercropping system were susceptible to whitefly infestation than those of the other intercropping systems due to an increase in maize plant density from 33 to 100 per cent of solid culture of maize. These results are in parallel with Ali *et al.* (1994), who observed that the number of whitefly was considerably increased as the density of maize plants increased.

With respect to leaf miner fly, intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean could form warmer environment around soybean plants as a result of increasing light intensity within soybean canopy (Tables 10 and 11), which reflected on life cycle of this insect inside soybean leaves than those of mixed intercropping system. It is known that development rates of insects decreased with increasing air temperature (Leibee, 1984). Obviously, maize plants act as a safe refuge for leaf miner fly, which increased leaf miner fly infestation within soybean leaves under mixed intercropping system. With respect to thrips, soybean plants of mixed intercropping system had higher infestation than those of the other intercropping systems. These results probably due to mixed intercropping system formed cooler environment around soybean plants, which accelerated thrips growth and development on soybean leaves. High temperature appeared to inhibit egg development (Murai, 2000), which retard thrips growth and development on soybean leaves under intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean. Therefore, thrips has a lesser capacity to develop in soybean leaves by increasing maize plant density per unit area from 33 to 100 per cent of solid culture of maize.

Soybean cultivars: Soybean *cvs.* Giza 22 and Giza 35 had aphids, whitefly, leaf miner fly and thrips assemblages; the converse was true for *cv.* Crawford in both the seasons (Tables 7). These results could be attributed to genetic makeup of the studied soybean cultivars translated into different canopies architectures for tolerating the insects attack through mechanical and chemical defenses in their leaves. The mechanical defense for tolerating all the tested insects attack was due to higher length of leaf pubescence in leaves of *cv.* Giza 22 and higher leaf pubescence density and number of leaf pubescence per 500 μm in leaves of *cv.* Giza 35 than those of *cv.* Crawford (Fig. 1 and Table 4). These results are in agreement with those obtained by Gunasinghe *et al.* (1988), who found that increasing length of leaf pubescence and pubescence density acting as a mechanical barrier to aphid probing. With respect to the chemical defense, leaves of *cv.* Giza 35 tolerated all the tested insects attack due to lower leaf N content than those of the other cultivars (Table 5). Similar results were observed by Abdel-Wahab *et al.* (2019), who showed that the variation in leaf N content of the tested soybean cultivars was probably attributed to difference in their genetic makeup among them.

The interaction between intercropping systems and soybean cultivars: Susceptibility of the studied soybean varieties to the infestation of aphids, whitefly, leaf miner fly and thrips statistically varied according to the interaction between intercropping systems and cultivars (Tables 7). Higher aphids assemblages on leaves were obtained by growing *cv.* Crawford with maize in intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean than the others in the first and second seasons, respectively. These results could be due to the highest leaf N content in *cv.* Crawford as compared with the others (Table 5), which enhanced amino acids synthesis in soybean leaves especially under intercropping system 2 maize: 4 soybean as a result of increasing light intensity around soybean canopy (Tables 10 and 11). Moreover, leaves of *cv.* Crawford had shorter length of leaf pubescence with normal pubescence density than the others (Fig. 1 and Table 4), which contributed in increasing this biologically negative situation for aphids assemblages. N normally increased herbivore feeding preference, food consumption, survival, growth, reproduction and population density (Bala *et al.*, 2018).

Lower aphids assemblages on leaves of *cv.* Giza 22 was due to the higher length of pubescence (Fig. 1 and Table 4) and total phenols content (Table 5), which integrated positively with spatial arrangement of mixed intercropping system to tolerate aphids attack than the others. Moreover, this biologically negative situation for aphids' assemblages was increased through higher water consumptive use (Table 6) under mixed intercropping system which could have played a negative role on growth and development of larvae, pupa and adult aphids than the others. Lower whitefly infestation on soybean leaves was obtained by growing *cv.* Giza 35 with maize under intercropping system 2 maize: 4 soybean than the others in both the seasons (Tables 7). These results were due to the higher leaf JA and POD contents of *cv*. Giza 35 (Table 3), which integrated positively with higher number of leaf pubescence per 500 μm and pubescence density (Fig. 1 and Table 4), which reflected on whitefly growth and development. Presence of glandular trichomes has been shown to confer a high level of resistance against whiteflies (Freitas *et al*., 2002). These results are in accordance with Taggar *et al*. (2012), who found that whitefly infestation increased the activity of POD where resistant genotypes recorded higher POD under whitefly-stress conditions compared with non-stressed plants.

Lower leaf miner fly infestation on soybean leaves was obtained by growing *cv.* Giza 22 with maize in intercropping system 2 maize: 4soybean than the others (Tables 7). These results were due to the highest leaf pubescence per 500 μm of *cv.* Giza 22 as compared to the others (Fig. 1 and Table 4) and the highest leaf JA, POD and total phenols contents (Table 5) that reflected on growth and development of this insect and this positive effect was increased through intercropping system 2 maize: 4 soybean. According to Xie and Wang (2006), phenolic biosynthesis is enhanced by light and is related to light intensity and density. With respect to thrips, lower thrips infestation rate on soybean leaves was obtained by growing *cv.* Giza 35 with maize under intercropping system 2 maize: 2 soybean than the others in both the seasons (Tables 7). These results were due to the highest leaf JA, POD and total phenols contents of *cv*. Giza 35 (Table 3), as well as number of leaf pubescence per 500 μm and dense leaf pubescence (Fig. 1 and Table 4) and this effect was improved in intercropping system 2 maize: 2 soybean. These results showed that the infestation rate with thrips depended on soybean cultivar and the occupied area of this cultivar under the intercropping system, where the proportion of legume component under intercropping system 2 maize: 4 soybean reached 67 per cent of solid culture of soybean. Moreover, leaves of *cvs.* Giza 35 and Giza 22 tolerated this insect through high leaf JA, POD and total phenols contents under intercropping conditions. It seems that *cvs*. Giza 35 and Giza 22 had genes involved in the JA pathways were up-regulated compared with their expression in the susceptible *cv.* Crawford. It is known that JA is signaling molecules that mediate the stress response of a resistant plant upon being attacked by an insect and hence JA produced defensive allele-chemicals that are deterrent or lethal to the insect (Bansal *et al*., 2013). In another study, Sirhindi *et al*. (2016) indicated that the activity of POD over the control in nickel treated seedlings and further enhancement in the antioxidant activity was occurred by the application of JA. Moreover, higher total phenols in leaves of the tolerant *cvs.* Giza 35 and Giza 22 could have caused a detrimental effect on the physiology and behaviour of the considered insects. These results indicated that the total phenols in leaves of the tolerant *cvs.* Giza 35 and Giza 22 inhibited feeding of these insects. These results showed that the genetic differences among the studied soybean cultivars that translated into length of leaf pubescence, density and number of leaf pubescence, as well as leaf N, JA, POD and phenol contents played a major role in tolerance of insect attack.

Maize grain yield and its attributes

Intercropping systems: The studied maize traits were significantly affected by intercropping systems in both the seasons (Tables 8 and 9). Mixed intercropping system had the maximum plant height, number of green leaves per plant, 100-grain weight and grain yield per ha as compared with the other intercropping systems. There was a significant difference in plant height between mixed and intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean, whereas no significant differences between intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean for this trait was observed. Mixed intercropping system had the maximum plant height followed by intercropping system 2 maize: 2 soybean then intercropping system 2 maize: 4 soybean. This variation in plant height could be attributed to differences in spatial arrangements of the studied intercropping systems where maize plants of mixed intercropping system suffered from mutual shading than other intercropping systems. Mutual shading is known to increase the proportion of invisible radiation, which has a specific elongating effect upon plants (Change, 1974). Maize plants of mixed intercropping system had higher number of green leaves probably due to high intra-specific competition between plants for climatic and edaphic environmental resources that reflected on plant height than the intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean. Intercropping system 2 maize: 4 soybean gave the maximum number of ears per plant, ear weight and grain yield per plant as compared with the other intercropping systems. Also, mixed system increased intra-specific competition between maize plants for basic growth resources especially solar radiation. These results revealed that intercropping system 2 maize: 4 soybean had growth advantages than those of sole planting where maize plant greatly benefited from available environmental resources that reflected on leaf area and grain yield per plant as reported by Abdel-Galil *et al*. (2014). However, maize plants of mixed system recorded higher grain yield per ha as a result of increasing maize plant density from 33 to 100 per cent of solid culture of maize than those of the other intercropping systems. As a result of intercropping, grain yield per ha was decreased by 26.00 per cent in the first season and 28.57 per cent in the second season than solid culture of maize as a result of the differences in maize plant density per unit area. Similar results were observed Abdel-Wahab and Abd El-Rahman (2016), who found that maize yield attributes were significantly increased by decreasing maize plant density under intercropping systems, meanwhile the converse was true for plant height and grain yield per ha.

Soybean cultivars: Maize grain yield and its attributes were not significantly affected by soybean cultivars in both the seasons (Tables 8 and 9). These results may be due to higher ability of maize as C_4 plant of photosynthetic pathways to be grown successfully during growth and development than soybean, and hence all the tasted soybean cultivars did not exert any effect on maize crop. The results are in accordance with those obtained by Metwally *et al.* (2018), who showed that grain yields per plant and per unit area were not affected by soybean cultivars.

Table 8. Maize grain yield and its attributes as affected by intercropping systems, soybean cultivars and their interaction in the first season

Intercropping system	Soybean cultivar	Plant height (cm)	Green leaves (No/ plant)	Ears (No/ plant)	Ear weight (g)	Grain yield (g/ plant)	100 – kernel weight (g)	Grain yield (t/ha)
				First season (2016)				
2 maize : 2 soybean	**Giza 22**	240.33	12.65	1.52	210.30	248.53	36.77	6.88
	Giza 35	240.00	12.36	1.55	212.68	249.30	36.99	6.80
	Crawford	243.66	12.65	1.59	209.60	259.21	36.75	6.89
	Mean	**241.33**	**12.55**	**1.55**	**210.86**	**252.34**	**36.84**	**6.85**
2 maize : 4 soybean	**Giza 22**	224.00	11.79	1.81	234.10	343.30	32.68	5.57
	Giza 35	228.33	11.66	1.84	230.53	333.60	32.70	5.46
	Crawford	228.33	11.95	1.83	232.64	348.90	32.52	5.54
	Mean	**226.88**	**11.80**	**1.83**	**232.42**	**341.76**	**32.63**	**5.52**
Mixed intercropping system	**Giza 22**	263.00	14.08	1.05	180.46	149.65	39.51	8.38
	Giza 35	264.33	14.03	1.04	183.43	154.59	39.30	8.44
	Crawford	265.33	14.01	1.03	179.38	151.33	38.92	8.42
	Mean	**264.22**	**14.04**	**1.04**	**181.09**	**151.85**	**39.25**	**8.41**
Average of soybean cultivars	**Giza 22**	**242.44**	**12.84**	**1.46**	**208.28**	**247.16**	**36.32**	**6.71**
	Giza 35	**244.22**	**12.68**	**1.48**	**208.88**	**245.83**	**36.33**	**6.64**
	Crawford	**245.77**	**12.87**	**1.48**	**207.21**	**252.98**	**36.06**	**6.48**
				L S D (P = 0.05)				
Intercropping systems		**15.97**	**0.37**	**0.15**	**22.62**	**7.80**	**0.49**	**0.26**
Soybean cultivars		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**NS.**
Interaction		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Solid culture of maize								**8.86**

The interaction between intercropping systems and soybean cultivars: The interaction between intercropping systems and soybean cultivars did not affect maize grain yield and its attributes in both seasons (Tables 8 and 9).

Soybean seed yield and its attributes

Intercropping systems: Percentages of light intensity at middle and bottom of the plant, plant height, numbers of branches and pods per plant, seed yield per plant, 100– seed weight, seed yield per ha and HI were significantly affected by intercropping systems in both seasons (Tables 10 and 11). Intercropping system 2 maize: 4 soybean had the highest percentages of light intensity at middle and bottom of the plant, numbers of branches and pods per plant, seed yield

Table 9. Maize grain yield and its attributes as affected by intercropping systems, soybean cultivars and their interaction in the second season

Intercropping system	Soybean cultivar	Plant height (cm)	Green leaves (No/ plant)	Ear (No/ plant)	Ear weight (g)	Grain yield (g/ plant)	100 – kernel weight (g)	Grain yield (t/ha)
				Second season (2017)				
2 maize : 2 soybean	Giza 22	268.07	13.00	1.55	230.40	270.42	39.18	7.53
	Giza 35	273.19	13.04	1.52	227.38	268.38	39.21	7.47
	Crawford	268.93	13.16	1.56	232.34	272.45	39.43	7.44
	Mean	**270.06**	**13.07**	**1.54**	**230.04**	**270.42**	**39.27**	**7.48**
2 maize : 4 soybean	Giza 22	249.61	12.60	1.78	262.53	373.63	36.41	6.12
	Giza 35	252.79	12.67	1.81	266.10	369.30	36.35	6.03
	Crawford	256.41	12.56	1.77	264.49	373.16	36.28	6.01
	Mean	**252.93**	**12.61**	**1.78**	**264.38**	**372.03**	**36.34**	**6.05**
Mixed intercroppin g system	Giza 22	294.44	14.44	1.01	205.45	159.51	41.60	8.94
	Giza 35	297.34	14.53	1.03	201.55	169.52	41.29	8.99
	Crawford	292.63	14.34	1.01	202.74	161.26	41.44	8.91
	Mean	**294.80**	**14.44**	**1.02**	**203.25**	**163.43**	**41.44**	**8.94**
Average of soybean cultivars	Giza 22	**270.70**	**13.35**	**1.45**	**232.79**	**267.85**	**39.06**	**7.53**
	Giza 35	**274.44**	**13.41**	**1.45**	**231.68**	**269.07**	**38.95**	**7.49**
	Crawford	**272.65**	**13.35**	**1.44**	**233.19**	**268.96**	**39.05**	**7.45**
				L S D (P = 0.05)				
Intercropping systems		**16.10**	**0.44**	**0.08**	**16.06**	**12.63**	**0.97**	**0.15**
Soybean cultivars		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**NS.**
Interaction		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Solid culture of maize								**9.47**

per plant, 100–seed weight, seed yield per ha and HI, but the shortest plants. The advantage of intercropping system 2 maize: 4 soybean in intercepted light intensity by soybean canopy over intercropping system 2 maize: 2 soybean and mixed intercropping system probably due to lower number of maize plants per unit area that reflected on lower shading and whitefly numbers on soybean leaves (Tables 7). Infestation of whiteflies usually heaviest during the pod-filling period and can cause severe yield reductions (Khanzada *et al*., 2013).

Despite the low water consumption of intercropping system 2 maize: 4 soybean, the light intensity counterbalanced this shortage and increased soybean productivity. These results could be due to the high rate of evaporation from the soil because of low maize plant density per unit area which contributed negatively in water consumptive use of intercropped soybean plants. It is known that water consumptive use of maize (500-800 mm) is almost equal to that of soybean (450-700 mm) for the growing period (Brouwer and Heibloem, 1986). Hence, evaporation from the soil played the major role in lowering water consumptive use for intercropped soybean plants. Conversely, mixed intercropping system recorded lower

Table 10. Soybean seed yield and its attributes as affected by intercropping systems, soybean cultivars and their interaction in the first season

Intercropping system	Soybean cultivar	Percentages of light intensity at: Middle of the plant	Percentages of light intensity at: Bottom of the plant	Plant height (cm)	Branches (No/ plant)	Pods (No/ plant)	Seed yield (g/ plant)	100 – seed weight (g)	HI (%)	Seed yield (t/ha)
First season (2016)										
2 maize : 2 soybean	Giza 22	7.17	3.69	102.56	3.23	75.61	21.87	15.71	24.31	1.28
	Giza 35	6.63	3.37	95.87	3.31	79.29	20.23	15.27	22.43	1.16
	Crawford	7.60	3.91	100.38	2.21	75.27	15.27	16.04	16.45	0.72
	Mean	**7.13**	**3.65**	**99.61**	**2.91**	**76.72**	**19.12**	**15.67**	**21.06**	**1.05**
2 maize : 4 soybean	Giza 22	7.61	4.00	95.99	3.67	81.64	24.52	16.00	26.17	1.54
	Giza 35	7.03	3.86	90.81	3.97	86.39	21.18	15.75	23.89	1.42
	Crawford	8.02	4.21	94.53	2.43	84.64	16.84	16.25	17.64	0.87
	Mean	**7.55**	**4.02**	**93.77**	**3.36**	**84.22**	**20.85**	**16.00**	**22.56**	**1.27**
Mixed intercropping system	Giza 22	5.51	3.40	110.83	2.75	62.29	15.76	13.68	19.29	1.11
	Giza 35	4.84	3.16	100.51	2.93	69.18	13.48	12.40	17.29	0.99
	Crawford	6.21	3.66	103.84	1.87	66.10	11.47	14.46	13.64	0.64
	Mean	**5.52**	**3.41**	**105.06**	**2.52**	**65.85**	**13.57**	**13.51**	**16.74**	**0.91**
Average of soybean cultivars	Giza 22	**6.76**	**3.70**	**103.12**	**3.22**	**73.18**	**20.72**	**15.13**	**23.26**	**1.31**
	Giza 35	**6.16**	**3.46**	**95.73**	**3.40**	**78.29**	**18.30**	**14.47**	**21.20**	**1.19**
	Crawford	**7.28**	**3.92**	**99.58**	**2.17**	**75.33**	**14.53**	**15.58**	**15.91**	**0.74**
L S D (P = 0.05)										
Intercropping systems		**0.36**	**0.37**	**1.45**	**0.23**	**4.82**	**1.96**	**0.53**	**1.60**	**0.07**
Soybean cultivars		**0.28**	**0.14**	**1.24**	**0.14**	**2.10**	**1.36**	**0.43**	**1.27**	**0.04**
Interaction		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**2.11**	**N.S.**	**N.S.**	**0.11**
Solid culture of soybean	Giza 22									**3.59**
	Giza 35									**3.14**
	Crawford									**2.47**

Table 11. Soybean seed yield and its attributes as affected by intercropping systems, soybean cultivars and their interaction in the second season

Intercropping system	Soybean cultivar	Percentages of light intensity at		Plant height (cm)	Branches (No/ plant)	Pods (No/ plant)	Seed yield (g/ plant)	100 – seed weight (g)	HI (%)	Seed yield (t/ha)
		Middle of the plant	Bottom of the plant							
		Second season (2017)								
2 maize : 2 soybean	**Giza 22**	7.35	3.82	95.11	3.53	82.49	24.77	16.30	24.76	1.45
	Giza 35	6.86	3.64	80.91	3.62	86.66	23.41	15.11	22.86	1.28
	Crawford	7.87	4.11	86.43	2.35	85.08	17.86	16.81	17.53	0.95
	Mean	**7.36**	**3.85**	**87.48**	**3.17**	**84.74**	**22.01**	**16.07**	**21.72**	**1.23**
2 maize : 4 soybean	**Giza 22**	7.88	4.38	92.64	3.87	90.40	25.76	16.80	26.76	1.73
	Giza 35	7.11	3.99	76.97	4.17	94.56	24.46	15.57	24.50	1.61
	Crawford	8.11	4.54	81.39	2.67	93.33	19.40	17.25	19.29	1.23
	Mean	**7.70**	**4.30**	**83.67**	**3.57**	**92.76**	**23.21**	**16.54**	**23.51**	**1.52**
Mixed intercropping system	**Giza 22**	5.86	3.66	103.43	2.95	75.08	18.74	14.25	19.66	1.21
	Giza 35	5.10	3.26	93.89	3.18	78.87	16.85	13.13	17.70	1.07
	Crawford	6.66	3.71	99.51	2.06	76.37	14.88	15.21	14.56	0.90
	Mean	**5.87**	**3.54**	**98.94**	**2.73**	**76.77**	**16.82**	**14.19**	**17.31**	**1.06**
Average of soybean cultivars	**Giza 22**	**7.03**	**3.95**	**97.06**	**3.45**	**82.66**	**23.09**	**15.78**	**23.73**	**1.46**
	Giza 35	**6.36**	**3.63**	**83.92**	**3.66**	**86.70**	**21.57**	**14.60**	**21.68**	**1.32**
	Crawford	**7.54**	**4.12**	**89.11**	**2.36**	**84.92**	**17.38**	**16.42**	**17.13**	**1.02**
		L S D (P = 0.05)								
Intercropping systems		**0.32**	**0.30**	**2.54**	**0.19**	**2.46**	**3.67**	**0.54**	**3.25**	**0.17**
Soybean cultivars		**0.26**	**0.21**	**2.39**	**0.12**	**2.29**	**3.01**	**0.18**	**1.04**	**0.12**
Interaction		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**3.88**	**N.S.**	**N.S.**	**0.23**
Solid culture of soybean	Giza 22									**3.80**
	Giza 35									**3.40**
	Crawford									**3.08**

percentages of light intensity at middle and bottom of the plant, numbers of branches and pods per plant, seed yield per plant, 100–seed weight, seed yield per ha and HI, but the tallest plants as compared with the other intercropping systems (Tables 10 and 11). These results showed that shading effects of mixed intercropping system formed unfavorable conditions for soybean plant during early stages of soybean growth and development, consequently more amounts of plant hormones were produced which reflected on plant height and seed yield attributes. It is important to note that increasing plant density to 100 per cent of maize sole planting increased shading intensity around soybean plants and consequently little dry matter accumulation of soybean plant (Abdel-Galil *et al.*, 2014). Although mixed intercropping system increased water consumptive use of the intercrops than those of intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean, but the effect of shading intensity was severe on soybean growth and development. Consequently, this biological situation reduced number of pods that resulted in reduction in seed yield per ha, and this effect was increased by increasing whitefly, leaf miner fly and thrips assemblages in soybean leaves (Tables 7), which was reflected on HI.

Soybean cultivars: Soybean cultivars significantly differed for percentages of light intensity at middle and bottom of the plant, plant height, numbers of branches and pods per plant, seed yield per plant, 100–seed weight, seed yield per ha and HI in both the seasons (Tables 10 and 11). Cultivar Giza 22 gave the maximum plant height, seed yields per plant and per ha and HI. Leaves of *cv*. Giza 22 that had higher length of leaf pubescence (Fig. 1 and Table 4), permitted more solar radiation to leaf surface and increased their tolerance to aphids, whitefly, leaf miner fly and thrips attack (Tables 7). Cultivar Giza 35 had the highest numbers of branches and pods per plant but it recorded lower light intensity at middle and bottom of the plant, plant height and 100–seed weight as compared with the others (Tables 10 and 11).

These results could be due to the highest leaf pubescence density, number of leaf pubescence per 500 µm (Fig. 1 and Table 4) and N content (Table 5) of *cv*. Giza 35, that led to high tolerance to aphids, whitefly, leaf miner fly and thrips attack (Tables 7).

Soybean *cv*. Crawford, gave the highest light intensity at middle and bottom of the plant and 100– seed weight, but it recorded lower number of branches per plant, seed yields per plant and per ha and HI as compared with the others (Tables 10 and 11). These results were accounted for the highest infestation rate with all the tested insects in case of this cultivar, (Tables 7) that reflected on reduction in soybean productivity as compared with the others. These results are in the same context with those obtained by Abdel-Galil *et al.* (2014), who found that *cv*. Giza 22 had the highest seed index, seed yields per plant and per ha as compared with the others.

Table 12. Relative yield of both crops and LER of intercropping three soybean cultivars with maize under different intercropping systems in both seasons

Intercropping systems	Soybean Cultivar	Relative yield of maize	Relative yield of soybean	LER	Relative yield of maize	Relative yield of soybean	LER
		First season (2016)			*Second season (2017)*		
2 maize : 2 soybean	Giza 22	0.78	0.36	1.14	0.80	0.38	1.18
	Giza 35	0.77	0.37	1.14	0.79	0.38	1.17
	Crawford	0.78	0.30	1.08	0.79	0.31	1.10
	Mean	**0.78**	**0.34**	**1.12**	**0.79**	**0.36**	**1.15**
2 maize : 4 soybean	Giza 22	0.63	0.43	1.06	0.65	0.46	1.11
	Giza 35	0.62	0.45	1.07	0.64	0.47	1.11
	Crawford	0.63	0.36	0.99	0.63	0.41	1.04
	Mean	**0.63**	**0.41**	**1.04**	**0.64**	**0.45**	**1.09**
Mixed intercropping	Giza 22	0.95	0.31	1.26	0.94	0.32	1.26
	Giza 35	0.95	0.31	1.26	0.95	0.31	1.26
	Crawford	0.95	0.26	1.21	0.94	0.29	1.23
	Mean	**0.95**	**0.29**	**1.24**	**0.94**	**0.31**	**1.25**
Solid culture		**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 13. Economic returns of intercropping three soybean cultivars with maize under different intercropping systems in both seasons

Intercropping systems	Soybean cultivar	Income of maize (USD/ ha)	Income of soybean (USD ha)	Total returns (USD/ ha)	Net returns (USD/ ha)	Income of maize (USD/ ha)	Income of soybean (USD/ ha)	Total returns (USD/ ha)	Net returns (USD/ ha)
		First season (2016)				*Second season (2017)*			
2 maize : 2 soybean	Giza 22	1376	576	1952	1175	1506	652	2158	1382
	Giza 35	1360	522	1882	1105	1494	576	2070	1293
	Crawford	1378	324	1702	925	1488	427	1915	1139
	Mean	**1371**	**474**	**1845**	**1069**	**1496**	**552**	**2048**	**1271**
2 maize : 4 soybean	Giza 22	1114	693	1807	1057	1224	778	2002	1252
	Giza 35	1092	639	1731	981	1206	724	1930	1180
	Crawford	1108	391	1499	749	1202	553	1755	1005
	Mean	**1104**	**574**	**1679**	**929**	**1210**	**685**	**1896**	**1146**
Mixed intercropping	Giza 22	1676	499	2175	1234	1788	544	2332	1391
	Giza 35	1688	445	2133	1192	1798	481	2279	1338
	Crawford	1684	288	1972	1031	1782	405	2187	1246
	Mean	**1682**	**411**	**2093**	**1152**	**1789**	**477**	**2266**	**1325**
Solid culture of maize		**1612**	**---**	**1612**	**759**	**1734**	**---**	**1734**	**881**

The interaction between intercropping systems and soybean cultivars: The interaction between intercropping systems and soybean cultivars significantly affected seed yields per plant and per ha in both seasons (Tables 10 and 11). Growing soybean *cv.* Giza 22 under intercropping system 2maize : 4 soybean recorded the highest seed yields per plant and per ha in both seasons, but the reverse was true for soybean *cv.* Crawford of mixed intercropping system. These results were due to leaves of soybean *cv.* Giza 22 of intercropping system 2 maize: 4 soybean had the highest leaf pubescence per 500 µm (Fig. 1 and Table 4) and JA, POD and total phenols contents (Table 5), which reflected on insects resistance and soybean productivity. These results are in agreement with those obtained by Abdel-Wahab and Abd El-Rahman Rehab (2016), who found thatsoybean *cv.* Giza 22 gave the highest seed yield per plant than the others under all the intercropping systems.

Land equivalent ratio (LER)

Intercropping soybean with maize increased LER as compared to solid cultures of both crops in both the seasons (Table 12). In general, mixed intercropping system had the highest LER in both the seasons. LER ranged from 0.99 to 1.04 (by intercropping *cv.* Crawford with maize under intercropping system 2 maize: 4 soybean) and 1.26 (by intercropping *cv.* Giza 22 or Giza 35 with maize under mixed intercropping system) in the first and second season, respectively. Intercropping *cv.* Giza 22 or Giza 35 with maize under mixed intercropping system achieved the highest LER in both the seasons (Table 13). Advantages of intercropping *cv.* Giza 22 with maize under mixed intercropping system was due to foliar characteristics of this cultivar that had the highest length of pubescence (Fig. 1 and Table 4) and total phenols content (Table 5). Disadvantage of intercropping *cv.* Crawford with maize under intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean was due to the highest aphids infestation rate (Tables 7), which affected negatively dry matter accumulation and economic yield. Also, relative yield of maize was decreased because of decreasing maize plant density per unit area from 50 and 33 per cent of solid culture of maize under intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean, respectively, which reflected on grain yield per unit area. Although soybean plant density reached 50 and 67 per cent of solid culture of soybean under intercropping systems 2 maize: 2 soybean and 2 maize: 4 soybean, respectively, but relative yield of soybean remained below 50 per cent. These results may be due to the decrease in light penetration through soybean canopies under intercropping with maize.

Economic returns

The economic returns of intercropping soybean with maize varied between treatments from USD 1,499 to 2,175 per ha as compared with solid culture of maize (USD 1,612 per ha) in the first season (Table 13). Also, total returns from intercropping soybean with maize varied between treatments from USD 1,755 to 2,332 per ha as compared with solid culture of maize (USD 1,734 per ha) in the second one. The net returns of intercropping soybean with maize varied between treatments from USD 749 to 2,175 per ha as compared with solid culture of maize (USD 1,612 per ha) in the first season.

Also, net returns of intercropping soybean with maize varied between treatments from USD 1,755 to 2,332 per ha as compared with solid culture of maize (USD 1,734 per ha) in the second season. In general, it seems that growing soybean with maize achieved higher total and net returns than solid culture of maize in both the seasons. These results indicated that intercropping *cv.* Giza 22 with maize under mixed intercropping system achieved the highest economic returns per ha (USD 1,234 in the first season and USD 1,391 in the second season). The results may be due to the highest water consumptive use and lowest aphid infestation rate which reflected on Land equivalent ratio of this treatment. On the other hand, intercropping *cv.* Crawford with maize under intercropping system 2 maize: 4 soybean had the highest leaf miner rate and lowest financial return per ha.

These results demonstrate that intercropping soybean *cv.* Giza 22 with maize under mixed intercropping system will be more profitable than solid maize for Egyptian farmers. These results are in agreement with those obtained by Metwally *et al*. (2017).

It could be concluded that intercropping soybean with maize could be recommended for minimizing the infestation of aphids, whitefly, leaf miner fly or thrips in soybean crop. Growing two rows of soybean *cv.* Giza 22 in middle of maize beds (140 cm width) increased water consumptive use and decreased aphid infestation rate which reflected on soybean productivity, land usage and economic returns.

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Soybean Research 18(1): 31-59 (2020)

Water Consumptive Use and Soybean Mosaic Virus Infection in Intercropped Three Soybean Cultivars with Maize under Different Soybean Plant Densities

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ABSTRACT

A two–year study was carried out at Giza Agricultural Experiments and Research Station, Agricultural Research Center, during the two summer seasons 2016 and 2017 to evaluate water consumptive use and soybean mosaic virus (SMV) infection of intercropped three soybean cultivars with maize under different soybean plant densities in order to increase land usage and economic returns. Nine treatments were the combinations of three soybean plant destinies (two rows, three rows and four rows per bed were expressed as 50, 75 and 100 per cent of solid soybean plant density) and three soybean cultivars (Giza 21, Giza 82 and Giza 111) under intercropping culture with maize in addition to solid cultures of both the crops. A split plot distribution in randomized complete blocks design with three replicates was used. The results indicated that increasing soybean plant density from 50 to 100 per cent of solid culture of soybean increased water consumptive use of the intercrops (100 % maize + 100 % soybean cv. Giza 111). Leaves of soybean cvs. Giza 21 and Giza 111 had the lowest SMV infection and transmission by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean as compared with the others. Leaf storage proteins revealed variations among all soybean cultivars under different soybean plant densities in intercropping system. Soybean cv. Giza 21 had presence of six protein bands by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean. Meanwhile, soybean cv. Giza 82 was susceptible to SMV infection by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean. Soybean cv. Giza 111 had one protein band was newly formed by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean. With respect to maize crop, all

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the studied maize traits were not affected by soybean plant densities, soybean cultivars or the interaction between them. Most the studied soybean traits were significantly affected by soybean plant densities. With respect to soybean crop, cv. Giza 111 gave the highest seed yield per ha as compared with the others. Increasing soybean plant density of cv. Giza 111 from 50 to 100 per cent of solid culture of soybean recorded the highest seed yield per ha as compared with the others. Highest LER was achieved by increasing soybean plant density of cv. Giza 111 from 50 to 100 per cent of solid culture of soybean. With respect to economic returns, increasing soybean plant density of cv. Giza 111 from 50 to 100 per cent of solid culture of soybean recorded the highest economic returns per ha as compared with the solid culture of maize. The best treatment was obtained by growing four rows of soybean cv. Giza 111 in middle of maize beds where it gave 2.72 and 2.41 ton of soybean seeds per ha and 8.25 and 9.07 ton of maize grains per ha in the first and second seasons, respectively. Also, this treatment recorded the highest water consumptive use (818 and 750 mm), LER (1.68 and 1.63) and net return (USD 1,938 and 1,962/ha), as well as, the lowest SMV infection (8.3 and 7.8 %) in the first and second seasons, respectively, compared with the other treatments.

Key words: Intercropping, maize, soybean cultivars, soybean plant densities, water consumptive use, SMV, LER, economic returns

Water content of soybean [*Glycine max* (L.) Merrill] seeds plays an important role not only in physiological, but also in chemical processes (Pietrzak *et al*., 2002). If irrigation schedule is not harmonized with soybean requirements and physical soil properties, its effect on soybean yield may be negligible or missing (Maksimović *et al*., 2005). However, Colaizzi *et al.* (2006) showed that soybean yield and seasonal water use increased significantly with increase in irrigation depth.

Soybean is known to be naturally infected by at least 50 viral diseases belonging to different groups. It is known that soybean mosaic virus (SMV) is transmitted by aphids, which feeds using sucking, needle like mouth parts to extract plant juices, to infect soybean and likely to cause yield reductions as high as 35 per cent (Hill, 1999). Thus, seed yield is reduced indirectly by transmitting SMV and other soybean viruses (Clark and Perry, 2002 and Wang and Ghabrial, 2002) and directly by aphids (Macedo *et al*., 2003). However, the effect of pubescence may be positive, negative, or non-existent, depending on the leaf hair type (glandular or non-glandular), density, and length (Andres and Connor, 2003). These pubescence characteristics could play a major role in tolerance to aphids. Secondary spread of SMV occurs only by feeding on infected plants which result from the seed transmission of SMV from the previous generation (Pfeiffer *et al*., 2003). On the other hand, plant hormones could play an important role for defensive system to SMV where it influenced physiological processes in plants at very low concentrations (Davies, 2004). The intimate interaction between a plant virus and its host is complicated by the systemic nature of infection and global alterations in host gene expression (Whitham and Wang, 2004). Hence, plant hormones play an important role in plant growth and development; some of these hormones are essential for plant immunity (Pieterse *et al*., 2009). The plant hormone jasmonic acid (JA) mediates a variety of physiological processes, including the basal plant defense responses induced by viral infections (Pieterse *et al*., 2012).

Fahmy and Salama (2002) found nineteen bands in some soybean cultivars by using sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) technique. Soybean *cvs*. Giza 21, Giza 22, Giza 35, Giza 111 and Toano occupied relatively lower ranks for seed yield per unit area, meanwhile Giza 82, Giza 83, DR 101 and Hatchison performed better ranking for most studied characters under intercropping cultures (Metwally *et al*., 2003). It is believed that if susceptible plants are scattered among resistant plants within a field, vectors are less likely to encounter susceptible ones than if they were in solid cultures (Hooks and Fereres, 2006). Thus, seed protein data could play an important role in soybean cultivars identification under stress conditions; particularly Malik *et al*. (2009) obtained the genetic variation among ninety-two accessions of soybean by using SDS-PAGE. However, mosaic disease is one of the obstacles adoption soybean cultivars (Andayani *et al*., 2011). The genome of SMV is approximately 10 kb in length and encodes 11 mature proteins as reported by Hajimorad *et al*. (2018).

A little knowledge is yet available about virus associated with intercropped soybean cultivars under different soybean plant density per unit area. According to Trenbath (1993), intercrops reduced pest incidence and damage to the crop. Therefore, the breeding and adoption of desirable mixtures of crop cultivars with resistance to pests and pathogens for increased production should be encouraged (Irwin *et al*., 2000). Additionally, plant spacing will change the plant growth rate and affect the timing of canopy closure in some cropping systems and can be an insect management tool (Pedigo and Rice, 2008). Optimum plant population is a pre-requisite to obtain higher productivity of soybean (Walker *et al*., 2010). Increasing soybean plant density from 50 to 75 per cent per unit area increased seed yield per ha by about 25.28 per cent under intercropping conditions (Metwally *et al*., 2012). On the other hand, increasing soybean plant density from 3,33,200 to 3,36,056 of *cv.* Giza 35 could decrease the probability of foliar disease problems compared to the other treatments as a result of comparatively warmer environment under intercropping cultures (Gadallah and Selim, 2016). Metwally *et al*. (2017) concluded that intercropping soybean with maize in beds 140 cm increased land equivalent ratio (LER) and water use efficiency (WUE), as well as total economic returns than sole maize under recommended level of applied irrigation water of sole plantings. They added that increasing soybean plant density from 50 to 100 per cent did not affect negatively WUE of economic yield. However, during the symbiosis of maize and soybean, the light environment was changed, as well as disease resistance of soybean (Wu *et al*., 2017), where the incidence of viral diseases in shaded soybean was much lower than that of un-shaded soybean as a result of genes associated with signaling pathways such as JA was down regulated (Zhang *et al.*, 2019).

Consequently, choice of suitable soybean cultivar with optimum plant density per unit area could be used for the management of water consumption and virus infection in soybean crop under intercropping conditions. Therefore, the objectives of the present research were to evaluate water consumptive use and SMV infection of intercropped three soybean cultivars with maize under different soybean plant densities in order to increase land usage and economic returns.

MATERIAL AND METHODS

A two-year experiment was carried out at Giza Agricultural Research Station (Lat. 30°00′30″ N, Long. 31°12′43″ E, 26 m a.s.l), Agricultural Research Center, during two summer seasons (2016 and 2017) to evaluate water consumptive use and SMV infection of intercropped three soybean cultivars with maize under different soybean plant densities in order to increase land usage and economic returns. This study included nine treatments, which were the combination between three soybean plant density (2, 3 and 4 rows per bed were expressed as 50, 75 and 100 per cent of solid soybean plant density) and three soybean cultivars (Giza 21, Giza 82 and Giza 111) under intercropping culture with maize, as well as, solid cultures of both crops. Maize variety T.W.C. 321 was used in this study. Origin, pedigree and maturity group of the studied soybean cultivars are shown in table 1. Mechanical and chemical analyses of the soil (0–15 and 15–30 cm depth) were done by Water, Soil and Environment Research Institute, Agricultural Research Center (Table 2). Mechanical and chemical analyses of the soil were determined using the methods described by Chapman and Pratt (1961) and Jackson (1965). The soil texture was clay loamy and the preceding winter crop was wheat in both seasons. Calcium super phosphate (15.5 % P_2O_5) at the rate of 357 kg per ha was applied during soil preparation in the two summer seasons. Soybean seeds were inoculated with *Bradyrhizobium japonicum* using gum Arabic as a sticking agent. Soybean seeds were sown on 23rd and 28th May in 2016 and 2017 seasons, respectively. Maize variety T.W.C. 321 was sown 15 days later. Mineral N fertilizer was added for maize at a rate of 285.6 kg N per ha as ammonium nitrate (33.5 % N) in two equal doses applied before the first and the second irrigation, respectively, under

Table 1. Origin, pedigree and maturity group of the studied soybean cultivars

Soybean cultivar	Origin	Pedigree	Maturity group
Giza 21	Egypt	Crawford x Forrest	IV
Giza 82	Egypt	Crawford x Maple presto	III
Giza 111	Egypt	Crawford x Celest (late)	IV

Table 2. Mechanical and chemical properties of the soil at the experimental site

Soil properties	Soil depth (cm)	
	0-15	15-30
Particle size distribution:		
Coarse sand (%)	2.98	2.95
Fine sand (%)	12.97	13.00
Silt (%)	30.10	29.95
Clay (%)	53.95	54.10
Texture class	clay	clay
Bulk density (Mg m^{-3})	1.16	1.25
Field capacity (% w/w)	42.10	34.60
Permanent wilting point (% w/w)	18.70	16.60
Available water (%)	23.40	18.00
pH (1:2.5)	7.15	7.36
ECe, soil paste extract (dS m^{-1})	0.95	
Soluble cations (meq L^{-1})		
Ca^{2+}	3.54	3.42
Mg^{2+}	1.15	1.3
Na^{+}	2.36	2.44
K^{+}	0.38	0.44
Soluble anions (meq L^{-1})		
CO_3^{2-}	nd*	nd
HCO_3^{-}	2.10	2.25
Cl^{-}	2.22	2.35
SO_4^{2-}	2.40	3.70
Available N (ppm)	38.00	42
Available P (ppm)	16.5	17.88

intercropping and sole plantings. Also, mineral nitrogen (N) fertilizer was added for soybean at a rate of 35.7 kg N per ha as ammonium nitrate (33.5% N) before the first irrigation under intercropping and solid cultures. Three soybean plant densities were grown in mixed intercropping system (140 cm beds width) as follows: growing maize plants in both sides of raised beds and soybean seeds were drilled in two rows in middle of the raised beds (100% maize + 50% soybean). Growing maize plants in both sides of raised beds and soybean seeds were drilled in three rows in middle of raised beds (100% maize + 75% soybean). Growing maize plants in both sides of raised beds and soybean seeds were drilled in four rows in middle of raised beds (100% maize + 100% soybean). With respect to solid cultures of both crops, solid culture of maize was conducted by growing maize plants in one side of ridges (70 cm width), meanwhile solid culture of soybean was conducted by drilling two rows of soybean in ridges 70 cm width.

Solid cultures of both crops were used to estimate the competitive relationships. Maize was grown in hills distanced at 25 cm between hills with one plant per hill under intercropping and solid cultures. Soybean was thinned to 20 plants per one meter length under intercropping and solid cultures. All normal agricultural practices were performed. Furrow irrigation was the irrigation system in this study where the amounts of applied irrigation water were 922 and 927 mm in 2016 and 2017 seasons, respectively. Soybean *cvs*. Giza 21 and Giza 111 were harvested on 2nd and 4th October in 2016 and 2017, respectively, meanwhile soybean *cv*. Giza 82 was harvested on 29th and 31st August in 2016 and 2017 seasons, respectively. Maize plants were harvested on 25th and 28th September in 2016 and 2017 seasons, respectively.

A split plot distribution in randomized complete blocks design with three replicates was used. Soybean plant density were randomly assigned to the main plots, soybean cultivars were allocated in sub-plots. Plot area was 12.6 m^2. Each plot consisted of three raised beds, 3.0 m long and 1.4 m wide (in case of sole plantings, each plot consisted of six ridges, 3.0 m long and 0.7 m wide).

Data recorded

Jasmonic acid (JA) of soybean leaves: Jasmonic acid (JA) in soybean leaves of the three soybean cultivars were taken after 60 days from sowing. This analysis was done by Food Technology Research Institute, Agricultural Research Center, Giza, Egypt.

Pubescence traits of soybean leaves: Pubescence traits were taken after 60 days from soybean sowing on three soybean cultivars exhibiting a range of insect infestation levels and pubescence ratings. Pubescence density was divided into two phenotypes: dense and normal according to Singh (2010). Pubescence traits were estimated by pubescence length (µm), number of pubescence per 500 µm and pubescence density. Pubescence traits were estimated as an indication of direct defense for insect infestation by using SEM Model Quanta 250 FEG (Field Emission Gun) in the Egyptian Mineral Resources Authority Central Laboratories Sector.

Leaf N content**:** Leaf N content was analyzed after 60 days from soybean sowing by the General Organization for Agricultural Equalization Fund, ARC, Giza, Egypt: The leaves (blade only) from three plants were separated, dried, in an oven set at 75^{o} C until reaching constant mass (approximately 48 h), and weighed. Leaves samples were finely ground, thoroughly mixed, and then stored dry in closed containers until analyzed for N content. N was determined by Kjeldahl digestion, followed by colorimetric assay for ammonia–N (Jackson, 1965).

Water relation measurements: The amounts of applied irrigation water were calculated according to Vermeiren and Jopling (1984). Crop water use was estimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

$$WCU = \sum_{i=1}^{i-4} \frac{\theta 2 - \theta 1}{100} \times Bdxd$$

Where: WCU = water consumptive use or actual evapo-transpiration, ETa (mm), i= number of soil layer, θ2 = soil moisture content after irrigation, (%, by mass), θ1 = soil moisture contents just before irrigation, (%, by mass), Bd= soil bulk density (g/cm3), d= depth of soil layer (mm).

Aphids assemblages and SMV infection and transmission: The susceptibility of soybean cultivars to the infestation of aphids was investigated after 60 days from soybean sowing in both seasons. Five soybean plants, represented the sample, were randomly collected from the diagonals of each plot and examined to record the population density of aphids.

Survey of viral infected soybean plants: Samples of soybean plants naturally displaying symptoms of soybean mosaic diseases were counted in each row of a plot. The infected plants were labeled. Percentage of infestation was estimated by visual examination for virus symptoms. The percentage of infected soybean plants was calculated as number of SMV infected plants/number of plants in plot. Labeled plastic bags containing the collected samples were brought to Virus and Phytoplasma Research Department, Plant Pathology Research Institute, Agricultural Research Center, Giza. Indirect ELISA used for detection of SMV. Three plants, represented the the diagonals of each plot and examined to record the population density of virus.

Biochemical genetic studies (SDS – protein analysis): SDS–PAGE was used to study the banding patterns of the studied soybean cultivars after 60 days from soybean sowing. Fresh and young leaves were collected from all treatments for this analysis. Protein fractionation was performed on vertical slab (16.5 cm x 18.5 cm, Hoefer E600, Amersham Pharmacia biotech) according to the method of Laemmli (1970), as modified by Studier (1973). This analysis was performed in Cairo University Research Park, Faculty of Agriculture, Cairo University, Giza, Egypt.

Maize traits: Ten guarded plants were randomly taken from each sub-plot at harvest to record plant height (cm), number of green leaves per plants, number of ears per plant, ear weight (g), grain yield per plant (g) and 100–kernel weight. Grain yield (ton) was determined from weight of each sub-plot and converted to ton per ha.

Soybean traits: Light intensity (lux) inside the soybean canopy at the middle and bottom of the plant after 85 days from soybean sowing was recorded by a Lux-meter apparatus at mid-day on ten plants for each sub-plot and expressed as the percentage from full sunlight intensity (100 %) measured above the plants. At harvest, the observations on traits, namely plant height (cm), numbers of branches and pods per plant, seed yield per plant and 100-seed weight were recorded on 10 guarded plants from each sub-plot. The yield data were utilized to work out the harvest index (HI) according to Donald

(1962). HI was calculated as percentage of seed yield to total biomass. Seed yield per plot (kg) was recorded on basis of experimental plot and expressed as ton per ha.

Land equivalent ratio (LER): LER defines the ratio of area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield (Mead and Willey, 1980). It is calculated as follows: LER = (Y_{ab} / Y_{aa}) + (Y_{ba} / Y_{bb}), Where Y_{aa} = Pure stand yield of crop a (maize), Y_{bb} = Pure stand yield of crop b (soybean), Y_{ab} = Intercrop yield of crop a (maize) and Y_{ba} = Intercrop yield of crop b (soybean).

Economic returns (USD/ha): Economic returns were calculated by determining each of total returns, costs and net returns of intercropping and solid cultures. Total return per ha (USD) = maize grain yield × price of maize grains + soybean seed yield × price of soybean seeds. The prices were presented by market prices (2018), where one ton of maize grains and soybean seeds are USD 200 and USD 450, respectively. Net return per ha (USD) = total return - variable costs for the crops in intercropping and solid cultures. Financial costs were presented by Bulletin of Statistical Cost Production and Net Return (2018).

Statistical analysis: All obtained data were subjected to statistical analysis of variance according to Snedecor and Cochran (1980) and the least significant differences (LSD) at 5 per cent level of significance, tests were done according to Freed (1991) to compare the means of studied traits.

RESULTS AND DISCUSSION

JA content in soybean leaves after 60 days from soybean sowing

JA in leaves of the three soybean cultivars after 60 days by intercropping with maize under high plant density (100 % maize + 100 % soybean) ranged from 305 µg per 100 µg FW (*cv*. Giza 82) to 429 g per 100 g FW (*cv*. Giza 111) (Table 3).

Pubescence density

Soybean cultivars significantly differed in their leaf pubescence length and number (Fig. 1 and Table 4). Soybean *cv.* Giza 111 had the highest leaf pubescence length (393.19 µm) and the lowest number of leaf pubescence (77.50/500 µm) than soybean *cv.* Giza 21 or Giza 82, meanwhile soybean *cv.* Giza 82 had the opposite trend.

Non-significant differences between *cvs.* Giza 21 and Giza 111 for leaf pubescence length were noticed. These results may be due to the genetic makeup of the studied soybean cultivars translated into differences in leaf morphology and structure. These results revealed that leaves mechanical characteristics of *cvs.* Giza 21 and Giza 111 are acting as a mechanical barrier to aphid probing to tolerate SMV infection. Pubescence density can be an important factor in controlling SMV infection (Gunasinghe *et al.*, 1988).

Table 3. JA content in leaves of the studied soybean cultivars under different soybean plant densities after 60 days from soybean sowing

Soybean plant density	JA (µg /100 g FW)		
	Giza 21	Giza 82	Giza 111
100 % maize + 100 % soybean	421	305	429
100 % maize + 75 % soybean	392	342	408
100 % maize + 50 % soybean	376	376	393

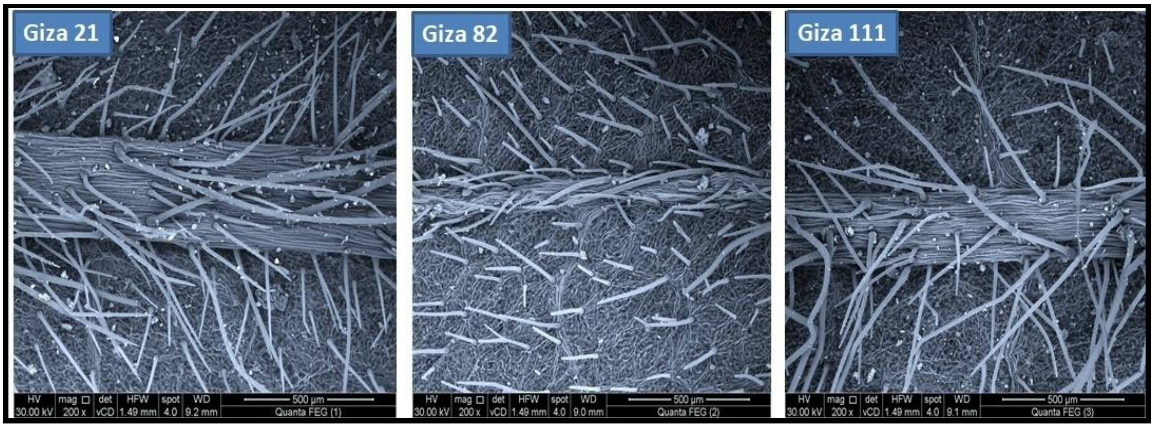

Fig. 1. Scanning of the studied soybean cultivars pubescence density by electronic microscope

Table 4. Means of pubescence length, number of pubescence per 500 µm and pubescence density of the studied soybean cultivars after 60 days from soybean sowing

Soybean cultivar	Leaf pubescence length (µm)	Number of leaf pubescence (500 µm)	Pubescence density
Giza 21	299.95	111.00	Dense
Giza 82	133.93	137.50	Normal
Giza 111	393.19	77.50	Dense
L. S. D. 0.05	**160.91**	**10.41**	**---**

Leaf N content of soybean

Soybean plant densities: Leaf N content was significantly affected by soybean plant densities (Table 5). Decreasing soybean plant density per unit area from 100 to 50 per cent of solid culture of soybean gave the highest leaf N content, whereas the lowest leaf N content was achieved by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean. These results may be due to decrease in soybean plant density from 100 to 50 per cent of solid culture of soybean, which furnished suitable environmental condition for soybean growth and development as compared with the others under intercropping culture. At high plant densities, shaded leaves may not contribute to canopy photosynthesis (Board *et al*., 1992), and are likely to achieve senesce and/or be susceptible to disease (Pons and Pearcy, 1994).

Soybean cultivars: Soybean cultivars significantly differed for leaf N content (Table 5). Soybean *cv.* Giza 82 had the highest (27.46 mg/g) and *cv.* Giza 111 the lowest leaf N content (24.93 mg/g). These results could be due to genetic makeup of the studied soybean cultivars translated into different canopies architectures for benefiting from the surrounding environmental conditions with this canopy adequately during growth and development stages.

Interaction between soybean plant densities and soybean cultivars: The interaction between soybean plant densities and soybean cultivars did not affect leaf N content under intercropping culture (Table 5).

Table 5. Effect of soybean plant densities, soybean cultivars and their interaction on leaf N content of soybean after 60 days from soybean sowing

Soybean plant densities	Leaf N content (mg/g)			
	Giza 21	Giza 82	Giza 111	Mean
100% maize + 100% soybean	24.80	26.70	24.10	**25.20**
100% maize + 75% soybean	25.60	27.60	25.00	**26.06**
100% Maize + 50% soybean	26.20	28.10	25.70	**26.66**
Mean	**25.53**	**27.46**	**24.93**	**25.97**
	Soybean plant densities	**Soybean cultivars**	**Interaction**	
L.S D. (P = 0.05)	**0.74**	**0.61**	**N.S.**	

Water relations

Soybean plant densities: Water consumptive use was significantly affected by soybean plant densities in both the seasons (Table 6). Increasing soybean plant density from 50 to 100 per cent of solid culture of soybean led to increased water consumptive use than the others The increase in soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture could be due to increased intra-specific competition between plants of the same species (soybean) and inter-specific competition between the two species (soybean + maize) for basic growth resources, which was reflected in lower leaf N content than the others (Table 5).

Soybean cultivars: Water consumptive use was not affected by soybean cultivars in both the seasons (Table 6).

Interaction between soybean plant densities and soybean cultivars: The interaction between soybean plant densities and soybean cultivars significantly affected water consumptive use in both the seasons (Table 6). In general, growing soybean *cv.* Giza 111 with maize under high plant density (100 % maize + 100 % soybean) recorded the highest water consumptive use as compared with the others. Conversely, intercropping soybean *cv.* Giza 82 with maize under low plant density (100 % maize + 50 % soybean) recorded the lowest water consumptive use as compared with the others. Generally, water needs of soybean plants of *cv.* Giza 111 increased by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean. These results could be due to increase in plant density of *cv.* Giza 111 from 50 to 100 per cent of solid culture of soybean under intercropping, which culture increased intra- specific competition between plants of the same species and inter- specific competition between the two species for basic growth resources. It is expected that canopy architecture of late maturity soybean *cv.* Giza 111 (Table 1) was more compatible with increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture. Densely pubescence lines have a greater root density and a deeper root extension (Garay and Wilhelm, 1983). Consequently, it is likely that leaves characteristics of soybean *cv.* Giza 111 disregard high shading of intercropping culture (100 % maize + 100 % soybean) by maintaining soil water absorption through roots and even out of the leaves by transpiration.

Aphids assemblages and SMV infection and transmission

Soybean plant densities: Susceptibility of the soybean plants to infestation of aphids and SMV infection statistically varied according to soybean plant density under intercropping culture in both seasons (Table 7). Decrease in soybean plant density from 100 to 50 per cent of solid culture of soybean reduced susceptibility of soybean leaves to aphids infestation and SMV infection in both the seasons. These results were due to increase in leaf N content (Table 5) and decrease in water consumptive use than the others (Table 6).

These results showed that increasing soybean plant density from 50 to 100 per cent of solid culture of soybean is biological tool for obstructing aphids movement within soybean leaves under intercropping culture which was reflected on SMV infection and transmission. SMV infection was reduced in soybean by restricting transpiration water loss (Specht *et al.*, 1985).

Soybean cultivars: Leaves of soybean *cv.* Giza 111 had the lowest aphids assemblages, meanwhile the converse was true for *cv.* Giza 82 in both the seasons (Table 7). Plants of the tolerant *cv.* Giza 111 for aphids attack had mechanical and chemical defences in their leaves. The mechanical defence in leaves of this cultivar was due to its higher length of leaf pubescence and pubescence density than other two cultivars. Conversely, leaves of *cv.* Giza 82 had shorter length of leaf pubescence with normal pubescence density than those of the others (Fig. 1 and Table 4). These results are in parallel with those of Gunasinghe *et al*. (1988), who observed that increasing length of leaf

Table 6. Effect of soybean plant densities, soybean cultivars and their interaction on water consumptive use in both the seasons

Soybean plant density	Soybean cultivar	Applied irrigation water (mm)		Water consumptive use (mm)	
		First season	Second season	First season	Second season
100 % maize + 100 % soybean	Giza 21	922	927	729	656
	Giza 82	922	927	760	710
	Giza 111	922	927	818	750
	Mean	**922**	**927**	**769**	**705**
100 % maize + 75 % soybean	Giza 21	922	927	692	627
	Giza 82	922	927	708	704
	Giza 111	922	927	755	615
	Mean	**922**	**927**	**718**	**648**
100 % maize + 50 % soybean	Giza 21	922	927	656	561
	Giza 82	922	927	575	570
	Giza 111	922	927	615	576
	Mean	**922**	**927**	**615**	**569**
Average of soybean cultivars	**Giza 21**	**922**	**927**	**692**	**614**
	Giza 82	**922**	**927**	**681**	**661**
	Giza 111	**922**	**927**	**729**	**647**
				L. S. D. (P = 0.05)	
Soybean plant densities				**47.17**	**53.52**
Soybean cultivars				**N.S.**	**N.S.**
Interaction				**61.34**	**68.08**

pubescence and pubescence density are acting as a mechanical barrier to aphid probing. With respect to the chemical defense, leaves of *cv.* Giza 111 tolerated aphids attack due to the lowest leaf N content as compared with other cultivars (Table 5). Similar results were obtained by Abdel-Wahab *et al*. (2019), who indicated that the variation in leaf N content of the tested soybean cultivars was probably due to difference in their genetic makeup. With respect to SMV infection, leaves of *cvs*. Giza 21 and Giza 111 had the lowest SMV infection, meanwhile the converse was true for soybean *cv.* Giza 82 in both the seasons (Fig. 2 and Table 7). After SMV infection, the leaves of the susceptible *cv.* Giza 82 produced symptoms such as mosaic, shrinkage and deformity, whereas these symptoms were not visible in the tolerant *cvs.* Giza 21 and Giza 111. Plants of the tolerant *cvs.* Giza 21 and Giza 111 to SMV infection had mechanical and chemical defences in their leaves. The

Table 7. Effect of soybean plant densities, soybean cultivars and their interaction on aphid's infestation and SMV infection after 60 days from soybean sowing in the both seasons

Soybean plant density	Soybean cultivar	Infestation with aphids (No/plant)		Infection with SMV / plant (%)	
		First season	Second season	First season	Second season
Intercropping system **100 % maize + 100 % soybean**	Giza 21	1.3	2.0	5.9	8.9
	Giza 82	1.6	1.3	18.4	20.2
	Giza 111	0.5	0.3	8.3	7.8
	Mean	**1.1**	**1.2**	**10.8**	**12.3**
100% maize + 75% soybean	Giza 21	1.5	1.0	11.9	14.3
	Giza 82	2.3	2.3	16.7	16.1
	Giza 111	1.3	1.3	11.9	11.9
	Mean	**1.7**	**1.5**	**13.5**	**14.1**
100% maize + 50% soybean	Giza 21	1.6	2.0	13.1	17.9
	Giza 82	1.7	1.7	11.9	8.9
	Giza 111	1.0	1.0	15.5	19.0
	Mean	**1.4**	**1.5**	**13.5**	**15.2**
Average of soybean cultivars	**Giza 21**	**1.4**	**1.6**	**10.3**	**13.7**
	Giza 82	**1.8**	**1.7**	**15.6**	**15.0**
	Giza 111	**0.9**	**0.8**	**11.9**	**12.9**
			L. S. D. (P = 0.05)		
Soybean plant densities		**0.38**	**0.22**	**2.86**	**1.03**
Soybean cultivars		**0.26**	**0.14**	**1.71**	**0.82**
Interaction		**0.44**	**0.29**	**3.49**	**1.17**

mechanical defence in leaves of soybean of these two cultivars was due to higher length of leaf pubescence and pubescence density than the susceptible *cv*. Giza 82 (Fig. 1 and Table 4). These results show that length of leaf pubescence and pubescence density can be an important factor in controlling SMV infection by acting as a mechanical barrier to aphid probing.

The chemical defence found in leaves of *cv*. Giza 111 was due to lower leaf N content followed by *cv*. Giza 21 than the susceptible *cv*. Giza 82 (Table 5). These results revealed that the genetic differences among these soybean cultivars that translated into leaf N content, has played a major role in tolerance of SMV infection and transmission through negative effects on aphids growth and development. These results are in accordance with those obtained by Maule *et al.* (2002), who reported that systemic infections of plant viruses result from the complex molecular interplay between the host plant and the invading virus.

Fig. 2. SMV symptoms in leaves of the studied soybean cultivars at maturity stage under field conditions

Interaction between soybean plant densities and soybean cultivars: Susceptibility of the studied soybean cultivars to the aphids infestation and SMV infection statistically varied according to soybean plant densities (Table 7). The highest aphids infestation and SMV infection within leaves of soybean *cv.* Giza 82 were recorded by increasing plant density from 50 to 75 per cent of solid culture of soybean under intercropping culture. These results were due to leaves of soybean *cv.* Giza 82, an early maturing cultivar (Table 1), had the lowest leaf JA content (Table 3) and the highest water consumptive use (Table 6) than other cultivars, which enhanced amino acids and carbohydrates synthesis in soybean leaves by increasing plant density from 50 to 75 per cent of solid culture of soybean. Additionally, leaves characteristics of *cv.* Giza 82 (Fig. 1 and Table 4) reflected in increasing this biological negative situation for aphids assemblages. It is known that population of aphids was reduced under saturated conditions (Mewis *et al*., 2012). Moreover, Rostami *et al*. (2016) showed that N is the major nutrient required by insects and in most cases the main limiting factor for optimal growth of insects. Meanwhile, aphids assemblages in leaves of ~~soybean~~ *cv.* Giza 111 was decreased by increasing plant density from 50 to 100 per cent of solid culture of soybean (Table 7). These results were due to leaves of *cv.* Giza 111 had the lowest JA content (Table 3) and the highest water consumptive use (Table 6), which obstructs aphids movement within soybean leaves. Accordingly, it is expected that some aphids by increasing plant density from 50 to 100 per cent of solid culture of soybean that succeeded in avoiding the mechanical barrier (pubescence) of leaves did not complete their life cycle because soybean *cv.* Giza 111 under intercropping culture had high water consumptive use than others.

The interaction between soybean plant density and soybean cultivars was significant for SMV infection in both the seasons (Table 7). Leaves of *cvs.* Giza 21 and Giza 111 had the lowest SMV infection by increasing plant density from 50 to 100 per cent of solid culture of soybean as compared with the others. These results could be due to high plant density interacted positively with leaves of soybean *cvs.* Giza 21 or Giza 111 to reduce cysteine proteases as a result of SMV infection which reflected on reduction in leaf JA contents (Table 3) during soybean growth and development. The protease inhibitor proteins synthesized cysteine proteases (Bryant *et al*., 1976) through catalyzing the breakdown of linolenic acid and increasing of JA levels in tissues of soybean plant to induce the protease inhibitor gene expression (Koiwa *et al.*, 1997). It is known that cysteine proteases play an important role in programmed cell death and in responses to biotic and abiotic stresses (Zamyatnin, 2015). The synthesis of JA is regulated by endogenous proteases that affect the induction of pathogenesis-related genes where the main function of proteases is proteolysis (Balakireva and Zamyatnin, 2018).

Biochemical genetic studies

The total soluble proteins were separated electrophoretically using SDS-PAGE technique to find out genotypic variation under different soybean plant densities in intercropping culture to induce protein upon to SMV infection. The major variations are expressed as changes in appearance or disappearance of some bands. A total of 12 bands were detected with different molecular weights ranging from 245 to 11 kDa. These protein bands were distributed into 3 monomorphic bands (25.0 %) and 9 polymorphic bands (75.0 %). Soybean *cvs.* Giza 111 and Giza 21 had the highest number of protein bands (30 and 20 bands, respectively), meanwhile *cv.* Giza 82 had the lowest number of protein bands (13 bands). The unique bands appeared only in *cvs.* Giza 21 (11 kDa) and Giza 111 (63 KDa) were achieved by decreasing soybean plant density from 100 to 75 per cent of solid culture of soybean and from 100 to 50 per cent of solid culture of soybean under intercropping culture. With respect to *cv.* Giza 21, absence of one protein band (11 kDa) and presence of six protein bands (35, 75, 100, 135, 180 and 245 kDa) were observed by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture (Fig. 3 and Table 8).

Obviously, there were newly appeared protein bands with molecular weight of35, 75, 100, 135, 180 and 245 kDa, which were produced by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture. These results suggested that these proteins have an important role in defense to SMV infection indicating *cv.* Giza 21 to be a tolerant cultivar to SMV infection by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under

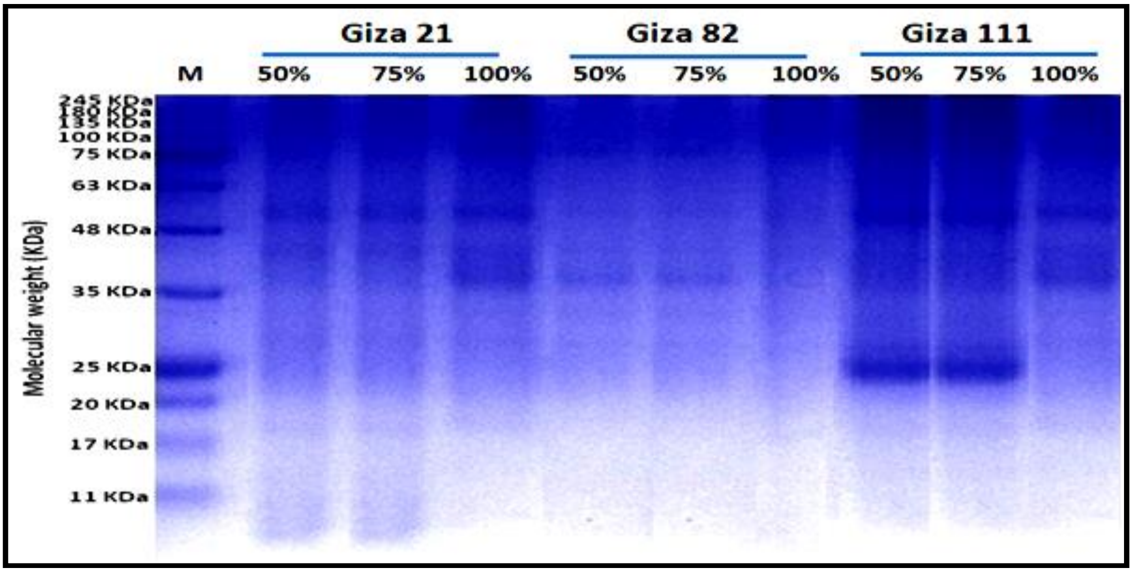

Fig. 3. Leaf protein banding patterns for intercropping some soybean cultivars with maize under different soybean plant densities

Table 8. Leaf protein banding patterns for intercropping some soybean cultivars with maize under different soybean plant densities

Band no.	M.W. (kDa)	Giza 21 Soybean plant density			Giza 82 Soybean plant density			Giza 111 Soybean plant density		
		50%	75%	100%	50%	75%	100%	50%	75%	100%
1	245	-	-	+	-	-	-	+	+	+
2	180	-	-	+	-	-	-	+	+	+
3	135	-	-	+	-	-	-	+	+	+
4	100	-	-	+	-	-	-	+	+	+
5	75	-	-	+	+	+	-	-	-	+
6	63	-	-	-	-	-	-	+	+	-
7	48	+	+	+	+	+	+	+	+	+
8	35	-	-	+	+	+	-	+	+	+
9	25	+	+	+	+	+	+	+	+	+
10	20	+	+	+	+	+	+	+	+	+
11	17	+	+	+	-	-	-	+	+	+
12	11	+	+	-	-	-	-	-	-	-
Total	12	**5**	**5**	**10**	**5**	**5**	**3**	**10**	**10**	**10**
Positive bands		0	0	6	0	0	0	0	0	1

(+) presence of band; (-) absence of band; M.W= Molecular weight.

intercropping culture. With respect to *cv.* Giza 82, two protein bands with molecular weights of 35 and 75 kDa disappeared by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture (Fig. 3 and Table 8), which indicated that *cv.* Giza 82 is susceptible cultivar to SMV infection.

With respect to soybean *cv.* Giza 111, one protein band with molecular weight of 75 kDa was newly formed by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture (Fig. 3 and Table 8), indicating induction of synthesis a new protein, which may play a positive role in tolerating SMV infection by *cv.* Giza 111. The tolerant reaction might have resulted from rapid synthesis or less degradation of responsive proteins to SMV infection especially for the proteins that possess a higher molecular weight. It is known that the genome of SMV is approximately 10 kb in length and encodes 11 mature proteins (Hajimorad *et al*., 2018), these proteins work together to successfully attack the plants. One possible explanation for appearance of some proteins formed by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture is that the gene (s) responsible for certain proteins had been completely enhanced as a result of SMV infection. The specifically synthesized protein formed by increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture appears to have a role in providing adaptation to *cvs.* Giza 21 and Giza 111 to SMV infection. Variation in protein pattern via the appearance of new bands and disappearance of the others indicated either enhancement or repression of gene expression in these cultivars. This might alter the produced proteins in response to SMV infection either on the transcription or post-transcription levels of gene expression. This expression may have a role in defence against SMV infection especially when increasing soybean plant density from 50 to 100 per cent of solid culture of soybean under intercropping culture.

Maize grain yield and its attributes

Soybean plant densities: All the studied maize traits were not significantly affected by soybean plant densities in both seasons (Tables 9 and 10). These results are in accordance with those obtained by Metwally *et al*. (2009), who observed that increasing intercropped soybean plant density without adverse effects on maize crop.

Soybean cultivars: Maize grain yield and its attributes were not significantly affected by soybean cultivars in both the seasons (Tables 9 and 10). These results may be attributed to higher ability of maize as C_4 plant of photosynthetic pathways to be grown successfully during growth and development than soybean, and hence all the investigated soybean cultivars did not exert any effect on maize plant. The results are in the same context with those of Metwally *et al.* (2018), who proved that maize grain yields per plant and per unit area were not affected by soybean cultivars.

Interaction between soybean plant densities and soybean cultivars: All the studied maize traits were not significantly affected by the interaction between soybean plant densities and soybean cultivars in both seasons (Tables 9 and 10).

Soybean seed yield and its attributes

Soybean plant densities: Percentages of light intensity at middle and bottom of the plant, plant height, number of pods per plant, 100 – seed weight, HI and seed yield per ha were significantly affected by soybean plant densities in both the seasons (Tables 11 and 12). Increasing soybean plant density from 50 to 100 per cent of solid culture of soybean had the highest percentages of light intensity at middle and bottom of the plant, number of branches per plant, 100–seed weight and HI under intercropping culture (100 % maize + 50 % soybean). These results probably due to decrease soybean plant density per unit area to 50 per cent of solid culture of soybean, which decreased intra-specific competition between plants of the same species (soybean) and inter- specific competition between the two species (soybean + maize) for basic growth resources under intercropping culture. Consequently, decreasing soybean plant density from 100 to 50 per cent of solid culture of soybean increased intercepted light intensity within soybean canopy which reflected on leaf N content (Table 5) and dry matter accumulation under intercropping culture.

Obviously increasing leaf N content (Table 5) and light intensity within soybean canopy were the main reasons for increasing soybean yield attributes despite low water consumptive use (Table 6) and high viral infection (Table 7). Conversely, increasing soybean plant density from 50 to 100 per cent of solid culture of soybean decreased light intensity at middle and bottom of the plant, number of branches per plant, 100 – seed weight and HI, meanwhile it had the highest plant height and seed yield per ha under intercropping culture (Tables 11 and 12). These results show that increasing plant density to reach 100 per cent of solid culture of soybean formed unfavorable conditions for soybean growth and development, consequently more amounts of plant hormones under intercropping culture. This biological situation led to little dry matter accumulation in soybean, which reflected on soybean yield (Metwally *et al.*, 2012). However, seed yield per ha increased by increasing soybean plant density per unit area from 50 to 100 per cent of sole planting under intercropping conditions. It is worth to note that increasing soybean plant density per unit area from 50 to 100 per cent of sole planting resulted in decrease in light intensity within soybean canopy and increase in water consumptive use of the intercrops under intercropping conditions in both the seasons (Table 6). However, it seems that the effect of shading intensity was severe on soybean plants despite their high water consumption which reflected negatively on 100-seed weight and thereby HI. Although irrigation allowed full canopy closure, shade reduced the amount of intercepted photosynthetic active radiation and subsequently reduced the total dry matter produced (Verghis *et al.*, 1999). These results are in agreement with those obtained by Metwally *et al*. (2012).

Soybean cultivars: Soybean cultivars significantly differed for percentages of light intensity at middle and bottom of the plant, plant height, numbers of branches and pods per plant, seed yield per plant, 100–seed weight, seed yield per ha in both the seasons, meanwhile HI was not affected (Tables 11 and 12). Cultivar Giza 82 had the highest percentages of light intensity at middle and bottom of the plant, meanwhile it had the lowest values of plant height and 100–seed weight than the others (Tables 11 and 12). These results were as *cv.* Giza 82 was susceptible to SMV infection (Table 7), which was reflected on photosynthesis process and dry matter accumulation during growth and development. With regard to *cv*. Giza 21, it had the highest values of plant height and the lowest values of numbers of branches and pods per plant, seed yield per plant, HI and seed yield per ha than the other cultivars (Tables 11 and 12). Since, *cv*. Giza 21 being tallest, it depressed seed yield over other cultivars on account of enhanced self-shadding. (Noureldin *et al*., 2002 and Safina *et al*., 2018). Although this cultivar was tolerant to SMV infection (Table 7), yield attributes could not counterbalance the reduction in seed yield (Tables 11 and 12). Soybean *cv*. Giza 111 recorded the lowest light intensity at middle and bottom of the plant, but had the highest numbers of branches and pods per plant, seed yield per plant, 100–seed weight and seed yield per ha as compared with the other cultivars (Tables 11 and 12) may be accounted for its tolerance to SMV infection and transmission (Table 7), which reflected on photosynthetic process during growth and development.

The interaction between soybean plant densities and soybean cultivars: The interaction between soybean plant densities and soybean cultivars significantly affected percentages of light intensity at middle of the plant and seed yield per ha in both the seasons, whereas other parameters were not affected (Tables 11 and 12). Increasing soybean plant density of *cv*. Giza 82 from 50 to 100 per cent of solid culture of soybean recorded the highest light intensity at middle of the plant in both seasons as a result of decreased SMV infection and transmission than the others under intercropping culture (Table 7). Conversely, increasing plant density of *cv*. Giza 111 from 50 to 100 per cent of solid culture of soybean decreased light intensity at middle of the plant and increased seed yield per ha than the others under intercropping culture (Tables 11 and 12). Although *cv*. Giza 111 had broader leaves than the other cultivars (Metwally *et al*., 2012), but high water consumption (Table 6) and low SMV infection (Table 7) could reflect this trait during growth and development. Conversely, decreasing soybean plant density of *cv*. Giza 21 from 100 to 50 per cent of solid culture of soybean decreased seed yield per ha than the others under intercropping culture (Tables 11 and 12). This biological situation was due to low water consumptive use (Table 6) and high SMV infection and transmission (Table 7),

Table 9. Maize grain yield and its attributes as affected by soybean plant densities, soybean cultivars and their interaction in the first season

Soybean plant density	Soybean cultivar	Plant height (cm	Green leaves (No/ plant)	Ears (No/ plant)	Ear weight (g)	Grain yield (g/plant)	100 – kernel weight (g)	Grain yield (t/ha)
				First season (2016)				
100 % maize + 100 % soybean	Giza 21	262.55	12.79	1.03	189.32	150.68	36.85	8.26
	Giza 82	269.56	12.98	1.03	178.69	141.12	37.14	8.23
	Giza 111	259.38	12.80	1.02	183.73	142.19	36.89	8.25
	Mean	**263.83**	**12.86**	**1.03**	**183.91**	**144.66**	**36.96**	**8.24**
100 % maize + 75 % soybean	Giza 21	264.42	12.80	1.03	179.34	148.40	36.88	8.26
	Giza 82	263.56	12.90	1.03	183.54	143.72	37.13	8.20
	Giza 111	255.79	12.75	1.04	176.47	143.43	37.10	8.22
	Mean	**261.26**	**12.82**	**1.03**	**179.78**	**145.18**	**37.04**	**8.22**
100 % maize + 50 % soybean	Giza 21	258.87	12.96	1.03	182.83	138.66	36.79	8.11
	Giza 82	266.27	12.87	1.02	175.40	138.57	36.96	8.45
	Giza 111	260.66	12.94	1.03	179.39	134.48	37.12	8.23
	Mean	**261.93**	**12.92**	**1.03**	**179.20**	**137.23**	**36.96**	**8.26**
Average of soybean cultivars	**Giza 21**	**261.95**	**12.85**	**1.03**	**183.83**	**145.91**	**36.84**	**8.21**
	Giza 82	**266.46**	**12.91**	**1.03**	**179.21**	**141.13**	**37.08**	**8.29**
	Giza 111	**258.61**	**12.83**	**1.03**	**179.86**	**140.03**	**37.04**	**8.23**
				L. S, D. (P = 0.05)				
Soybean plant densities		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Soybean cultivars		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Interaction		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Solid culture of maize								**8.33**

which decreased dry matter accumulation during growth and development than the others.

Land equivalent ratio (LER)

LER values were estimated by using data of recommended solid cultures of both crops. Intercropping soybean with maize increased LER as compared with solid cultures of both crops in both the seasons (Table 13). In general, increasing soybean plant density to reach 100 per cent of solid culture of soybean under intercropping culture increased LER in both the seasons. Conversely, decreasing soybean plant density to reach 50 per cent of solid culture of soybean under intercropping culture decreased LER in both the seasons. LER ranged from 1.33 and 1.28 (by decreasing soybean plant density of *cv*. Giza 21 from 100 to 50 per cent of solid culture of soybean) to 1.68 and 1.63 (by increasing soybean plant density of *cv*. Giza 111 from 50 to 100 per cent of solid culture of soybean) under intercropping culture in the first and second seasons, respectively. Advantages of increasing soybean plant density of *cv*. Giza 111 from 50 to 100 per cent of solid culture of soybean was due to high seed yield per ha (Tables 11 and 12) as a result of increasing water consumptive use

Table 10. Maize grain yield and its attributes as affected by soybean plant densities, soybean cultivars and their interaction in the second season

Soybean plant density	Soybean cultivar	Plant height (cm	Green leaves (No/ plant)	Ears (No/ plant)	Ear weight (g)	Grain yield (g/plant)	100 – kernel weight (g)	Grain yield (t/ha)
				Second season (2017)				
100% maize + 100% soybean	Giza 21	289.38	13.59	1.07	210.73	171.03	39.18	9.08
	Giza 82	288.36	13.90	1.07	204.84	170.66	39.04	8.92
	Giza 111	280.99	14.05	1.08	206.60	174.02	39.18	9.07
	Mean	**286.24**	**13.84**	**1.07**	**207.39**	**171.90**	**39.13**	**9.02**
100% maize + 75% soybean	Giza 21	284.33	13.87	1.05	201.20	180.05	39.09	9.08
	Giza 82	285.28	14.16	1.07	205.24	171.56	39.02	8.91
	Giza 111	282.56	14.14	1.07	201.01	169.87	38.97	9.06
	Mean	**284.05**	**14.06**	**1.06**	**202.48**	**173.83**	**39.03**	**9.01**
100% maize + 50% soybean	Giza 21	285.45	13.88	1.06	208.10	173.66	38.95	9.01
	Giza 82	282.64	14.18	1.08	209.62	171.34	38.86	9.14
	Giza 111	285.02	13.85	1.06	201.33	180.62	39.04	9.08
	Mean	**284.37**	**13.97**	**1.07**	**206.35**	**175.21**	**38.95**	**9.07**
Average of soybean cultivars	Giza 21	**286.39**	**13.78**	**1.06**	**206.68**	**174.91**	**39.07**	**9.05**
	Giza 82	**285.42**	**14.08**	**1.07**	**206.57**	**171.19**	**38.97**	**8.99**
	Giza 111	**282.86**	**14.01**	**1.07**	**202.98**	**174.84**	**39.06**	**9.07**
Soybean plant densities		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Soybean cultivars		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Interaction		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
Solid culture of maize								**9.17**

(Table 6) and low SMV infection (Table 7) than the others under intercropping culture. Meanwhile, disadvantages of decreasing soybean plant density of *cv*. Giza 21 per unit area from 100 to 50 per cent of solid culture of soybean was due to decreased water consumptive use (Table 6) and increased SMV infection (Table 7) than the others under intercropping culture. The results are parallel with Metwally *et al*. (2017).

Economic returns

The economic returns of intercropping soybean with maize varied between treatments from USD 2,117 and 2,175 to 2,874 and 2,898 per ha as compared with solid culture of maize (USD 1,666 and 1,834 per ha) in the first and second seasons, respectively (Table 14). Similarly, Meanwhile, net returns of intercropping soybean with maize varied between treatments from USD 1,258 and 1,316 to 1,938 and 1,962 per ha as compared with solid culture of maize (USD 883 and 1,051 per ha) in the first and second seasons, respectively. In general, it seems that growing soybean with maize achieved the highest economic returns than solid culture of maize. These results indicated that increasing soybean plant density of *cv*. Giza 111 from 50 to 100 per cent of solid culture of soybean recorded the highest economic returns per ha as

Table 11. Soybean seed yield and its attributes as affected by soybean plant densities, soybean cultivars and their interaction in the first season

Soybean plant density	Soybean cultivar	Percentages of light intensity at: Middle of the plant	Percentages of light intensity at: Bottom of the plant	Plant height (cm)	Branches (No/ plant)	Pods (No/ plant)	Seed yield (g/ plant)	100 – seed weight (g)	HI (%)	Seed yield (t/ha)
					First season (2016)					
100 % maize + 100 % soybean	Giza 21	2.82	1.36	125.50	1.60	21.76	8.82	11.42	13.69	1.99
	Giza 82	3.31	1.83	107.90	1.80	30.11	9.20	10.26	14.20	2.39
	Giza 111	2.49	1.04	112.80	2.10	37.22	11.47	11.81	15.98	2.72
	Mean	**2.87**	**1.41**	**115.40**	**1.83**	**29.70**	**9.83**	**11.16**	**14.62**	**2.36**
100 % maize + 75 % soybean	Giza 21	3.67	1.92	117.10	2.06	28.96	10.74	11.99	14.75	1.35
	Giza 82	3.99	2.42	104.30	2.40	38.72	11.83	10.94	15.92	1.67
	Giza 111	3.08	1.51	108.40	2.76	53.89	12.77	12.48	17.21	1.88
	Mean	**3.58**	**1.95**	**109.93**	**2.41**	**40.52**	**11.78**	**11.80**	**15.96**	**1.63**
100 % maize + 50 % soybean	Giza 21	4.44	2.56	111.70	3.06	33.14	10.89	12.44	16.01	1.10
	Giza 82	4.82	2.90	95.30	3.36	42.63	12.54	12.11	17.76	1.21
	Giza 111	4.18	1.98	102.50	3.50	58.66	12.93	13.03	18.80	1.49
	Mean	**4.48**	**2.48**	**103.16**	**3.31**	**44.81**	**12.12**	**12.53**	**17.52**	**1.26**
Average of soybean cultivars	**Giza 21**	**3.64**	**1.94**	**118.10**	**2.24**	**27.95**	**10.15**	**11.95**	**14.81**	**1.48**
	Giza 82	**4.04**	**2.38**	**102.50**	**2.52**	**37.15**	**11.19**	**11.10**	**15.96**	**1.75**
	Giza 111	**3.25**	**1.51**	**107.90**	**2.78**	**49.92**	**12.39**	**12.44**	**17.33**	**2.03**
					L. S. D. (P = 0.05)					
Soybean plant densities		**1.13**	**0.64**	**5.56**	**0.54**	**N.S.**	**N.S.**	**0.22**	**2.22**	**0.22**
Soybean cultivars		**0.82**	**0.50**	**3.56**	**0.33**	**18.59**	**1.82**	**0.30**	**N.S.**	**0.08**
Interaction		**1.15**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.21**
Solid culture of soybean	**Giza 21**									**3.03**
	Giza 82									**3.69**
	Giza 111									**3.90**

compared with the others under intercropping culture. These results were due to increasing soybean plant density of *cv*. Giza 111 per unit area from 50 to 100 per cent of solid culture of soybean consequent upon an increase in water consumptive use (Table 6) and decrease in SMV infection (Table 7), which reflected on LER (Table 13) under intercropping culture. On the other hand, decreasing soybean plant density of *cv*. Giza 21 per unit area from 100 to 50 per cent of solid culture of soybean had lower economic returns per ha than the others under intercropping culture (Table 14). These results were due to decrease in soybean plant density of *cv*. Giza 21 per unit area from 100 to 50 per cent of solid culture of soybean, decreased water consumptive use (Table 6) and increased SMV infection (Table 7) as compared with the others, which reflected on LER under intercropping culture (Table 13).

Table 12. Soybean seed yield and its attributes as affected by soybean plant densities, soybean cultivars and their interaction in the second season

Soybean plant density	Soybean cultivar	Percentages of light intensity at		Plant height (cm)	Branches (No/ plant)	Pods (No/ plant)	Seed yield (g/ plant)	100 – seed weight (g)	HI (%)	Seed yield (t/ha)
		Middle of the plant	Bottom of the plant							
				Second season (2017)						
	Giza 21	3.01	1.62	116.82	1.33	20.82	7.12	10.57	13.24	1.66
100 % maize + 100 % soybean	Giza 82	3.56	2.04	103.44	1.66	30.66	8.92	9.81	13.83	2.12
	Giza 111	2.87	1.19	110.13	2.00	37.03	10.23	11.55	15.50	2.41
	Mean	**3.14**	**1.61**	**110.13**	**1.66**	**30.17**	**8.75**	**10.64**	**14.19**	**2.06**
	Giza 21	3.98	2.21	111.65	1.83	24.05	8.01	10.70	14.92	1.11
100 % maize + 75 % soybean	Giza 82	4.22	2.66	97.62	2.16	37.16	10.94	10.21	15.43	1.45
	Giza 111	3.36	1.75	104.58	2.66	44.48	11.81	11.53	17.47	1.63
	Mean	**3.85**	**2.20**	**104.61**	**2.22**	**35.23**	**10.25**	**10.81**	**15.94**	**1.39**
	Giza 21	4.73	2.89	106.32	2.60	26.41	8.41	11.11	16.49	0.83
100 % maize + 50 % soybean	Giza 82	5.02	3.16	91.15	3.23	40.14	11.72	10.49	18.03	0.99
	Giza 111	4.41	2.27	93.91	3.40	48.10	12.36	12.08	19.62	1.19
	Mean	**4.72**	**2.77**	**97.12**	**3.07**	**38.21**	**10.83**	**11.22**	**18.04**	**1.00**
Average of soybean cultivars	Giza 21	**3.90**	**2.24**	**111.59**	**1.92**	**24.42**	**7.84**	**10.79**	**14.88**	**1.20**
	Giza 82	**4.26**	**2.62**	**97.40**	**2.35**	**35.99**	**10.52**	**10.17**	**15.76**	**1.52**
	Giza 111	**3.54**	**1.73**	**102.87**	**2.68**	**43.20**	**11.46**	**11.72**	**17.53**	**1.74**
					L. S. D. (P = 0.05)					
Soybean plant densities		**0.90**	**0.78**	**8.21**	**0.54**	**N.S.**	**N.S.**	**0.25**	**2.07**	**0.16**
Soybean cultivars		**0.42**	**0.72**	**2.54**	**0.36**	**14.17**	**1.18**	**0.23**	**N.S.**	**0.12**
Interaction		**1.10**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.21**
Solid culture of soybean		**Giza 21**								**2.70**
		Giza 82								**3.43**
		Giza 111								**3.71**

These results reveal that growing four rows of soybean *cv*. Giza 111 with maize is more profitable than solid culture of maize for Egyptian farmers and should be recommended. These results are in agreement with those obtained by Metwally *et al*. (2017).

It could be concluded that increasing soybean plant density from 50 to 100 per cent of solid soybean under intercropping culture played an important role in the tolerance of soybean *cvs*. Giza 21 and Giza 111 to SMV infection. Growing four rows of soybean *cv*. Giza 111 in the middle of maize beds increased water consumptive use and decreased SMV infection which reflected positively on soybean productivity, LER and economic returns.

Table 13. Relative yields of both crops and LER of intercropping some soybean cultivars with maize under different soybean plant densities in both seasons

Soybean plant density	Soybean cultivar	Relative yield of maize	Relative yield of soybean	LER
		First season		
	Giza 21	0.99	0.65	1.64
Intercropping system	Giza 82	0.98	0.64	1.63
100 % maize + 100 % soybean	Giza 111	0.99	0.69	1.68
	Mean	**0.98**	**0.66**	**1.65**
	Giza 21	0.99	0.44	1.43
100 % maize + 75 % soybean	Giza 82	0.98	0.45	1.43
	Giza 111	0.98	0.48	1.46
	Mean	**0.98**	**0.46**	**1.44**
	Giza 21	0.97	0.36	1.33
100 % maize + 50 % soybean	Giza 82	1.01	0.32	1.34
	Giza 111	0.98	0.38	1.37
	Mean	**0.99**	**0.35**	**1.34**
Solid culture		**1.00**	**1.00**	**1.00**
		Second season		
Intercropping system	Giza 21	0.99	0.61	1.60
100 % maize + 100 % soybean	Giza 82	0.97	0.61	1.59
	Giza 111	0.98	0.64	1.63
	Mean	**0.98**	**0.62**	**1.61**
100 % maize + 75 % soybean	Giza 21	0.99	0.41	1.40
	Giza 82	0.97	0.42	1.39
	Giza 111	0.98	0.43	1.42
	Mean	**0.98**	**0.42**	**1.40**
100 % maize + 50 % soybean	Giza 21	0.98	0.30	1.28
	Giza 82	0.99	0.28	1.28
	Giza 111	0.99	0.32	1.31
	Mean	**0.98**	**0.30**	**1.29**
Solid culture		1.00	1.00	1.00

Table 14. Economic return of intercropping some soybean cultivars with maize under different soybean plant densities in both seasons

Soybean plant density	Soybean cultivar	Income of maize (USD/ha)	Income of soybean (USD/ha)	Total return (USD/ha)	Net returns (USD/ha)
			First season		
	Giza 21	1652	895	2547	1611
Intercropping system	Giza 82	1646	1075	2721	1785
100 % maize + 100 % soybean	Giza 111	1650	1224	2874	1938
	Mean	**1648**	**1062**	**2710**	**1774**
	Giza 21	1652	607	2259	1362
	Giza 82	1640	751	2391	1494
100 % maize + 75 % soybean	Giza 111	1644	846	2490	1593
	Mean	**1644**	**733**	**2377**	**1480**
	Giza 21	1622	495	2117	1258
	Giza 82	1690	544	2234	1375
100 % maize + 50 % soybean	Giza 111	1646	670	2316	1457
	Mean	**1652**	**567**	**2219**	**1360**
Solid culture of maize		**1666**	**---**	**1666**	**883**
			Second season		
	Giza 21	1816	747	2563	1627
100 % maize + 100 % soybean	Giza 82	1784	954	2738	1802
	Giza 111	1814	1084	2898	1962
	Mean	**1804**	**927**	**2731**	**1795**
	Giza 21	1816	499	2315	1418
100 % maize + 75 % soybean	Giza 82	1782	652	2434	1537
	Giza 111	1812	733	2545	1648
	Mean	**1802**	**625**	**2427**	**1530**
	Giza 21	1802	373	2175	1316
100 % maize + 50 % soybean	Giza 82	1828	445	2273	1414
	Giza 111	1816	535	2351	1492
	Mean	**1814**	**450**	**2264**	**1405**
Solid culture of maize		1834	---	1834	1051

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Soybean Research 18(1): 60-68 (2020)

Break-even Yield and Cost of Cultivation of Different Soybean Varieties – An Analysis

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Received: 15.01.2019; Accepted: 31.08.2019

ABSTRACT

Frontline demonstrations (FLDs) on soybean production technologies and varieties are being conducted at farmer's field across the country since 1989-90 with the objective to demonstrate their impact on productivity under real farm situations. FLD's data from 2013-2017 were used to analyze the break-even yield and break-even cost in the present investigation. The results of 44,162 frontline demonstrations revealed that the planting of new soybean varieties along with adoption of improved soybean production technology enhanced the soybean yield to the tune of 26 per cent as compared to farmer's practice. The analysis indicated that the soybean break-even yield varied from 470 to 1,305 kg per ha under improved variety and 398 to 1,315 kg per ha under farmer's practice. However, the break-even cost of cultivation ranged from 20.01 to 30.61 and 19.28 to 30.80 Rs per kg under improved varieties and farmer's practice, respectively. The results envisaged that the soybean varieties had their own break-even yield and cost.

Key words: Break-even yield, break-even cost, yield gap

The commercial cultivation of soybean was initiated during early 1970s in India. Thereafter the rapid growth was observed in area and production of the crop (Chand, 2007; Sharma, 2016a) mainly due to its suitability in the cropping sequence, comparative profitability as compared to competitive crops, lower requirement of labour and other inputs, *etc*. (Sharma *et al,* 2015; Sharma, 2016a,b). The crop has helped to raise the socio-economic status of soybean farmers in central and peninsular India (Dupare *et al,* 2009; Sharma *et al,* 2016). At present, soybean has established itself as a leading oil yielding leguminous crop in the country and presently occupies premier position among the nine oilseeds cultivated in India. Although, an unparallel growth in area and production, availability of varieties with yield potential up to 3.5 t per ha and improved production technology, the national average yield remains around 1 t per ha. The major reasons for sub-optimal yield include; total dependence on rainfall, slow pace of technology transfer and its adoption, lack of awareness about production technologies in newer areas, non-availability of quality non-availability of quality seed and that too of improved varieties, imbalanced nutrition

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devoid of integrated approach, timely unavailability of agro-chemicals and other inputs, *etc*. (Dupare *et al,* 2011). In order to facilitate effective technology transfer and to achieve the targets, Government of India through Indian Council of Agricultural Research (ICAR) launched a programme during 1989-90, called Frontline Demonstrations (FLDs) on oilseeds and pulses. FLDs are being conducted at farmers' fields under the direct supervision of scientists, with the major objective of demonstrating the production potential of improved soybean technologies and varieties developed by research system for different agro-climatic regions on location specific basis under real farm situations. The ultimate aim of the programme was to increase the rate of adoption of newly released varieties and improved productivity, and thus, farmers' income. Popularization of newly released varieties has always been a concern for research institutes and extension agencies. Demonstration of potential of the variety and its profitability at farmers' fields is best way to increase the demand of seed and to bring the variety in the seed chain.

Many scholars have proposed and discussed break-even analysis for agricultural decision-making (Kay, 1986; Schmisseur and Landis, 1985; Forster and Erven, 1981; Herbst, 1976; Barnard and Nix, 1979; Giles and Stansfield, 1980). Enterprise budgeting enables the farm managers to carry-out break-even analysis, estimate cost of production, and select between competing crop production alternatives. The more common break-even yield and price relationships have been expanded to include acreage or usage levels for machinery management by some of the researchers (Herbst, 1976; Forster and Erven, 1981; Barnard and Nix, 1979), and break-even output price and yield analysis between agricultural enterprises (Casey, 1977; Herbst, 1976). While these serve as worthwhile decision-making tools, development of advanced break-even analytical procedures havebeen suggested (Giles and Stansfield, 1980; Forster and Erven, 1981). Break-even output price can be used as a simple risk management tool to evaluate the impacts of marketing decisions under price volatility. Maximum potential yield losses due to detrimental weather can be investigated with break-even yield analysis. Break-even analysis is also useful from the input side. Keeping these in view, the break-even analyses were carried out to assess the profitability of soybean varieties cultivation in different states of India.

MATERIALS AND METHODS

The pooled data from FLDs conducted from 2013 to 2017 at different centres spread over 15 states of the country was used for the analysis. A total of 44,162 FLDs (Table 1) were conducted in different states of India at farmer's field on0.4 ha each with research emanated improved soybean production technology (IT) and that were compared with farmer's practice (FP). The seed of newly released varieties (52 varieties) and critical inputs were supplied to the farmers under improved production technology. The cost of cultivation under both the treatments was determined by using the prevailing market price of inputs and outputs. The data of varieties having less than five FLDs planted for less than three years have been discarded, thus leaving 26 varieties for analysis.

Break-even (BE) analysis was used to determine the values at which price, production, output and so on are adequate enough to cover specific costs (Chambers *et al*., 1979; Baute *et al*., 2002; Cook *et al*., 2012). Based on current production and marketing systems, break-even analysis was conducted for soybean production in different states of India. The minimum yield and price required matching the performance of the improved production technology and farmers practice was determined in order to cover the costs. The basic formula for break-even analysis was adapted and solved for the variables of interest was as under.

Break-even yield (kg/ha)	=	Total Cost of cultivation / Output price (Rs/kg)
Incremental Benefit cost ratio (IBCR)	=	Incremental gross returns from the demonstrated technology/Incremental cost involved in demonstrated technology
Incremental net returns	=	Net returns from IT – Net returns from FP

The percentage yield increment in improved practice for each variety over farmers' practice was calculated across the states and for the country as a whole as weighted average using number of demonstrations as weights. The cost and returns data were deflated using wholesale price index for soybean with the base 2011-12.

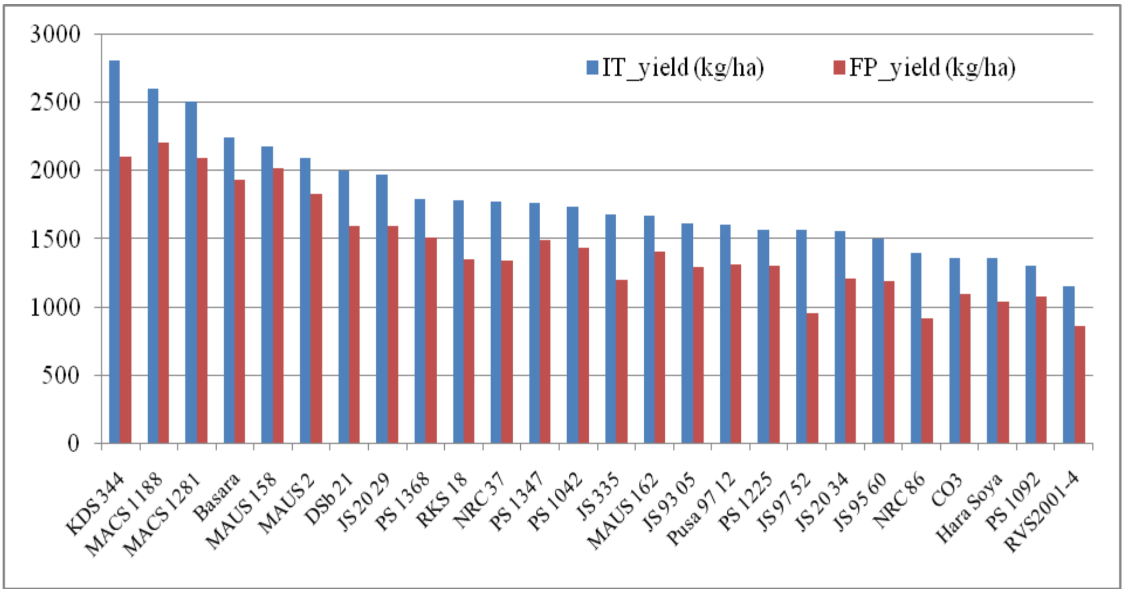
Break-even revenue and price are the minimum revenue and price of soybean that is required to match the cost of production of soybean. Total revenue is the product of yield and price. Cost of all material inputs, machines and labour inputs used were considered for analysis. Gross returns have been worked out at prevailing market price in the respective area. The data of improved technology where comparable farmers practice was not available have been excluded from the analysis. Break-even (BE) yield is the minimum yield of soybean required to match the profitability of commercial soybean. BE yield can be compared between improved technology and farmer's practice and also be used as an indicator for the competitiveness of improved production technology. In order to attempt to sell at a profit rather than taking a hit, it is important for soybean producers to know their break-even yields.

RESULTS AND DISCUSSION

A total of 52 soybean improved varieties have been demonstrated on 4,735 FLDs, which were conducted across the country during the period under study. Of these, 162 FLDs were taken for analysis and remaining data have not been included due to non-availability of comparable farmers practice data or less data points for some of the varieties. The highest number (>2300) of FLDs were conducted using variety JS 95-60 followed by JS 93-05 and JS 335 (Fig. 1). Of the 52 soybean varieties, 34 were demonstrated on more than 10 farmer's field, whereas demonstrations conducted with remaining varieties were below ten during the five year period. Moreover, some of the varieties demonstrated in one year only were also not considered for analysis. Among the varieties, the highest soybean yield was recorded with variety KDS 344 under IT and the lowest yield was associated with variety RVS 2001-4. Out of 26 varieties, three (KDS 344, MACS 1188 and MACS 1281 under IT) yielded more than 2,500 kg per ha, four (MAUS 2, MAUS 158, Basara) produced in between 2,000 to 2,500 kg per ha, 13 yielded between 1,500 to 2,000 kg per ha, and yield of 6 ranged between 1,000 to 1,500 kg per ha. The improved soybean varieties substantially improved the soybean productivity to the tune of 8 to 64 per cent as compared to the farmer's practice, and generated higher net income to the tune of 15 to 166 per cent under IT as compared to farmers' practice (Fig. 1). Under farmer's practice, a similar trend was noted in terms of higher yield realized. Similar results were also reported by Billore *et al*. (2005 and 2009) and Joshi *et al*. (2004).

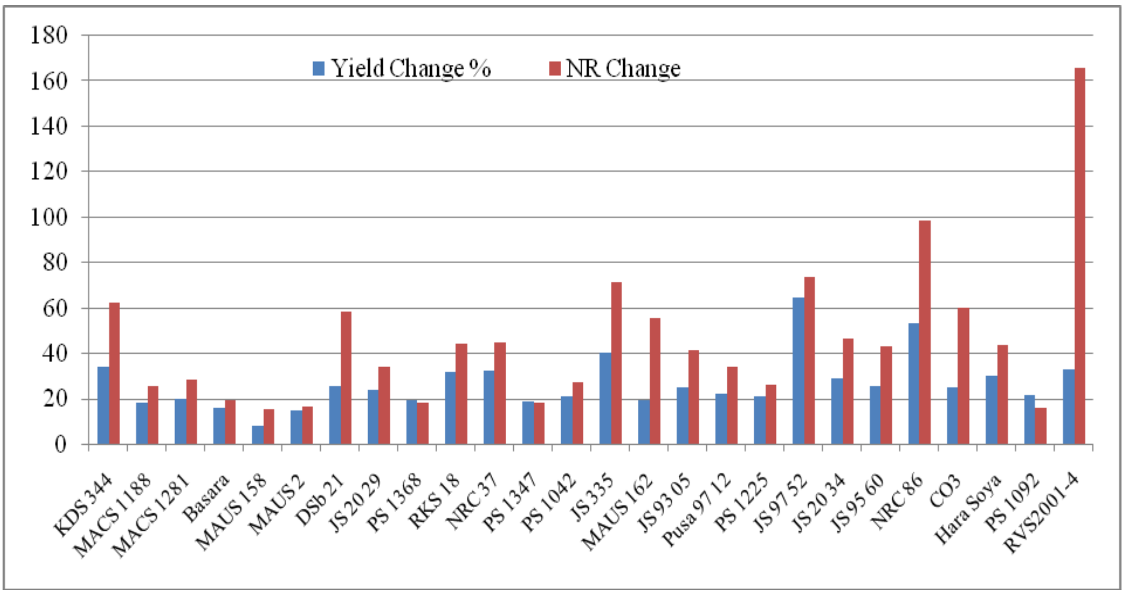
On an average, an increase of 26 per cent (1,636 kg/ha) could be achieved, which was about 60 per cent higher than the national average productivity (1,000 kg/ha), and productivity with improved technology (1,846 kg/ha) during normal year (*kharif* 2016). Even if we consider the predicted 80 per cent possibility (Cassman, 1999) of bringing FLDs Frontline Demonstration performance as ground reality or bridging the yield gap, the productivity of above 1,500 kg per ha can be achieved. This leads to belief that from the present area of around 11.25 million hectares in the country (last five year average), an additional production of 5.85 million tonnes of soybean can be realized with adoption of available improved technology against 10.98 million tones achieved on an average during last five years.

Adoption of improved soybean varieties not only enhances the yield realization, but also helps in improving monitory returns to the farmers. Change in net returns under IT over farmers' practices (Fig. 2) and benefit cost ratio (BCR) from adoption of improved soybean varieties over farmers' practice (Fig. 3) revealed that farmers can earn net returns to the tune of Rs. 18,600 to Rs. 54,400 per ha across different varieties under IT and Rs. 9,700 to Rs. 39,100 per hectare under farmers' practice. The maximum net returns were recorded with variety KDS 344. The improved production technology was found economically viable (Mathur and Gupta, 1985; Thakur *et al*., 1998; Joshi *et al*., 2004). The returns to investment determine the profitability and thus, the extent of adoption of technology. The benefit cost the profitability and thus, the extent of adoption of technology. The benefit cost ratio was in the range of 1.53 to 2.89 across the varieties, indicating that adoption of improved soybean varieties generates sufficient returns over investment and is profitable. The variation in net returns and BCR across varieties was mainly on account of differences in practices adopted by farmers. The incremental net benefit cost ratio from adoption of IT over farmers' practice was found to be in the



IT-improved technology, FP-Farmer's practice

Fig. 1. Average yield achieved for different varieties under FLDs for the period 2013-2017

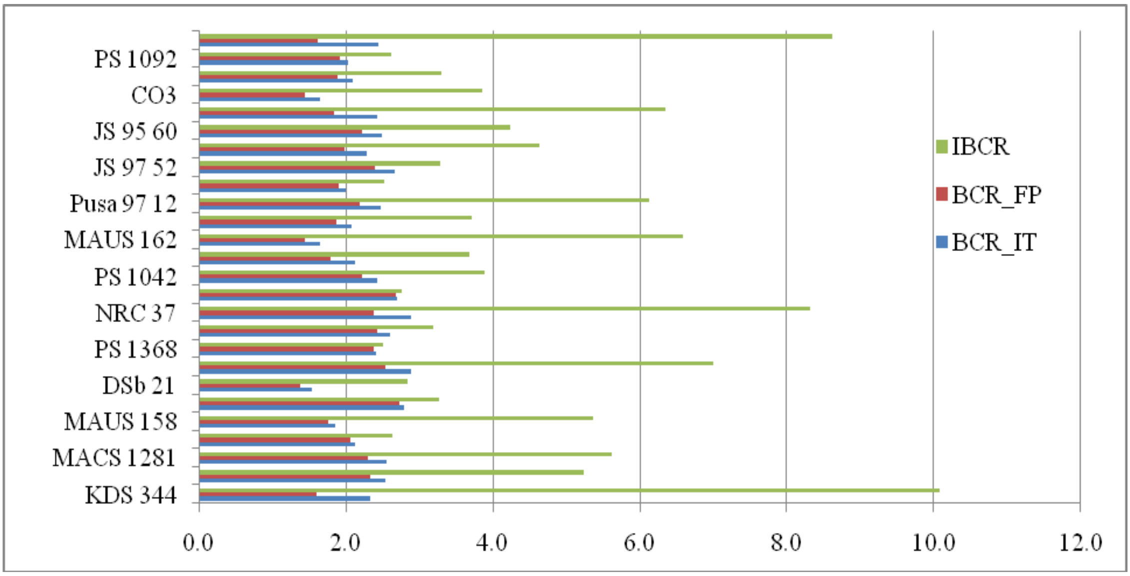


NR-Net returns

Fig. 2. Percentage change in average yield and net returns under IT over FP for the period 2013-2017

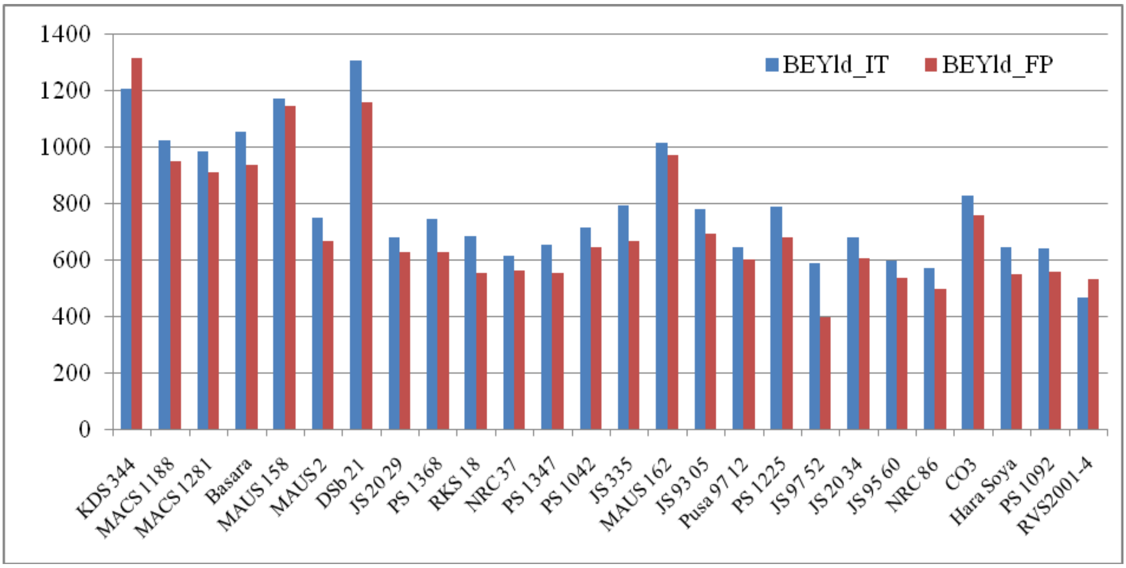
range of 2.51 to 10.07, indicating that the adoption of improved soybean production technology generated about 2.5 to 10 times higher net returns as compared to farmers' practice.

Break-even yield analysis reveals potential profit losses if yields and premiums are below the critical thresholds. Based on the cultivation cost and selling price of soybean, the break-even yield was worked out (Fig. 4). The results of analysis revealed that the break-even yield, on an average basis, varied from 470 kg per ha (RVS 2001-4 to 1,305 kg per ha (DSb 21) under IT. The overall average soybean yield needed to break-even was 793 kg per ha to receive positive returns under improved soybean technology. However, in farmers practice, average break-even yield varied from nearly 398 kg per ha to more than 1,315 kg per ha at 2011-12 prices. The break-even yield points, *i.e.* 793 and 719 kg per ha indicated that these yield levels showed no profit no loss in soybean cultivation and for profitable soybean production yield should be higher than this break-even yield. The results revealed that the break-even yield level was higher under improved technology than farmers practice. Similar results were also reported in a study by Mayata *et al*., (2014). The average break-even cost of production of soybean varieties varied from 20.01 to 30.61 Rs per kg under IT where as it ranged from 19.28 to 30.80 Rs per kg under farmer's practice at 2011-12 prices (Fig. 5).



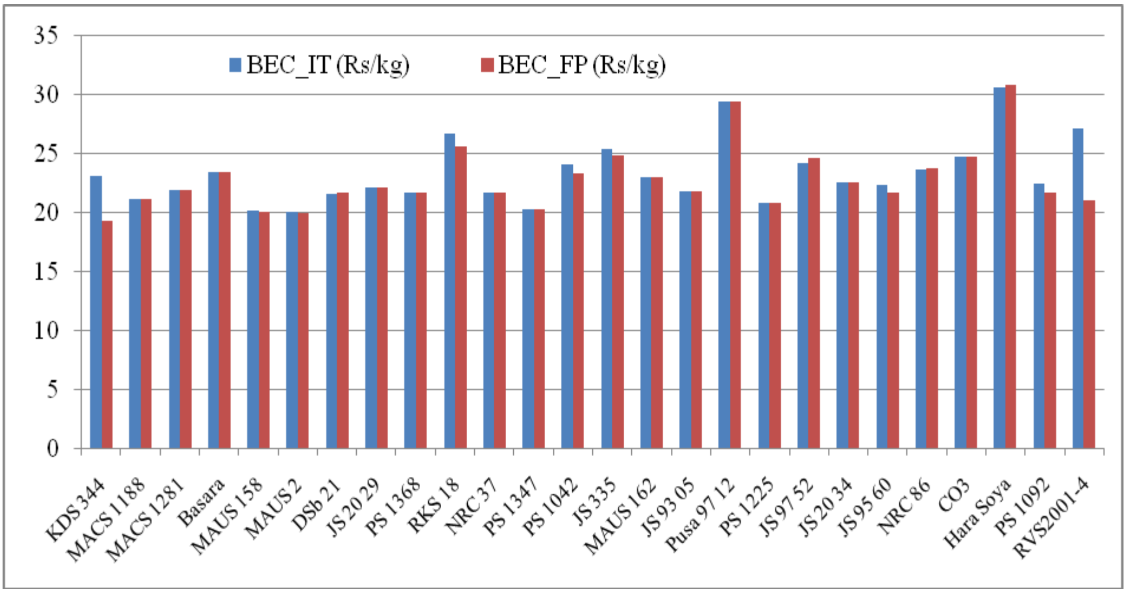
ICBR-Incremental benefit cost ratio, BCR-Benefit cost ratio, IT-improved technology, FP-Farmer's practice

Fig. 3. Benefit: cost ratio under IT and FPs and IBCR from production of soybean



BE-Break-even, IT-improved technology, FP-Farmer's practice

Fig. 4. Break-even yield of soybean varieties under FLDs



BE-Break-even, IT-improved technology, FP-Farmer's practice

Fig. 5. Break-even cost of production of soybean varieties under FLDs

Careful selection of recommended variety and their testing in the local environments and production systems are needed if farmers are to consider the adoption of improved soybean varieties at current market conditions. Also, as commodity prices fluctuate, additional break-even analyses must be conducted to accurately estimate future profitability from soybean production. Adequate testing will ensure optimal yields for the growers and desired soybean quality for the processors.

In summary, any yields above 793 and 719 kg per ha under improved soybean varieties and farmers practice for soybeans sold at harvest represented profitable income over break-even prices. Achieving consistent production at these high levels without causing environmental damage requires improvements in soil quality and precise management of all production factors in time and space.

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Soybean Research 18(1): 69-76 (2020)

Response of Soybean [*Glycine max* (L.) Merrill] to Sowing on Ridges and Furrows at Different Planting Geometries

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Received: 17.11.2019; Accepted: 04.03.2020

ABSTRACT

A field experiment was carried out during kharif *2018 with an objective to evaluate the performance of soybean varieties on ridges and furrow planting at different spacing and its economic feasibility. The treatments comprised of two soybean varieties (JS 93-05 and MACS 1188) and four planting geometries (45 cm x 5 cm, 45 cm x 10 cm, 45 cm x 20 cm and 45 cm x 30 cm) were laid out in split plot design with three replications. Results revealed that growth parameter (plant height) and yield attributes (pods per plant, seed index), seed yield and net returns were high in soybean variety MACS 1188 as compared to JS 93-05. Seed yield was significantly higher in MACS 1188 (2,791 kg/ha) than JS 93-05 (2,313 kg/ha). Maximum net returns (Rs 49,512 /ha) and cost: benefit ratio (1:2.16) were also recorded with soybean variety MACS 1188. Soybean growth, yield attributes and net returns were significantly higher with 45 cm x 5 cm planting geometry than the rest. Soybean sown with 45 cm x 5 cm gave significantly higher seed yield (2,827 kg/ha), more net returns (Rs 50,727/ha) with cost: benefit ratio of 1:2.19 than rest of the crop geometries. Soybean variety MACS 1188 sown at 45 cm x 5 cm planting geometry gave maximum seed yield (3,065 kg/ha).*

Key words: Improved soybean varieties, optimum yield, planting geometry, ridges and furrows, soil moisture

Soybean [*Glycine max* (L.) Merrill] is an important oilseed crop cultivated in diverse climatic conditions of the India. India is ranked forth at global level in terms of area under soybean. In India, 10.80 million ha area was under this crop during *kharif* 2018, out of which 48.51 per cent and 36.38 per cent was in Madhya Pradesh and Maharashtra states, respectively (Anonymus, 2018-19). Maharashtra is the second soybean producing state after Madhya Pradesh with 3.93 m ha area, 4.39 m ton production and 1,117 kg per ha productivity during 2018 (Anonymous, 2018-19). In Maharashtra, soybean crop is mainly cultivated in Vidarbha, Marathwada, Western Maharashtra and northern Maharashtra regions. Due to the impact of global climatic change in the past few years, rainfall experienced in this part is uneven and scarce, which leads to

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reduction in seed yield of soybean crop as a result of drought condition during the crop growth stages. Long dry spells are being experienced in the major parts of the Maharashtra during June to October, which hinders the soybean production. To make an optimum use of soil moisture, ridge and furrow planting in soybean proved to be beneficial during dry spells as the conserved moisture leads to better growth and yield (Ramesh *et al.,* 2006). Ridge and furrow planting of crops facilitates increase in soil depth, soil moisture storage and provides more volume of soil for root growth which results in yield increase by 10-33 per cent under rainfed condition, in areas where long dry spells during crop growth period prevails (Yadav *et al.*, 2003; Verma *et al.*, 2017). The JS 93-05 and MACS 1188 are the popular improved varieties of soybean grown by farmers of the Maharashtra. The response these varieties to ridge and furrow planting need to be evaluated for their technical suitability and economic feasibility. Similarly, spacing of the sowing is one of the important factors which directly influence the plant stand and crop yields. Keeping this in mind, this study was undertaken with the objectives to evaluate the performance of soybean varieties with respect to ridges and furrow planting at different spacings.

MATERIAL AND METHODS

An experiment was conducted during the *kharif* 2018 at research farm of MACS-Agharkar Research Institute, Pune, Maharashtra ($18^0 14'$ N latitude, $75^0 21'$ E longitude and at an altitude of 548.6 m from mean sea level). During this year (from June to October) total rainfall received was 595.70 mm. Experimental soil was slightly alkaline (pH 7.4) and belonged to Vertisols. The experiment laid out in split plot design was comprised of two varieties (JS 93-05 and MACS 1188) as main factor and planting geometries (45 cm x 5 cm, 45 cm x 10 cm, 45 cm x 20 cm and 45 cm x 30 cm) as sub-factor and was replicated thrice. Experiment was sown on 9th July with a gross plot of size of 3.6 m x 6 m and net plot 2.7 m x 5 m with 45 cm row to row and 5, 10, 20 and 30 cm spacing between the plants on ridges and furrows on both sides. Crop was raised by following recommended package of practices to maintain good crop condition. After attaining the maturity, crop in each plot was manually harvested separately using sickle. The data on growth parameters, yield and its attributes were recorded. Harvest index (%) was determined using the formula: Harvest index (%) = (Seed yield / Biological Yield) x 100. Crop growth rate (CGR) and relative growth rate (RGR) were calculated using formula, given by Watson (1947) and Williams (1946).

$$CGR = W_2 - W_1 / t_2 - t_1$$

$$RGR = (Log_{10} W_2 - Log_{10} W_1) / (t_2 - t_1)$$

where, W_2 and W_1 are plant dry weight per plant at time period (t_2) and (t_1), respectively.

Economics evaluation of the respective treatment in terms of gross returns, net returns and benefit: cost ratio was worked out. Analysis of the data was carried out using standard variance techniques given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on growth and its attributes

The data on growth attributes (Table 1) revealed that the differences for branches per plant, plant dry weight, CGR and RGR were non-significant except for plant height due to the varieties under study. Soybean variety MACS 1188 (51.23 cm) recorded significantly superior plant height over JS 93-05 (36.20 cm) at harvest. The difference in the plant height might be due to genetic character of the varieties under study. The results are in the conformity with the results of the Siddiqui *et al.* (2007), Shergo *et al.* (2010) and Singh (2011), who reported that the soybean genotype differs in growth, yield attributes, duration and resistance to insect-pests and diseases. Whereas, under

Table 1. Effect of planting geometries and varieties on growth parameters of soybean

Treatment	Plant height (cm)	Branches /plant	Plant dry weight (g)			CGR		RGR	
			30 DAS	45 DAS	60 DAS	30-45 DAS	45-60 DAS	30-45 DAS	45-60 DAS
Varieties									
JS 93-05	36.20	5.77	5.30	12.33	26.24	0.462	0.934	0.0242	0.0219
MACS 1188	51.23	4.92	5.63	14.24	28.05	0.574	0.921	0.0268	0.0195
SEm (±)	0.15	0.32	0.11	0.46	1.69	0.03	0.10	0.001	0.001
CD (P=0.05)	**0.53**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Planting geometry									
45 cm x 5 cm	53.43	4.80	5.37	12.45	26.68	0.471	0.949	0.0241	0.0212
45 cm x 10 cm	45.37	5.17	4.90	12.42	25.51	0.501	0.873	0.0267	0.0212
45 cm x 20 cm	38.58	5.73	5.77	14.27	27.95	0.566	0.912	0.0262	0.0195
45 cm x 30 cm	35.53	5.67	5.83	13.81	28.45	0.532	0.976	0.0250	0.0210
SEm (±)	1.57	0.37	0.32	1.13	1.94	0.06	0.13	0.002	0.003
CD (P=0.05)	**5.43**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Varieties x Planting geometry									
SEm (±)	2.22	0.53	0.45	1.59	2.75	0.09	9.04	0.003	0.004
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

planting geometries, JS 93-05 and MACS 1188 sown at different geometries on ridges and furrow showed significant increase in plant height while, rest of the growth parameters had non-significant differences. Soybean crop sown on ridges and furrow with geometry of 45 cm x 5 cm had significantly higher plant height (53.43 cm) than rest of the three planting geometries. Whereas, the values for plant height were at par with 45 cm x 10 cm, 45 cm x 20 cm and 45 cm x 30 cm planting geometries. Increase in plant height with reduced plant to plant spacing (5 cm) might have been observed due to the competition for sunlight arising due to close spacing. Lone *et al*. (2010) and Ram *et al*. (2011) reported higher plant height due to closer spacing and high seed rate resulted into competition for sunlight. The interaction of the soybean varieties and planting geometries was non-significant for the growth and its attributes.

Effect on yield and its attributes

Data on yield and its attributes (Table 2) showed that variety MACS 1188 (83 pods/plant) produced significantly higher number of pods per plant over JS 93-05 (72 pods/plant). The seed index was significantly high with soybean variety MACS 1188 (15.23 g) over JS 93-05 (11.08 g). Soybean variety MACS 1188 gave significantly higher seed yield (2,791 kg/ha) over JS 93-05 (2,313 kg/ha), which might have resulted due to more number of pods per plant and increase in seed weight (seed index). Maximum yield of MACS 1188 might be due to its genetic character as well as more number of days of maturity. This might have catalysed conversion and translocation of photosynthates to sink as a result of longer maturity duration (101-104 days) as compared to JS 93-05 (95 days). Muchlish and Ayda (2017) reported that early maturing/short duration soybean genotype yields less compared to late maturing or long duration genotypes. Under planting geometries, soybean varieties sown at different geometries showed significant differences for number of pods per plant, seed yield per hectare, straw yield and harvest index. Soybean varieties sown at 45 cm x 5 cm (83 pods/plant) geometry gave significantly higher number of pods per plant over 45 cm x 20 cm and 45 cm x 30 cm while, at par with 45 cm x 10 cm planting geometry. The seed yield per hectare was significantly higher with planting geometry 45 cm x 5 cm (2,827 kg/ha) over 45 cm x 20 cm and 45 cm x 30 cm and was at par with 45 cm x 10 cm (2,678 kg/ha). More number of pods per plant resulted into higher seed yield per hectare, which evidenced that the optimum plant population is required for obtaining the higher yield of the soybean and also higher availability of moisture to roots of crop due to sowing on ridges and furrow. Soybean crop sown at 45 cm x 5 cm spacing helped to maintain the crop stand of 4.5 lakhs per hectare, which is recommended plant stand per hectare to obtain the optimum yield of soybean. Several studies reported that soybean sown at 45 cm x 5 cm yields higher than the closer or wider spacing. These results are in conformity with the findings of Dhakad *et al.* (2014), who reported the increase in pod number and seed yield of

Table 2. Effect of planting geometries and varieties on yield, its components and economics

Treatment	Pods/ plant	Seed index (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	C:B ratio
Varieties									
JS 93-05	72	11.08	2313	1639	59.74	42578	76326	33748	1:1.79
MACS 1188	83	15.23	2791	2857	49.55	42578	92090	49512	1:2.16
SEm (±)	0.14	0.39	72.78	101.57	1.57	0.0057	2402	2402	0.06
CD (P=0.05)	**0.51**	**1.37**	**251.83**	**351.44**	**5.45**	**NS**	**8310**	**8310**	**0.19**
Planting geometry									
45 cm x 5 cm	83	12.87	2827	2612	52.30	42578	93304	50727	1:2.19
45 cm x 10 cm	81	12.82	2678	2668	50.75	42578	88387	45809	1:2.08
45 cm x 20 cm	74	13.20	2425	2032	55.61	42578	80014	37437	1:1.88
45 cm x 30 cm	72	13.73	2276	1680	59.92	42578	75125	32548	1:1.77
SEm (±)	2.29	0.25	89.02	139.67	1.84	0.042	2938	2938	0.07
CD (P=0.05)	**7.95**	**NS**	**308.02**	**483.26**	**6.36**	**NS**	**10164**	**10164**	**0.23**
Varieties x Planting geometry									
SEm (±)	3.25	0.36	125.89	197.53	2.60	0.006	4155	4155	0.09
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

soybean planting on ridges and furrows at recommended spacing. Similarly, Ram *et al*. (2011) also reported that ridge and furrow sowing has advantage in saving of moisture which is required for completion of different growth stages of soybean crop. The values for seed index were statistically non-significant in all the planting geometries studied. Data on overall performance of varieties showed that soybean seed yield was maximum (3,065 kg/ha) with MACS 1188 when planted at 45 cm x 5 cm planting geometry than the rest of the combinations of variety and planting geometry (Table 3).

Table 3. Effect of interaction of soybean varieties and planting geometries on seed yield

Planting geometry	**Varieties**		
	JS 93-05	**MACS 1188**	**Mean**
45 cm x 5 cm	2590	3065	2827
45 cm x 10 cm	2455	2902	2678
45 cm x 20 cm	2149	2700	2425
45 cm x 30 cm	2058	2495	2276
SEm (±)		125.90	
CD (P=0.05)		**NS**	

Effect on economics of the study

Economic evaluation of the treatments (Table 2) revealed that the values for cost of cultivation were non-significant for both the varieties (JS 93-05 and MACS 1188). Whereas, the gross (Rs 92,090/ha) and, net (Rs 49,512/ha) returns, and cost-benefit ratio (1: 2.16) were significantly higher in MACS 1188 than JS 93-05. Maximum values for net returns and cost-benefit ratio were due to the high yield of MACS 1188 over JS 93-05. While under planting geometries the data on economic evaluation revealed that soybean varieties sown at 45 cm x 5 cm gave significantly higher gross returns (Rs 93,304 /ha), net returns (Rs 50,727 /ha) and cost-benefit ratio (1:2.19) over 45 cm x 20 cm and 45 cm x 30 cm and was at par with 45 cm x 10 cm. Higher monetary returns per hectare and cost-benefit ratio obtained with sowing of soybean varieties at 45 cm x 5 cm might be due to optimum plant stand, crop vegetative cover and utilization of available resources to the optimum extent enough for getting the high yield. Increase in yield due to sowing on ridges and furrows at 45 cm x 5 cm spacing ultimately resulted into earning of the more returns per hectare. Jain and Dubey (1998) and Paliwal *et al*. (2011) reported maximum net returns with ridge and furrow planting of soybean at recommended spacing between rows and plant.The above study inferred that the soybean variety MACS 1188 gave higher yield and is profitable in terms of net returns. Soybean crop sown with 45 cm x 5 cm planting geometry on ridges and furrows is economical. Soybean variety MACS 1188 sown with 45 cm x 5 cm planting geometry on ridges and furrows yields higher and is more remunerative.

ACKNOWLEDGEMENTS

Authors are grateful to Director, MACS Agharkar Research Institute, Pune for providing facilities and ICAR-Indian Institute of Soybean Research, Indore for funding.

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Soybean Research 18(1): 77-86 (2020)

Performance of Soybean Varieties under Frontline Demonstrations

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Received: 04.11.2019; Accepted: 01.03.2020

ABSTRACT

A total of 7,191 frontline demonstrations (FLDs) were organized on soybean across the country during 2011 to 2018 to assessthe yield gaps between improved soybean varieties (Nos 65) with improved package of practices (IP) and framers' practice (FP). The objective of the study was to assess the performance of improved varieties of soybean as compared to farmers' preferred varieties. Maximum number of FLDs (47 %) were conducted on variety JS 95-60. Of these 65 varieties, four of them (JS 95-60, JS 93-05, JS 335 and MAUS 58) represented 67 per cent of the demonstrations. The highest and lowest yielding ability of varieties KDS 344 and MAUS 71 respectively, was recorded under IP. The magnitude of yield variation between maximum and minimum was 236 per cent under IP. All the soybean varieties under IP led to enhanced yield between 7 per cent (JS 20-69) and 102 per cent (VLS 65) over FP. The cost of cultivation among the soybean varieties varied from Rs 15,520 and Rs 12,707 per ha (NRC 7) to Rs. 46,308 and Rs. 47,808 per ha (VLS 63) under IP and FP, respectively. The maximum net returns were achieved with the variety MACS 1460 [Rs 72,625 (IP) and 44,818 (FP)], while the minimum cost of cultivation (Rs 17,937/ha) was required for variety CO3 under IP and Rs. 8,399 per ha for NRC 86 under FP. Sustainable yield index (SYI) varied from 0.41 (CO3) to 0.95 (RKS 45) under IP, while it was from 0.35 (JS 20-34) to 0.92 (VLS 47) under FP. It indicated that the minimum guaranteed soybean yield varied from 41 to 95 per cent of the maximum yield in former and 35 to 95 per cent in later. Invariably varieties under IP showed higher SVI values than FP with reference to gross and net returns. The break-even yield (BEY) varied from 516 (NRC 7) to 1,464 kg per ha (VLS 63) with the mean of 795 kg per ha under IT, while it ranged from 377 (DSb 19) to 1,439 kg per ha (VLS 63) with the average of 698 kg per ha under FP. The break-even cost (BEC) oscillated between 7.38 (DS 228) and 39.53 Rs per kg (VLS Bhatt 201) with the mean of 15 kg per ha under IT, while it varied from 7.67 (DS 228) to 57.27 Rs per kg (VLS Bhatt 201) with an average of Rs 17 kg per ha under FP, which indicated a difference of 435.64 and 647 per cent, respectively.

Key words: Break-even yield, break-even cost, coefficient of variation, frontline demonstration, sustainable yield index, sustainable value index

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Soybean growing region is spread over in latitudinal belt of about 158^{0}N to 258^{0}N covering nearly 98 per cent of the total area in India. Soybean is predominantly grown on Vertisols and associated soils experiencing an average crop season rainfall of about 900 mm; which is varying greatly across locations and years. Introduction of soybean in these areas after 1970 has led to a shift in the cropping systems from rainy season fallow-post-rainy season (wheat/ chickpea) to soybean-wheat/chickpea, enhancing the cropping intensity and profitability per unit area of land. Besides improving the socio-economic conditions of small and marginal farmers in this region, the crop helped in meeting out 21 per cent of the total domestic edible oil production and earning foreign exchange of worth Rs.5459.50 million by exporting de-oiled cake in 2016-17 (DAC&FW, 2018). Despite a phenomenal growth in area and production, the average national productivity of soybean has remained more or less stagnated at 1,000 kg per ha due to several abiotic, biotic and socio-economic constraints (Paroda, 1999; Joshi and Bhatia, 2003; Bhatnagar and Joshi, 2004; Tiwari, 2014). Several studies (Aggarwal and Kalra, 1994; Lansigan *et al*., 1996; Evenson *et al*., 1997; Naab *et al*., 2004) have shown that assessment of potential yield and yield gaps can help in identifying the yield limiting factors and in developing suitable strategies to improve the productivity of soybean.

The frontline demonstrations (FLDs) programme sponsored by Ministry of Agriculture was executed under the close supervision of scientists of the National Agriculture Research System (NARS), wherein the improved technologies were demonstrated for the first time before being transferred to the main extension system of the State Department of Agriculture. These demonstrations were proved to be an effective tool to disseminate the latest developed research emanated technologies among the farming community (Gautam *et al*., 2007). These demonstrations have created greater awareness and motivated the respondents and other fellow farmers to adopt appropriate oilseed production technologies (Singh *et al*., 2014). The main objective of FLDs is to demonstrate the performance of newly released soybean varieties along with recommended package of practices including production and protection technologies in the farmers' field in different agro-climatic regions and farming situations.

METHODS AND MATERIAL

A total of 7,191 FLDs (each on 0.4 ha) on 65 soybean varieties along with improved package of practices (IP) were organized across the country during 2011 to 2018 which were compared with farmers' practice (FP). The seed of improved variety and critical inputs, as per norms, were supplied to the farmers to conduct the demonstrations. The yielding ability of soybean varieties was categorized in 5 yield groups (>2,500, 2,000-2,500, 1,500-2,000, 1,000-1,500 and >1,000 kg per ha). The performance of IP was assessed by comparing the yield and monetary advantages over FP. The variety-wise sustainable yield index (SYI), sustainable value index (SVI) standard deviation and coefficient of variation were determined as per the standard procedures (Singh *et al.,* 1990). Break-even yield (BEY) and break-even cost (BEC) were determined as used by Dupare *et al.* (2019).

RESULTS AND DISCUSSION

Out of the 65 soybean varieties, the maximum number of FLDs were organized on JS 95-60 (47.05 %) followed by JS 93-05 (10.71 %), JS 335 (5.25 %), MAUS 158 (3.46 %), Hara soya (2.10 %) and RKS 18 (2.04 %) and rest (> 2%).

Yield variability

Soybean varieties exhibited differential yielding ability during the period of study. The maximum yield was recorded with KDS 736, which was closely followed by KDS 344, MACS 1281, DS 228 and MACS 1188, while the lowest yield was with MAUS 71. The magnitude of yield variation ranged between maximum and minimum was 236 per cent under IP. The maximum varieties (Table 1) were under yield category of 1,500-2,000 (50 %), followed by 1,000-1,500 (24 %), 2,000-2,500 (16 %), >2,500 (9%) kg per ha and minimum under less than 1,000 kg per ha (2%). Out of 65 varieties, 17 were demonstrated in only one year and hence other parameters were not worked out. The coefficient of variation indicated that the highest yield variability associated with variety Shivalik (38.57 %) and lowest with RKS 45 (3.29 %) under IP, while in case of farmers' practice, the maximum was with JS 20-34 (44.96 %) and minimum with VLS 63 (4.15 %) over the years. Out of 49 varieties, 10 varieties (MAUS 158, VLS 47, VLS 63, Pusa 97-12, RVS 2001-4, MAUS 612, PS 1042, PS 1368, DSb 1 and SL 688) showed higher yield variability under IP than FP. Five varieties (MAUS 162, NRC 7, MAUS 2, GJS 2 and Basar) showed more or less similar yield variability under both the conditions (IP and FP). Rest of the varieties showed lesser yield variability under IP as compared to FP.

All the soybean varieties under IP enhanced the yield by 7.13 (JS 20-69) to 101.79 per cent (VLS 65) over FP.
The results gain support from the findings reported by (Singh *et al*., 2019; Singh *et al*., 2018; Singh *et al*., 2007). The effective narrowing of yield gap due to popularization of improved varieties and technology through FLDs at farmers field has earlier been documented (Kumar and Meena, 2013; Raut *et al*., 2016).

Sustainable yield index (SYI)

Sustainable yield index (SYI) varied from 0.41 (CO3) to 0.95 (RKS 45) under IP, while it was 0.35 (JS 20-34) to 0.92 (VLS 47) under FP, which indicated that the minimum guaranteed soybean yield varied from 41 to 95 per cent of the maximum yield under IP and 35 to 95 per cent under FP (Table 2). Of the 65 soybean varieties, fourteen (RKS 18, MACS 1188, VLS 65, VLS 63, JS 97-52, MAUS 81, PS 1347, Pusa 97-12, SL 688, SL 525, SL744, PS 1042, PS 1368 and DSb 1) showed higher SYI under FP as compared to IP. While of nine varieties (Hara soya, VLS 47, CO3, NRC 7, MAUS 2, Himsoya, GJS 3, Basar and MAUS 612), both under IP and FP,

Table 1. Categorization of soybean varieties based on yield performance

Yield (kg/ha)	Variety	Coverage of varieties
2500-3000	DS 228, MACS 450, KDS 344, KDS 736, MACS 1281 and MACS 1188	9.09
2000-2500	PS 23, JS 20-69, PS 24, RKS 24, MACS 1460, Basar, VLS 59, MAUS 2, MAUS 81 and VLS 63	15.15
1500-2000	SL 688, RVS 2002-04, DS 228, DSb 1, RKS 113, MAUS 612, JS 20 98, Bragg, PS 1368, PUSA 12, RVS 24, PS 1042, PS 1225, DSb 19, SL 744, RKS 45, SL 525, GJS 3, Him soya, PUSA 97 12, PS 1347, SL 958, CO 3, JS 20 29, NRC 37, JS 20-34, JS 97-52, DSb 21, VLS 47, RKS 18, MAUS 158, JS 335 and JS 93-05	50.00
1000-1500	PS 1477, Shivalik, RVS 18, Palam soy, NRC 86, PS 1092, BSS 2, Ankur, RVS 2001-4, NRC 7, VLS 65, VL Bhatt 201, MAUS 162, Hara soya and JS 95 60	22.73
<1000	MAUS 71	1.52

Table 2. Categorization of varieties based-on sustainable yield index (SYI)

SYI	Variety	Percentage to total varieties
>0.90	VLS 47, GJS 3, RKS 45	6
0.80 to 0.90	RKS 18, KDS 344, VLS 63, VLS 59, Pusa 97 12, Basar, KDS 736, MACS 450, DSb 19, RVS 24, NRC 86	22
0.70 to 0.80	JS 95 60, JS 93 05, DSb 21, NRC 7, MACS 1188, SL 958, Him Soya, SL 525, SL 744, MACS 1281, PS 1225, PS 1042, MACS 1460, RKS 24	28
0.60 to 0.70	JS 335, Hara soya, NRC 37, VLS 65, MAUS 81, MAUS 2, MAUS 612, PS 1092, BSS 2, Bragg, SL 688	22
0.50 to 0.60	MAUS 156, JS 97 52, JS 20 29, PS 1347, RVS 2001-4, PS 1368, DSb 1	14
0.40 to 0.50	MAUS 162, JS 20 34, CO3, Shivalik,	8

behaved identical with reference to SYI. Rest of the varieties showed higher SYI values under IP than FP

Economic performance

The cost of cultivation of among the soybean varieties with improved production technologies varied from Rs 15,520 to Rs 12,707 per ha in case of NRC 7. It varied from Rs 46,308 to Rs 47,808per ha (VLS 63) under IP and FP, respectively. The highest gross returns was obtained from variety MACS 1460 (Rs 1,05,841 and Rs70,613/ha) under both the situations (IP and FP). However, the lowest gross returns were recorded from variety MAUS 71 (Rs 28,438/ha) under IP and variety RVS 2001-4 (Rs 25,786/ha) under FP (Data not shown). The maximum net returns were observed with the variety MACS 1460 (Rs 72,625 and Rs 44,818 under IP and FP, respectively), while the minimum (Rs 17,937/ha) was obtained from variety CO3 under IP and Rs 8,399 per ha from NRC 86 under FP. The improved production technologies including improved soybean varieties gave higher B:C ratio than FP except in case ofsoybean varieties PS 1225, PS 1042, Bragg, Shivalik and PS 1368. The maximum B:C ratio was recorded from soybean variety JS 20-69 under IP (3.61) and FP (3.54). The lowest B:C ratio obtained from CO3 (1.44) under IP and from KDS 736 (1.00) under FP (Table 3).

The gross returns variability indicated that the improved practices showed higher variability than FP except in 13 varieties (MACS 158, VLS 47, DSb 21, JS 20-34, VLS 65, JS 20-29, VLS 59, RVS 2002-4, RKS 45, RVS 24, NRC 86, DSb1 and SL 688). Similarly, cost of cultivation under IP showed higher variability as compared to FP except in 9 varieties (MAUS 158, Hara soya, VLS 47, KDS 344, MACS 450, MAUS 612, MACS 1460, Bragg and Shivalik). In all 17 varieties (JS 93-05, MAUS 158, RKS 18, JS 20-34, JS 20-29, MAUS 2, Himsoya, RKS 45, SL 744, KDS 736, MAUS 612, PS 1092, RVS 24, MACS 1468, NRC 86, Bragg and SL 688) showed higher variability under FP with regards to net returns. Invariably variability in IP with reference to B:C ratio was found lower than FP except in 13 varieties (JS 335, RKS 18, MAUS 162, MAUS 2, Pusa 97-12, GJS 3, SL 525, RKS 45, KDS 736, DSb 19, BSS2, DSb1 and SL 688). Similar variations among varietal behavior were also stipulated by (Singh *et al*., 2019; Singh *et al*., 2018; Kirar *et al*., 2005 and Billore *et al*., 2004).

Sustainable value index (SVI)

Gross returns sustainable value index revealed that the maximum value was obtained from variety GJS 3 (0.95) under IP, where as it was highest from variety KDS 344 and PS 1042 (1.00) under FP (Table 3). However, the variety SL 688 showed the maximum SVI (0.98) under IP and the lowest was from variety DSb 21 (0.10) under FP. Invariably varieties under IP showed higher SYI values than FP with reference to gross returns except 12 varieties (RKS 18, JS 97-52, MACS 1188, PS 1347, Pusa 97-12, MAUS 612, PS 1225, MACS 1281, PS 1042, MACS 1460, PS 1368 and RKS 24). However, varieties namely JS 95-60, MAUS 162, NRC 7, CO3, MAUS 2, Himsoya, GJS 3, Basar and DSb 19 behaved more or less identically under IP and FP (local varieties). In case of net returns, varieties like RKS 18, JS 97-52, Pusa 9712, MACS 1281, BSS2, PS 1042, MACS 1460, PS 1368, RKS 24 and DSb1 indicated higher SVI under FP as compared to IP. Only 6 varieties, namely MACS 1188, PS 1347, Him soya, GJS 3, Basar and DSb 19 performed more or less similar SVI under both the situation(IP and FP) with regards to net returns. The planting of soybean improved varieties with IP showed lower variability in economic returns (gross and net returns) as compared to FP. However, few varieties like MAUS 162, NRC 7, CO3, MAUS 2,DSb 19, MACS 1281, Basar and BSS 2 showed more or less similar variability under IP and FP in terms of gross and net returns, respectively. Improved varieties namely, JS 335, RKS18, JS 97-52, PS 1347, GJS 3, SL 525, MACS1281, Basar, PS 1092, MACS 612, PS 1225, PS 1042, PS 1368, PS 1460 and RKS 24

Table 3. Economics of soybean varieties tested under frontline demonstrations

Variety	Net returns (Rs/ha)		B:C ratio		SVI		Variety	Net returns (Rs/ha)		B:C ratio		SVI	
	IP	FP	IP	FP	IP	FP		IP	FP	IP	FP	IP	FP
JS 95 60	29503	21708	2.76	2.51	0.61	0.57	MACS 1281	55796	43550	2.70	2.44	0.57	0.60
JS 93-05	28111	19085	2.22	2.02	0.54	0.40	Basar	40805	34442	2.23	2.22	0.81	0.81
JS 335	38931	24095	3.08	2.11	0.44	0.42	KDS 736	55685	37091	2.32	1.00	0.70	0.53
MAUS 158	24764	19434	1.81	1.66	0.58	0.43	MAUS 61-2	29980	24221	2.38	2.29	0.72	0.63
Hara Soya	31382	22727	2.31	2.29	0.76	0.70	Ankur	26359	-	2.06	-	-	-
RKS 18	39884	28727	2.53	2.43	0.43	0.47	MACS 450	36061	29731	2.16	2.05	0.40	0.31
MAUS 162	19513	13292	1.65	1.46	0.16	0.08	DSb 19	69795	44818	3.11	3.03	0.67	0.67
VLS 47	31723	18238	2.14	2.69	0.81	0.71	PS 1092	26517	21545	2.34	2.38	0.49	0.43
DSb 21	24640	16574	1.96	1.86	0.23	0.10	BSS 2	18747	12515	2.07	1.93	0.38	0.39
KDS 344	56005	35141	2.38	1.55	0.71	0.65	PS 1225	30213	24214	2.60	2.63	0.44	0.34
JS 97-52	35023	22201	2.84	2.72	0.43	0.46	PS 1042	32313	26830	2.67	2.73	0.25	0.31
VL Bhatt 201	40122	20240	1.80	1.41	-	-	MAUS 71	1669	109	1.06	1.00	-	-
JS 20-34	31435	20695	2.60	2.18	0.31	0.13	PS 1368	32751	27614	2.31	2.30	0.20	0.23
VLS 63	35333	13187	1.80	1.30	-	-	RVS 24	30287	17254	2.62	2.04	0.82	0.64
VLS 77	35028	20101	1.78	1.46	-	-	MACS 1460	72625	45465	3.18	2.98	0.48	0.70
NRC 37	36024	26163	2.96	2.56	0.32	0.28	Pusa 12	38665	29922	2.46	2.23	-	-
VLS 65	24740	18302	1.96	1.38	-	-	NRC 86	21433	8399	2.08	1.49	0.86	0.28
JS 20-29	35487	25357	2.74	2.36	0.46	0.29	Bragg	24219	19250	2.33	2.56	0.52	0.43
NRC 7	25808	18904	2.63	2.47	0.52	0.50	Palam soy	34749	22066	1.91	1.64	-	-
MACS 1188	50711	41131	2.62	2.47	0.65	0.65	RKS 24	40739	34469	3.38	3.28	0.87	0.92
CO3	17937	11555	1.62	1.44	0.75	0.65	JS 20 98	44394	35098	3.05	2.83	-	-
SL 958	37833	-	-	-	-	-	RKS 113	40897	35743	2.85	2.81	-	-
MAUS 81	34410	29362	2.69	2.73	0.31	0.26	DSb 1	37137	24174	3.37	2.86	0.54	0.79
MAUS 2	34197	28185	2.75	2.76	0.51	0.44	DS 228	38378	28037	2.90	2.80	-	-
PS 1347	34859	29305	2.82	2.94	0.44	0.43	RVS 2002 - 04	27536	12683	2.43	1.74	-	-
VLS 59	31708	15880	1.70	1.36	-	-	RVS 18	25136	11683	2.31	1.68	-	-
Pusa 97-12	41921	30424	2.65	2.29	0.70	0.79	PS 24	42908	25510	2.37	1.96	-	-
Him Soya	32587	23790	2.37	2.45	0.70	0.92	SL 688	17464	14954	2.21	2.06	0.98	0.76
GJS 3	23603	19577	2.25	2.11	0.90	0.91	Shivalik	20915	17288	2.17	2.41	0.47	0.32
SL 525	32142	16796	2.30	2.19	0.28	0.70	JS 20-69	57087	52733	3.61	3.51	-	-
RVS 2001-4	26040	9769	2.43	1.61	0.73	0.27	PS 23	38375	27697	2.23	2.04	-	-
RKS 45	33747	28381	2.61	2.50	0.94	0.86	PS 1477	14505	11481	1.51	1.45	-	-
SL744	24899	17615	2.30	2.17	0.54	0.38							

Table 4. Break-even yield (BEY) and break-even cost (BEC) of soybean varieties tested under frontline demonstrations

S No	Variety	BEY (kg/ha)		BEC (Rs/kg)		Incremental net returns (Rs/ha)	S No	Variety	Break even yield (kg/ha)		Break even cost (Rs/kg)		Incremental net returns (Rs/ha)
		IP	FP	IP	FP				IP	FP	IP	FP	
1	JS 95 60	548	470	11.65	12.56	7795	**34**	MACS 1281	1025	949	11.79	13.11	12246
2	JS 93 05	791	701	14.36	15.72	9026	**35**	Basar	1024	882	14.62	14.79	6363
3	JS 335	763	596	15.86	17.36	14836	**36**	KDS 736	1237	1146	14.67	17.45	18594
4	MAUS 158	970	927	17.35	18.81	5330	**37**	Ankur	712	-	17.01	-	-
5	Hara soy	673	556	17.38	18.73	8655	**38**	MACS 450	1087	971	12.67	13.37	6330
6	RKS 18	702	547	14.02	14.07	11157	**39**	DSb 19	566	377	19.09	19.27	24977
7	MAUS 162	891	845	19.64	22.12	6221	**40**	PS 1092	642	534	12.98	13.31	4972
8	VLS 47	1073	990	17.83	23.08	13485	**41**	BSS 2	619	480	14.28	15.41	6232
9	DSb 21	1144	1000	18.16	20.12	8066	**42**	MAUS 61 2	884	807	12.27	13.10	5759
10	KDS 344	1190	1092	14.35	17.53	20864	**43**	PS 1225	745	626	13.07	13.40	5999
11	JS 97 52	555	394	13.27	14.14	12822	**44**	PS 1042	681	574	12.33	12.35	5483
12	VLS bhatt 201	710	689	39.53	57.27	19882	**45**	MAUS 71	804	727	31.35	33.15	1560
13	JS 20 34	621	551	12.47	14.85	10740	**46**	RVS 24	623	552	11.44	14.68	13033
14	VLS 63	1464	1439	21.46	30.08	22146	**47**	MACS 1460	737	558	14.15	15.20	27160
15	VLS 77	1102	1065	23.09	28.07	14927	**48**	PUSA 12	658	606	16.39	18.17	8743
16	NRC37	569	497	11.66	13.38	9861	**49**	PS 1368	729	630	14.70	15.03	5137
17	VLS 65	1034	1067	32.57	66.68	6438	**50**	NRC 86	640	556	14.98	21.74	13034
18	JS 20 29	646	594	11.73	13.59	10130	**51**	Bragg	694	500	11.79	11.13	4969
19	NRC 7	516	422	11.30	12.09	6904	**52**	Palam soy	735	664	27.23	31.72	12683
20	MACS 1188	1016	927	12.02	12.91	9580	**53**	RKS 24	653	574	8.11	8.29	6270
21	CO3	948	856	19.01	21.34	6382	**54**	JS 20 98	639	566	11.14	12.01	9296
22	SL 958	840	-	14.73	-	37833	**55**	RKS 113	652	582	11.89	12.05	5154
23	MAUS 81	815	709	10.64	10.70	5048	**56**	DSb 1	691	565	10.25	12.07	12963
24	MAUS 2	730	637	9.75	9.83	6012	**57**	DS 228	940	725	7.38	7.67	10341
25	PS 1347	697	587	11.62	11.62	-	**58**	RVS 2002 4	640	569	12.33	17.20	14853
26	VLS 59	1388	1342	22.18	29.44	15828	**59**	RVS 18	640	569	13.00	17.82	13453
27	PUSA 97 12	637	592	15.12	17.51	11497	**60**	PS 24	921	785	14.35	17.38	17398
28	Him soy	689	558	16.62	17.66	8797	**61**	SL 688	821	793	8.14	8.78	2510
29	GJS 3	725	681	11.51	12.31	4026	**62**	Shivalik	645	481	13.43	12.66	3627
30	SL 525	740	487	11.60	8.28	15346	**63**	JS 20 69	646	619	9.40	9.66	4354
31	RVS 2001-4	486	428	15.37	18.54	16271	**64**	PS 23	921	785	15.28	16.69	10678
32	RKS 45	626	564	12.81	13.36	5366	**65**	PS 1477	934	836	20.21	21.02	3024
33	SL 744	778	562	11.68	8.46	7284		**Mean**	**795**	**698**	**15**	**17**	**10489**
								SD	**209**	**226**	**6**	**10**	**6529**

Table 5. Categorization of varieties based on break-even yield (BEY) and break-even cost (BEC)

Category	BEY		BEC		INR
	IP	FP	IP	FP	
<mean-SD	NRC 7, RVS 2001-4	JS 95- 60, JS 97- 52, NRC 7, RVS 2001-4, DSb 19	RKS 24, DS 228, SL 688	SL 744, SL 525, RKS 24, DSb 228, SL 688	MAUS 71, SL 688, Shivalik, PS 1477
Mean-SD	JS 95- 60, JS 93- 05, JS 335, JS 97- 52, Hara soy, RKS 18, VLS Bhatt 201, JS 20- 34, NRC 37, JS 20-29, MAUS 2, PS 1347, Pusa 97- 12, Him soy, GJS 3, SL 525, RKS 45, SK 744, Ankur, DSb 19, PS 1092, BSS 2, PS 1225, PS 1042, RVS 24, MACS 1460, Pusa 12, PS 1368, NRC 86, Bragg, Palam soy, RKS 24, JS 20-98, RKS 113, DSb 1, RVS 2002-4, PS 24, Shivalik, JS 20- 69	JS 335, Hara soy, RKS 18, VLS Bhat 201, JS 20-34, NRC 37, JS 20- 29, MAUS 2, PS 1347, Pusa 97- 12, Him soy, GJS 3, SL 525, RKS 45, SL 744, PS 1092,BSS 2, PS 1225, PS 1042, RVS 24, MACS 1460, Pusa 12, PS 1368, NRC 86, Bragg, Palamsoy, RKS 24, JS 20-98, RKS 113, DSb 1, Shivalik, JS 20- 69	JS 95- 60, JS 93- 05, RKS 18, KDS 344, JS 97- 52, JS 20- 34, NRC 37, JS 20- 29, NRC 7, MACS 1188, SL 958, MAUS 81, MAUS 2, PS 1347, GJS 3, SL 525, RKS 45, SL 744, MACS 1281,Basar, KDS 736, MACS 450, PS 1092, BSS 2, MAUS 61 2, PS 1225, PS 1042, RVS 24, MACS 1460, PS 1368, NRC 86, Bragg, Palam soy, RKS 24, JS 20-98, RKS 113, DSb 1, DS 228, RVS 2002-4, RVS 18, PS 24, SL 688, Shivalik, JS 20- 69	JS 95-60, JS 93- 05, RKS 18, JS 97-52, JS 20-34, NRC 7, JS 20-29, NRC 37, MACS 1188, MAUS 81, MAUS 2, PS 1347, GJS 3, RKS 45, MACS 1281, Basar, MACS 450, PS 1092, BSS 2, PS 1225, PS 1042, RVS 24, MACS 1460, PS 1368, Bragg, JS 20- 98, RKS 113, DSb 1, Shivalik, JS 20- 69	JS 95-60, JS 93-05, MAUS 158, Hara soy, MAUS 162, DSb 21,JS 20-34, NRC 37, VLS 65, JS 20-29, NRC 7, MACS 1188, CO 3, MAUS 81, MAUS 2, PS 1347, Basar, MACS 450, PS 1092, BSS 2, MAUS 61 2, PS 1225, PS 1042, Pusa12, PS 1368, Bragg, RKS 24, JS 20 98, RKS 113, JS 20-69, GJS 3, Hara soy, RKS 45, SL 744
Mean + SD	MAUS 158, MAUS 162, VLS 47, VLS 65, MACS 1188, CO3, SL 958, MAUS 81, MACS 1281, Basar, MACS 450, MAUS 61 2, MAUS 71, BSb 228, PS 24, SL 688, PS 23, PS 1477	JS 93 05, MAUS 162, CO3, MAUS 81, Basar, MAUS 61 2, MAUS 71, DSb 228, PS 24, SL 688, PS 23, PS 1477	JS 335, MAUS 158, Hara soy, MAUS 162, VLS 47, DSb 21, CO 3, Pusa 97-12, Him soy, Ankur, DSb 19, Pusa 12, JS 20-69, PS 1477	JS 335, MAUS 158, MAUS 162, VLS 47, DSb 21, KDS 344, CO 3, Pusa 97 12, Him soy, RVS 2001-4, DSb 19, Pusa 12, NRC 86, RVS 2002-4, RVS 18, PS 1477	JS 335, RKS 18, VLS 47, JS 97-52, JS 20-34, VLS 77, VLS 59, Pusa 97-12, RVS 2001-4, SL 525, MACS 1281, RVS 24, NRC 86, Palam soy, DSb 1, RVS 2002-4, RVS 18, PS 24, PS 23
>mean +SD	DSb 21, KDS 344, VLS 63, VLS 77,VLS 59, KDS 736	MAUS 158, VLS 47, DSb 21, KDS 344, VLS 63, VLS 77, VLS 65, VLS 59,MACS 1281, KDS 736, MACS 450	VLS Bhatt 201, VLS 63, VLS 77, VLS 65, VLS 59, MAUS 71, Palam soy	BLS Bhatt 201, VLS 63, VLS 65, VLS 59,VLS 77, MAUS 71, Palam soy	KDS 344, VLS Bhatt 201, VLS 63, SL 958, KDS 736, DSb 19, MACS 1460, PS 24

showed higher variability under IP than FP in terms of gross returns, while in case of net returns10 varieties (JS 335, RKS 18, JS 97 52, PS 1347, GJS 3, SL 525, PS 1042, PS 1368, RKS 24 and DSB 1 showed higher variability under IP as compared to FP.

Break-even yield (BEY) and cost (BEC) and economic performance

The categorization of varieties based on mean (±) standard deviation and less/more than (±) standard deviation, indicated that the maximum number of varieties belonged to the category mean– standard deviation followed by mean + standard deviation in case of BEY, BEC and incremental net returns.

The break-even yield (BEY) varied from 516 (NRC 7) to 1,464 kg per ha (VLS 63) with the mean of 795 kg per ha under IT (Table 4 and 5). The magnitude of difference between maximum and minimum BEY was observed to the tune of 183.72 per cent. However, BEY ranged between 377 (DSb 19) and 1,439 kg per ha (VLS 63) with the average of 698 kg per ha under FP which showed a difference of 281.70 per cent. The BEC ranged between 7.38 (DS 228) to 39.53 Rs per per kg (VLS Bhatt 201) with the mean of 15 kg per ha under IP, while it varied from 7.67 (DS 228) to 57.27 Rs per kg (VLS Bhatt 201) with an average of 17 Rs per kg under FP, which indicated a difference of 435.64 and 646.68 per cent, respectively (Table 3). The BEY of improved soybean varieties was found higher (13.90 %) than the local varieties used under FP. However, the BEC of improved varieties were lower (13.33 %) than the varieties used under FP. Similar variations were also recorded by Dupare *et al*. (2019). The incremental net returns ranged between Rs. 2,510 (SL 688) and Rs. 27,160 per ha (MACS 1460), which indicated a difference of 982.07 per cent (Table 3).The varieties were categorized based on standard deviation (Table 4).

On the basis of above results it could be concluded that the adoption of new soybean varieties along with improved soybean production technologies was found to be helpful in narrowing the yield gap and able to enhanced the income from soybean cultivation.

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Soybean Research 18(1): 87-97 (2020)

Impact of Climate Change on Soybean Cultivation in Malwa and Nimar Region of Madhya Pradesh: Farmers' Perspective

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Received: 13.01.2020; Accepted: 04.03.2020

ABSTRACT

Soybean, a relatively new crop for the farmers of Central India, has established itself as a major kharif crop and is commercially grown by the farmers since last five decades starting from 1970s. The crop, predominantly grown by small and marginal famers, has seen remarkable increase in area and production so far. The largest producer of soybean in India, soy state Madhya Pradesh alone is contributing nearly 56 per cent area and production in the country. But national productivity of soybean is hovering around 1,000 kg per ha since last decade. The reasons are being the climatic adversities as the crop is grown under rainfed conditions. The studies conducted in the past have also indicated changes in weather parameters including regular events of long dry spell and incidence of pest and disease complexes. In this background, a study was conducted to know the farmers perception about the climate change in the area and its relative impact on soybean yield levels. The data for the study was collected from 280 farmers belonging to six villages of three districts, namely Indore, Dewas and Dhar representing Malwa and Nimar Plateau using random sampling technique. The sample size of respondents included 60 farmers belonging to four villages from Indore as well as Dewas and 40 from two villages of Dhar district. The information was collected from these farmers using structured interview schedule containing decade-wise data on their perception of changes in soybean yield in the corresponding climatic situation. The results of the study revealed that the farmers are concerned about the changes in prevailing climate particularly delayed arrival and uneven distribution of monsoon, long dry spell as well as increased temperature during the crop growth period. They also perceived that the yield of soybean was affected due to delayed sowing, poor germination and establishment of the crop resulting in less podding, increased cost of cultivation on account of increased incidences of pest and diseases. More than 40 per cent farmers also perceived that the yield losses due to climatic adversities were even up to 50 per cent during the last two decades in spite of following management practices. The results also indicated that there has been a declining trend in yield for in the farmers who used to achieve more than 2,000 kg per ha. In order to mitigate the impact of adverse climate, the strategies involved are change in cropping pattern, preference for short duration and pest and diseases resistant varieties, planting of soybean on altered land configuration (BBF and/or Ridge andFurrow systems) and taking benefits of crop insurance scheme.

Key words: Climate change, farmers' perception, Madhya Pradesh, soybean

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Climatic variability and climate change poses formidable challenge on agricultural sector globally, particularly in developing countries, as the agricultural sector is most vulnerable to climate change which is supporting large proportion of population. The negative impact of climate change on agricultural sector and crop productivity has been reported by earlier studies globally (Vermeulen *et al*., 2012; Field *et al*., 2012; Stocker *et al*., 2013, Lobell *et al*., 2011; Bates *et al*., 2010; Thornton and Gerber, 2010) as well as in India (Kumar and Parikh, 2001; Mall *et al*., 2006; Zacharias *et al*., 2014; Yadav *et al*., 2016, Bal and Minhas, 2017; Singh *et al*., 2019). Cline (2007) projected that the agricultural productivity for the entire world is going to decline between 3 and 16 per cent by 2080 and the sharp concentration of losses in the developing countries. Vermeulen (2014) reported that climate change poses a serious threat to food access to rural as well as urban populations by way of reducing agricultural incomes, increasing risks and disrupting markets. Lobell and Gourdji (2012) estimated that without adaptation and mitigation strategies, climate change is likely to reduce world food levels by about 1.5 per cent per decade. The impact of climate change on soybean productivity in India was reported by Lal *et al.* (1999); Mall *et al.* (2004 and 2006) and Mohanty *et al.* (2017).

Soybean, a vehicle of socio-economic transformation for millions of small and marginal farmers of central India (Dupare *et al*., 2009; Sharma *et al*., 2016), is being commercially cultivated by the farmers since last 5 decades. During this period the crop has scripted resounding history of increase in area and production in the country from merely 30,000 hectares in 1970-71 to more than 11.6 million ha during 2018-19. However, the average productivity of soybean in India although, improved from 426 kg per ha during early 1970 to 1,219 kg per ha in 2016-17 (Anonymous, 2017), is stagnated at around 1,000 kg per ha since last few years and is a matter of concern. The increase in soybean yield has come mostly through improvement in harvest index, increased biomass, high number of pods per plant, and increased seed-filling duration (Agarwal *et al*., 2013). Most of Indian soybean varieties have yield potential of 2,500–3,500 kg per ha, while some can yield up to 4,000 kg per ha. Since, the crop is grown mainly under rainfed conditions, extreme variability in the duration, time and quantity of rains exposes the soybean crop to soil moisture deficit as well as excess moisture (Sharma *et al.,* 2019). The delayed monsoon, longer dry spells or early withdrawal of monsoon have been identified as major constraints for poor performance of the soybean crop (Dupare *et al*., 2017; Tiwari, 2014; Sharma *et al.* 2018). In last 10 years, there is a shift in the peak rainfall from July to August, and the total rainfall during the peak month was reduced (Ramteke *et al*., 2015). The rainfall during the emergence and vegetative growth of the soybean crop has been reduced. Earlier studies explicitly indicated that increase in temperature is most likely to significantly reduce the soybean grain yield due to accelerated growth and effect on rate and duration of grain filling (Lal *et al*., 1999; Mall *et al*., 2004; Mohanty *et al*., 2017). The prolonged dry spells during monsoon season led acute water stress (Lal *et al*., 1999; Mohanty *et al*., 2017) or heavy rainfall could be the critical factors for the soybean productivity.

The climatic variation have been noticed particularly by the incidences of delayed onset of monsoon, prolonged dry spells during the crop growth stages coupled with high intensity rains for short period, early cessation of monsoon and sometime damage to the crop produce during maturity period of soybean (Dupare *et al*., 2017). The negative effects of climate change can be ameliorated to certain extent through adaptation measures ranging from changes in production practices to transformative shifts in farming practices. Adaptation as defined by IPCC is "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2014). In this background, it is necessary to understand the perception of farmers and their adaptation to the changing climate scenario. They need to make aware about the adaptive strategies considering different socio-economic, situational, technological and environmental factors.

MATERIAL AND METHODS

The study was conducted in three districts of Madhya Pradesh, namely Indore, Dewas and Dhar located in *Malwa* and *Nimar* Plateau, where the golden crop of soybean is commercially grown since last 5 decades. These districts are very popular for soybean cultivation as the crop covers more than 95 per cent of the cropped area under *kharif* season. The data was collected from randomly selected 280 farmers (*60 farmers belonging to four villages from Indore as well as Dewas and 40 from two villages of Dhar district),* for which sample were drawn from 6 villages using structured and pre-tested interview schedule. The response of farmers on season-wise crops grown, pattern of arrival of monsoon and its distribution, receipt of total rainfall, prevailing temperature, humidity and sunlight/photoperiod along with changes in agricultural practices like sowing method, sowing time, crop duration, insect/disease load, weed infestation and the strategies followed by the farmers for their management, yield losses and soybean yield during the period 1960-2010 were recorded decade-wise along with some open ended questions related to the farmers' experience and their opinion about the prevailing climatic situation as well as its impact on crops. After the data collection, the entire interview schedules were coded and the responses of farmers were computed. For some parameters, the qualitative data have been converted into quantifiable data. The quantitative data were tabulated and analyzed after applying statistical tools like percentage, mean, and standard deviation.

RESULTS AND DISCUSSION

Farmers' perception of prominent changes in various attributes of climate

When asked to enlist most prominent changes occurred in climatic parameters during the period of last 60 years (Table 1), majority of the farmers (97 %) reported a shift of monsoonic pattern (both its arrival time and its distribution during the crop season). According to them, the distribution of monsoon in their area during the last 10 years has mostly been erratic/scanty. Further they are experiencing the long dry spells more often during the *kharif* season affecting the crop growth and thereby yield (92.85 %). The condition become more vulnerable when there is increase in atmospheric temperature during the drought period resulting sometime in soil cracks (Vertisols), which are devastating. Further, 45.71 per cent of the farmers also reported to have observed the soil moisture deficit condition more frequently now days because of long dry spells resulting in short growth of the plants which bears very few/undersized pods. About 25 per cent of the farmers were also of the opinion that in addition to enhanced temperature, there is also a change in relative humidity (decreased) which in turn aggravates the problem of crop management in moisture stress condition. The results clearly suggested that the farmers in the study area are aware of the change in rainfall pattern and temperature during monsoon season.

Table 1. Most prominent changes in climatic parameters during last sixty years

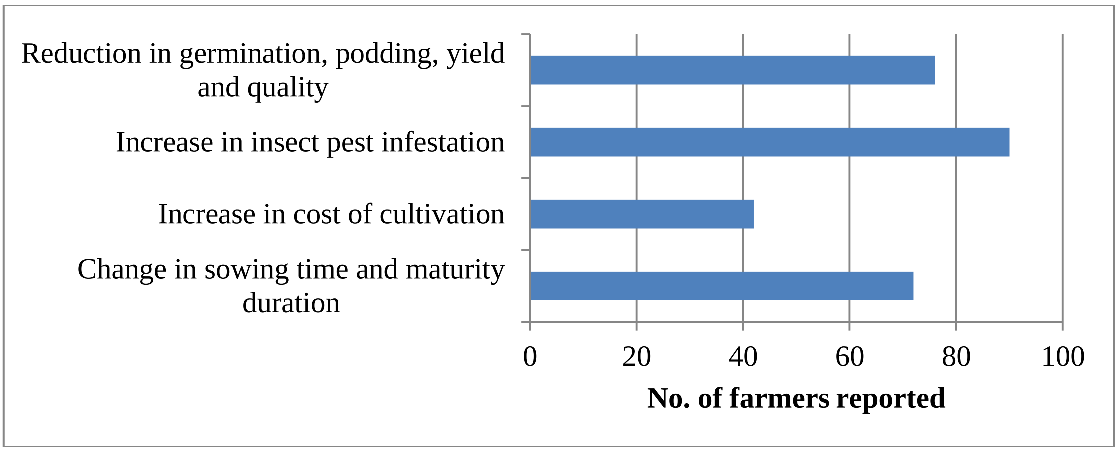
Change	No. of farmers	Per cent
Change in rainfall pattern (Less, uneven and erratic)	272	97.14
Less soil moisture during crop season and cracking in soil	128	45.71
Increase in frequency of long dry spell	174	62.14
Increase in temperature	260	92.85
Change in humidity	70	25.00

The results of farmers perception on climate change corroborates with the actual climate change study by Mishra and Shah (2015) in Madhya Pradesh, which indicated that a significant decline in monsoon season rainfall during the period 1951-2013, significant increase in air temperature in the post-monsoon season and increase in frequency of severe, extreme, and exceptional droughts. Study further indicated that there were severe and wide-spread droughts in the recent years along with significant increase in number of hot days and more frequent number of heat waves in the Madhya Pradesh.

Farmers' perceived impact of climate change on agricultural crops

An effort was made to understand the experience of farmers on the major impact of climatic variation with the overall condition of crop cultivation and its productivity. As has been mentioned, soybean is a major *kharif* crop grown by the farmers in the area; the farmers could relate their experience of perceived impact of climate change on soybean (Fig. 1). Out of 280 sample farmers, majority of them (32.14 %) expressed that the infestation of insect-pests and diseases has increased tremendously, particularly during the last decade. Secondly, the productivity of soybean is also decreased consequent to poor germination and plant stand, less podding, and at times quality of the produce also gets affected with the high rainfall coinciding harvest season. Another 25.71 per cent farmers attributed the impact of climate change to delayed time of sowing as well as use of short duration soybean varieties in order to manage the crop from long dry spells or terminal drought. Rest of the farmers (15 %) have expressed the impact of climate change on increase in cost of cultivation of *kharif* crops due to expenditure on management of insect-pests and diseases, which were found in increasing order. Earlier studies have also indicated that there is significant increase in the share of plant protection chemicals in operational cost of soybean cultivation in all major soybean growing states (Sharma *et al.*, 2015; Sharma, 2016).

Fig. 1. Farmers' perceived impact of climate change on crops and productivity

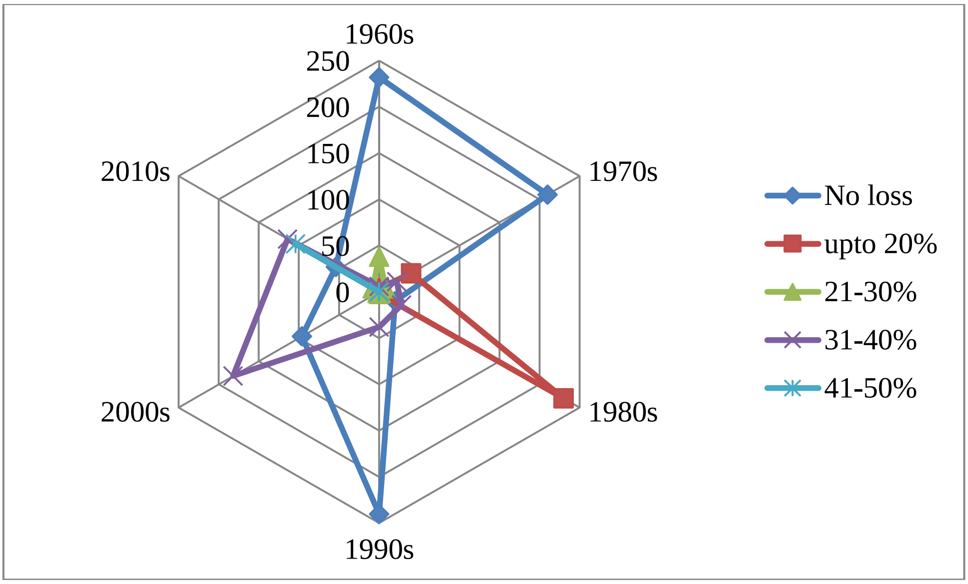


Farmers' perception of extent of yield loss due to climatic adversities

The farmers were asked whether they felt any effect of changing climate for reduction in yield of *kharif* crops. Majority perceived that the adverse climate contributed to about 20 per cent yield loss in their *kharif* crop. But it is astonishing to know that during the decades 2000-2009 of the farmers (Fig. 2) reported that there was no significant yield loss due to adverse climatic conditions during the period of1960s and 1970s. However, During 1980s, majority of farmers (82 %)

and 2010-2019, about 65 per cent and 40 per cent of the farmers felt that the climatic adversities have resulted in about 31-40 per cent yield loss of soybean crop in their area. Further, more than 37 per cent farmers also believed that during the last decade, the yield losses due to climatic adversities could be as high as 40-50 per cent in spite of adoption of recommended production technologies. The results clearly indicated that yield loss in the *kharif* crops due to aberrant weather conditions has increased over the years as perceived by the farmers in the study area.

Fig.2. Perception of yield loss due to adverse weather



Farmers' perception of changes in soybean yield during last 40 years

As the soybean crop became more popular among the farmers from 1980 onwards, majority of the farmers could reply to yield data of soybean only for the subsequent period and the same data (Table 2) was considered for the present study. As very few farmers initially started growing this crop, those who were cultivating soybean crop before eighties said that the yield of soybean in its primitive period (sixties and seventies) was very less (sometime less than 500 kg/ha). It was observed that in subsequent forty years there has been substantial increase in yield of soybean (Table 2). As responded by the sample farmers on the yield levels achieved, majority of the farmers harvested around 2,100-3,000 kg per ha soybean (61 %, 74 % and 64 % during 1980s, 1990s, and 2000s, respectively). However, the number of farmers getting average soybean yield of about 600-1,000 kg per ha showed a gradual decline. Similarly, the percentage of farmers who harvested around 1,100-2,000 kg per ha during 1980s and 1990s showed declination with the corresponding increase in higher yield category of 2,100-3,000 kg per ha and >3,000 kg per ha. The increase in yield of soybean was possible because of the release and adoption of short duration high yielding varieties, varieties resistant to biotic and abiotic stresses, climate smart agronomic practices and farm machines for soil moisture conservation.

The average productivity of soybean during the last decade (2010s) showed a decline for majority of the farmers (only 25 % farmers with the productivity of 2,100-3,000 kg/ha and 75 per cent farmers with only 1,000-2,000 kg/ha). Furthermore, same trend was also seen in case of those farmers who achieved productivity levels of >3,000 kg per ha (12% during 1980s to only 1 % during 2010). The reduction in productivity of soybean during the recent decade could be attributed to effect of adverse climatic conditions which the farmers have encountered during last 20 years particularly related to increase in atmospheric temperature, reduction in atmospheric humidity, increased sunny days with less and erratic monsoon distribution coupled with decrease in total rainfall. Kawadia and Tiwari (2017) while studying the perception of the farmers about the climate change in Madhya Pradesh also found that 70 per cent of them identified significant decrease in crop yield due to climate change.

Table 2. Soybean yield (kg/ha) over the period

Range	1980	1990	2000	2010
< 500	-	-	-	-
600-1000	10 (3.57)	18 (6.43)	8 (2.86)	2 (0.71)
1100-2000	64 (22.86)	48 (17.24)	92 (32.86)	210 (75.00)
2100-3000	170 (60.71)	206 (73.57)	178 (63.57)	64 (22.86)
>3000	36 (12.86)	8 (2.86)	2 (0.71)	4 (1.43)

Adaptation strategies followed by the farmers for perceived climate change

When asked about the adaptation and mitigation strategies followed by them to overcome climatic adversities, the farmers have outlined changes mostly in the cropping pattern, varietal diversification, and crop management practices for biotic factors. About two third of the respondents (75.71 %) reported that they have started adoption of short duration soybean varieties as the best strategy to overcome the terminal drought which frequently occurs in the region since last few years. Similarly, more than 60 per cent farmers were found preferring cultivation of varieties resistant to pest and diseases. According to them, the trend of insect-pest-disease infestation now-a-days has got increased as compared to initial period of soybean cultivation. Interestingly, about 48 per cent farmers opined that their cost of crop cultivation has increased with the increase in cost of application of plant protection chemicals for saving the crop from biotic problems particularly weed, insect-pest and diseases. About one forth of the respondents (24.28 %) have agreed that they have changed in the sowing time of soybean as an adaptation strategy whereas few farmers (17.85 %) have emphasized upon availing the benefits of crop insurance scheme, use of newly developed farm equipments like BBF/FIRB seed drills in order to escape the risk associated with severe drought during the crop season whereas few farmers (9.28 %) have agreed for creation of irrigation facilities facilitating the need based irrigation in adverse climatic situation (Table 3). Ramteke *et al*. (2015) and Billore *et al*. (2018) also reported the adaptation option such as delay in sowing, adoption of short duration and disease-insect resistant varieties, for farmers in order to minimize the impact of climate change. Sharma *et al.* (2019) reported that the adoption of BBF for sowing of soybean has increased soybean yield and net income of farmers.

Table 3. Adaptation strategies followed by the farmers to cope up with the climate change

Adaptation strategies	No. of farmers	Per cent
Change in cropping systems	82	29.28
Change of seed/Resistant Varieties	170	60.71
Shift toward short duration crop	70	25.00
Increased use of chemicals for management of insect, diseases and weeds	134	47.85
Change in sowing time	68	24.28
Short duration varieties	212	75.71
Increased use of FYM	30	10.71
Intercropping with soybean	4	1.42
Irrigation facilities created	26	9.28
Mechanization followed	30	10.71
Crop insurance	50	17.85

Soybean is a rainfed crop dependent primarily on seasonal monsoon. The farmers of the study area during the last few years have experienced adverse climatic conditions particularly the delayed, erratic and uneven distribution of rainfall, increased chances of long dry spell and increase in atmospheric temperature during the soybean crop season which affected the yield losses. They have followed several adaptation mechanisms in order to maintain soybean yield levels. Use of farm machineries such as BBF/FIRB seed drills along with other changes in management practices particularly forinsect-pest and diseases to some extent has helped them to address the problem. However, more efforts should be taken to develop climate resilient varieties as well as technologies considering the prevailing climate factors. Concerted efforts are also needed for popularization of location specific technologies and practices for their adoption among the farming community.

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Soybean Research 18(1): 98-103 (2020)

NRC 127: First Kunitz Trypsin Inhibitor Free Indian Soybean Variety Developed through Marker Assisted Backcrossing

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Received: 10.01.2020; Accepted: 17.02.2020

Key words: Kunitz trypsin inhibitor, simple sequence repeat marker, soybean

Soy-food, which has been the exclusive preserve of China, Korea, Japan and some of the South-East Asian countries for the last several centuries, has drawn the attention of health-conscious people across the globe due to its high protein content (40%) and the other nutritional/nutraceutical molecules, that combat malnutrition and life-style diseases, as reviewed in several studies (Kumar *et al*., 2010, Messina, 2016). Paradoxically, presence of antinutritional factor trypsin inhibitor, which is proteinaceous in nature, in seed affects protein digestibility, thereby constraining its utilization in food uses. Even the use of deoiled soymeal, obtained after extraction of oil, as animal feed for non-ruminants is traded with the caveat of maximum limit of trypsin inhibitor activity. Though, trypsin inhibitoris present in several legumes, however, its concentration in soybean is very high. Trypsin inhibitor activity in soybean is attributed to the two polypeptides: Kunitz trypsin inhibitor (KTI) and Bowman Birk inhibitor. It is the former polypeptide (21 kDa), consisting of 181 amino acids with 2 disulfide linkages, which has detrimental effects on human health, while the latter having 71 amino acids polypeptide chain with 7 disulfide linkagesis being recognized more as nutraceutical molecule due to its anticancer properties. Presence of less number of disulphide linkages in KTI polypeptide renders it heat-labile, but the insufficient heat treatment may leave KTI active in the final products (Kumar *et al*., 2018). Therefore, its genetic elimination from the seed would benefit both soy food processing industries and soy-feed manufacturing industries. In India, the easiest mode for availing health benefits of soybean is through fortifying *chapatti*-making wheat flour with soy-flour. For this purpose, soybean is recommended to be boiled for 20 min, dried and mixed with wheat in the ratio of 1:9 to prepare soy fortified flour, which is a time consuming process.

Kunitz trypsin inhibitor free soybean grains would obviate the need of the boiling treatment in soy-food processing units. Availability of KTI free

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soybean grains as raw material would reduce the cost incurred in bringing the trypsin inhibitor activity in soy-meal within the limits of international compliance. KTI ismonogenic trait and governed by co-dominant multiple alleles , namely , *Ti*^{a} , *Ti*^{b} , *Ti*^{c} and *Ti*^{d}), while the fifth form lacking Kunitz trypsin inhibitor activity is controlled by a recessive allele *ti*. Linkage group (LG) A2, corresponding to chromosome 8, has been reported to carry this gene (Cregan*et al.,* 1999). Plant breeding programme to develop much sought-after KTI free specialty soybean has been initiated in several soybean growing countries across the globe (Rani *et al.*, 2011; Carpentieri-pipolo, 2015; Bulatova *et al.*, 2019). In India, hitherto, all the soybean varieties released for cultivation are Kunitz trypsin inhibitor positive, and the contribution of KTI to the total trypsin inhibitor activity in soybean is genotype-dependent (Kumar *et al.*, 2019). KTI free soybean genotypes NRC 101 and NRC 102 have been developed through marker assisted forward breeding. Marker assisted backcrossing (MABC) was deployed to introgress null allele of KTI in elite Indian soybean varieties. NRC 127 is the first KTI free soybean variety developed through this approach by introgressing null allele of

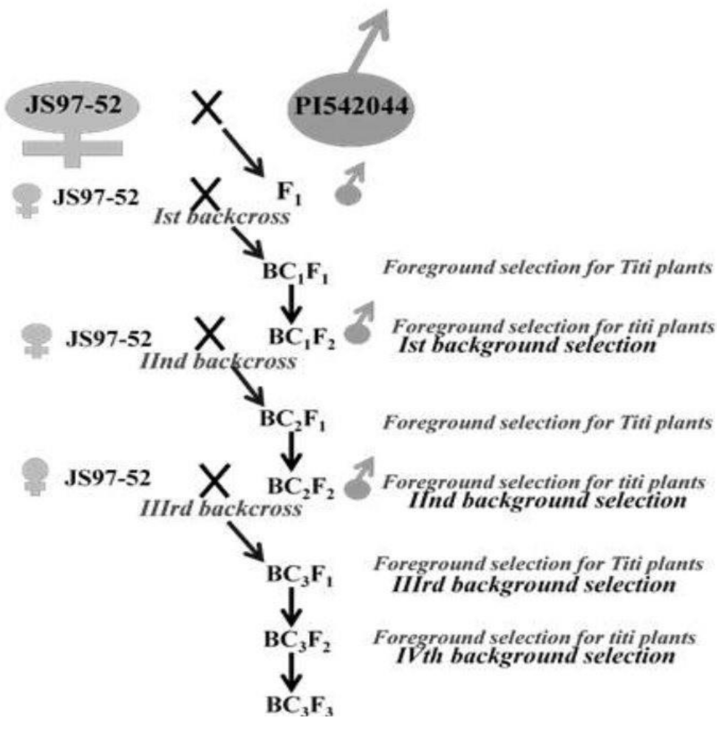

Fig. 1. Schematic diagram of backcrossing for introgression of null allele of Kunitz trypsin inhibitor in JS97-52

KTI in JS 97-52. The detailed backcrossing plan is given in Fig. 1. JS 97-52 was crossed with PI542044 to obtain F_1 plants, which were backcrossed to obtain BC_1F_1. As the size of BC_1F_1 generation was small, true BC_1F_1 were selfed to obtain BC_1F_2. Plants homozygous recessive (titi) for KTi were backcrossed to obtain BC_2F_1, which were selfed to increase the population size. The selected BC_2F_2 plants homozygous recessive for KTi were backcrossed to obtain BC_3F_1 plants, which were selfed and selection was made for the homozygous recessive (titi) plants.

JS 97-52 is a released variety from JNKVV, Jabalpur and has been found to be tolerant to water-logging and resistant to multiple diseases. PI542044 is a Kunitz trypsin inhibitor free germplasm accession developed from the cross William 82 x PI157440 at Illinois Agricultural Experimentation Station and United States Department of Agriculture-ARS, and is an isogenic line of William 82. This accession was obtained through ICAR-National Bureau of Plant Genetic Resources, New Delhi. DNA was extracted through the standard protocol (Doyle and Doyle, 1990). Genotyping using SSR markers across the genome for the recipient variety JS97-52 and the donor parent PI542044 revealed 45.9 per cent polymorphism for this parental combination (Kumar *et al.*, 2011). Null allele specific marker was used for identification of F_1 plants and this molecular marker in tandem with the *Ti* locus linked Satt228 simple sequence repeat (SSR) marker, was deployed for the foreground selection as reported in the earlier studies **(**Rani *et al.*, 2011**,** Kumar *et al.*, 2013**)**. Null allele specific marker used for the foreground selection was originally designed by de Moraes *et al.* (2006) from PI157440. PCR amplification was carried out as described elsewhere (Rani *et al.*, 2011). The representative gel is presented in Fig. 2, which showed the amplicon (420 bp) generated by null allele Kunitz trypsin inhibitor specific marker in the plants carrying null allele of Kunitz trypsin inhibitor in both heterozygous (Titi) and homozygous recessive plants (titi). To identify homozygous recessive (titi) plants, Satt228 was deployed which generated amplicon of 220 and 200 bp for JS 97-52 and PI542044, respectively. For assessing the recovery of genome of JS97-52,113 polymorphic SSR markers (for the parental combination JS 97-52 × PI542044) across the genome were surveyed in NRC 127, JS 97-52 and PI542044. A representative gel of background selection is given in **Fig. 3**, which shows the amplicon generated by the SSR markers, namely, Satt416(LG B2), Satt496(LG I), Satt281(LG C2), Sat_043(LG K), Sat_331(LG B1), Sat_298(LG D2), Satt375(LG K), Sat_218(LG H), Satt278(LG L), and Satt539(LG K) on different linkage groups. NRC 127 inherited110 SSR loci from the recurrent parent (JS 97-52), with 96.5 per cent recurrent parent genome content, with null allele of KTI from the donor PI542044, thereby fall into the category of essentially derived variety (EDV).

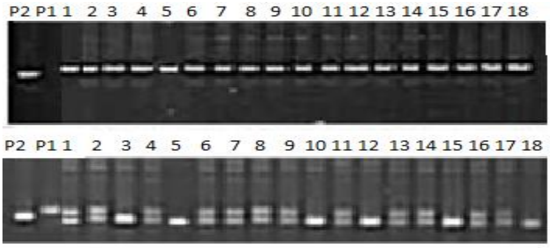

Fig. 2. Representative profile of foreground selection carried out in BC3F2 (heterozygotes and homozygote recessives) using gene specific marker (420 bp) (Upper panel) in tandem with linked SSR marker Satt228. Lanes P1 and P2 correspond to JS 97-52 (220 bp) and PI542044 (200 bp), respectively

NRC 127 is distinguishable from the parent variety JS 97-52 for the absence of Kunitz trypsin inhibitor (21kDa protein). Fig. 4 depicts the absence of Kunitz trypsin inhibitor polypeptide (21 kDa) in NRC 127, in contrast to its presence in the original variety JS 97-52 as confirmed through native polyacrylamide gel electrophoresis (10%) PAGE. Enzyme linked immunosorbent (ELISA) assay performed using Kunitz trypsin inhibitor polyclonal primary antibody and secondary alkaline phosphatase anti-rabbit antibody as described elsewhere (Kumar *et al.,* 2018) also showed the absence of immune reaction and hence the absence of Kunitz trypsin inhibitor in NRC 127. The variety bears multiple branching, white flowers, and its plants attain maturity in 102 days (Fig. 5). The planting of this variety is recommended at the seed rate of 50 kg per ha in row-to-row distance of 45 cm and plant-to-plant distance of 5 cm. Under All India Research Project on Soybean, average yield of NRC 127 was 1,807 kg per ha which was 4 per cent higher than the yield of the original variety (1,733 kg per ha) in Central zone, though the genetic potential for the yield was 3,200 kg per ha (AICRPS, 2018). Average protein content of this variety is 39.0 per cent while average oil content is 19.1 per cent on dry weight basis. NRC 127 was found to possess resistance against yellow mosaic virus, alternaria leaf spot (ALS), target leaf spot (TLS), soybean crinkle virus (SCV) and bacterial pustule and was identified as potential donor for resistance/tolerance against pest complex, pod borer and lepidopteran defoliators (AICRPS, 2018). It has been released by Central Varietal Release Committee for the cultivation in

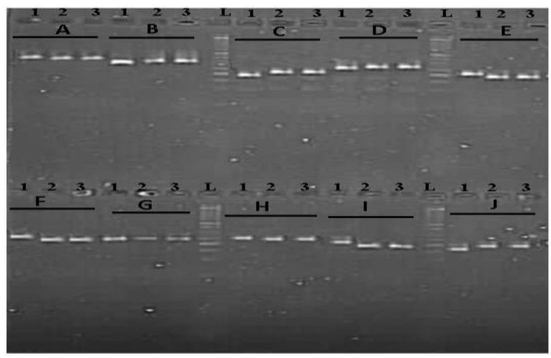

Fig. 3. Representative gel depicting comparative amplicon profiling of NRC 127 with original variety JS 97-52 and donor parent PI542044 through selected SSR markers A. Satt416 (LG B2), B. Satt496 (LG I), C. Satt281 (LG C2), D. Sat_043 (LG K), E. Sat_331 (LG B1), F. Sat_298 (LG D2), G. Satt375 (LG K), H. Sat_218 (LG H), I. Satt278 (LG L), J. Satt539 (LG K); where lane 1 -PI542044, lane 2- NRC127, lane3- JS 97-52 and L-50 bp DNA ladder

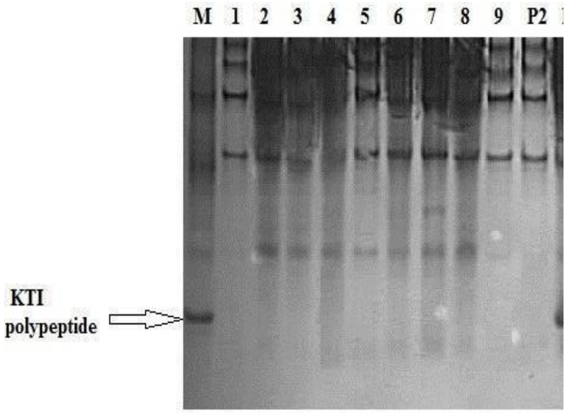

Fig. 4. Confirmation for the absence of KTI polypeptide in NRC 127 seeds (Lanes 1-9) developed from JS 97-52 × PI 542044 on 10% PAGE. P1, P2 and M denote JS 97-52“ (KTI +ve) and PI542044 (KTI –ve) and standard for KTI polypeptide, respectively

Fig. 5. NRC 127 plant at maturity

the state of Madhya Pradesh, Bundelkhund region of Uttar Pradesh, Rajasthan, Gujarat, and Marathwada and Vidharbha regions of Maharashtra. National Identity number of this variety is IC625905. NRC 127 being free from Kunitz trypsin inhibitor has the potential to boost the utilization of soybean in food uses in the country to ensure nutritional security of the masses. Besides, this variety would serve an excellent raw material for the organic soy-feed manufacturers, who have to extract the oil from the regular soybean through mechanical extruders, leaving trypsin inhibitor activity in the meal to a level, which is higher than the international trading norm.

Acknowledgement

The authors acknowledge the financial grant (Sanction No BT/PR11691/AGR/02/639) received from Department of Biotechnology, Ministry of Science and Technology, Government of India. NRC 127 has been released as essentially derived variety (EDV) of JS 97-52. Dr A N Srivastava, the breeder of JS 97-52 has been credited as co-developer of NRC 127.

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LIABILITIES	AMOUNT	ASSETS	AMOUNT
Capital Fund		**Fixed Assets**	
Opening Balance	4,872,468	Computer & Printer	41
Add : Life Membership	14,000	Less :- Depreciation	16
Add : Surplus of the year	510,011		25
	5,396,479		
		Furniture & Fixture	10,909
		Less :- Depreciation	1,091
			9,818
		Investments	
		Fixed Deposit	991,932
		Mutual Fund	4,217,310
		(in Canara Bank)	
		Current Assets	
		TDS Recievable	6,930
		Bank Balance - Canara Bank	170,464
TOTAL `	**5,396,479**	**TOTAL** `	**5,396,479**

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED ON 31.03.2020

EXPENDITURE	AMOUNT	INCOME	AMOUNT
Printing of Soybean Research	52,920	Membership Fees	7,500
Web Designing Expenes	7,750	Sale of Publications	250
Legal & Professional Fees	5,000	Interest Received	
		- On Fixed Deposit	75,866
TDS	69,398	- On Saving Account	5,260
Depreciation	1,107	Income from Mutual Fund	557,310
Excess of Income over Expenditure	510,011		
TOTAL `	**646,186**	**TOTAL** `	**646,186**

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