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Addressing Climate Change Impact on Soybean through Resilient Technology

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ABSTRACT

Many studies projected impact of climate change on agriculture in general and with reference to soybean in India in particular. However, the projections may arguably be too general to understand the magnitude of impact and to make aware adaptation strategies tailored to promoting climate smart agriculture among soybean growers of the country. This paper was synthesized from several scholarly literature aimed at providing up-to-date information on climate change impacts, adaptation strategies and its related issues in soybean crop. With the growing climate change risk, development and adoption of climate-smart practices to improve resilience of soybean farming systems and livelihoods of soybean growers is inevitable. The climate resilient soybean production technologies includes efficient conservation and use of natural resources like soil, water and energy, genetic and crop diversity, reduced/ conservation tillage, integrated crop management techniques, use of microorganisms, crop residue management, managing sowing window, scouting for insect, pathogen and weeds, agro-forestry, use of ITKs, management of degraded land, capacity building and effective weather forecasting system etc. *are enabling the farmers to minimize the risk of climatic adversities.*

Key words: Adaptation, climate change, climate smart, soybean

More than 60 per cent of the world's food comes from rainfed farms that cover 80 per cent of the lands. Of the total net sown area in India, about 60 per cent comes under rainfed lands. About 48 per cent area under food crops and 68 per cent under non-food crops is rainfed. The importance of the rainfed agriculture can be gauged from the fact that it contributes to 40 per cent of the country's food production; accounts for much of the national area under coarse cereals (85 %), pulses (83 %), oilseeds (70 %) and cotton (65 %); and holds 60 per cent of the total livestock populations (Venkateswarlu and Prasad, 2012).

The climate change is affecting almost all sectors and systems. However, agriculture sector is most vulnerable to it and the impact is likely to be a great threat to the food and livelihood security of the world, in general, and that of

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India, in particular as rainfed farming is mainstay of the large number of farmers. Climate change has been reported to have a significant and generally negative impact on agriculture and growth prospects in the lower latitudes (Vermeulen *et al*., 2012; Field *et al*., 2012; Stocker *et al*., 2013). As a result of climatic change, an estimated reduction in productivity of two major staple crops (maize and wheat) globally amounts to 3.8 and 5.5 per cent after 1980 (Lobell *et al*., 2011). Bates *et al*. (2010) predicted that by 2050, climate-related increases in water stress are expected to affect land as twice the size of those areas that will experience decreased water stress. Increased climate variability in the coming decades is likely to increase the frequency and severity of floods and droughts, and will increase production risks for both, farmers as well as livestock keepers and reduce their coping ability (Thornton and Gerber, 2010). In the past decades, consistent warming trends and more frequent and intense extreme weather events have been experienced across Asia and the Pacific. Ongoing climate change poses a serious threat to food access for rural and urban populations, by way of reducing agricultural incomes, increasing risk and disrupting markets (Vermeulen, 2014). Resource-poor producers, landless and marginalized ethnic groups are at a particular risk. Vermeulen *et al.* (2012) also reported that the food systems contribute significantly to global warming and are responsible for 19–29 per cent of global emissions, the bulk of which come directly from agricultural production activities (*i.e.* N_2O and CH_4) and indirectly from land cover change driven by agriculture CO_2. As a result of global warming phenomenon, it is projected that overall global productivity of crops may decline between 3 and 16 per cent by 2080. Most of the developing countries, particularly those with average temperature near or above crop tolerance levels, are predicted to suffer an average 10 to 25 per cent decline in agricultural productivity in the 2080s. To a certain extent these negative impacts can be ameliorated through adaptation, ranging from relatively minor changes in production practices to major, transformative shifts in farming and food systems.

Impact of climate change on soybean productivity

Although, soybean exhibited phenomenal growth in area and production in nearly past five decades, the average productivity of soybean is hovering around 1,000 kg per ha due to several abiotic, biotic and socio-economic factors (Paroda, 1999; Joshi and Bhatia, 2003; Bhatnagar and Joshi, 2004; Tiwari, 2014).

In India, rainfed regions cover 177 districts and exist in all agro-climatic regions, but are mostly concentrated in the arid and semi-arid areas. Most of these districts are the country's poorest. Rainfed cultivation accounts for 68 per cent of the total net sown area in the country. An assessment done by S M Jharwal, Principal Advisor to the Government of India brought out that even if we extend full irrigation potential of 140 million ha, about 85 million ha would still remain rainfed. However, during 1993-94 and 2003-04, the rainfed area declined from 90.88 million ha to 85.78 million ha.

Analyzing the data over years under different climatic conditions, Bhatia *et al*. (2008) has reported that the average water non-limiting potential yield of soybean was 3,020 kg per ha, while the water limiting potential was 2,170 kg per ha; a 28 per cent reduction in yield due to adverse soil moisture conditions. The study provides the silver lining that the existing national yield levels can be doubled under real farm conditions even under rainfed cultivation with adoption of research emanated production technology. If the area under irrigation can be increased, there is further scope to optimize the yield levels of soybean.

Future climatic change is likely to have substantial impact on soybean production depending upon the magnitude of variation in atmospheric CO_2 and temperature. Studies indicated that increase in temperature is likely to reduce the grain yield significantly due to accelerated growth and affect rate or duration of grain filling (Seddigh and Joliff, 1984a,b; Baker *et al*., 1989; Adams *et al*., 1990; Sinclair and Rawlins, 1993; Haskett *et al*., 1997; Lal *et al*., 1999).

Soybean seed yield and yield components have been reported to be affected by temperature and enhanced CO_2 concentration in the atmosphere. Although, increase in CO_2 concentration is likely to increase the soybean yield, but rise in surface air temperature coupled with doubling of CO_2 concentration may decrease soybean seed yield in the range of 10-20 per cent (Mall *et al*., 2004) irrespective of varieties grown. At about 30^0C the yield components not significantly affected, but further rise in temperature to 35^0C may lead to negative and significant reduction between R1 and R2, and R1 and R5, growth stages. Study further indicated that bold seeded genotypes were found more prone to deterioration at higher temperature as indicated by yield components as compared to small seeded ones. Less sensitiveness of small seeded varieties to high temperature can serve as a trait to select temperature tolerant soybean genotypes at elevated temperature conditions (Puteh *et al*., 2013) and also in breeding programme to develop newer varieties. Thanacharoenchanaphas and Rugchati (2011) reported that unfavorable environmental conditions (temperature and rainfall variability) during the reproductive growth stage can reduce seed yield of soybean. The rise in day/night temperature between 18/12 (day/night) and 26/20°C normally leads to increased seed yield of soybean, but decreased beyond this (Sionit *et al*., 1987). Dornobos and Mullen (1991) also indicated that the seed yield of soybean decreased significantly when day/night temperature rise from 29/20 to 34/20°C during seed filling stage. However, other reports (Huxley *et al*., 1976; Sionit *et al*., 1987; Baker *et al*., 1989) in the past revealed that the yield component seeds per pod remained least affected by temperature. Hike in temperature by 0.4°C and 0.7°C in soybean canopy air and soil temperature resulted in advancement of anthesis stage by 3.8 days and shortening of the length of entire growth stage by 4.5 days. Warming is also coupled with decreased leaf photosynthetic rate by 6.6 per cent at anthesis and 10.3 per cent at seed fill stage, but increased the leaf vapor pressure deficit by 9.4 per cent at anthesis, 15.7 per cent at pod setting, and 14.1 per cent at seed fill stage. The leaf soluble sugar and starch were decreased by 25.6 per cent and 20.5 per cent, respectively, whereas stem soluble sugar was reduced by 12.2 per cent at the anthesis stage under experimental warming. At the same time under warming, the transportation amount of leaf soluble sugar and contribution rate of transportation amount to seed weight were reduced by 58.2 per cent and 7.7 per cent, respectively. Cumulative effect of above led to significant reduction of 100 seed weight and seed yield 20.8 per cent and 45.0 per cent, respectively (Zhang *et al*., 2016).

Climate smart agriculture (CSA)

To mitigate the impact of climate change on crop performance, it is advocated to resort to climate smart agriculture (CSA) with its major components, namely crop diversification, conservation agriculture, mulching, intercropping, crop rotation, integrated crop-livestock management, agro-forestry, improved grazing, improved water management, and effective use of soil microbial consortium and innovative practices better weather forecasting, early warning systems and risk insurance. Two pronged approach at macro- and micro-level may make it feasible to adopt CSA. Macro-level approach envisages the creation of enabling policy environment for adaptation. Micro-level approach encompasses the availability of the shelf technologies for farmers and the development of novel technologies like drought/thermo tolerant crops to meet the demands of the changing climate. Resorting to sustainable intensification through CSA is with the objective to optimize yield from a unit area to meet present requirement within the current resources, preferably conserving the resources needed for the future production of crops.

Two basic measures, which are essential to lessen the adverse impacts of climate change are: (i) practicing mitigation (reducing causes of climate change) by reducing emission of greenhouse gases (GHGs) from the source, substitution and conservation of energy, improving carbon sequestration, *etc.* and (2) practicing potential adaptation measures (reducing the impacts of climate change). Important examples of adaptations are; (a) reducing vulnerability (degree of susceptibility of a system to a certain damage) focusing on coping strategies and practices to become beneficial by using opportunities associated to climate change by external forces to develop the ability of resilience (increasing tackling capacity of the community and sectors to reduce risk and damages); (b) improving productivity in terms of quality and quantity through adjusting different growth factors and resolving effects of (management of pathogens, extreme events and associated problems weeds and insect and pests); (c) minimizing the cause and effects through research to identify the responses of plant species to different variable climate conditions, and prior prediction of uncertain climate and propagation of adoptable technology; and restoration of biodiversity to minimize the degradation of natural resources.

Adaptation technologies for soybean production

For desired adaptation of technologies, efforts to strengthen adoptive capacity of a eco-system, efforts are necessary to set in resilience through soil, water and plant nutrient management, as well as improved on-farm water storage and irrigation, access to heat/drought/flood/salinity and alkalinity tolerant crop varieties, crop diversification (intercrops/extended cropping systems/mixed cropping in fruits orchards) and capacity building of organizations (research institutions/ extension agencies/private sector) to jointly function to disseminate knowledge and undertake local adaptation planning (Bennett *et al*., 2014). Provision of information on predicted climate for ensuing cropping season and on crop culture aspects like appropriate planting dates, pest and disease management, and water availability are crucial and need to be provided by such organizations. At policy level, the policy makers should ensure availability of crop insurance in case of crop failures. The possible approaches to amicably deal with the climate change impact in soybean are as under.

Minimum tillage

Conventional or excess tillage exposes soil to wind and water erosion, thereby burning of soil organic carbon and making soil less productive. Adoption of minimum tillage for raising of crops will lead to reduced soil compaction, increased/stabilized soil organic matter content, infiltration capacity of soil, and water retention in soil profile, that ultimately results in reduced soil/water erosion and increased drought resilience as reported by past workers (Frye *et al*., 1981; Phillips, 1984; Sprague, 1986). In addition, reduced weed (Standifer and Beste, 1985) and pest problems (Phillips, 1984) by practicing minimum tillage have been reported, which shall check the erosion of soybean productivity. Minimum soil disturbance provides / maintains optimum proportions of respiration gases in the rooting-zone, moderate organic matter oxidation, porosity for water movement, retention and release and limits the re-exposure of weed seeds and their germination (Kassam and Friedrich, 2009). The soybean cultivation under minimum tillage less relied on fossil fuel, means more energy efficient without compromising the yield levels and profitability (Billore *et al.,* 2006a,b, 2009, 2013; Billore, 2014). Farm machinery for reducing tillage practices may be more acceptable to soybean growers to sustain the productivity and deterioration of soil and water resources.

Varietal selection and cafeteria approach

Crop/varietal diversification may serve as a key to mitigate the impact of climate change. Soybean breeders functional in R&D system have laid down special emphasis on development of varieties with drought and thermo-tolerance to meet the future challenges. The early duration cultivars, *viz.*, JS 95-60, JS 20-34, NRC 7 may escape the impact of early cessation of monsoon. Varieties with extended maturity duration and small seeded like JS 97-52 and NRC 37 are suitable for high rainfall regions. Soybean research system has developed and released varieties tolerant/resistant to different biotic and abiotic stresses. The variety JS 97-52 performed very well under normal as well as water logging conditions. Accordingly, planting of more than one variety, suitable for the prevailing situation(s) may serve as insurance against aberrated monsoon.

Use of anti-transpirants

Water loss on account of evapo-transpiration becomes critical under drought conditions. To minimize such losses and enhance water use efficiency, the use of well-known 'anti-transpirants' is advocated. 'Anti-transparent' effect of atmospheric CO_2 enrichment, which is often more strongly expressed in C4 plants than in C3 plants, and that typically allows C4 plants to better cope with water stress (Pospisilova and Catsky, 1999). Studies revealed that spray of anti-transpirants like KNO_3 @ 1 per cent, $MgCO_3$ and Glycerol @ 5 per cent at 15 days after flowering stage were effective to minimize the drought effect on soybean productivity during drought period (Billore, 2017).

Seed treatment

Climate change is likely to favour insurgence of pests of crops. The possible repercussions could be geographical range expansion of existing pests and invasion by new pests, increased damaged potential, increase in life cycles and conversion of minor into major pests and disruption of proportion of crop-pests-beneficial insects' dynamics (Padgham, 2009). The appearance seed-borne and early season diseases and insect-pests may create serious consequences in performance of soybean, if not managed timely. Considering these limitations, there has been a growing interest to develop such management practices/tools which alone or in combination with other practices could bring about a reasonably good degree of reduction of inoculums potential and at the same time ensure the sustainability of the production, cost effectiveness and healthy ecosystem and 'seed treatment' is one of these tools (Kumar, 2012). Seed treatment is like baby care (Heydecker and Coolbear, 1977) and it ranges from a basic dressing to coating and pelleting (ASF, 2010; Dubey, 2011). Seed treatment with biological and chemical agents are effective against primary soil and seed borne infestation of insects and diseases, leading to good establishment of healthy and vigorous plants resulting in better yields. In addition to the management of pests and diseases, the other benefits associated with seed treatment are increased germination per cent, uniform seedling emergence and improved growth. Seed treatment with fungicide like thiram and carbendazim (2:1) @ 3 g per kg seed or *Trichoderma viride* @ 10 g per kg seed ensure optimum germination and plant stands in soybean. Treated seed with thiamethoxam 30 FS @ 10 ml per kg seed or imidachloprid 48 FS @ 1.25 ml per kg seed provides safety against yellow mosaic disease, which is raising major concern in the soybean command area. Healthy seedlings can stand better against adverse climate.

Microbial inoculation

Many microbes in symbiotic relationship with higher plants impart tolerance against abiotic and biotic stresses emerging from climatic aberrations (Rodriguez *et al*., 2004; Read, 1999; Marks and Clay, 1990; Verma *et al*., 1999; Redman *et al*., 2002) and enhance nutrient acquisition (Read, 1999). *Bradyrhizobium japonicum*, PSM (PSB and VAM) and PGPR improve nodulation, N uptake, AM colonization and grain yield in soybean (Sharma *et al*., 2012 and 2016).

PGPR enhance plant growth through mechanisms of (i) imparting tolerance against abiotic stresses; (ii) nutrient fixation for easy uptake by plant; (iii) plant growth regulators; (iv) producing siderophores; (v) producing volatile organic compounds; and (vi) producing chitinase, glucanase, and ACC-deaminase for the prevention of plant diseases (Choudhary *et al*., 2011; García-Fraile *et al*., 2015). However, the mode of action of PGPR varies depending on the type of host plants (Dey *et al*., 2004).

Improving soil health

Good soil health imparts strength to plants against stresses of changing climate. Adoption of established proven technologies, like minimizing tillage (De Gryze *et al*., 2009; Boddey *et al*., 2010), cover crops, crop residues recycling and mulching, including legumes in system as cover crop, planting against slope, cultivation on contour bund and intercropping with trees, applying organic manures, *etc.* improves organic matter (Rosenzweing and Tubiello, 2007), soil fertility, its structure / physical properties, and water holding capacity (Fließbach *et al*., 2007; Mader *et al*., 2002), water infiltration/percolation, nutrients acquisition, microbial population, thereby providing resilience to erratic rainfall (Bot and Benites, 2005; Lal, 2008; Pan *et al*., 2009; Riley *et al*., 2008) and extreme situations of droughts and floods and may also contribute to climate change mitigation through carbon sequestration (Rosenzweing and Tubiello, 2007).

Managing planting time

The late arrival or early cessation of monsoon coupled with intermittent dry spells adversely affects the growing period and ultimately yield levels of soybean. Planting of suitable genotype and shifting the planting date may address these challenges to a certain extent. Shifting planting dates in response to variability in arrival of monsoon has been suggested by Falcon and Naylor (2004) and Tadross *et al*. (2005). In rust prone areas of India (in the vicinity of Krishna river in southern India), early planting (shifting the normal sowing in the month of May) appears to be helpful to escape the impact of this disease on soybean productivity. Resorting to this, the rust infestation during maturity period does not affect performance of the crop.

Efficient water management (In-situ moisture conservation/management)

Efficient water management using integrated approach will be increasingly necessary to mitigate the adverse impacts, particularly under uncertain onset of monsoon and the intermittent dry spells, on crop productivity. Singh *et al*. (2006) suggested water productivity concept, to achieve same or higher yield with same or less water resources (Zwart and Bastiaanssen, 2004), for arid and semi-arid regions (Singh *et al*., 2006). Crop water productivity can be increased significantly if irrigation is reduced and the crop water deficit is widely induced. Adoption of water productivity concept and attempting positive soil water balance by adopting available measures appears to be apt water use strategy. Soil water balance is a reliable evidence to calculate crop water requirements and water use efficiency.

Measures undertaken to increase the infiltration/percolation of water into soil profile and thereby reduce the impact of drought and extreme rainfall events by way of facilitating the increase in water holding capacity and available water in soil are essential. Conserving the moisture, thus, will not only help in growing crops better under changed climate, but will also reduce erosion of fertile soil and plant nutrients. In the sub-tropical and tropical soils, maintaining the higher content of soil organic matter by regular incorporation of organic resources constitutes an essential ingredient for the purpose.

To deal with the extremities (drought and excess moisture) of precipitation, provision of effective drainage and conservation of excess water in farm ponds is one of the strategies. This may not only provide the much needed water for the existing crop, but also for the another crop in sequence. This will maintain the adequate moisture in the root zone and provide stability to productivity. Adoption of such a system will reduce the loss of plant nutrients from the field.

Water conservation and water productivity, are approaches for efficient water management and their synergistic use may reduce water consumption per unit of crop produced. The former approach uses a range of tools such as zero or conservation tillage, the management of crop residues on the soil surface, furrow irrigation, terracing, contour ridge tillage, and laser land leveling. The tools under water productivity largely encompass plant breeding and use of integrated approach for nutrient, pest, and diseases and weed management. Adoption of these tools will optimize the use of water in agriculture culminating to realize higher productivity of crops. Soils having high water holding capacity may help in reducing the impact of drought (Popova and Kercheva, 2005). Climate change can decrease the crop rotation period, so farmers need to consider crop varieties, adjustments in sowing dates, appropriate crop densities and need based fertilization while planting crops (Cuculeanu *et al*., 2002).

The planting of soybean on altered land configuration [broad bed furrow (BBF) or furrow irrigated raised bed system (FIRBS)] or opening of conservation furrow each after 3/6 rows may reduce the deleterious effect of both extreme situations (deficit and excess) of rains. The raised bed and sunken bed is also beneficial system in saline soils to grow soybean on raised bed and water loving crop like paddy in sunken beds. As much of the water loss in agriculture through run off may be curtailed by laser land leveling of fields. Singh *et al*. (2009) and Lybbert and Summer (2012) reported enhancement of water efficiency in laser leveled fields. Opting to an intercultural operation during the dry spells in the cropping season creating a soil mulch to reduce water loss from soil is as well a simple technique to deal with water stress. The research information on predominant cropping systems (soybean-wheat and soybean-chick pea) on BBF and FIRB systems with integrated nutrient management over years has established that the practice not only helped in retention of higher moisture in the profile, but also enhanced yield and soil quality in terms of increased soil organic matter stock, fertility status and physical, chemical and biological indicators of soil quality (Ramesh *et al*., 2006 and 2007). The supplemental irrigation at any of the critical soybean growth stage (seedling, flowering and pod filling) substantially improved the soybean productivity and sustainability (Billore and Srivastava, 2014).

Management of degraded land

As per revised estimates of NBSS&LUP (1994), in India approximately 146.82 m ha comes under degraded land (Anonymous, 2010), which can be put to agriculture use after amelioration. This is the result of progressive climate change and ill management of land and water resources. The amelioration of this land through wind and water erosion management, putting appropriate use under trees and suitable crops, encouraging natural regeneration, and use of technological developments to crop culture, in general, and in saline and alkaline and acid soils in particular. The degradation of land culminates into both, the decline in quality and quantity of soil organic matter and erosion in yields of crops in the most intensive agriculture areas in India, such as Punjab (Dawe *et al*., 2003; Yadav *et al*., 2000; Ladha *et al*., 2003).

Judicious use of nutrient sources (Nutrient use efficiency)

In general, Indian agricultural lands are medium to low in soil organic matter and decline in organic matter content continues owing to skewed and inadequate incorporation of synthetic fertilizers and dispensing with recycling of organic resources; practices that are *in vogue* in the most of the intensive agriculture areas in India (Masto *et al*., 2008; Singh *et al*., 2005). The prevailing practice of over- application of nitrogen (usually only as urea) is not only responsible for causing nutrient imbalances, but also negatively affecting the physical and biological properties of the soils and acidification, which impacted on soil living organisms, crucial also for natural nutrient cycling and water-holding capacity (Darilek *et al*., 2009; Kibblewhite *et al*, 2008). The balanced application of major nutrients in soybean was found to be sustainable and energy efficient (Billore and Vyas, 2012).

Integrated approach for crop management

Integrated approach for crop management encompasses use of management options for nutrient, pest, weed and water involving eco-friendly measures keeping chemical option as need based (Braun and Duveskog, 2008; Feder *et al*., 2004). The climate change may alter the population dynamics and nature of incidence of insect-pests, pathogens causing diseases and weeds in most of the crops as well as in soybean. It is likely that the life cycle of insect-pests will be shortened and number of cycles for their multiplication increased due to climate change. The efficacy of insecticide/fungicide/herbicide may also be altered and over reliance on these chemicals may not be able to offer desired control. Therefore, it is imperative to adopt the integrated approaches for management of menaces with emphasis on adoption of cultural and biological measures.

Increased variability and higher frequency of extreme events due to future climate change is likely to adversely influence the soil organic carbon storage leading to lower soil quality and ultimately limiting/reducing production of crops. To diminish this impact, nutrient management using integrated approach (INM) is one of the viable options to improve the soil quality and productivity of crops. This relies on balanced nutrient application and conservation by adoption of newer technologies to increase nutrient availability to plants from applied and native resources (Raghuwanshi *et al*., 2017). Sustainable nutrient management involves optimization of crop production, prevention of onsite soil degradation and limiting off-site involvement of nutrients. INM is established approach, which can enhance the yield potential of crops over and above achievable yield with recommended fertilizers. Adoption of INM, involving nutrient resources on priority and need based fertilization, will enhance the soil quality/health; make the regulated nutrient availability over the cropping season and equitable nutrient use from applied and native sources in the soil.

INM enhances the yield potential of crops over and above achievable yield with recommended fertilizers, and results in better synchrony of crop N needs due to (a) slower mineralization of organics, (b) reduced N losses *via* de-nitrification and nitrate leaching, (c) enhanced nutrient use efficiency and recovery by crops, and (d) improvements in soil health and productivity, and hence could sustain high crop yields in various cropping systems ensuring long-term sustainability of the system (Aulakh, 2010). The lessons learned through a a number of Long-Term Fertilizer Experiments have clearly brought out that adoption of integrated nutrient management in existing cropping systems including soybean based cropping systems in India in different agro-ecological regions have not only sustained the productivity, but also improved the physico-chemical and biological properties of soil (Singh and Wanjari, 2015; Wanjari *et al*., 2013; Hemlata *et al*., 2013; Billore and Joshi, 2005; Billore *et al.,* 1999, 2006a, 2009, 2008 a,b). Looking to the deficiency of nutrients, particularly Zn in soils of soybean command area, the use of microbial component to enable plants to thrive well in these soils need be looked into.

Crop diversification

Diversification of crops and livestock varieties, including replacement of plant types, cultivars, hybrids, and animal breeds with new varieties/breeds intended for higher drought or heat tolerance is being advocated as having the potential to increase productivity against temperature and moisture stresses. Diversity in the seed genetic structure and composition has been recognized as an effective defense against disease and pest outbreak and climatic alterations. Crop biodiversity is known to play an important role in adaptation to a changing environment. The increasingly adopted monocultures of genetically identical plants are not likely to cope-up with a changing climate. On the contrary, increasing the biodiversity of an agro-ecosystem can help maintain its long-term productivity and contribute significantly to food security *(*Matson *et al. 1997;* Altieri*, 1999*). For crop diversification in India, *a*doption of appropriate crop rotations (sequencing of leguminous crops with cereals and consideration of long cycles of crop rotations rather than one year rotation) can go a long way to ensure sustainable crop production under conservation as well as conventional agriculture. By resorting to this, several benefits like improvement in productivity (Martin *et al*., 1976; Edwards *et al*., 1988), reduction in cost of cultivation, smashing the relationship between host-insect-pest (Francis and Clegg, 1990)/pathogens (Leighty, 1938) /weeds (Froud-Williams, 1988), improvement in soil fertility (Peterson and Varvel, 1989; Karlen *et al*., 1991) and soil physical environment (Monroe and Kladivko, 1987; Habib *et al*., 1990; Dexter, 1991), optimum use of native and applied nutrients and efficient use of available/recipient water can be realized. This may lead to lesser risk and more secure incomes under uncertain weather conditions (Nel and Loubser, 2004). The research conducted at ICAR-Indian Institute of Soybean Research for nine years showed that replacing soybean with maize once in three years crop rotation of soybean-wheat increases overall productivity from the system (Vyas *et al.,* 2010). Even introducing intercrops like maize/ sorghum/finger-millet increases the system productivity (Billore *et al.,* 2011) and covers the risk of failure of one of the crop in the system. Research on soybean with different crops have brought out that the income of farmers can be substantially raised as the combined yield of both the crops exceeds the single crop in the system and the average Land Equivalent Ratio in these intercropping systems ranges between 1.20 to 1.70 *(*Billore *et al., 2011).* Adoption of legume based intercropping leads to increased fertility by biological nitrogen fixation (Mousavi and Eskandari, 2011). It has been realized that research carried out on prevailing cropping systems coupled of minimum tillage in soybean command area of Central India had variable response to increase the soil organic carbon stock (Yadav *et al.,* 2014), which provides sustainability to land resource thereby contributing to lessen the impact of climate change.

Biodiversity

Biodiversity in both above and below ground levels is needed to sustain key functions of the ecosystem (its structure and process) and shall provide essential ecosystem services. It is an important regulator of agro-ecosystem functions, not only in the strictly biological sense of its impact on production, but also in satisfying a variety of needs of the farmer and society at large. In particular, biodiversity increases resilience of agro-ecosystems and is, as such, a means for reducing risk and adapting to climate change (Pimentel *et al*., 1997). The conservation and enhancement of biodiversity in cropping systems both above and below ground, and the management of ecosystem services underpin sustainable farming practices.

Existence of high soil biodiversity is helpful in providing the drought resistance. Although the performance of the plant dependent on the medium on which they grow, but also gets benefitted with the soil microbial diversity. Naturally growing plants are invariably associated with the microbial consortia, particularly with fungi (mycorrhizal), which provides the plants with resistance against drought and facilitates the water uptake (Marquez *et al*., 2007; Rodridguez *et al*., 2004).

Resource conservation technologies

The conservation agriculture approach involves the management of natural biological processes for resource saving in production of agricultural crops, with an objective of obtaining competitive agricultural yields without deterioration of natural resources. Resorting to no till or minimum till leading to least disturbance of soil constitute a suitable niche for soil fauna on account of sufficient supply of soil organic matter in addition to proliferation of the populations of earthworms, millipedes, mites and other animals living in the soil. Presence of these organisms jointly builds up soil porosity and structure for plant growth. These organisms intake organic matter from surface and their excrements helps in formation of stable soil aggregates and macro-pores created by them facilitates infiltration and percolation of excess water for ground water recharge and drainage. Consequently the increased water holding capacity/available water capacity benefits crop plant to survive longer during water stress period. Both are important strategies for farming adaptations to changing climate effects and contribute to mitigation efforts. By managing biological processes, conservation agriculture can contribute to climate change adaptation and mitigation by reducing GHG emissions and sequestering carbon (FAO, 2012). Resultant formation of stable organic matter through the process of humification in soil mediated by microbial activity, thus, help in mitigating the climate change effect through carbon sequestration form atmosphere (Bassi, 2000; Saturnino and Landers, 2002). The technologies of conservation provide opportunities to reduce the cost of production, save water and nutrients, reduction of the incidence of weeds, enhancement of soil quality, *i.e.* soil physical, chemical and biological conditions, long-term C sequestration, increase yields, increase crop diversification, improve efficient use of resources, and benefit the environment, reduction in greenhouse gas emission and improved environmental sustainability (Malik *et al*., 2005; Jat *et al*., 2005, 2009 a,b, 2012; Abrol and Sangar, 2006; Sidhu *et al*., 2007; Pathak *et al*., 2011; Gathala *et al*., 2011; Saharawat *et al*., 2012; Bhan and Behra, 2014).

Agri-horticultural system/Agro-forestry

Soybean and other *kharif* crops can successfully be grown in any horticultural crops like mango, guava, anola, stone fruit (chiku), coconut, papaya oranges, particularly during their juvenile period depending on the sufficient availability of sunlight in the interspaces (Bhatnagar *et al.,* 1996). One can learn lesson from the practice of successful growing crops like turmeric and ginger in coconut/areca nut plantation in Kerala (Nelliat and Bhat K Shama, 1979). Soybean and other crops offer good scope to be grown in agro-forestry/socio-forestry and can support farmers financially during the initial years of establishment of orchards. Efforts need be made as well in this direction on utilizing newly created forests. The tree based intercropping can be of help in breaking the compactions in the sub-soil (FAO, 2009) and may support rainwater conservation to a reasonable extent.

Energy conservation techniques and new energy sources for agriculture

The present agriculture is mostly relying on fossil fuel energy which is exhaustible in nature as well as costly input. The use of non-renewable energy sources on farm will be cost effective as well as environmental protectant. The energy conservation and efficient use of energy in agriculture sector have been critically reviewed by Gellings and Parmenter (2004). Minimizing the tillage constitutes a viable option to conserve the energy in soybean based cropping systems (Billore *et al*., 2009).

Crop residue management

The practice of burning wheat/rice stubbles before seed bed preparation for soybean and other *kharif* crops is also a common practice in most of the parts of India. Leaving last year's crop residue on the surface before and during planting operations provides cover for the soil at a critical time of the year. The residue is left on the surface by reducing tillage operations and turning the soil less. Pieces of crop residue shield soil particles from rain and wind until plants can produce a protective canopy. Ground cover prevents soil erosion and protects water quality (Verhulst *et al*., 2009). Residue improves soil tilth and adds organic matter to the soil as it decomposes. The use of crop residue in soybean–wheat cropping system brought out the sustainability and stability in system productivity (Billore *et al*., 2008 a,b). Fewer trips and less tillage reduce soil compaction and save time, energy and labor.

Harnessing indigenous technical knowledge of farmers

Farmers, often poor and marginal, are experimenting with the climatic variability for centuries. There is a wealth of knowledge on the range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness that knowledge and fine-tune them to suit the modern needs. Traditional ecological knowledge developed and adopted by farmers' and which had stood the test of time could provide insights and viable options for adaptive measures. Anthropological and sociological studies have highlighted the importance of community based resource management and social learning to enhance their capacity to adapt to the impacts of future climate change. Tribal and hill knowledge systems are pregnant with potential indigenous practices used for absorption and conservation of rainwater, nutrient and weed management, crop production and plant protection. Their belief systems have effectively helped in weather forecasting and risk adjustment in crop cultivation. During the course of their habitation, the indigenous people of Himalayan terrain region through experience, experimentation and accumulated knowledge, have devised ways of reducing their vulnerability to natural hazards. Studies have shown that their understanding was fairly evolved in the matters of earthquake, landslide and drought and they have devised efficient ways of mitigating the effect of natural or climatic changes. In case of soybean based cropping systems some of the ITKs have proven the utility (Vinaygam *et al*., 2006).

Better weather forecasting

Under the on-going climate change scenario, it will be obligatory to make weather forecasting and early warning systems sounder, particularly for rainfed agriculture. If such system is in place, it will be of immense utility in minimizing risks of climatic adversaries for the farmers. Sound weather forecasting and early warning system coupled with the information and communication technologies (ICT) could greatly help the researchers and administrators also in developing contingency plans.

Regular scouting for insects, diseases and weeds

Inculcation of the practice of regular scouting of the crop and timely taken measures against adversities by the farmers will enable them to carry cost effective and eco-friendly management of crop menaces to optimize their yield of crops.

Climate change and variability will affect soybean substantially, requiring farmers to adapt mitigation technologies in order to increase and sustain productivity level taking care of reducing emissions at the farm level. Choosing effective adaptation and mitigation strategies will represent a key challenge for farmers over the coming decades. Optimal strategies are those that, *via* careful management of natural resources like land and water, maintain or increase the resilience and stability of production systems, while also sequestering soil carbon and/or reducing fluxes from farm activities.

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Productivity, Profitability and Sustainability of Soybean (*Glycine max*)-wheat (*Triticum aestivum*) Cropping System as Influenced by Improved Water Management Technology in South Eastern Rajasthan

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The study was conducted to increase water productivity, sustainability and economics of soybean-wheat cropping system during 2012-13 to 2017-18 at farmer's field under ORP of AICRP on irrigation water management at Agricultural Research Station, Kota. Treatments comprised irrigation scheduling at flowering and pod development stages in soybean and four irrigation at CRI, late tillering, flowering and milk stages with 6 cm depth by border strip (6 m x 50 m) method using 80 per cent cut-off ratio (improved water management practices), which was compared with farmer's practice (wild flooding). Results revealed that improved water management technology (IWMT) gave higher and sustainable soybean yield and system yield over the years. The mean productivity of soybean – wheat cropping system recorded was 4,409 kg per ha under IWMT, being 7.9 per cent higher than the system yield (4,086 kg/ha) under farmer's practice. Mean sustainability yield index (0.94) and value index (0.93) of soybean-wheat cropping system were found 3.18 and 3.55 per cent higher, respectively. IWMT possessed higher water expanse efficiency (110.2 kg/ha/cm), water productivity (1.10 kg/M³), water profitability (21.0 Rs/M³), production efficiency (12.1 kg/ha/day), monetary efficiency (230 Rs/ha/day), and incremental benefit cost ratio (5.1) and technology index (25.4) of the soybean-wheat cropping system over farmer's practices.

Key words: Improved water management technology, soybean equivalent yield, sustainability yield index and value index, system productivity

Soybean [*Glycine max (L.)* Merrill] - wheat [*Triticum estivum (L.)* emend. Fiori & Paol] is the one of the most dominant cropping system on the Vertisols of central India. Cultivation of soybean in *kharif* season has witnessed a phenomenal growth, while wheat has considerable potential due to congenial climate in the last two decades in the region. Higher productivity with sustainability remains the major concerns of any crop planning. Any system,

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which requires less input and contributes more, is considered to be the efficient. There is closer relationship between cropping system productivity, economics, energy and environment (Tuti *et al.*, 2013). In India, irrigated area is about 65.7 million ha, which is 47 per cent of net cultivated area of about 141 million ha, and only about 26 million ha is under irrigated double cropping. Water has become a crucial input for agricultural development.

The per capita water availability in India is shrinking at an alarming rate which is estimated to be less than 1000 M^3 by 2020, a critical limit which makes it water scarce as per UN guideline. Out of different areas of water requirement for human survival, the food production requires maximum water.

About 85 per cent of utilizable water from all sources is being used for agriculture production only. Hence, it is important that the water use in agriculture needs special attention, so that it can be used judiciously and an effective manner so that its overall production is maximized. The sources for water for agricultural production includes rainfall and harvested rain water, surface water sources, *e.g.* canal, reservoirs, small ponds water streams, rivers and ground water. The availability of water from such different sources has different reliability (Dixit *et al.*, 2014). Keeping in view of these emerging challenges, efficient production technology in soybean – wheat cropping system need to be developed and adopted utilizing the available water resources in the right perspective without compromising on production and productivity of the system and hence, field trials were conducted at farmer's field under operational research programme (ORP) with the aim to increase water productivity soybean-wheat cropping system.

MATERIALS AND METHODS

A total of 18 on-farm trials (9 each at left main and right main canal of Chambal command) of soybean in *kharif* and wheat in *rabi* were conducted each year at adopted villages, namely Manasganv, Soli, Kotsuan Mandawari of Kota and Kotkhera, Khothiya and Lesarda of Bundi districts for six consecutive years (2012-13 to 2017-18) in the selected farmers' field. A farmer's group meeting was convened each year and receptive and innovative farmers were selected to conduct the demonstrations on soybean - wheat cropping system. Selected villages of Chambal command lies between 25^o and 26^o N latitude and 75^o-30' and 76^o-6' E longitude in the south-eastern part of Rajasthan. It comes under agro climatic zone V, which is also known as humid south eastern plain of Rajasthan. The soils of the adopted villages for demonstrations belong to the order Vertisols and Inceptisols, mainly comprised of Chambal series (62 %) and Kota variant (23 %). The bulk density, pH and cation exchange capacity of these soils varies between 7.6 - 8.6, 1.34-1.60 Mg per m^3 and 30-40 C mol per kg, respectively. The soils have a very low water intake rate approximately 0.25 cm per h on surface, but are almost impermeable at 1.2 to 1.5 m depth. The potential moisture retention capacity is almost 120 mm of water in 1 m depth.

The soils of the selected villages for demonstrations are poor in organic carbon (0.50 ± 0.06) and available nitrogen (270 ± 12 kg/ha) but are low to medium in available P_2O_5 (24.2 ± 0.8 kg/ha) and medium to high in available K_2O (298 ± 10 kg/ha).

IWMT included two irrigation, one each at flowering and pod development stage in soybean and four irrigation at CRI, late tillering, flowering and milk stages in wheat with 6 cm depth, by border strip method (6 m x 50 m at 80 % cut-off ratio) with recommended package of practices. Seed treatment, crop geometry (30 cm x 10 cm, 22.5 cm x 5 cm) and weed management were followed as per recommended package of practices of the zone. Recommended dose of fertilizers in test block of soybean (20:40:40:30:: N:P:K:S kg/ha) and wheat (120:40:30:: N:P:K kg/ha) were applied using 80 kg per ha seed of JS 95-60 variety of soybean and 100 kg per ha seed of Raj 4037 variety of wheat during each year of the study and compared with farmer's practice.

For assessing impact of IWMT the adjoining field with similar area cultivated to soybean and wheat by the farmer himself were considered which served as check plot (FP). IMMT was compared with FP (flooding method of irrigation with no control over the depth of irrigation; usually about 10 cm). Four irrigation excluding pre-sowing irrigation in wheat at critical stages and only one irrigation at pod development stage in soybean were applied. Each field trial in soybean – wheat cropping system was laid out in an area of 0.4 ha and velocity-area method at field level was also used for the measurement of water in test block.

The demonstration plots were sown with IWMT of soybean and wheat during first fortnight of July and second week of November every year, respectively. Harvesting of soybean and wheat was done in the second week of October and April, respectively. The rainfall received during 2012, 2013, 2014, 2015, 2016 and 2017 were 781 mm (38 rainy days), 1,021 mm (67 rainy days), 814 mm (40 rainy days), 770.9 mm (rainy days 55), 1,015.2 mm (rainy days 38) and 549.5 mm (rainy days 32), respectively. Net returns of the system and incremental benefit cost ratio were worked out on the basis of prevailing market prices of inputs and produce. Potential yield of system was calculated on the basis of potential yield (3,000 kg/ha, 7,000 kg/ha) in the zone and mean selling price of soybean (Rs 26.75 /kg) and wheat (Rs 15.45 /kg) during the course of study. Total irrigation water applied was calculated by adding the depth of water applied in irrigation. System productivity was worked out by converting wheat yield into soybean equivalent yield.

Production efficiency of system was calculated by dividing 365 days in a year to system yield (Devkant Prasad *et al.*, 2013). Data were recorded from demonstration blocks and farmer's practice blocks. These recorded data were analyzed for different parameters, using following formulae, suggested by Prasad *et al.* (1993). For economic evaluation in term of gross and net returns and incremental benefit ratio, the prevailing market rates for input, labour and produce was utilized. Data were recorded from demonstration blocks and farmer's practice blocks.

(A) Extension Gap = Demonstration yield (Di)- Farmers practice yield (Fi)
(B) Technology Gap = Potential yield (Pi)- Demonstration yield (Di)
(C) Technology Index = (Pi-Di)/Pi x 100

Statistical analysis of the data for standard deviation and coefficient of variation was done as described by Panse and Sukhatme (1985). Sustainability indices (Sustainability yield index and sustainability value index) were work out using formula (Singh *et al.*, 1990).

$$\text{SYI} = \frac{\text{Estimated average soybean-wheat cropping system yield (kg/ha) - Standard deviation}}{\text{Maximum soybean-wheat cropping system yield (kg/ha)}}$$

$$\text{SVI} = \frac{\text{Estimated net returns of soybean-wheat cropping system (Rs/ha) – Standard deviation}}{\text{Maximum net returns of soybean-wheat cropping system (Rs/ha)}}$$

Water expanse efficiency = Economic crop yield (kg/ha)/Water applied (ha cm)

Water profitability = Net returns (Rs/ha)/ Water applied (m^3)

RESULTS AND DISCUSSION

Grain yield

While comparing total productivity of system, it was observed that IWMT influenced the system productivity positively during six year (Table 1). Mean data revealed that, soybean yield (1,347 kg/ha), wheat yield (5,261 kg/ha) and system productivity (4,409 kg/ha) were found to be 6.9, 8.4, and 7.9 per cent, respectively higher in IWMT than FP. Mean production efficiency (12.1 kg/ha/day) and monetary efficiency (Rs 230/ha/day) (Table 2) of soybean-wheat cropping system were also achieved under IWMT than the FP. Year-wise per cent increase in system productivity under IWMT over FP ranged from 7.1 to 8.9. The higher production efficiency of system under demonstrations could be attributed to adoption of IWMT by the farmers. Year-wise observed variation in yield might be due to variation in the environmental conditions prevailed during that particular year. This fact has earlier been reported by Prasad *et al.* (2014) and Prasad *et al*. (2013) stating that improved water management practices along with recommended practices of soybean have shown positive effect on yield.

Water use

Efficiency indices for water use were estimated in terms of water expanse efficiency water productivity and water profitability. Cumulative data (Table 2) of six years indicated that water expanse efficiency (110.2 kg/ha/cm), water profitability (Rs 21.0/M^3 water) and water productivity (1.10 kg/ M^3) being

61.8, 64.1 and 61.8 per cent higher in soybean-wheat cropping system with IWMT as compared to FP farmers practices, respectively. During the six years study, maximum water expanse efficiency (122.9 kg/ha/cm), water productivity (1.23 kg/ M^3 water) in 2012-13 and water profitability (Rs 25.4/M^3 water) in 2017-18 were observed which was due to lesser quantities of water used in test blocks. Results were reported by the Chery *et al.* (2014) and Prasad *et al.* (2014).

Gap analysis

Extension gap, Technology gap and Technological index for the system were evaluated for all the six years. Extension gap is a parameter to know the yield difference between the demonstrated technology and farmer's practice; for study this ranged from 271 to 384 kg per ha with an average of 323 kg per ha (Table 4). This indicated a wide gap between the demonstrated improved technology and its adoption by the farmers. Technology gap is a measure of difference between potential yield (7,043 kg/ha) and yield obtained under IWMT demonstration, this is of greater significance than other parameters as it indicates the constraints in implementation of package of practices. This also reflects the poor extension activities, which resulted in lesser adoption of IWMT and package of practices by the farmers. Technology gap can be lowered down by strengthening the extension activities and further research to improve the package of practices. Technology index is dependent on technology gap and is a function expressed in per cent. For the six years of study it varied from 30.2 percent to 47.9 per cent, with an average of 37.4 per cent. The very low technology index (30.2 %) during the year 2012-13 could be due to adoption of IWMT, favourable climatic conditions, crops free from insect-pests and disease incidence. High technology index (47.9 %) observed in the year 2015-16. This was mainly due to early withdrawal of monsoon and unfavourable climatic conditions with incidence of insect-pests and diseases. Such higher technology indices have been also reported by Narolia *et al.* (2017).

Economic analysis

Mean data (Table 3) of six years revealed that 7.94 per cent higher net returns from system was found in IWMT (Rs 1,17,096/ha) as compared to farmers practices (Rs 108477/ha). Grain yield, cost of inputs and sale price of produce determine the economic returns and these vary from year to year. The year-wise additional returns from IWMT over FP varied from Rs. 7495 to Rs. 11,139. The mean additional cost of input of all the demonstrations for six years was Rs. 1682 per ha. This additional investment along with non-monitory management factors gave an additional mean return of Rs 8, 618 per ha. The higher sale price of produce, in spite of low production and higher additional cost of input during 2017-87 gave highest additional returns (Rs. 11,139/ha) under IWMT over FP. The incremental benefit cost ratio (IBCR) on overall average basis was 5.1. The highest IBCR (5.6) during six year was observed in 2017-18. This was due to comparatively higher grain yield, less

Table 1. Effect of improved water management technology on system productivity, efficiency indices for water use and profitability in soybean-wheat cropping system

Year	Soybean yield (kg/ha)		Wheat yield (kg/ha		System Productivity (kg/ha)		% increase in system productivity over FP	System production efficiency (kg/ha/day)	
	IWMT	FP	IWMT	FP	IWMT	FP		IWMT	FP
2012-13	1711	1609	5268	4900	4918	4592	7.1	13.5	12.6
2013-14	1184	1111	5368	4956	4615	4279	7.9	12.6	11.7
2014-15	1218	1152	5114	4710	4169	3870	7.7	11.4	10.6
2015-16	1075	1012	5184	4769	3667	3396	8.0	10.0	9.3
2016-17	1310	1225	5280	4870	4367	4044	8.0	12.0	11.1
2017-18	1582	1450	5350	4920	4718	4334	8.9	12.9	11.9
Mean	**1347**	**1260**	5261	4854	**4409**	**4086**	**7.9**	**12.1**	**11.2**

IWMT= Improved water management technology, FP= Farmers practice

Table 2. Effect of improved water management technology on efficiency indices for water use and profitability in soybean-wheat cropping system

Year	System net return (Rs./ha)		Total water applied in system (cm)		Water expanse efficiency (kg/ha-cm)		System water productivity (kg/M³)		System water profitability (Rs/ M³)		System monetary efficiency (Rs/ha/day)	
	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP
2012-13	81255	75169	40	60	122.9	76.5	1.23	0.77	20.3	12.5	223	206
2013-14	74045	67803	40	60	115.4	71.3	1.15	0.71	18.5	11.3	203	186
2014-15	76195	69641	40	60	104.2	64.5	1.04	0.64	19.0	11.6	209	191
2015-16	79777	73074	40	60	91.7	56.6	0.92	0.57	19.9	12.2	219	200
2016-17	90112	82712	40	60	109.2	67.4	1.09	0.67	22.5	13.8	247	227
2017-18	101517	92387	40	60	118.0	72.2	1.18	0.72	25.4	15.4	278	253
Mean	**88817**	**76798**	**40**	**60**	**110.2**	**68.1**	**1.10**	**0.68**	**21.0**	**12.8**	**230**	**210**

Table 3. Effect of improved water management technology on sustainability yield and value index of soybean-wheat cropping system

Particulars	2012-13		2013-14		2014-15		2015-16		2016-17		2017-18		Mean	
	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP	IWMT	FP
Mean system yield (kg/ha)	4918	4592	4615	4278	4168	3869	3667	3396	4206	3896	4718	4334	4382	4061
S D	117	121	157	156	116	187	91	89	129	117	90	118	110	125
CV (%)	2.39	2.64	3.40	3.64	2.77	4.84	2.47	2.62	3.06	3.01	1.91	2.72	2.51	3.08
SYI	0.946	0.934	0.935	0.906	0.945	0.906	0.945	0.918	0.909	0.909	0.957	0.930	0.941	0.919
Mean net return of system (Rs./ha)	81255	75169	74045	67803	76195	69641	79777	73074	90112	82712	101517	92387	83817	76798
S D	2701	2790	3605	3579	2585	4873	2806	2763	2302	2017	2613	3421	2671	3089
CV (%)	3.32	3.71	4.87	5.28	3.39	7.00	3.52	3.78	2.55	2.44	2.57	3.70	3.19	4.02
SVI	0.926	0.909	0.908	0.867	0.934	0.867	0.922	0.884	0.939	0.939	0.943	0.906	0.931	0.899

SYI/SVI= Sustainability yield/value index of soybean-wheat cropping system; SD = Standard deviation; CV = Coefficient of variation

Table 4. Economic analysis of improved water management technology on soybean-wheat cropping system at farmer's field

Years	System cost of input (Rs./ha)		System additional cost in IWMT	Sale price (Rs/kg)		System total gross returns (Rs/ha)		Additional returns (Rs/ha) in IWMT	Effective gain (Rs/ha)	IBCR	Extension gap (kg/ha)	Technology gap (kg/ha)	Technology index
	IWMT	FP		Soybean	Wheat	IWMT	FP						
2012-13	31850	30450	1400	23.0	14.0	113105	105611	7495	6095	5.4	326	2125	30.2
2013-14	32100	30600	1500	23.0	14.7	106136	98406	7730	6230	5.2	336	2428	34.5
2014-15	32650	30960	1690	26.0	15.0	108382	100608	7774	6084	4.6	299	2874	40.8
2015-16	33900	32200	1700	31.0	15.5	113677	105290	8387	6687	4.9	271	3376	47.9
2016-17	34350	32550	1800	28.5	16.5	124451	115265	9185	7385	5.1	322	2676	38.0
2017-18	35300	33300	2000	29.0	17.0	136824	125684	11139	9139	5.6	384	2325	33.0
Mean	33358	31677	1682	26.75	15.45	117096	108477	8618	6937	5.1	323	2634	37.4

Potential yield of the system= 7043 kg/ha2 cost of input and a good sale price.

Sustainability

Lower coefficient of variation in the mean soybean - what cropping system yield was recorded under the demonstrations on IWMT as compared to the farmer's practices for all the six years, except during 2012-13 and 2016-17. Coefficient of variation in terms of mean net returns of soybean - wheat cropping system was also higher in FP as compared to test block. This may be due to lesser variation in the yield from farmer to farmer under IWMT and higher in FP demonstrations. However, the sustainability yield index (SYI) and sustainability value index (SVI) of the system was more under IWMT than FP (Table 3). The mean SYI and SVI over these 6 years under IWMT, ranged from 0.909 to 0.946 and 0.877 to 0.922 with the mean of 0.941 and 0.897, while the corresponding values under farmers practice were 0.906 to 0.934 and 0.867 to 0.939 with the mean of 0.919 and 0.899, respectively (Table 4). Moreover, sustainability yield index of system during 2016-17 was found equal in IWMT and FP due more variation in yield of soybean as well as wheat in test block. Similar results have been reported by Narolia *et al*. (2017).

Based on six years results at different locations of farmer's field of Chambal command area of Rajasthan it may be concluded that productivity, sustainability, water profitability of soybean - wheat cropping system can be enhanced with IWMT along with recommended production technology.

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Integrated Nutrient Management in Soybean using Cow dung Manure with Natural Resources in Vindhyan Plateau of Madhya Pradesh

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ABSTRACT

An experiment was conducted at research farm, College of Agriculture, Ganj Basoda at fixed site for consecutive three years (2013-16) on Vertisols of Vindhyan Plateau of Madhya Pradesh to evaluate the effect of cow dung manure with variable levels of natural carriers, namely rock phosphate, feldspar and gypsum on growth, yield, protein and oil content of soybean in soybean-wheat cropping system. Yield attributes like plant height, dry matter accumulation, pods per plant seed and harvest index were maximum and differed significantly from recommended dose of nutrient through natural nutrient carriers (control) on application of recommended dose of natural carriers coupled with incorporation of cow dung manure @ 5 t per ha. In general, the value of these attributes increased with integration of cow dung manure in different proportions with recommended dose of natural resources. The enhanced yield attributes by application of recommended dose of natural carriers coupled with incorporation of cow dung manure @ 5 t per ha was reflected in increase of seed and stover yield by 16.51 and 16.11 per cent, respectively over control. In this treatment, the quality parameters in terms of oil and protein contents also significantly improved over control.

Key words: Cow dung manure, Integrated nutrient management, natural resources, soybean

Soybean [*Glycine max* (L.) Merrill] is maintaining premier position among nine oilseeds grown in India. Although, the crop area and production has expanded rapidly in Central India, the growth in productivity was not parallel. The sub-optimal, imbalanced and skewed nutrient management constituted one of the major constraints in optimizing productivity of soybean (Joshi, 2004). Behera *et al.* (2007) also reported that sub-optimal application of nutrients by the farmers leads to lower yields of soybean. The information on integrated nutrient management in predominant soybean-wheat cropping system using organic

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manures with natural nutrient carriers in place of synthetic fertilizers is lacking. Hence, present investigation deals with integrated nutrient management involving incorporating different levels of cow dung manure coupled with natural nutrient carriers and its impact on yield attributes, yield and oil and protein contents of soybean in soybean-wheat cropping system on Vindhyan Plateau of Madhya Pradesh.

MATERIAL AND METHODS

An experiment was conducted during *kharif* and *rabi* seasons of 2013-14, 2014-15 and 2015-16 at research farm, College of Agriculture, Ganj Basoda, Vidisha of Vindhyan Plateau of Madhya Pradesh. The soil of experimental site belonged to Vertisols with clayey texture, pH 7.60, organic carbon 0.48 per cent and EC 0.38 dS per m. The available N, P_2O_5, K_2O and S contents were 190, 12.4, 290 and 9.2 kg per ha, respectively. The experiment was laid out in a randomized block design with four replications and six treatments encompassing recommended doses of nutrients through natural carriers (RDN) and its combination with five graded quantity of cow dung manure. The RDN was taken as control for comparison. The cow dung collected form *Goushala* was used for preparation of manure without addition of any other material. It analyzed: N- 0.3 per cent, P_2O_5 – 2 per cent, K_2O – 1 per cent. All the agronomic operations were carried out as per recommendations for raising the crop. Soybean *var*. JS 95-60 was sown on 9th July 2013, 3rd July 2014 and 5th July 2015 and harvested on 12th October 2013, 11th October 2014 and 10th October, 2015 during the experimentation. The recommended dose of nutrients for soybean (20:60:20:20 kg N: P_2O_5:K_2O:S/ha) was applied as basal through rock phosphate, feldspar and gypsum and N was with urea. Full dose of phosphorus and potassium along with one third dose of nitrogen were applied as basal and the remaining dose of nitrogen was applied in two equal splits at the time of first and second irrigation to wheat. The nutrient carriers remained the same as for soybean and applied as basal. Cow dung manure as per treatment was incorporated 15 days prior to sowing of soybean. The data on plant height, pods per plant, dry matter per plant and seed index were recorded on five randomly selected plants and yield (seed and stover) from each plot was recorded at harvest. The oil and protein contents were analysed by methods described by Kjeldhal (1983) and AOAC (1984), respectively. The recorded data was pooled for three years and statistically analysed as described by Panse and Sukhatme (1978). The economic analyses was carried out using prevailing cost of inputs and produce and reported as net returns and benefit cost ratio. The crop suffered during the three years of experimentation due to either excess or deficit rainfall coupled with uneven distribution. Against the average rainfall of 1229.9 mm, in 2013-14, the received quantity was 2038.6 mm in 62 rainy days. During 2314-15, it was 770.6 mm in34 rainy days and in 2015-16, it was 899.2 mm in 41 rainy days. During later two years, the crop experienced long dry spells. Overall, the rainfall pattern was erratic, which hampered expression of optimum productivity.

RESULTS AND DISCUSSION

The plant height and dry matter accumulation were significantly higher in RDN integrated with cow dung manure @ 5 t per ha as compared to RDN. Plant height showed significant difference with RDN (36.47 cm) on its integration with cow dung manure @ 4 t per ha (39.67 cm) and @ 5 t per ha (40.37 cm). The dry matter accumulation was maximum in later treatment (20.26 g/plant), and ranged between 15.17 and 18.18 g per plant in rest of the integrated treatments and was significantly higher than RDN (14.27 g/plant). The integration of cow dung manure with RDN @ 2 t per ha on wards significantly increased number of pods per plant (36.27 to 46.87) as compared to RDN (28.13) (Table 1). Seed and harvest index did not differ significantly. The improvement in dry matter and pod number per plant was reflected in seed and stover yield. The integration of RDN with cow dung manure @ 2 t per ha and beyond increased seed and stover yield significantly over RDN. Maximum seed (757 kg/ha) and stover (1,136 kg/ha) was recorded in incorporation of cow dung manure @ 5 t per ha with RDN (632 and 953 kg/ha, respectively) (Table 1). These results are in conformity of findings of Chakraborty and Hazari (2016), who found a significantly higher yield by

Table 1. Effect of integration of cow dung manure with natural nutrient carriers on yield attributes, seed and stover yield of soybean (Data pooled for three years)

Treatments	Plant height (cm)	Dry matter accumu-lation (g/plant)	Pods (No/plant)	Seed index	Harvest Index (%)	Yield (kg/ha) Seed	Stover
RDN	36.47	14.27	28.13	10.02	39.85	632	953
RDN + Cow dung @ 1 t/ha	37.07	15.17	32.07	10.24	40.02	667	999
RDN + Cow dung @ 2 t/ha	38.17	16.26	36.27	10.53	39.99	699	1048
RDN + Cow dung @ 3 t/ha	38.87	17.26	37.27	10.75	39.89	722	1087
RDN + Cow dung @ 4 t/ha	39.67	18.18	41.57	10.79	39.97	739	1109
RDN + Cow dung @ 5 t/ha	40.37	20.26	46.87	10.83	39.97	757	1136
SEm (±)	1.01	0.51	1.70	0.08	0.03	17.33	30.57
CD (P = 0.05)	**3.04**	**1.54**	**5.09**	**NS**	**NS**	**52**	**91.70**

RDN- Recommended dose through natural carriers, nitrogen through urea application of 100 per cent RDF (through synthetic fertilizers + FYM @ 5 t /ha). Sharma *et al.* (2014) also found a significantly higher yield by 75 per cent NPKS + FYM + PSB + *Rhizobium* + Zn + Mo. Waghmare *et al.* (2014) as well reported increase in pods per plant, seed yield per plant, 100 seed weight, seed yield, protein and oil yield in soybean seed by application of 75 per cent NPK with FYM @ 5 t per ha and biofertilizers (*Rhizobium* + PSB).

The integration of RDN with graded levels of cow dung manure, in general, led to significant increase in N, P, K, S, oil and protein contents in seed and there was progressive increase with graded levels of cow dung manure. The highest contents of nitrogen (6.40 %), phosphorus (0.54%), potassium (2.28%), sulphur (0.18 %), oil (19.74 %) and protein (36.57 %) were recorded when RDN was integrated with cow dung manure @ 5 t per ha (Table 2). It has been reported that the integrated nutrient management not only increases the microbial activity, enzymatic activities, nutrient availability and improves soil physico-chemical environment in the soil for plant growth, but also optimizes the productivity (Anonymous, 1998) as evidenced in the present study. The earlier reports (Mandal *et al*., 2000; Sable, 2005) also confirm the present findings.

Economic analysis revealed that the net returns increased progressively with integration graded levels of cow dung manure with RDN (Rs 17,816-21827/ha) as compared to RDN

Table 2. Effect of integration of cow dung manure with natural nutrient carriers on nutrient, oil and protein contents in seed of soybean (Data pooled for three years)

Treatments	Nutrient content (%) N	P	K	S	Protein (%)	Oil (%)	Net returns (Rs/ha)	B:C ratio
RDN	5.60	0.28	1.94	0.08	31.97	19.38	16478	1.49
RDN +Cow dung @ 1 t/ha	5.93	0.41	2.04	0.10	33.87	19.50	17816	1.61
RDN + Cow dung @ 2 t/ha	6.15	0.43	2.14	0.12	35.13	19.56	19110	1.74
RDN + Cow dung @ 3 t/ha	6.27	0.49	2.19	0.14	35.79	19.64	20442	1.86
RDN + Cow dung @ 4 t/ha	6.37	0.52	2.23	0.16	36.36	19.68	20893	1.91
RDN + Cow dung @ 5 t/ha	6.40	0.54	2.28	0.18	36.57	19.74	21827	1.98
SEm (±)	0.07	0.013	0.05	0.006	0.18	0.113	679.44	0.051
CD (P = 0.05)	**0.22**	**0.038**	**0.16**	**0.017**	**0.54**	**0.338**	**2028.33**	**0.152**

RDN- Recommended dose through natural carriers, nitrogen through urea

(Rs 16,478/ha). Similar was the trend in case of B: C ratio. The maximum net returns (Rs 21,827/ha) and B: C ratio (1.98) was recorded in incorporation of cow dung manure @ 5 t per ha and lowest was with RDN (Rs 16,478/ha and 1.49, respectively) (Table 2).

The outcome of three years study established that integration of cow dung manure with RDN even @ 1 t per ha leads to enhancement in productivity, profitability and quality parameters of soybean and nutrient management schedule provides optional use of natural carriers. To harness better advantage, these natural carriers of nutrients may be integrated with incorporation of cow dung manure @ 5 t per ha.

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Peach Organic Sources, Phosphorous and Beneficial Microbes Application Enhance Productivity and Profitability of Soybean

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ABSTRACT

*Field experiments were conducted for two consecutive summer seasons of 2016 (year 1) and 2017 (year two) at Agriculture Research Institute Mingora Swat, Pakistanon on soybean (*cv. *Malakand-96) to find out the impact of peach residues (leaves and fruits having no stones (not decomposed), its well decomposed compost comprised of leaves and fruits having no stones and its biochar (peach tree stem, with peach stones, leaves and twigs), three phosphorus levels and beneficial microbes on growth and productivity and profitability of soybean. Results revealed that organic sources showed profound effect in term of thousand seed weight. Highest thousand seed weight (164.6 g) was noted in those plots where biochar was applied. Beneficial microbes had also ameliorating effect on thousand seed weight; phosphorus solubilising bacteria (PSB)was superior over* Trichoderma*. Phosphorus levels exerted significant effect over thousand seed weight. Highest thousand seed weight (167.3 g) was recorded at 100 kg P per ha followed by 75 kg Pper ha application (162.5 g). Highest seed yield (2,140 kg/ha) was produced by plots, which received compost amendments and was on par with biochar application (2,120 kg/ha). Lowest seed yield (1,808 kg/ha) was recorded with peach residues (dry based non-composted) incorporated plots. Beneficial microbes as well played a significant role in maximizing seed yield of soybean. Maximum seed yield (2,132 kg/ha) was produced by* Trichoderma *inoculated treatments as compared to PSB (1,913 kg/ha) inoculation. Phosphorus application boosted soybean yield significantly, and highest seed yield (2,364 kg/ha) was recorded in those plots, which received P at the rate 100 kg per ha and at par with75 kg per ha P application (2,335 kg/ha), whereas the lowest seed yield (1,569 kg/ha) was recorded in those plots where P was applied at the rate of 50 kg per ha. Combined over the two years, economic analysis showed that net returns (PKRs 62.082 /ha), were highest in biochar amendment followed by compost (PKRs 60,168 /ha), whereas least (PKRs 41,548 /ha) was in peach residues. The VCR was highest in compost amendment (5.48) among the organic sources followed by biochar (5.37), while the least VCR (4.67) was obtained in peach residues incorporated plots. In case of P, highest net returns (PKRs 76,528 /ha) were gained with P at the rate of 100 kg per ha followed by 75 kg P per ha (PKRs 64,459 /ha) and least (PKRs 30,580 /ha) were achieved with 50 kg P per ha. In case of beneficial microbes, average pronounced net returns (PKRs 67,453 /ha) were attained with* Trichoderma *followed by PSB (PKRs 62,695/*

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ha). When compared the average VCR of both years, greater VCR (14.35) was attained by Trichoderma *followed by PSB (9.98).*

Key words: Beneficial microbes, biochar, carbon sources, compost, peach residues, profitability, seed yield, soybean

Soybean [*Glycine max* (L.) Merrill] is one of the most important protein as well as oil seed crop. It supplies approximately 65 per cent world protein meal and 20 to 24 per cent of the world edible oil. Soybean seed contains about 37-42 per cent good quality protein, 6 per cent ash, 29 per cent carbohydrate and 19-28 per cent oil comprising 85 per cent poly-unsaturated fatty acid with two essential fatty acids (Linoleic and linolenic acid), not synthesized by the human body. It is soil building crop and requires less water as compared to other crops (Imran *et al.,* 2017). As soybean is a soil building crop, it is recommended to plant on soils which have come under intensive cultivation and has exhausted its capacity and need to be replenished. Such areas are located in sugarcane, rice and cotton cropping systems in fruit orchards or newly reclaimed soils. Few countries including Pakistan have opportunity of harvesting two crops (spring and autumn) in a year and has a great potential (Imran *et al.*, 2016). Soybean is known to be grown in the northern region of Pakistan since times immemorial. Soybean has a number of advantages over other oilseed crops. It is nitrogen fixing crop, hence need less chemical fertilizer (Chakarborty and Sujoy, 2016).

In Pakistan, soybean has suffered a setback and has therefore, not been able to attain a respectable position among the oilseed crops (Muhammad *et al*., 2016). Phosphorus deficiency has also been shown to be an important fertility problem limiting legume production and reduces nodulation, N_2 fixation and plant growth. It is well known that symbiotic N_2 fixation is a high P demanding process; hence nodule formation and N_2 fixation are generally limited by low P availability which adversely affects nodule number and mass, as well as nitrogenase activity. The reason for this reduction has been indicated by the fact that plants dependent on symbiotic N_2 fixation have high ATP requirements for nodule development and function and need additional P for signal transduction and membrane biosynthesis (Thakur*et al.*, 2011). Adequate phosphorus results in higher grain production, improved crop quality, greater stalk strength, increased root growth, and earlier crop maturity (Paliwal *et al.*, 2011). Phosphorus nutrition depends on the ability of the soil to replenish the soil solution with phosphorus as the crop removes it and on the ability of the plant to produce a healthy and extensive root system that has access to the maximum amount of soil phosphorus (Waghmare *et al.,* 2014). Arif *et al.* (2017) concluded biochar enhanced maize and wheat productivity, soil properties and phosphorous use efficiency (PUE) when applied with organic P sources as either farmyard manure (FYM) or poultry manure (PM) and diammonium phosphate (DAP) chemical fertilizer.

MATERIALS AND METHODS

Field experiments were conducted at Agriculture Research Institute Mingora Swat for two consecutive summer seasons of 2016 (year one) and 2017 (year two) on soybean (*cv.* Malakand-96) to find out the impact of: (i) peach residues (leaves and fruits having no stones (not decomposed), (ii) its well decomposed compost comprised of leaves and fruits having no stones, and (iii) its biochar (peach tree stem, with peach stones, leaves and twigs), three phosphorus levels (50, 100, 150 kg P/ha), two beneficial microbes (PSB and *Trichoderma*-strain G 8) and control on growth and productivity and profitability of soybean. The experiment was laid out in simple randomized complete block design having three replications. The organic sources @ 10 t per ha were applied one month before sowing. Peach residues of early maturing cultivars (Early grand and A-69) for dry based application (residues), compost and biochar preparation were collected from Matta Tehsil, Village Sambat Cham, Chalghazy. Peach bark, leaves and twigs were collected in the month of January and February (winter season) after pruning of peach orchards. Though leafs and fruit stones were collected in fall season. The required P levels using single superphosphate (SSP) and beneficial microbes were applied at sowing time. Basal dose of N (urea) (25 kg/ha) was applied at the time of sowing. The field was ploughed twice up to the depth of 30 cm with the help of cultivator followed by planking. The plot size kept was 4 m in length and 2.7 m in width (10.8 m^2) with row to row spacings of 45 cm and plant to plant distance of 5 cm. Soybean (*cv.* Malakand-96) was sown @ 100 kg per ha on July 4th 2016 and 2017, respectively. PSB was inoculated to soybean seed (@ 100 g/kg seed) for the required treatment at the time of sowing, whereas *Trichoderma* was incorporated (@ 800 g/0.4 ha) in to the soil in each plot at the time of sowing. Both PSB and *Trichoderma* are commercially available at Agriculture Research Institute Mingora Swat. The data was analysed statistically as described by Panse and Sukhatme (1978). Climatic data and physico-chemical properties of soil before planting soybean for both the years are presented in (Fig. 1) and table 1.

RESULTS AND DISCUSSION

Thousand seeds weight (g)

Statistical analysis showed that thousand seed weight was significantly influenced by organic sources, phosphorus and beneficial microbes (Table 2). The mean values revealed that these sources significantly produced higher thousand seed weight (156.5 g) than control plots (123.8 g). Among organic sources, soil incorporation of peach biochar showed maximum value for thousand seed weight (164.6 g) followed by that of compost (149.5 g), whereas peach residues led to lowest value (155.5 g). Beneficial microbes also

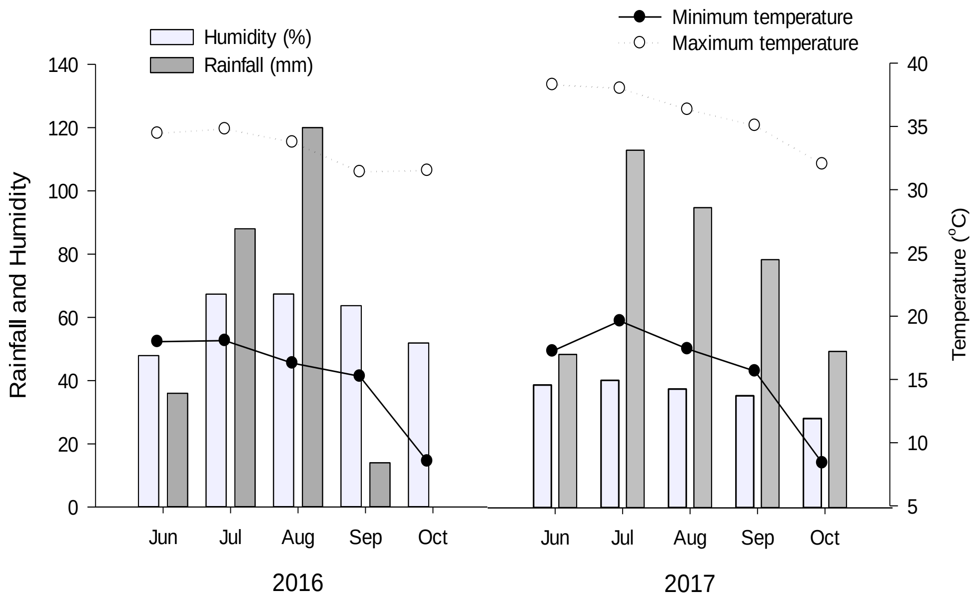

Fig: 1 Rain fall, humidity and temperature (Max, Min) for the year of 2016 and 2017

Table 1. Physio-chemical analysis of soil before sowing and after harvesting of Soybean plots for the growing year of 2016 and 2017

Soil property	Unit	Year 2016	Year 2017
		Before sowing Soybean Plot	Before sowing Soybean Plot
Clay	%	11.6	11.6
Silt	%	50	50
Sand	%	38.4	38.4
Textural Class	-	Silt loam	Silt loam
pH (1:5)	-	5.8	6
Organic Matter	%	1.38	4.18
Lime contents	%	4	2
Total Nitrogen	%	0.069	0.16
AB-DTPA extract. P (ppm)	mg kg^{-1}	10.28947	14.26
AB-DTPA extract. K (ppm)	mg kg^{-1}	76	186

revealed ameliorating effect on thousand seed weight; it was significantly higher (159.3 g) with PSB inoculated treatment than soil incorporation of *Trichoderma* (153.8 g). In case of P treatments, significantly higher values of thousand seed weight (167.3 g) was recorded by application of 100 kg P per ha followed by 75 kg P per ha (162.5 g), whereas it was lowest (139.8 g) with 50 kg P per ha.

The values for thousand seed weight recorded for year 1 (159.4 g) was significantly higher than year 2 (153.6 g) owing to prevailing climatic conditions.

Table 2. Influence of organic sources, beneficial microbes and phosphorus levels on 1000 seed weight and seed yield of soybean (data pooled for two years)

Treatments	1000 seed weight (g)	Seed yield (kg/ha)
Organic Sources (OS)		
Peach Residues	155.5b	1808b
Peach Compost	149.5c	2140a
Peach Biochar	164.6a	2120a
LSD For OS	3.41	73
Beneficial Microbes (BM)		
PSB	159.3a	1913b
Trichoderma	153.8b	2132a
LSD For BM	***	***
Phosphorus Levels (PL)		
50 kg/ha	139.8c	1569b
75 kg/ha	162.5b	2335a
100 kg/ha	167.3a	2364a
LSD For P	3.41	73
Year (Y)		
Y 1	159.4a	1875b
Y 2	153.6b	2171a
LSD For Y	*	***
Planned Mean Comparison		
Control	123.8b	928b
Rest	156.5a	2023a
Sig Level	***	***
Interaction	Sig Level	Sig Level
OS x BM	NS	*
OS x PL	***	NS
BM x PL	NS	*
OS x BM x PL	**	NS
Y x OS	NS	**
Y x BM	NS	NS

Mean of the similar groups, followed by similar letters are non-significantly different from each other at (P < 0.05) 5 % level of probability using LSD test.

The interactions between OS x PL, Y x OS, Y x OS x BM and Y x BM x PL was found significant (data not shown). Imran and Amanullah (2018 unpublished reported that soil amendments increased significant shoot length, nodules number and biomass, thousand seed weight and number of pods per plant. These results gains support from findings of Chakraborty *et al.* (2016), who reported that soybean growth and yield was better by incorporation of compost than FYM. It could be attributed to comparatively better regulated supply of nutrients by the former. These results are also in corroboration with Sharma *et al*. (2014), Imran (2018) and Imran and Amanullah (2018), who reported that plant growth, yield, seed weight and nodulation was tremendously improved in soybean by incorporation of organic amendments.

Seed yield

Organic sources, phosphorus levels, beneficial microbes and year's over the both years had significant effect on seed yield (Table 2). Mean values of all the treatments revealed that the seed yield of soybean was significantly higher (2,023 kg/ha) than control plots (928 kg/ha). In case of organic sources, significantly higher seed yield was produced by incorporation of peach compost (2,140 kg/ha), which was on par with peach biochar (2,120 kg/ha). Peach residues recorded the lowest seed yield (1,808 kg/ha) Beneficial microbes played a significant role in maximizing seed yield. Soil incorporation of *Trichiderma* produced significantly higher seed yield (2,132 kg/ha) over seed inoculation with PSB (1,913 kg/ha). There was a progressive increase in yield with increasing levels of P; however application of P @ 100 kg per ha (2,364 kg/ha) was on par with 75 kg per ha (2,335 kg/ha). The lower dose of P @ 50 kg per ha culminated in lowest yield (1,569 kg/ha). Year to year variation in yield revealed that higher yield was recorded in year 2 (2,171 kg/ha) than year 1 (1,875 kg/ha). Interactions between OS x PL, BM x PL, Y x OS,

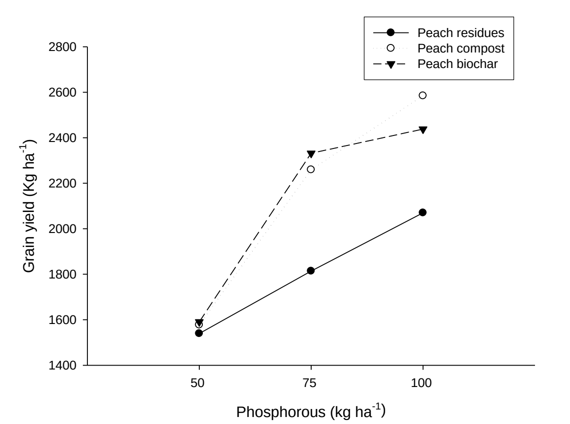

Fig. 2. Interaction between organic sources and P levels

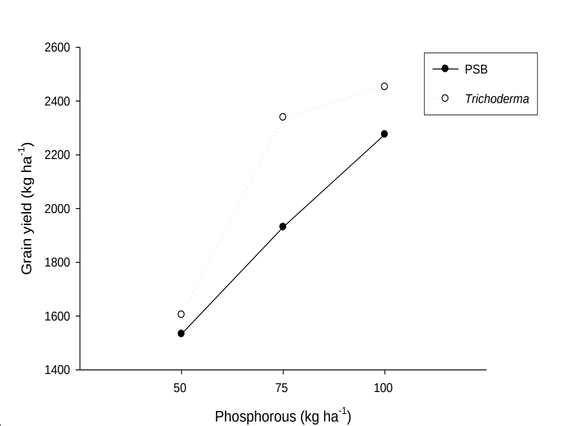

Fig. 3. Interaction between beneficial microbes and P levels

Y x P, Y x OS x BM x PL were found significant (data not shown). Interaction between OS x PL showed that highest seed yield was produced by incorporation of peach compost amendments and P level @ 100 kg per ha followed by biochar and coupled with 100 kg P per ha (Fig.2). Interaction between BM x PL revealed that maximum seed yield was produced by *Trichoderma* along with 100 kg P per ha followed by the *Trichoderma* with P application @ 75 kg per ha (Fig. 3). Among the interaction of OS x BM x PL, maximum seed yield was recorded with the application of compost with *Trichoderma* along with 100 kg P per ha followed by peach biochar with *Trichoderma* and 100 kg P per ha. Imran (2018) obtained highest maize grain yield with highest level of P (100 kg/ ha) along with organic matter amendments and beneficial microbes with advantage of improvement in soil health.

Economic evaluation

Profitability and economic analysis was done for organic sources, P levels and beneficial microbes independently considering the prevailing cost incurred.

Profitability of organic sources

Highest net returns and value cost ratio for seed in year one were obtained with peach biochar having value in PKRs 69,586 per ha and 6.44 followed by peach compost PKRs 59,126 per ha and 5.66, respectively (Table 3). The lowest net returns (PKRs 34,583/ha) and VCR (4.19) were associated with peach residues. In year two, maximum net returns (PKRs 40,167/ha) and value cost ratio (3.50) were obtained with peach compost followed by peach biochar with net returns (PKRs 33,535/ ha) and value cost ratio (2.73). Minimum net returns (PKRs 27,473/ ha) were recorded by peach residues, but value cost ratio was slightly higher (2.89) than peach residues. When combined over the two years, net returns (PKRs 62,082/ha), were highest in peach biochar followed by peach compost (PKRs 60,168/ ha), whereas least net returns (PKR 41,548/ ha) were with peach residues. The VCR was highest in peach compost amendment (5.48) among the organic sources followed by peach biochar (5.37), while the least (4.67) in peach residues incorporated plots.

Profitability of phosphorous

In year one, maximum net returns in PKRs 72,521 per ha were attained by soybean plots treated with 100 kg P per ha followed by 75 kg P per ha (PKRs 65,366 per ha), whereas minimum (31,272 PKR/ha) was with 50 kg per ha (Table 4). The VCR was higher in 75 kg P per ha treated plots (8.30) followed by 100 kg P per ha (6.91) and 50 kg P per ha was the least (5.96) among all the P levels. In year two, highest net returns (PKRs 80,532/ ha) was achieved by P treated at the rate of 100 kg P per ha followed by P at the rate of 75 kg per ha (PKRs 63,550/ ha) and minimum (PKRs 29,887/ ha) with 50 kg per ha. Highest VCR value was given by P at the rate of75 kg per ha followed by 100 kg P per ha (7.67). When combined over the two years, maximum net returns (PKRs 76,528/ha) were gained with P at the rate of 100 kg per ha followed by 75 kg P per ha (PKRs 64459/ha), although least (PKRs 30580/ha) were with 50 kg P per ha. The least value cost ratio with lowest P rate (5.8) was reasonably increased to 8.2 as P levels increased to 75 kg per ha and then decreased to 7.3 at 100 kg P per ha.

Table 2. Profitability (PKRs/ha) of soybean cultivation on account of incorporation of organic sources, phosphorus application and beneficial microbes (data pooled for two years)

Treatment	Seed value	Soybean straw value	Total value	Cost of respective treatment	Increase over control	Net returns	Value cost ratio*
Organic sources							
Control	51977	22607	74584	-	-	-	-
Peach Residues	101232	23780	125012	8880	50428	41548	4.67
Peach Compost	119859	25858	145717	10965	71133	60168	5.48
Peach Biochar	118717	29499	148216	11550	73632	62082	5.37
Phosphorus levels							
Control	51977	22607	74584				
50 kg/ha	87867	22547	110414	5250	35830	30580	5.8
75 kg/ha	119552	27366	146918	7875	72334	64459	8.2
100 kg/ha	132389	29223	161612	10500	87028	76528	7.3
Beneficial microbes							
Control	51977	22607	74584	-	-	-	-
PSB	107141	25418	132559	5280	57975	52695	9.98
Trichoderma	119397	27340	146737	4700	72153	67453	14.35

*Retail price of 1 kg soybean grain in PKRs = 56.00; Retail price of 1 kg soybean straw in PKRs = 04.00; Material of peach residues (peach leaves, expire fruits, stones, twigs, etc.) for compost and biochar preparation was available without any cost at the peach orchards during peach season (April- August) although the cost of organic sources was for transportation, labor cost and other expenses; Residues cost in PKRs = 8,250.00 and 9,510.00; Compost cost in PKRs = 10,440.00 and 11,490.00; Biochar cost in PKRs = 10,800.00 and 12,300.00 was in each year of study (2016 and 2017); Price for 1 kg phosphorous in PKRs = 105.00; Price of Trichoderma for 1 hectare in PKRs = 4,700.00; Price of PSB for 1 hectare in PKRs = 5,280.00; * Value cost ratio determined using net returns values.*

Profitability of beneficial microbes

Economic analysis brought out that net returns (PKRs 67,248/ ha) were higher with *Trichoderma* inoculated plots (14.31) than PSB (9.71). In year two, maximum net returns were attained with followed by PSB (PKRs 51295/ha) in year one (Table 5). The value cost ratio (VCR) was greater with *Trichoderma* inoculation *Trichoderma* (PKRs 67655/ ha) followed by PSB (PKRs 54,095/ha). Greater VCR

(14.39) was gained with *Trichoderma* inoculation tailed by PSB (10.25). When combined over the two years, average pronounced net returns (PKRs 67,453/ha) were attained with *Trichoderma* followed by PSB (PKRs 62,695/ ha). Comparison of average value cost ratio of both years revealed greater value (14.35) with *Trichoderma* followed by PSB (9.98).

Seed yield and profitability was much higher with biochar amendments along with P at the rate of 75 kg per ha along with *Trichoderma* inoculation. It is suggested that income of the farmers can be enhanced with biochar amendment coupled with P at the rate of 75 kg P per ha and *Trichoderma* incorporation.

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Evaluation of Sulfentrazone in Comparison to Other Herbicides to Control Major Weeds of Soybean

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ABSTRACT

An experiment was conducted during kharif *2012 and 2013 to evaluate the bio-efficacy of sulfentrazone 39.6 per cent w/w (48 % w/v) SC as pre-emergence herbicide for weed control and higher productivity of soybean under Vertisols of Malwa region. The experiment was laid out in randomized block design with three replications. The results over two years revealed that the application of herbicides significantly minimized the weeds during the critical period of crop-weed competition. The sulfentrazone was also found to be effective against sedges and maintained more than 60 per cent weed control efficiency. The yield reduction due to weeds was 55.95 per cent. Among the different treatments, hand weeding twice had substantial weed control efficiency, which was reflected in higher soybean yield. Among herbicidal treatments, the maximum weed control efficiency and highest yield was with sulfentrazone @ 480 g a i per ha as pre-emergence and remained at par with imazethapyr @ 100 g a i per ha applied as post-emergence and sulfentrazone @ 360 g a i per ha and all these treatments were significantly superior to pendimethalin @ 1 kg a i per ha and chlorimuron ethyl @ 9 g a i per ha. The economic optimum of sulfentrazone application was to be 470 g a i per ha with the yield level of 2,283 kg per ha. The pre-emergence and post-emergence herbicides were equally effective to control the weeds in soybean.*

Key words: Soybean, weeds, weed control efficiency

Weed management is essential for any current system of agricultural crop production, especially for large monoculture areas, which exert high pressure on crop environment. Soybean is among the largest monocultured crop registered worldwide (Vivian *et al.*, 2013). The leading countries of production are United States, Brazil and Argentina, accounting for more than 70 per cent of the total cultivated area. Along with China and India, these five countries represent 90 per cent of world production of soybean. Meanwhile, weeds are considered to be the number one problem adversely affecting productivity in major soybean producing countries. Even with advanced technologies, producers note high losses due to incidence of weeds. According to estimates, weeds, alone,

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cause an average reduction of 37 per cent in soybean yield, while other fungal diseases and agricultural pests account for 22 per cent of losses (Oerke and Dehne, 2004).

Sulfentrazone is a protoporphyrinogen oxidase (PPO) inhibitor herbicide (Group 14) of the triazinone class (Mallory-Smith and Retzinger, 2003). Sulfentrazone may be applied as pre-emergence (PE) and provides residual control of both broadleaf and grassy weeds (Dayan *et al*. 1996; Niekamp *et al*., 1999; Dirks *et al*., 2000). Although excellent weed control (90 %) has been reported for sulfentrazone, however, level of control was dependent upon weed community composition (Walsh *et al*., 2015). The objective of this study was to evaluate weed control using sulfentrazone applied as pre-emergence, using imazethapyr post-emergence (PoE), pendimethalin PE and chlorimuron ethyl PE as an standard comparator, in soybean under agro-climatic conditions of Malawa region of Madhya Pradesh.

MATERIAL AND METHODS

An experiment was conducted during *kharif* 2012 and 2013 at Research farm of ICAR- Indian Institute of Soybean Research, Indore, situated at latitude and longitude of 22° 44' N and 75° 50' E with mean sea level of 550 m, to evaluate the bio-efficacy of Sulfentrazone 39.6 per cent w/w (48 % w/v) SC as PE herbicide for weed control in soybean. The soil belonged to fine, montmorrillonitic, isothermic family of Typic Haplusterts. It analyzed: pH 7.8, EC 0.14 dS per m, organic carbon 0.3 per cent, available phosphorus 10.1 kg per ha and potassium 280 kg per ha. The experiment consisted of nine treatments, namely, four levels of sulfentrazone as PE (240, 300, 360 and 480 g a i/ha); three check herbicides (imazethapyr @ 100 g a i/ha and chlorimuron ethyl @ 9 g a i/ha as PoE and Pendimethalin @ 1 kg a i/ha as PE) along with hand weeding twice at 20 and 40 days after sowing and a weedy check (Table 1). All the nine treatments were replicated thrice in randomized block design. Soybean "JS 95-60" was sown on July 5st, 2012 and June 21st, 2013 and harvested on October 8th, 2012 and September 19th, 2013. Soybean was raised following the recommended package of practices. Weed count and their dry biomass were recorded at 30, 45 and 60 days after sowing. Weed control efficiency (WCE) of each treatment was determined by using the standard formula (WCE = dry weight of weeds in control - dry weigh of weeds in treatment/ dry weight of weeds in control x 100). Yield and yield attributes were recorded at the time of harvesting. The physical maximum level of sulfentrazone was determined by using the quadratic equation - $Y= a + bx - cx^2$. The data on different parameters of weeds were subjected to angular transformation for statistical analysis and were used after change of scale (240=2.40).

RESULTS AND DISCUSSION

During the investigation, soybean was infested mainly with *Alternenthera* spp., *Digera arvensis*, *Alternenthera* spp., *Digera arvensis*, and *Euphorbia geniculata* among broad leaf weeds and *Dinebra arabica, Digitaria sanguinalis* and *Echinocloa* spp. among grassy weeds *Cochoru* spp and *Cyperus rotundus* (sedges).

The highest weed control efficiency was observed at 30, 45 and 60 days after sowing (DAS) with twice hand weeding. The weed control efficiency under sulfentrazone at all these three stages of observations was higher than that recorded under check herbicides chlorimuron ethyl and pendimethalin, but remained at par with imazethapyr. The application of sulfentrazone was also found to be very effective to control the sedges as evidenced from the weed control efficiency data (Table 1, 2 and 3). The variation in weed control efficiency in different treatments is the function of weed counts and their dry matter recorded under these treatments. The dry matter of weeds followed the same trend as was observed in weed control efficiency. However, the number of weeds and their dry matter is not linearly correlated because the dry matter accumulation depends on the size, age of weed species at different stages of crop growth. The weed control efficiency decreased as the age of crop advanced. Earlier research (Vidrine *et al.,* 1996; Kimberly *et al*., 2015: and Walsh *et al.*, 2015) as well reported that sulfentrazone may be used as a valuable weed control option in soybean. Krausz and Young (2003) stipulated that sulfentrazone alone controlled giant foxtail 97 to 100 per cent, yellow nutsedge 96 to 98 per cent, common water hemp 97 to 98 per cent, common cocklebur 91 to 94 per cent, and ivyleaf morningglory 100 per cent. Sulfentrazone was also reported to provide the highest control of yellow nutsedge (Dayan *et al.,* 1996; Grichar *et al.,* 2003). This could be inferred that such a good control over sedges which provide competition for relatively longer period showed increased WCE due to sulfentrazone in the present study also which improved the yields.

Results revealed that soybean plant height remained unaffected due to various treatments (Table 4). However, the marginally higher plant height was observed in control. This could be the effect of congestion at canopy level due to presence of weeds that pushed upward growth of soybean plants. The highest number of branches was noted with hand weeding twice at 20 and 40 days after sowing and remained at par with all the treatments except control, sulfentrazone @ 240, 300 and 360 g a i per ha as PE. The maximum pods per plant were also observed with hand weeding twice and showed non-significant difference with imazethapyr @ 100 g a i per ha and sulfentrazone @ 480 g a i per ha. The maximum seed index was also recorded with two hand weedings, which was significantly higher than control. The magnitude of soybean yield reduction was to the extent of 56 per cent when weeds were not controlled (700 kg/ha). Significantly highest seed yield was recorded with two hand weedings (Table 4). The yield enhancement due to different weed control treatments ranged between 39.6 and 127.0 per cent. Among the herbicides, application of

Table 1. Effect of different levels of sulfentrazone on weed parameters at 30 days after sowing in soybean (pooled data for two years)

Treatment	Dicot		WCE (%)	Monocot		WCE (%)	Sedges		WCE (%)	Total		WCE (%)
	Count (m²)	Dry matter (g/m²)		Count (m²)	Dry matter (g/m²)		Count (m²)	Dry matter (g/m²)		Count (m²)	Dry matter (g/m²)	
Sulfentrazone @ 240 g ai/ha	2.91 (7.84)	1.67	63.28	3.34 (10.99)	2.07	66.45	1.79 (2.55)	0.78	75.36	4.64 (21.38)	4.54	68.69
Sulfentrazone @ 300 g ai/ha	2.62 (6.17)	1.44	68.91	3.24 (10.44)	1.80	70.76	1.36 (1.10)	0.44	86.36	4.22 (17.71)	3.64	74.88
Sulfentrazone @ 360 g ai/ha	1.69 (2.33)	0.79	83.38	2.61 (6.29)	1.34	78.44	0.35 (0.50)	0.00	100.00	3.00 (8.62)	2.15	85.49
Sulfentrazone @ 480 g ai/ha	1.56 (1.84)	0.67	87.92	2.21 (4.27)	0.92	85.07	0.35 (0.50)	0.00	100.00	2.60 (6.10)	1.65	88.84
Imazathapyr @ 100 g i/ha	1.98 (3.60)	0.67	87.58	2.75 (7.74)	0.87	85.76	1.66 (2.15)	0.60	83.02	3.68 (13.49)	2.13	85.11
Chlorimuron ethyl @ 9 g ai/ha	2.38 (5.38)	1.11	78.34	4.18 (17.06)	6.15	12.73	2.21 (4.80)	1.53	56.90	5.29 (27.23)	8.75	40.15
Pendimethalin @ 1 kg ai/ha	2.24 (5.95)	1.51	66.71	1.91 (2.95)	1.03	83.14	2.30 (5.51)	1.90	46.45	3.86 (14.41)	7.20	68.10
Hand weeding twice	0.35 (0.50)	0.00	100.0	0.85 (0.00)	0.00	100.00	0.35 (0.50)	0.00	100.00	0.35 (0.50)	0.00	100.00
Untreated control	3.95 (15.00)	5.10		4.77 (22.33)	6.15		3.06 (8.84)	3.33		6.82 (46.17)	14.55	
SEm (±)	1.675	0.63		3.46	0.86		0.65	0.49		2.70	1.01	
CD (P = 0.05)	**4.88**	**2.22**		**7.34**	**2.53**		**1.97**	**1.44**		**8.09**	**2.88**	

** Square root transformed value of (x+1) used for statistical analysis; ** Data in parenthesis are original values*

Table 2. Effect of different levels of sulfentrazone on weed parameters at 45 days after sowing in soybean (pooled data for two years)

Treatment	Dicot		WCE	Monocot		WCE	Sedges		WCE	Total		WCE
	Count (m^2)	Dry matter (g/m^2)	(%)	Count (m^2)	Dry matter (g/m^2)	(%)	Count (m^2)	Dry matter (g/m^2)	%	Count (m^2)	Dry matter (g/m^2)	(%)
Sulfentrazone @ 240 g ai/ha	2.87 (7.57)	3.21	63.44	3.88 (14.96)	4.73	56.61	1.92 (3.05)	1.20	78.79	5.10 (25.57)	9.17	63.24
Sulfentrazone @ 300 g ai/ha	2.74 (6.68)	2.80	68.13	3.39 (11.39)	3.64	66.65	1.45 (1.65)	0.81	90.58	4.52 (19.72)	7.28	70.99
Sulfentrazone @ 360 g ai/ha	2.29 (4.50)	1.78	79.68	2.57 (5.94)	2.33	78.88	1.15 (1.65)	0.32	96.28	3.40 (11.09)	7.85	80.15
Sulfentrazone @ 480 g ai/ha	2.06 (3.50)	1.51	82.75	2.37 (5.00)	2.20	80.07	0.85 (0.00)	0.00	100.00	3.00 (8.50)	4.17	82.78
Imazathapyr @ 100 g i/ha	2.51 (6.03)	1.47	83.23	2.37 (5.01)	1.79	83.71	1.58 (1.88)	0.88	89.32	3.65 (12.91)	4.14	83.36
Chlorimuron ethyl @ 9 g ai/ha	1.87 (2.77)	2.30	73.72	6.61 (22.06)	9.21	15.70	2.70 (7.18)	3.07	55.03	5.72 (32.00)	14.65	41.00
Pendimethalin @ 1 kg ai/ha	3.48 (11.67)	3.67	58.29	2.41 (5.11)	3.28	69.98	2.45 (6.62)	3.25	62.79	4.88 (23.39)	10.15	60.40
Hand weeding twice	0.85 (0.00)	0.00	100.00	0.85 (0.00)	0.00	100.00	0.85 (0.00)	0.00	100.00	0.85 (0.00)	0.00	100.00
Untreated control	4.38 (18.52)	8.77		5.16 (26.17)	10.91		3.44 (11.77)	5.18		7.54 (56.46)	24.85	
SEm (±)	1.49	0.49		2.14	1.30		0.72	0.48		2.22	1.41	
CD (P = 0.05)	**4.48**	**1.40**		**6.41**	**3.80**		**2.18**	**1.29**		**6.67**	**3.81**	

** Square root transformed value of (x+1) used for statistical analysis; ** Data in parenthesis are original values*

Table 3. Effect of different levels of sulfentrazone on weed parameters at 60 days after sowing in soybean (pooled data for two years)

Treatment	Dicot		WCE (%)	Monocot		WCE (%)	Sedges		WCE %	Total		WCE (%)
	Count (m^2)	Dry matter (g/m^2)		Count (m^2)	Dry matter (g/m^2)		Count (m^2)	Dry matter (g/m^2)		Count (m^2)	Dry matter (g/m^2)	
Sulfentrazone @ 240 g ai/ha	3.24 (9.93)	5.24	58.04	4.15 (16.62)	8.30	48.11	2.27 (4.84)	3.00	51.66	5.63 (31.39)	21.63	54.25
Sulfentrazone @ 300 g ai/ha	3.23 (9.77)	4.66	62.85	3.72 (13.51)	7.24	54.99	1.70 (2.76)	1.86	85.99	5.15 (26.04)	13.79	61.99
Sulfentrazone @ 360 g ai/ha	2.57 6.14)	3.22	74.19	3.45 (12.07)	5.44	66.89	1.45 (1.55)	1.05	92.09	4.45 (14.75)	10.43	70.63
Sulfentrazone @ 480 g ai/ha	2.06 (3.50)	2.98	76.08	3.48 (12.39)	4.90	70.20	1.10 (0.50)	0.34	97.48	4.07 (16.37)	8.61	75.45
Imazathapyr @ 100 g i/ha	2.46 (5.42)	2.89	77.18	3.48 (8.50)	4.12	74.12	1.92 (2.99)	1.82	66.95	4.18 (16.91)	8.84	75.33
Chlorimuron ethyl @ 9 g ai/ha	2.41 (5.20)	3.54	71.61	4.50 (19.56)	14.97	10.25	2.77 (8.22)	5.38	30.58	5.81 (32.98)	23.90	32.89
Pendimethalin @ 1 kg ai/ha	3.67 (12.89)	5.83	53.30	2.69 (6.50)	5.62	65.30	2.50 (7.77)	5.26	60.39	5.25 (27.15)	16.81	54.63
Hand weeding twice	1.51 (2.17)	0.11	99.11	0.85 (0.00)	0.00	100.00	0.85 (0.00)	0.00	100.00	1.51 (2.17)	0.11	99.65
Untreated control	4.46 (19.43)	12.46		4.97 (23.88)	16.13		3.29 (11.43)	7.41	0.00	7.42 (54.75)	36.00	
SEm (±)	1.78	0.61		1.97	1.40		0.54	0.58		2.16	1.84	
CD (P = 0.05)	**5.35**	**1.65**		**5.90**	**4.11**		**1.64**	**1.46**		**6.47**	**4.98**	

** Square root transformed value of (x+1) used for statistical analysis; ** Data in parenthesis are original values*

Table 4. Effect of different levels of sulfentrazone on yield and yield attributes (pooled data for two years)

Treatment	Plant height (cm)	Bran-ches/ plant	Pods/ plant	Seed index (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	HI (%)
Sulfentrazone @ 240 g ai/ha	43.97	1.50	15.10	11.44	977	1212	43.22
Sulfentrazone @ 300 g ai/ha	42.77	1.59	15.55	11.59	1100	1362	43.02
Sulfentrazone @ 360 g ai/ha	43.27	1.57	16.55	12.03	1283	1526	43.57
Sulfentrazone @ 480 g ai/ha	43.60	2.10	18.40	12.58	1338	1602	43.41
Imazethapyr @ 100 g i/ha	41.77	1.89	17.38	12.39	1311	1576	43.40
Chlorimuron ethyl @ 9 g ai/ha	41.87	1.93	15.84	11.81	988	1223	43.41
Pendimethalin @ 1 kg ai/ha	42.94	1.87	15.17	11.97	1101	1355	43.16
Two hand weeding at 20 and 40 DAS	44.04	2.33	20.57	12.88	1589	1929	43.44
Untreated control	45.44	1.33	11.14	10.00	700	977	40.21
SEm (±)	1.24	0.23	1.11	0.56	36.68	84.14	0.49
CD (P = 0.05)	**NS**	**0.66**	**3.19**	**1.61**	**105.71**	**242.50**	**1.41**

sulfentrazone @ 480 g a i per ha was better (1,285 kg/ha), which remained at par with imazethapyr @ 100 g a i per ha and sulfentrazone @ 360 g a i per ha. The higher levels of sulfentrazone (360 and 480 g a i/ha) were found to be superior than check herbicides pendimethalin and chlorimuron ethyl. Application of sulfentrazone enhanced the seed yield to the tune of 39.6 to 91.1 per cent over weedy check, 11.3 to 35.4 per cent over chlorimuron ethyl @ 9 g a i per ha and 16.5 to 21.5 per cent over Pendimethalin @ 1 kg a i per ha in the two respective seasons. The physical maximum level of sulfentrazone was worked out to be 504 g a i per ha with the yield of 2,290 kg per ha ($Y = 937.31 + 535.78x - 53.06x^2$). The economic optimum level of sulfentrazone application was found to be 470 g a i per ha with corresponding yield of 2,283 kg per ha. Significantly highest straw yield was noted with two hand weedings. The highest harvest index was recorded with sulfentrazone @ 360 g a i per ha and remained at par with all the treatments except control. The adequate weed control during critical period of crop-weed competition offered better utilization of natural resources and applied inputs particularly nutrients enhanced the plant growth, accumulation of plant dry matter and yield attributes and yield. Vidrine *et al.* (1996) concluded that soybean yield was greater in sulfentrazone as compared to other treatments which is in conformity of the result of the present study.

On the basis of two years results it could be concluded that the use of sulfentrazone @ 360 g a i per ha as pre-emergence herbicide provided a good option for weed management in soybean.

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Impact of Foliar Spray of Nutrients on Yield and Economics of Soybean (*Glycine max* L. Merrill)

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ABSTRACT

A field experiment was conducted to evaluate the influence of foliar spray of nutrients on yield and economics of soybean cv. *JS 95-60 on Vertisols during* kharif *seasons of 2016 and 2017 at Agricultural Research Station, Ummedganj Farm, Kota. The results revealed that foliar spray of 2 per cent DAP at flower initiation stage of crop growth resulted in significantly higher number of pods per plant (32.44), seed index grain yield (1,544 kg/ha), net returns (Rs 21, 685/ha) and B:C Ratio (1.94). It was on par with RDF + 2 per cent urea and RDF + Zinc chillated 0.5 per cent spray.*

Key words: Economics, foliar spray, nutrients, soybean, yield

Soybean {*Glycine max* (L.) Merrill} with its 40-42 per cent protein and 18-22 per cent oil has already emerged as one of the major oil seed crop in India. It is also highly adaptable to varying soil and climatic conditions, giving fairly high yields compared to other pulse crops. Hence, soybean cultivation has to be popularized to meet the twin objectives of reducing the protein malnutrition and increasing the oil production. Among the factors responsible for low productivity, inadequate and skewed nutrition management plays an important role (Vyas and Khandwe, 2013). The deficiency of any nutrient during reproductive stage can be aptly managed through foliar nutrition, which is the fastest way to boost up crop growth as it facilitates the nutrient availability during pod fill stage. Under rainfed condition when the availability of moisture becomes scarce, the application of fertilizers as foliar spray resulted in efficient absorption and usage which are economical in respect the other methods of fertilizer application. Flower senescence and improper pod filling are the major drawbacks in soybean, which can be managed through foliar application of nutrients.

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In view of above points, the present investigation was carried out to find out the influence of foliar spray of nutrients on yield and economics of soybean.

MATERIAL AND METHODS

A field experiment was carried out during *kharif* sessions of 2016 and 2017 under AICRP on Soybean at Agricultural Research Station, Kota (26^o North latitude, 76^o-6' East longitude and 260 m above mean sea level), Rajasthan. The soil of the experimental field was Vertisols having bulk density - 1.52 Mg per m^3, pH - 7.78 and cation exchange capacity - 35 C mol per kg. The soil had a very low infiltration rate (0.25 cm/hr) on surface but at deeper layers (1.2 to 1.5 m) was impermeable. The potential moisture retention capacity of soil was 120 mm of water at 1 m soil depth. The soil of the experimental field was medium in organic carbon 6.3 g per kg, available nitrogen (317 kg/ha), available phosphorus (22.4 kg/ha) and available potash (308 kg K_2O /ha). The experiment was laid out in a randomized block design with three replications. Nine treatments tried were combination of recommended dose of fertilizers (RDF) as basal with foliar spray of urea 2 per cent, diammonium phosphate (DAP) 2 per cent, muriate of potash (MOP) 0.5 per cent NPK (19:19:19) 2 per cent, molybdenum 0.1 per cent, boron 0.2 per cent, zinc chillated 0.5 per cent and water (control) at R_3 (pod initiation) growth stage of soybean. Soybean variety JS 95-60 was sown on 5^{th} and 4^{th} July of 2016 and 2017 and harvested on 26^{th} and 27^{th} September of 2016 and 2017, respectively using 80 kg per ha seed rate. Seed treatment by carbendazim @ 1 g per kg seed followed by seed inoculated with *Bradyrhizobium japonicum* and *Bacillus subtalis* (PSB) @ 5 g per kg seed of each culture prior to sowing. The recommended dose of fertilizers (20: 40: 40 kg/ha of $N:P_2O^5:K_2O$) was applied as basal. DAP was dissolved in the water for 8-12 hours, filtered and then sprayed on stading crop at R3 stage. Other nutrients were also sprayed at R3 stage as per treatments. The standard agronomic practices for the zone for raising the crop were followed. Weed control was effected using imazethapyr (10 % SL) @ 75 g a. i. per ha at 15-20 DAS and later on weeds especially, *Celosia argentia* were uprooted by hand to raise weed free crop. The herbicides were applied with hand operated knapsack sprayer using spray volume of 500 liter water per ha. All the plant protection measures were adopted to ensure healthy crop. The effective rainfall observed were 1175.6 mm and 508 mm during growing seasons of 2016 and 2017, respectively.

RESULTS AND DISCUSSION

Growth parameters

The dry matter accumulation at 30 and 45 days after sowing (DAS), crop growth and relative growth rates at both the stages remained uninfluenced due to imparted treatments (Table 1). Application of RDF + DAP @ 2 per cent spray at pod initiation stage increased dry matter production per plant (17.87 g/plant) at 60 DAS and rain use efficiency

Table 1. Effect of foliar spray of nutrients on the plant dry weight, CGR, RGR and RUE of soybean (pooled data of 2 years)

Treatment	Plant dry weight (g/plant)			CGR ($g/m^2/day$)		RGR (g/g/day)		RUE (kg/ ha-mm)
	30 DAS	45 DAS	60 DAS	30-45 DAS	45-60 DAS	30-45 DAS	45-60 DAS	
RDF + water spray at pod initiation	1.98	5.39	12.97	7.59	16.83	0.029	0.025	1.865
RDF + Urea 2% spray at pod initiation	1.99	5.53	14.32	7.84	19.52	0.029	0.027	1.970
RDF + DAP 2% spray at pod initiation	2.15	6.46	17.87	9.57	25.33	0.032	0.029	2.145
RDF + MOP 0.5% at pod initiation	2.00	5.82	15.13	8.47	20.69	0.031	0.028	1.990
RDF + 19:19:19 (NPK) 2% at pod initiation	2.06	6.05	15.90	8.88	21.87	0.031	0.028	2.015
RDF + Molybdenum 0.1% at pod initiation	2.09	6.16	16.30	9.03	22.52	0.031	0.028	2.065
RDF + Boron 0.2% at pod initiation	2.02	5.91	15.50	8.64	21.30	0.031	0.028	1.990
RDF +Zinc chillated 0.5% at pod initiation	2.13	6.32	17.02	9.30	23.76	0.032	0.029	2.110
RDF only	1.98	5.05	11.80	6.82	14.99	0.027	0.025	1.605
SEm (±)	0.08	0.30	0.69	0.62	1.62	0.002	0.002	0.095
CD (P=0.05)	**NS**	**NS**	**2.07**	**NS**	**NS**	**NS**	**NS**	**0.29**

(2.145 kg/ha mm), which was highest by 51.4 and 33.6 per cent as compared to RDF only. However, RDF + DAP @ 2 per cent, RDF + zinc chillated @ 0.5 per cent, RDF + molybdenum @ 0.1 per cent, RDF + 19:19:19 (NPK) @ 2 per cent spray at pod initiation stage remained statistically at par with each other in relation to dry matter production per plant at 60 DAS and rain use efficiency. Foliar spray of 2 per cent DAP might have supplied nitrogen and phosphorus at the fag-end of the crop resulted in effective translocation of the nutrients from one plant part to other. This result is in confirmation with the report of by Solaiappan *et al.* (2002) in rainfed red gram.

Yield attributes

Yield attributes namely branches and pods per plant differed significantly due to different treatments (Table 2). The maximum branches per plant (1.80) and pods per plant (32.44) were recorded with the application of RDF + DAP @ 2 per cent

Table 2. Effect of foliar spray of nutrients on the yield parameters, yield and economics of soybean (pooled data of 2 years)

Treatment	Branches (No/ plant)	Pods (No/ Plant)	Seed index	Seed yield (kg/ha)	Straw yield (kg/ha)	HI (%)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
RDF + water spray at pod initiation	1.37	24.24	10.77	1340	2175	38.13	22935	38968	16033	1.70
RDF + Urea 2% spray at pod initiation	1.47	26.70	10.85	1407	2279	38.19	22992	40903	17911	1.78
RDF + DAP 2% spray at pod initiation	1.87	32.44	11.60	1545	2488	38.29	23184	44869	21685	1.94
RDF + MOP 0.5% at pod initiation	1.50	27.33	10.99	1428	2310	38.20	22979	41491	18512	1.81
RDF + 19:19:19 (NPK) 2% at pod initiation	1.67	28.10	11.23	1446	2339	38.23	23082	42062	18980	1.83
RDF + Molybdenum 0.1% at pod initiation	1.74	30.34	11.33	1470	2376	38.25	25735	42769	17034	1.66
RDF + Boron 0.2% at pod initiation	1.54	27.60	11.02	1431	2315	38.22	23035	41584	18549	1.81
RDF +Zinc chillated 0.5% at pod initiation	1.80	30.87	11.40	1516	2449	38.27	24935	44096	19161	1.77
RDF only	1.23	19.90	10.58	1159	1903	37.84	22557	33658	11101	1.49
SEm (±)	0.11	1.93	0.20	68.77	110.39	0.09	0.00	1996.64	1996.64	0.09
CD (P=0.05)	**0.34**	**5.86**	**NS**	**208.73**	**335.02**	**NS**	**0.00**	**6056.13**	**6056.13**	**0.26**

followed by RDF + zinc chillated @ 0.5 per cent, RDF + molybdenum @ 0.1 per cent, RDF + 19:19:19 (NPK) @ 2 per cent spray at pod initiation stage as compared to RDF and RDF + water spray at pod initiation, respectively. However, RDF + DAP @ 2 per cent, RDF + MOP @ 0.5 per cent, RDF +molybdenum @ 0.1 per cent and RDF + 19:19:19 (NPK) @ 2 per cent spray at pod initiation stage remained statistically at par with each other in relation to branches per plant and pods per plant. Non-significant differences were observed in seed index due to different treatments. Lowest values of yield attributes were found with recommended dose of fertilizers only (RDF). These results are in agreement with the findings of Ganapathy *et al.* (2008) and Solaiappan *et al.* (2002).

Seed and straw yield

Pooled analysis for two years revealed that different treatments of foliar spray of nutrient at pod initiation stage with RDF had significant effect on seed and straw yield of soybean (Table 1). Application of RDF + DAP @ 2 per cent spray at pod initiation stage gave maximum seed yield (1,544 kg/ha) and straw yield (2,488 kg/ha) followed by RDF + zinc chillated @ 0.5 per cent, RDF + molybdenum @ 0.1 per cent, RDF + 19:19:19 (NPK) @ 2 per cent, RDF + urea @ 2 per cent and RDF + water spray at pod initiation stage but significantly higher than RDF only. Application of RDF + DAP @ 2 per cent spray at pod initiation stage enhanced the yields significantly by 33.3 and 30.8 per cent, respectively. The increased yield might be due to enhanced yield attributes like number of pods per plant and increased uptake of nutrients in soybean by effective translocation of nutrients from source to sink. The positive effect of P application increased seed yield as reported by Abbas *et al* (1994) in soybean and Mathan *et al* (1996) in black gram. The straw yield enhancement due to the different treatments might be due to continuous supply of nutrients which in turn increased the leaf area and dry matter production resulting in higher haulm yield. Similar result of increased straw yield by soil and foliar application of nutrients has been reported by Ghosh and Joseph (2008) in green gram.

Economics

Application of RDF + DAP @ 2 per cent spray at pod initiation stages of crop growth recorded higher gross returns (Rs. 44,869/ha) and net returns (Rs. 21,695/ha) followed by RDF + zinc chillate @ 0.5 per cent (Rs 44,096/ha and Rs 19,161/ha) and RDF +19:19:19 (NPK) @ 2 per cent (Rs 42,062 and Rs 18,980. RDF treatment (control) only recorded the least gross returns (Rs. 33,650/ha) and net returns (Rs. 11,101/ha). With respect of B:C ratio, foliar application of RDF + DAP @ 2 per cent spray at pod initiation stage of crop growth registered higher B:C ratio (1.94) followed by foliar application of RDF + 19:19:19 (NPK) @ 2 per cent spray at pod initiation stage of crop growth (1.83) and the lowest B:C ratio (1.49) was recorded under the RDF treatment. Similar results were reported earlier by Chandrasekhar and Bangarusamy (2003) and Yakadari and Ramesh 2002~~.~~

The results of two years investigation revealed that foliar application of 2 per cent DAP at pod initiation stage of crop growth in addition to RDF recorded improved yield parameters, yield and economic returns in soybean.

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Productivity of Soybean Varieties under Intercropping Culture with Corn in Egypt

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ABSTRACT

A field experiment was carried out at the Agricultural Experiments and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt, during 2016 and 2017 to evaluate competitive ability of some American and Egyptian soybean varieties for intercropping with corn to achieve high land usage with economic viability. Intercropping system adopted was alternating 2:2 ridge. The results showed significant effects of cropping systems on all soybean traits. Intercropping system caused significant reductions in seed yield compared with solid planting. Soybean varieties differed significantly in their productivity under cropping system. Intercropped American varieties (Dr-101, Corosy 79 and Custer) gave the highest productivity as benifited largly from shading of corn plants during the growing seasons compared with the other varieties. Among local soybean varieties, namely Giza 21, Giza 22 and Giza 83 tolerated adverse effects of shading of corn plants and had higher yield than others. American soybean varieties Dr-101, Corosy 79 and Custer, as well as, local soybean varieties Giza 21, Giza 22 and Giza 83 had higher land equivalent ratio and coefficient, system productivity index and relative crowding coefficient. Dominance analysis proved that soybean is a dominated component. The highest monetary advantage index was obtained by intercropping soybean varieties, Dr-101, Corosy 79, Custer, Giza 22 and Giza 21 with corn. Growing two ridges of soybean varieties, Dr-101, Corosy 79, Custer, Giza 22 and Giza 21 with corn variety Cairo 1 had higher productivity and profitability under Egyptian conditions.

Key words*:* Corn, competitive relationships, cropping systems, economic returns, soybean varieties

Recently, the practice of intercropping soybean [*Glycine max* (L.) Merrill] with corn (*Zea mays* L.), is common particularly amongst smallholder farmers, who have to optimize their limited land use in Egypt. Intercropping is regarded to be an important agronomic practice, given the high pressure of food security due to the

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already large and increasing population with limited and decreasing area of arable land. It is the best way to keep the area of soybeans without significant change in crop structure. Several studies (Sayed Galal and Metwally, 1982; Sayed Galal *et al*., 1984; El-Habbak, 1985; Sayed Galal and Metwally, 1986; El-Douby *et al*., 1996) have reported that soybean–corn intercropping is more productive than the individual sole crops.

There is much less agreement about the mechanisms of interspecific competition. Higher yields associated with intercropping occur when the component crops are complementary to each other, resulting in a more effective use of environmental resources (light, water and nutrients) compared to when grown alone. Higher yields have been documented for intercropping of beans and corn (Willey and Osiru, 1972). Various measures of the efficiency of intercropping systems relative to sole cropping were employed (Hiebesch and McCollum, 1987). Several indices such as land equivalent ratio (LER), relative yield (RY), relative crowding coefficient (RCC) and aggressivity (Agg), as well as, net returns and monetary advantage index (MAI) have been suggested to describe competition and economic advantage of intercropping compared with solid plantings (Layek *et al*., 2014).

The local soybean varieties have a wide range of maturity and diverse morphology. Apart from these, they are high yielding with good desirable agronomic characteristics under intercropping conditions (Metwally *et al*., 2009, 2012). Moreover, there are some American varieties of soybean were developed under solid plantings and it is of interest to investigate their performance when intercropped with corn. Accordingly, it is expected that these soybean varieties will respond differently to intercropping conditions in terms of growth and yield. It is known that intercropping of incompatible species can result in one crop completely suffocating the other; that is adverse effects (Abdel-Galil*et al*., 2014b). Therefore, the main objective of the present research was to evaluate competitive ability of some American and Egyptian soybean varieties for intercropping with corn to achieve high land usage and farmer's benefit under intercropped conditions.

MATERIALS AND METHODS

A two-year study was carried out at the Agricultural Experiments and Research Station, Faculty of Agriculture, Cairo University, Giza, Egypt, during 2016 and 2017 to evaluate competitive ability of some American and Egyptian soybean varieties for intercropping with corn to achieve high land usage and farmer's benefit. Ten soybean varieties were tested under solid and intercropping system with corn, *cv*. Cairo 1. Corn was planted in 11th and 4th April in 2016 and 2017, respectively. Soybean was sown one week later. Maturity date of the tested soybean varieties was determined under the experimental conditions (Table 1).

Corn variety Cairo 1 and American soybean varieties were kindly provided by Agronomy Department,

Table 1. Maturity group and date, origin and growth habit of the studied soybean varieties

Soybean varieties	Maturity group	Maturity duration under Egyptian conditions (days)	Origin	Growth habit
Clark 63	IV*	120	USA	Indeterminate
Columbus	III*	90	USA	Indeterminate
Custer	IV*	120	USA	Indeterminate
Corosy 79	II*	75	USA	Determinate
Dr-101	V*	145	USA	Determinate
Forrest	V*	125	USA	Indeterminate
Giza 21	IV**	120	Egypt	Indeterminate
Giza 22	IV**	120	Egypt	Indeterminate
Giza 35	III**	95	Egypt	Indeterminate
Giza 83	III**	95	Egypt	Indeterminate

* *American classification;* ** *Egyptian classification.*

Faculty of Agriculture, Cairo University, Egypt. While, local soybean varieties were kindly provided by Food Legumes Research Department, ARC, Egypt. Intercropping system adopted was alternating two corn ridges with two soybean ridges (2:2 intercropping system). Corn variety Cairo 1 was thinned to two plants at 40 cm between hills under intercropping and one plant at 30 cm between hills under solid plantings, respectively. Soybean was thinned to two plants at 15 and 20 cm between hills under intercropping and solid plantings, respectively. The experiment included twenty treatments which were the combinations of two cropping systems with ten soybean varieties. The treatments were laid out in split plot design with three replications. Cropping systems (intercropping and solid) were randomly assigned to the main plots and soybean varieties were allocated in sub-plots. The area of sub plot was 16.8 m^2, each plot consisted of 6 ridges, and each ridge was 4.0 m in length and 0.7 m in width. Solid plantings of both crops were sown according to technical recommendations and used to estimate competitive relationships. Normal recommended cultural practices were used for growing corn and soybean crops. Egyptian clover was the preceding winter crop in both seasons. The experimental soil texture was clay.

Data of yield per plant was recorded on ten guarded plants from each sub-plot. Yield per plot (kg) was weighted and converted to ton per ha.

The competitive relationship, namely Land equivalent ratio (LER) (Mead and Willey, 1980), System productivity index (SPI) (Odo, 1991), Land equivalent coefficient (LEC) (Adetiloye *et al*., 1983), Relative crowding coefficient (RCC) (De Wit, 1960) and Aggrecivity (Agg) (Willey, 1979) were worked out to discuss the results obtained during the investigation. These relationships were worked out as follows.

$LER = (Y_{ab} / Y_{aa}) + (Y_{ba} / Y_{bb})$.

$SPI = [(Y_{aa}/Y_{bb}) \times Y_{ba}]+Y_{ab}$.$LEC = (Y_{ab} / Y_{aa}) \times (Y_{ba} / Y_{bb})$.

$RCC\ (K_{total}) = K_a \times K_b$; $K_a = Y_{ab} \times Z_{ba} / [(Y_{aa} - Y_{ab}) \times Z_{ab}]$; $K_b = Y_{ba} \times Z_{ab} / [(Y_{bb} - Y_{ba}) \times Z_{ba}$.

$Agg_{ab} = [Y_{ab} / (Y_{aa} \times Z_{ab})] - [Y_{ba} / (Y_{bb} \times Z_{ba})]$;

$Agg_{ba} = [Y_{ba} / (Y_{bb} \times Z_{ba})] - [Y_{ab} /(Y_{aa} \times Z_{ab})]$

where, Y_{aa} = Pure stand yield of crop a (corn); Y_{bb} = Pure stand yield of crop b (soybean); Y_{ab} = Intercrop yield of crop a (corn); Y_{ba} = Intercrop yield of crop b (soybean); Z_{ab} = The respective proportion of crop a in the intercropping system (corn); Z_{ba} = The respective proportion of crop b in the intercropping system (soybean).

To evaluate the economic viability, total returns were calculated by multiplying yields of the component crops by their respective American and Egyptian prices. Monetary advantage index (MAI) was calculated from the yield of corn and soybean in order to measure the productivity and profitability of intercropping as compared to solid planting of the associated component crops. MAI was computed as MAI = (value of combined intercrops) × (LER – 1)/LER according to Willey (1979). Crop value in the systems was calculated by converting the Egyptian pound value (L.E., Egyptian currency; 1 USD = L.E. 18) to US dollars Monetary returns' values were estimated based on American (USDA, 2018) and Egyptian market prices of corn and soybean in 2018.

Analysis of variance of the obtained results of each season was performed. The homogeneity test was conducted of error mean squares and accordingly, the combined analysis of the two experimental seasons was also carried out. The measured variables were analyzed by ANOVA using MSTATC statistical package (Freed, 1991**)**. Mean comparisons were performed using the east significant differences (L.S.D) test with a significance level of 5 per cent (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

A. Corn grain yield

1. Cropping systems

Results indicated that intercropping systems had higher grain yield per plant than solid planting, but the reverse was true for grain yield per ha. Intercropping system significantly increased grain yield per plant by 9.08 per cent in the combined data across the two seasons (Table 2). These results revealed that alternating ridges (2:2) possessed growth advantages than corn solid planting, where corn plants were benefited greatly from environmental resources that reflected positively on grain yield per plant. As a result of intercropping, grain yield per ha was decreased by 8.46 per cent as compared with solid planting. These results may be due to corn plant population density under intercropping system reached 75

Table 2. Corn grain and soybean seed yield (combined data across the two seasons)

Soybean varieties	Corn grain yield (g/plant)			Corn grain yield (t/ha)			Soybean seed yield (g/plant)			Soybean seed yield (t/ha)		
	Inter	**Solid**	**Mean**	**Inter**	**Solid**	**Mean**	**Inter**	**Solid**	**Mean**	**Inter**	**Solid**	**Mean**
Clark 63	152.56	138.87	145.71	6.64	7.21	6.92	9.06	13.29	11.17	1.47	3.55	2.51
Columbus	150.67	138.87	144.77	6.59	7.21	6.90	9.77	12.25	11.01	1.51	3.03	2.27
Corosy 79	151.13	138.87	145.00	6.56	7.21	6.88	10.28	16.29	13.28	1.78	3.05	2.41
Custer	150.32	138.87	144.59	6.57	7.21	6.89	10.41	18.56	14.48	1.74	3.00	2.37
Dr-101	152.72	138.87	145.79	6.66	7.21	6.93	19.24	21.86	20.55	2.52	3.08	2.80
Forrest	152.77	138.87	145.82	6.63	7.21	6.92	8.91	17.94	13.42	1.56	3.78	2.67
Giza 21	149.89	138.87	144.38	6.51	7.21	6.86	14.83	20.43	17.63	1.71	3.32	2.51
Giza 22	150.77	138.87	144.82	6.56	7.21	6.88	15.60	21.31	18.45	1.74	3.57	2.65
Giza 35	153.14	138.87	146.00	6.71	7.21	6.96	15.32	20.92	18.12	1.24	3.44	2.34
Giza 83	151.02	138.87	144.94	6.61	7.21	6.91	15.48	19.60	17.54	1.63	3.36	2.49
Mean	**151.49**	**138.87**	**145.18**	**6.60**	**7.21**	**6.90**	**12.89**	**18.24**	**15.56**	**1.69**	**3.31**	**2.50**
F. test 0.05 Cropping systems			*			*			**			**
L.S.D. 0.05 Soybean varieties			**N.S.**			**N.S.**			**3.90**			**0.12**
L.S.D. 0.05 Interaction			**N.S.**			**N.S.**			**5.52**			**0.33**

** *Significance at a level of 1% of probability (p <0.01)*; * *Significance at a level of 5% of probability (0.01 =< p < 0.05); N.S. - Non-Significant (p >= 0.05)* per cent of that in solid planting. According to Wang *et al.* (2007), corn as tall crop absorbed major part of the light, whereas soybean as shorter crop received low amounts of light for photosynthesis. These results are in harmony with those obtained by Sayed Galal *et al.* (1984), Metwally *et al.* (2009) and Abdel Galil *et al.* (2014b), who showed that corn solid planting recorded lower grain yield per plant, but it recorded higher grain yield per unit area than intercropped corn with soybean.

2. Soybean varieties

Corn grain yields per plant and per ha were not affected by soybean varieties (Table 2). Obviously, genetic variation of soybean varieties is still not sufficient to exert significant impact in high yielding ability of corn variety Cairo 1. These results may be attributed to high ability of corn plant as C_4 plant of photosynthetic pathways to be grown successfully during growth and development, and hence all the investigated soybean cultivars exerted the same effects on corn plant under intercropping culture. This may be due to soybean varieties were grown in separate ridges under intercropping system (2:2). The results are in accordance with those obtained by Metwally *et al*. (2009), Abdel-Galil *et al*. (2014a) and Abdel-Wahab and Abd El-Rahman (2016), who demonstrated that grain yields per plant and per unit area were not affected by soybean varieties.

3. The interaction between cropping systems and soybean varieties

The interaction between cropping systems and soybean varieties did not influence affect grain yields significantly (Table 2). The data showed that each of these two factors act independently on grain yields. These results are in corroboration with those obtained by Metwally *et al*. (2009), who found that grain yield was not affected by cropping systems x soybean varieties.

B. Soybean seed yield

1. Cropping systems

The results (Table 2) indicated that intercropping system significantly decreased soybean seed yield per plant by 29.33 per cent and per ha by 48.94 per cent. These results could be due to adverse effects of intercropping system increased inter-specific competition between corn and soybean plants for basic growth resources (Olufajo, 1992) compared to soybean solid planting. These data reflected that 2:2 intercropping system formed unfavorable conditions for soybean growth and development that culminated in severe decrease in yield attributes of soybean as compared to soybean solid planting. These results gains support from those obtained by El-Douby *et al.* (1996), Shafik (2000), Metwally *et al.* (2003, 2012) and Abdel-Galil *et al*. (2014a**),** who showed that intercropping produced lesser seed yield compared with soybean solid planting.

2. Soybean varieties

Soybean varieties differed significantly for seed yields per plant and per ha (Table 2). American soybean variety, Dr-101 had higher seed yield per plant as compared to the other soybean varieties; may be on account of comparatively more efficient interception of solar radiation. However, local soybean varieties, namely Giza 22, Giza 35, Giza 21 and Giza 83 acquired second rank. While, American soybean varieties, namely Clark 63 and Columbus had lower seed yield per plant compared to the other soybean varieties. These results revealed that the genetic potential of the studied varieties interacted with environmental basic resources through duration of vegetative and reproductive stages that translated finally into seed yield. Generally, it seems that American soybean variety Dr-101 and all the local soybean varieties were able to utilize the available environmental resources more efficiently than others.

With respect to seed yield per ha, American soybean varieties Dr-101 and Forrest, as well as, local soybean variety Giza 22 recorded higher seed yield per ha compared to others. American soybean varieties (Clark 63, Corosy 79 and Custer), as well as, local soybean varieties (Giza 83 and Giza 21) occupied second rank. Conversely, American soybean variety Columbus and local soybean variety Giza 35 gave lower seed yield per ha compared with the other soybean varieties. Harmony between seed yield per plant and plot basis was not good, it may be due to seed size between soybean varieties and survival plants per ridge. According to El-Habbak (1985), Columbus soybean variety was more sensitive than Clark in some growth characters under Egyptian conditions. These results are in harmony with those obtained by Sayed Galal *et al*. (1984), Sayed Galal and Metwally (1986), Noureldin *et al.* (2002) and Metwally *et al.* (2012), who indicated that there were significant differences among intercropped soybean varieties.

3. *The interaction between cropping systems and soybean varieties*

Significant effects of the interaction between cropping systems and soybean varieties on seed yields per plant and per ha were observed (Table 2). Although seed yield per plant of American soybean variety Dr-101 and all local soybean varieties did not differ significantly under intercropping and solid cultures. But American soybean varieties Dr-101, Custer and Forrest, as well as, all the local soybean varieties had higher seed yield per plant compared with the other soybean varieties under solid plantings. Also, soybean varieties Dr-101 and local soybean varieties produced high seed yield per plant under intercropping system than others. These results may be due to genetic makeup of American soybean variety Dr-101 and all local soybean varieties that translated into suitable some morphological and anatomical characteristics which responded positively to environmental conditions (Table 1) and ultimately reflected positively on their seed yields.

Although seed yield per ha of soybean varieties decreased significantly as compared with solid planting, but American soybean varieties Dr-101, Corosy 79 and Custer, as well as, local soybean varieties Giza 22, Giza 21 and Giza 83 had higher seed yield per ha under intercropping system than others.

American soybean variety Dr-101 had the highest seed yield per ha than other ones (2.52 ton/ha). These results are in accordance with Metwally *et al*. (2012) and Gadallah and Selim (2016), who reported that soybean varieties responded deferentially to cropping systems.

C. Competitive relationships

Soybean varieties differed significantly for $RY_{soybean}$, LER, SPI, LEC, $K_{soybean}$, K_{total} and Agg whereas did not differ significantly for RY_{corn} and K_{corn} in the combined data across the two seasons (Table 3). Results indicated that intercropping American soybean varieties Dr-101, Custer and Corosy 79 with corn had higher $RY_{soybean}$ compared with the others. With respect to local soybean varieties, intercropping soybean varieties, Giza 21, Giza 22 and Giza 83 recorded higher $RY_{soybean}$ (without significant differences among them) than the other one. Meanwhile, the converse was true for intercropped American soybean varieties Clark 63 and Forrest, as well as, local soybean variety Giza 35. Accordingly, these results probably due to the fact that tested soybean varieties differed among them in their maturity duration (Table 1). These differences among the varieties could be attributed to their development for growth in different environmental conditions.

It is likely that the potential yield of American soybean variety Dr-101 depended on comparatively extended photoperiod due to longer maturity duration that reflected in adequate vegetative growth to tolerate shading effects of corn compared with others. Conversely, American soybean variety, Corosy 79 was the earliest maturing one and completed its life cycle quickly as compared with the other varieties. It seems that plants of American soybean variety Corosy 79 was developed for cooler climate of American conditions, which reflected on shorter vegetative growth phase and a substantially shorter reproductive phase under Egyptian conditions. This biological situation would be required to benefit greatly from basic growth resources particularly low day temperatures increased carbon dioxide assimilation rates and more photosynthates for plants of American soybean variety Corosy 79 in first of the season (spring). Moreover, plants of this variety could be utilized from corn shading during seed filling period through maintaining carbon dioxide assimilation rates that reflected on better translocation of available assimilates from source to sink during the summer season.

Also, it is likely that American soybean variety Custer was developed for cooler climate under American conditions. Accordingly, it is expected that corn shading effected on plants of this variety to increase stem and hypocotyl elongation rates at their leaves and extended growth and development stages of corn. Consequently, photorespiration rate of plants of American soybean variety Custer could be reduced as a result of their botanical characteristics that adapted with low light intensity. However, it was quite apparent from the data (Table 3) that the rest soybean varieties differed in their

Table 3. Competitive relationships of intercropped soybean varieties with corn (combined data across the two seasons)

Soybean varieties	RY_{corn}	$RY_{soybean}$	LER	SPI	LEC	RCC			Agg	
						K_{corn}	$K_{soybean}$	K_{total}	Agg_{corn}	$Agg_{soybean}$
Clark 63	0.92	0.41	1.33	9.62	0.38	11.64	0.70	8.23	+1.01	-1.01
Columbus	0.91	0.49	1.40	10.18	0.45	10.62	0.99	10.55	+0.83	-0.83
Corosy 79	0.91	0.58	1.49	10.76	0.53	10.09	1.40	14.14	+0.65	-0.65
Custer	0.91	0.58	1.49	10.75	0.52	10.26	1.38	14.17	+0.66	-0.66
Dr-101	0.92	0.81	1.73	12.55	0.75	12.10	4.50	54.49	+0.21	-0.21
Forrest	0.92	0.41	1.33	9.60	0.37	11.43	0.70	8.03	+1.01	-1.01
Giza 21	0.90	0.51	1.41	10.22	0.46	9.30	1.06	9.87	+0.77	-0.77
Giza 22	0.91	0.48	1.39	10.07	0.44	10.09	0.95	9.59	+0.84	-0.84
Giza 35	0.93	0.36	1.29	9.30	0.33	13.42	0.56	7.56	+1.14	-1.14
Giza 83	0.91	0.48	1.39	10.10	0.44	11.01	0.94	10.37	+0.86	-0.86
Average of intercropping	**0.91**	**0.51**	**1.42**	**10.31**	**0.46**	**10.99**	**1.31**	**14.70**	**+0.79**	**-0.79**
L.S.D. 0.05	**N.S.**	**0.10**	**0.17**	**1.66**	**0.17**	**N.S.**	**0.47**	**15.32**	**+0.23**	**-0.23**
Solid planting	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

RY-Relative yield; LER-Land equivalent ratio; SPI- System productivity index; LEC-Land equivalent coefficient; RCC-Relative crowing coefficient; Agg-Aggressivity

Relative yields under intercropping conditions. These results showed that $RY_{soybean}$ of American soybean varieties, Dr-101, Vorosy 79 and Custer, as well as, local soybean variety Giza 83 could be related to shade tolerance which led to good productivity per unit area. Consequently, these varieties may be more adapted to low light intensity (Sayed Galal *et al.,* 1984; Shafik, 2000; Abdel-Wahab and Abd El-Rahman, 2016).

With respect to LER, intercropping American soybean varieties Dr-101, Corosy 79 and Custer with corn had higher values as compared to others (Table 3). As for as local soybean varieties are concerned, intercropping soybean varieties, Giza 21, Giza 22 and Giza 83 with corn recorded higher LER (without significant differences among them) than the other ones. Meanwhile, the converse was true for American soybean varieties Clark 63 and Forrest, as well as, local soybean variety Giza 35. Certainly, the fundamental reason to change the values of LER was relative yield of soybean varieties; particularly when relative yield of corn was constant under all the studied soybean varieties. In other words, growth and development of different parts of corn plant under cropping systems were similar during its growth stages. These results imply that genetic variation of the studied soybean varieties has not sufficient capacity to influence yield potential of corn.

Intercropping American soybean varieties Dr-101, Corosy 79 and Custer with corn had higher SPI compared with others (Table 3). Intercropped local soybean varieties, Giza 21, Giza 22 and Giza 83 recorded higher SPI (without significant differences among them) than the other ones. Meanwhile, the converse was true for intercropped American soybean varieties Clark 63 and Forrest, as well as, local soybean variety Giza 35.

With respect to LEC, it was a measure of interaction concerned with the strength of relationship. LEC is used for a two- crop mixture, the minimum expected productivity coefficient (PC) is 25 per cent, that is, a yield advantage was obtained if LEC value was exceeded 0.25. Intercropped American soybean varieties Dr-101, Corosy 79 and Custer had higher LEC compared with the others (Table 3). On the other hand, intercropping soybean varieties Giza 22, Giza 21 and Giza 83 with corn recorded higher LEC (without significant differences among them) than the other one. Meanwhile, the converse was true for intercropped American soybean varieties Clark 63 and Forrest, as well as, local soybean variety Giza 35. The highest advantage of LEC by intercropping American soybean varieties Dr-101, Corosy 79 and Custer, as well as, local varieties Giza 22, Giza 21 and Giza 83 with corn could be due to these varieties had some suitable morphological and physiological characteristics that played a major role in their competitive abilities to face intercropping conditions. Consequently, it is expected that these varieties decreased intra- and inter-specific competition between the same species and the two species, respectively, for above and underground environmental conditions. It is known that shading on seeds yield per unit area depends on duration of shading (Jiang and Egli, 1993).

With respect to RCC, it was higher than the unit advantage in all intercropped soybean varieties with corn (Table 3). The best results for RCC were achieved by intercropping American soybean varieties Dr-101, Corosy 79, Custer and Columbus with corn. With regard to local soybean varieties, intercropped soybean varieties, Giza 21, Giza 22 and Giza 83 recorded higher RCC (without significant differences among them) than the other ones.

A yield advantage occurred because the component crops differed in their utilization of growth resources in such a way that when they are grown in association, they are able to complement each other and to work better overall use environmental resources than when they were grown separately. This finding indicated that the inter-specific competition was reduced by intercropping American soybean varieties Dr-101, Corosy 79, Custer and Columbus with corn. It is important to mention that RCC of local soybean variety Giza 83 that reached 98.30 per cent of American soybean variety Columbus. Accordingly, local soybean variety Giza 83 had suitable morphological and physiological characteristics, which formed self-regulation mechanism of redistributing the available assimilates to components, in an attempt to maintain or improve its yield under high competitive pressure. Obviously, the inter-specific competition between varieties of both species tended to be gives a better measure of their competitive ability for basic growth resources.

The Agg values (Table 3), showed that corn was the dominant component by intercropping with all local soybean varieties. The best results for Agg were achieved by intercropping American soybean varieties Dr-101, Corosy 79, Custer and Columbus. Local soybean varieties, Giza 22, Giza 21 and Giza 83 achieved the best results for Agg compared to the other ones. All soybean varieties were the dominated component. The presented results indicated clearly that the competition of corn to American soybean varieties Dr-101, Corosy 79, Custer and Columbus, as well as, local soybean varieties Giza 22, Giza 21 and Giza 83 is less than the others. These results may be attributed to the yield advantage occurred for these intercropped American and local soybean varieties as growth resources were more completely absorbed and converted to crop biomass by the intercrop over time and space owing to the differences in their competitive ability for growth resources (Tsubo *et al*., 2001). These results are parallel with those obtained by Gadallah and Selim (2016), who found that soybean was negative for all combinations indicating that soybean is subordinate component.

D. Intercropping economic advantage

Soybean varieties differed significantly for income from soybean, total returns and MAI, meanwhile income from corn was not affected

Table 4.Economic returns from intercropping soybean varieties with corn (combined data across the two seasons)

Soybean varieties	American economic evaluation (US$/ha)				Egyptian economic evaluation (US$/ha)			
	Corn	Soybean	Total	MAI	Corn	Soybean	Total	MAI
Clark 63	1460.8	735.0	2195.8	544.8	1328.0	661.5	1989.5	493.6
Columbus	1449.8	755.0	2204.8	629.9	1318.0	679.5	1997.5	570.7
Corosy 79	1443.2	890.0	2333.2	767.2	1312.0	801.0	2113.0	694.8
Custer	1445.4	870.0	2315.4	761.4	1314.0	783.0	2097.0	689.6
Dr-101	1465.2	1260.0	2725.2	1149.9	1332.0	1134.0	2466.0	1040.5
Forrest	1458.6	780.0	2238.6	555.4	1326.0	702.0	2028.0	503.1
Giza 21	1432.2	855.0	2287.2	665.0	1302.0	769.5	2071.5	602.3
Giza 22	1443.2	870.0	2313.2	649.0	1312.0	783.0	2095.0	587.8
Giza 35	1476.2	620.0	2096.2	471.2	1342.0	558.0	1900.0	427.1
Giza 83	1454.2	815.0	2269.2	636.6	1322.0	733.5	2055.5	576.7
Average of intercropping	**1452.8**	**845.0**	**2297.8**	**683.0**	**1320.8**	**760.5**	**2081.3**	**618.6**
L.S.D. 0.05	**N.S.**	**108.33**	**196.47**	**84.91**	**N.S.**	**95.17**	**168.54**	**73.40**
Solid corn	**1586.2**	**---**	**1586.2**	**---**	**1442.0**	**---**	**1442.0**	**---**
Solid soybean	**---**	**1655.0**	**1655.0**	**---**	**---**	**1489.5**	**1489.5**	**---**

American prices of corn and soybean were US$ 220 per ton and US$ 500per ton, respectively (USDA, 2018); Egyptian prices of corn and soybean were US$ 200 per ton and US$ 450 per ton, respectively (Egyptian market price).

(Table 4). Total returns were higher for intercrops than solid plantings of both crops.

Intercropping cultures increased total returns by 44.86 and 44.33 per cent according to American and Egyptian process, respectively, as compared to solid planting of corn. Also intercropping culture increased total returns by 38384 and 39.73 per cent according to American and Egyptian prices, respectively as compared to solid planting of soybean.

Intercropped American soybean varieties Dr-101, Corosy 79 and Custer, as well as, local soybean varieties, Giza 22 and Giza 21 had higher total returns compared to others. The highest total returns were recorded by intercropping soybean varieties, Dr-101, Corosy 79, Custer, Giza 22 and Giza 21 with corn, where it reached US$ 2725.2, 2333.2, 2315.4, 2313.2 and 2287.2 per ha according to American price, while it reached US$ 2466.0, 2113.0, 2097.0, 2095.0 and 2071.5 per ha according to Egyptian price, respectively.

Also, MAI was positive for all intercropped soybean varieties with corn. Intercropped American soybean varieties, Dr-101, Corosy 79 and Custer, as well as, local soybean varieties, Giza 22 and Giza 21 had higher MAI compared with the others. The highest MAI was recorded by intercropping soybean varieties Dr-101, Corosy 79, Custer, Giza 22 and Giza 21 with corn where it reached US$ 1149.9, 767.2, 761.4, 649.0 and 665.0 per ha according to American price, while it reached US$ 1040.5, 694.8, 689.6, 587.8 and 602.3 per ha according to Egyptian price, respectively.

These results could be accounted for higher relative yield of the above soybean varieties, which had positive effect on LER. In general, the high total LER and MAI for intercrops suggest that intercropping soybean with corn is profitable. These findings are parallel with those obtained by Kamara *et al.* (2017), who reported that MAI was positive for all intercrop treatments in both locations and years, which shows definite yield and economic advantages compared with the solid planting. The results indicated that profitability could be achieved by intercropping American soybean varieties Dr-101, Corosy 79, Custer, Giza 21 and Giza 22 with corn variety Cairo 1.

Our results revealed that American soybean varieties have different growth habits, which can be contributed largely in shading tolerance. American soybean varieties Dr-101, Corosy 79 and Custer, as well as, local soybean varieties Giza 22 and Giza 21 had higher competitive ability, productivity and intercropping economic advantages under intercropping system with 2:2 configurations.

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Response of Soybean Insect Communities to Different Plant Densities of Some Soybean Varieties under Two Cropping Systems

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ABSTRACT

The present investigation was carried out at Giza Agricultural Experiments and Research Station, Agricultural Research Center (ARC), Egypt during 2016 and 2017seasons to evaluate population density of aphid, white fly and lima bean pod borer in some sole and intercropped soybean varieties under different plant densities. The experiment included nine treatments which were the combinations between three soybean plant densities (50, 75 and 100% of recommended sole culture) and three soybean varieties (Giza21, Giza 82 and Giza 111) either under intercropping or sole culture. The data indicated that there was a significant difference in infestation of soybean varieties by aphids, whitefly and lima bean pod borer with increasing soybean plant density from 50 to 100 per cent. The population of aphids and whitefly were more abundant during early growth stage, while lima bean pod borer was more abundant during advanced growth stage of soybean under intercropping or sole culture. The overall means of pest population showed that aphids were more abundant for plants of sole soybean, cv. *Giza 82 by increasing plant density from 50 to 100 per cent. The highest whitefly population for plants of sole soybean, cv. Giza 111 was 6.6 ± 1.0 in the first season and 8.5 ± 0.9in the second season by increasing plant density from 50 to 100 per cent. With respect to lima bean pod borer, sole soybean, cv. Giza 21 had the highest population of this insect by increasing plant density from 50 to 100 per cent. Growing soybean, cv. Giza 111 with high plant density showed high yield and water consumptive use, low soybean mosaic virus (SMV), and tolerance to aphid's infestation under intercropping or sole culture. Whiteflies did not prefer plants of intercropped soybean, cv. Giza 21 even with the highest plant density. Soybean, cv. Giza 82 was compatible with increasing soybean plant density from 50 to 100 per cent to tolerate lima bean pod borer under sole culture.*

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Key words: Cropping Systems, insects, plant density, SMV, soybean cultivars, water consumptive use

Soybean [*Glycine max* (L.) Merrill] is one of the most important legume crops cultivated all over the world. Unfortunately, this crop is attacked by 350 species of insects in different parts of the world (Luckmann, 1971). Among the insect-pests of soybean, aphids and whiteflies were reported to be severe in tropics and subtropics on several crops (El-Shazly, 1985). The cotton aphid (*Aphis gossypii*) is a major pest of soybean (Kobayashi and Cosenza, 1987), where the aphid feeds using sucking, needle-like mouthparts to extract plant juices.

Moreover, the whitefly (*Bemisia tabaci*) causes economic damage in soybean (Singh and Singh, 1990). On the other hand, Van Den Berg *et al*. (1998) showed that the damage of lima bean pod borer (*Etiella zinckenella*) usually occurs on pods and fed on seeds. Larvae destroy the seeds during development inside a pod (Semeada *et al*., 2001). However, the incorrect use of insecticides on soybean has also been identified as a factor that has contributed to the increase of this insect population, particularly by contributing to a high mortality of biological control agents (Sosa-Gómez *et al*., 2010).

Certainly, insecticides uses cause insect resistance and tolerance that has been shown to be generally quantitative and polygenic (Ojwang *et al*., 2011). Consequently, insect-pests can cause significant losses in soybean productivity, particularly in the absence of control measures (Oliveira *et al*., 2014) where soybean is an important crop that suffers severe damage from insect-pests (Silva *et al*., 2014). This emphasizes the critical need for other effective control means that minimize the adverse side effects by some agricultural practices. Intercropping, plant density and soybean varieties could be considered as one of integrated pest management (IPM) elements.

Intercropping is usually defined as growing together of two or more crop species simultaneously in the same field (Willey, 1979; Ofori and Stern, 1987). It is recommended to be used in many parts of the world for food productions, because of its overall high productivity, effective control of pests and diseases, good ecological services and economic profitability (Midega *et al*., 2014; Wu and Wu, 2014). Cereal crops intercropping with legumes are a popular option in intercropping. In Egypt, there is a decline in area under soybean in the Nile Valley and Delta, where it reached to about 13,440 thousand ha in 2017, while maize (*Zea mays* L.) area reached to about 679,898 thousand ha in the same season (Bulletin of Statistical Cost Production and Net Return, 2017).

On the other hand, soybean plant density in a unit area could be used for the management of insect infestation in soybean crop. In this concern, Altieri *et al.* (1981) studied the effects of different row-spacing patterns on insect abundance in soybean. They showed that variations in row spacing did not significantly affect the abundance of most studied predators and pests. Also, Lamand Pedigo (1998) reported that there were no significant differences between populations of insect pests from narrow versus wide row-spacing treatments. It seems that soybean plant density per unit area had no obvious effect on insect infestation (Omoloye *et al.*, 2015).

Moreover, plant resistance to insects is an important component of IPM programs (Adkisson and Dyck, 1980). Utilization of soybean varieties with potential levels of insect-resistance can increase profits by reducing the use of insecticides and risk of insecticide residues in the human food chain (Rowan *et al.*, 1991). Furthermore, Haile *et al.* (1998) found large differences in economic injury level among soybean varieties. The use of resistant soybean varieties to combat economic insect-pests has become a central feature of modern pest management programs, because of its compatibility with other control measures (Vinod, 2015). He added that the cultivation of resistant varieties under a minimum insecticide usage, with improved cultural practices appropriate to farmer's economic and managerial capacities, offers the distinct possibility of increased stable yields. Therefore, the objective of this investigation was to evaluate population density of aphid, white fly and lima bean pod borer in some sole or intercropped soybean varieties under different plant densities.

MATERIALS 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), ARC, Giza, Egypt during two successive summer seasons (2016 and 2017) to evaluate population density of aphid, whitefly and lima bean pod borer in some sole or intercropped soybean varieties under different plant densities. This study included nine treatments, which were the combination between three soybean plant density (2, 3 and 4 rows per ridge were expressed as 50, 75 and 100% of the recommended plant density) and three soybean varieties (Giza 21, Giza 82 and Giza 111) either under intercropping or sole conditions (Fig. 1). Maize variety, TWC321 was used in intercropping patterns. Maize was grown in one plant per hill distanced at 25 cm between hills under intercropping conditions, while soybean was thinned to two plants per hill distanced at 15 cm between hills under intercropping and sole conditions.

In the two summer seasons, calcium super phosphate (15.5% P_2O_5) at rate of 357 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, meanwhile, maize variety, TWC321 was sown 15 days later. Nitrogen 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 under intercropping and sole culture. All normal agricultural practices were performed and no insecticides were applied. Soybean was thinned to two plants spaced at 15 cm. Soybean varieties, Giza 21 and Giza 111 were harvested on

2nd and 4th October in 2016 and 2017, respectively. Meanwhile soybean variety, 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. Furrow irrigation was the irrigation system in this study where applied irrigation water in 2016 season was 922 mm while in 2017 season was 927 mm.

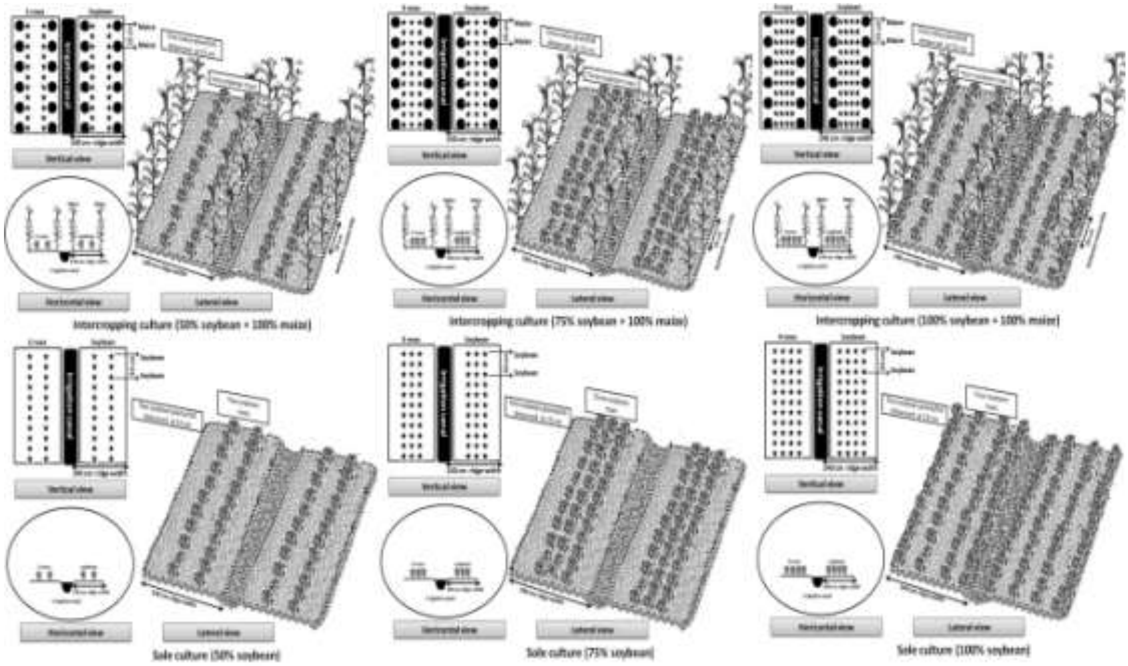

Fig. 1.Plant density of soybean varieties under intercropping and sole cultures

Pubescence traits were taken on three soybean varieties 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 was recorded as analyzed 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 48h), 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). The susceptibility of soybean varieties to the infestation of aphids and whitefly were investigated on vegetative growth of soybean during the two seasons. Sampling was started at 45 days from soybean planting and continued weekly until the end of the season. Five soybean plants, represented the sample, were randomly collected from the diagonals of each plot and examined to record the population density of two insects (adult only).

For field evaluation of soybean varieties under intercropping and sole cultures on natural infestation by lima bean pod borer, **s**amples were taken twice weeks and started after 75 days of soybean planting date and continued up to harvest. Samples consisting of 20 green pods collected randomly from each replicate. The green pods were kept in a paper bags then transferred to the laboratory to examine and determine mean percentage of infestation in soybean varieties under intercropping and sole cultures. Each sample was examined in the field, and the number of insects was recorded.

Ten guarded soybean plants were randomly taken from each sub-plot at harvest to record plant height, number of pods per plant and seed yield per plant (g). Seed yield was determined from seed weight of each sub-plot and converted to t per ha.

Survey of viral infected plants was carried out by labeling soybean plants naturally displaying symptoms of SMV at every row in each plot. 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 a sub-plot. Labeled plastic bags containing the collected samples were brought to the Department of Plant Virus and Phytoplasma Research, Plant Diseases Institute, Agricultural Research Center, Giza. Indirect ELISA used for detection of SMV. Sampling was started sixth weeks after planting and continued weekly until the end of the season. Three plants, represented the sample, were randomly collected from the diagonals of each sub-plot and examined to record the population density of insect.

For 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:

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

Where: WCU = water consumptive use or actual evapo-transpiration, ETa (mm), i = number of soil layer, $\theta 2$ = soil moisture content after irrigation, (%, by mass), $\theta 1$ = soil moisture contents just before irrigation, (%, by mass), Bd= soil bulk density (g/cm^3), d = depth of soil layer (mm).

The data were statistically treated using the analysis of variance (ANOVA) for randomized complete block design and the least significant difference (LSD) was used for mean separation ($P \leq 0.05$)

following T test (0.05) to compare between soybean varieties under intercropping and sole cultures. Plot area was 16.8 m^2. Each plot consisted of six ridges, 4 m long and 0.7 m wide. 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).

RESULTS AND DISCUSSION

I. Pubescence density

Soybean varieties differed significantly for mean of pubescence length and number of pubescence per 500 µm (Table 1, Fig. 2). Soybean, *cv*. Giza 111 had the longest pubescence coupled with the lowest number of pubescence per 500 µm. On the contrary, soybean, *cv*. Giza 82 had the shortest pubescence and highest number of pubescence per 500 µm.

II. Leaf N content of soybean

Leaf N content was influenced significantly by soybean plant density (Table 2). Increasing soybean plant density from 50 to 100 per cent decreased leaf N content by 5.47 and 4.82 per cent, respectively. Soybean varieties differed significantly for leaf N content (Table 2). Soybean, *cv*. Giza 82 had the highest leaf N content. Irrespective of intercropping or sole culture, no significant difference in leaf N content was observed between soybean, *cvs*. Giza 21 and Giza 111.

Table 1. Mean of pubescence length, number of pubescence per 500 µm and pubescence density in the studied soybean varieties

Soybean varieties	Pubescence length (µm)	Number of 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. (P = 0.05)	**160.91**	**10.41**	**---**

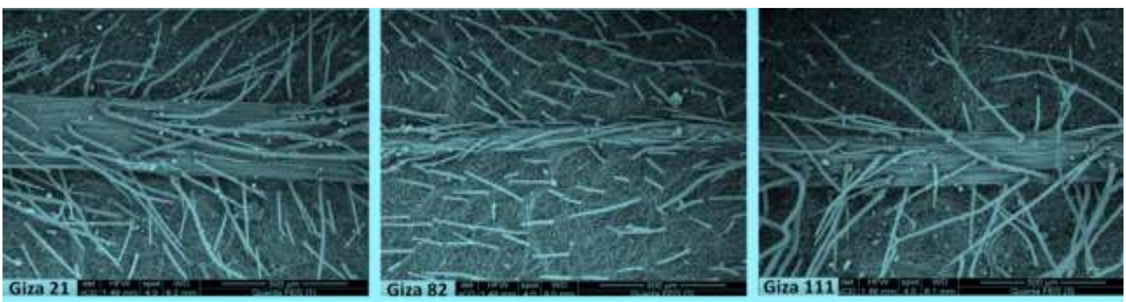

Fig. 2. Scanning of the studied soybean varieties pubescence density by electronic microscope

Table 2. Effect of soybean plant densities, soybean varieties and their interaction on leaf N content of soybean

Soybean plant density	Variety	Leaf N content (mg/g)	
		Intercropping culture	Sole culture
100%	Giza 21	24.80	30.60
	Giza 82	26.70	31.80
	Giza 111	24.10	30.00
	Mean	**25.20**	**30.80**
75%	Giza 21	25.60	31.50
	Giza 82	27.60	32.90
	Giza 111	25.00	31.10
	Mean	**26.06**	**31.83**
50%	Giza 21	26.20	32.10
	Giza 82	28.10	33.40
	Giza 111	25.70	31.60
	Mean	**26.66**	**32.36**
Average of soybean varieties	**Giza 21**	**25.53**	**31.40**
	Giza 82	**27.46**	**32.70**
	Giza 111	**24.93**	**30.90**
L.S.D. (P=0.05) Soybean plant density		**0.74**	**0.83**
L.S.D. (P=0.05)Soybean varieties		**0.61**	**0.69**
L.S.D. (P=0.05)Interaction		**N.S.**	**N.S.**

III. Water relations of sole and intercropped soybean

Increasing soybean plant density from 50 to 100 per cent resulted in an increase in water consumptive use of sole and intercropped soybean (Table 3). Water consumptive use of sole soybean was lower than that of intercropped soybean. The highest water consumptive use was obtained by growing all soybean varieties in high plant density (100 %) under intercropping or sole culture, while the lowest was with low plant density (50 %) under intercropping or sole culture in 2016 and 2017 seasons.

With respect to soybean varieties, the highest water consumptive use was obtained by growing soybean, *cv*. Giza 111 followed by Giza 82 then Giza 21.

IV. Soybean mosaic virus (SMV)

Soybean varieties differed significantly for infection with SMV under intercropping culture, whereas no differences were recorded in case of sole cropping during 2016 and 2017 seasons (Table 4). It was also noted that the number of SMV infected plants was lower in intercropping culture than sole culture. Intercropping soybean, *cv*. Giza 82 with maize was found to decrease SMV infection by 38.21 and 47.02 per cent in 2016 and 2017 seasons, respectively in comparison with sole culture.

Table 3. Water consumptive use (mm) of sole and intercropped soybean in the two seasons

Soybean plant density	Soybean varieties	Water consumptive use for sole soybean (mm)			Water consumptive use for intercropped soybean (mm)		
		2016	2017	Mean	2016	2017	Mean
	Giza 21	636	633	**634**	729	656	**692**
100% soybean	Giza 82	714	584	**649**	760	710	**735**
	Giza 111	788	714	**751**	818	750	**784**
	Giza 21	602	598	**600**	692	627	**659**
75% soybean	Giza 82	625	568	**596**	708	704	**706**
	Giza 111	640	610	**625**	755	615	**685**
	Giza 21	559	556	**557**	656	561	**608**
50% soybean	Giza 82	574	534	**554**	575	570	**572**
	Giza 111	521	518	**519**	615	576	**595**
Giza 21		**599**	**595**	**597**	**692**	**614**	**653**
Giza 82		**637**	**562**	**599**	**681**	**661**	**671**
Giza 111		**649**	**614**	**631**	**729**	**647**	**688**

Table 4. Infection soybean varieties with SMV under intercropping and sole cultures in 2016 and 2017 seasons

Soybean varieties	2016 season			2017 season		
	Inter culture	Sole culture	T test $0.05_{2.77}$	Inter culture	Sole culture	T test $0.05_{2.77}$
Giza 21	$10.13 \pm 2.3_{bB}$	$24.96 \pm 4.5_{A}$	2.92	$15.36 \pm 1.9_{bA}$	$24.66 \pm 3.1_{B}$	2.88
Giza 82	$16.93 \pm 3.3_{aB}$	$27.40 \pm 1.4_{A}$	1.58	$16.36 \pm 4.4_{aA}$	$30.80 \pm 0.5_{B}$	2.92
Giza 111	$12.53 \pm 1.7_{bB}$	$21.03 \pm 5.1_{A}$	3.05	$12.83 \pm 3.8_{bA}$	$28.56 \pm 3.7_{B}$	2.93
L.S.D. (P=0.05)	**4.65**	**-**		**3.37**	**-**	

Similarly, intercropped soybean, *cv*. Giza 21 decreased SMV infection by 59.41 and 37.71 per cent in 2016 and 2017 seasons, respectively. In a similar trend, intercropping of soybean, *cv*. Giza 111 led to decrease in SMV infection by 40.41 and 55.07 per cent during the two respective years.

V. Soybean seed yield and yield attributes

Plant height and seed yield per ha were influenced significantly by soybean plant density in 2016 and 2017 seasons, whereas number of pods and seed yield per plant remained uninfluenced (Tables 5 and 6). Increasing intercropped soybean

Table 5. Seed yield of intercropped soybean varieties and its attributes under three soybean plant densities in 2016 and 2017 seasons

Treatment	Variety	2016 season				2017 season			
		Plant height (cm)	Pods (No/plant)	Seed yield (g/plant)	Seed yield(t/ha)	Plant height (cm)	Pods (No/plant)	Seed yield (g/plant)	Seed yield(t/ha)
100% soybean + 100% maize	Giza 21	125.50	21.76	8.82	1.99	116.82	20.82	7.12	1.66
	Giza 82	107.90	30.11	9.20	2.39	103.44	30.66	8.92	2.12
	Giza 111	112.80	37.22	11.47	2.72	110.13	37.03	10.23	2.41
	Mean	**115.40**	**29.70**	**9.83**	**2.36**	**110.13**	**30.17**	**8.75**	**2.06**
75% soybean + 100% maize	Giza 21	117.10	28.96	10.74	1.35	111.65	24.05	8.01	1.11
	Giza 82	104.30	38.72	11.83	1.67	97.62	37.16	10.94	1.45
	Giza 111	108.40	53.89	12.77	1.88	104.58	44.48	11.81	1.63
	Mean	**109.93**	**40.52**	**11.78**	**1.63**	**104.61**	**35.23**	**10.25**	**1.39**
50% soybean + 100% maize	Giza 21	111.70	33.14	10.89	1.10	106.32	26.41	8.41	0.83
	Giza 82	95.30	42.63	12.54	1.21	91.15	40.14	11.72	0.99
	Giza 111	102.50	58.66	12.93	1.49	93.91	48.10	12.36	1.19
	Mean	**103.16**	**44.81**	**12.12**	**1.26**	**97.12**	**38.21**	**10.83**	**1.00**
Average of soybean varieties	**Giza 21**	**118.10**	**27.95**	**10.15**	**1.48**	**111.59**	**24.42**	**7.84**	**1.20**
	Giza 82	**102.50**	**37.15**	**11.19**	**1.75**	**97.40**	**35.99**	**10.52**	**1.52**
	Giza 111	**107.90**	**49.92**	**12.39**	**2.03**	**102.87**	**43.20**	**11.46**	**1.74**
L.S.D. (P=0.05) Soybean plant density		**5.56**	**N.S.**	**N.S.**	**0.22**	**8.21**	**N.S.**	**N.S.**	**0.16**
L.S.D. (P=0.05) Soybean varieties		**3.56**	**18.59**	**1.82**	**0.08**	**2.54**	**14.17**	**1.18**	**0.12**
L.S.D. (P=0.05) Interaction		**N.S.**	**N.S.**	**N.S.**	**0.21**	**N.S.**	**N.S.**	**N.S.**	**0.21**

Table 6. Seed yield of sole soybean varieties and its attributes under three soybean plant densities in 2016 and 2017 seasons

Treatment	Variety	2016 season				2017 season			
		Plant height (cm)	Pods (No/plant)	Seed yield (g/plant)	Seed yield(t/ha))	Plant height (cm)	Pods (No/plant)	Seed yield (g/plant)	Seed yield(t/ha))
100 % soybean	Giza 21	106.65	79.13	19.93	3.11	103.18	64.26	18.30	2.80
	Giza 82	89.11	69.27	20.70	3.81	86.14	60.51	19.91	3.63
	Giza 111	98.32	83.96	23.23	4.09	93.81	77.15	22.75	3.76
	Mean	**98.03**	**77.45**	**21.28**	**3.67**	**94.38**	**67.30**	**20.32**	**3.39**
75 % soybean	Giza 21	100.55	91.38	21.87	2.45	96.66	81.70	19.43	2.22
	Giza 82	82.82	67.80	22.73	2.99	80.37	68.00	20.72	2.77
	Giza 111	94.40	100.33	24.15	3.13	88.24	87.87	23.28	2.96
	Mean	**92.59**	**86.50**	**22.92**	**2.86**	**88.42**	**79.19**	**21.14**	**2.65**
50 % soybean	Giza 21	96.84	92.70	22.22	1.91	92.01	87.70	19.65	1.62
	Giza 82	78.56	70.97	23.15	2.22	76.59	69.65	20.95	2.05
	Giza 111	89.00	108.56	24.71	2.39	84.56	92.91	23.42	2.23
	Mean	**88.13**	**90.74**	**23.36**	**2.17**	**84.39**	**83.42**	**21.34**	**1.97**
Average of soybean varieties	**Giza 21**	**101.34**	**87.73**	**21.34**	**2.49**	**97.28**	**77.88**	**18.79**	**2.21**
	Giza 82	**83.49**	**69.34**	**22.19**	**3.00**	**81.03**	**66.05**	**20.19**	**2.81**
	Giza 111	**93.91**	**97.61**	**24.03**	**3.20**	**88.87**	**85.98**	**22.82**	**2.98**
L.S.D. (P=0.05) Soybean plant density		**6.20**	**N.S.**	**N.S.**	**0.09**	**3.93**	**N.S.**	**N.S.**	**0.05**
L.S.D. (P=0.05) Soybean varieties		**3.16**	**14.73**	**2.45**	**0.07**	**3.72**	**17.57**	**2.84**	**0.04**
L.S.D. (P=0.05) Interaction		**N.S.**	**N.S.**	**N.S.**	**0.12**	**N.S.**	**N.S.**	**N.S.**	**0.07**

plant density from 50 to 100 per cent increased plant height by 11.86 and 13.39 per cent and seed yield per ha by 87.30 and 106.00 per cent in 2016 and 2017 seasons, respectively. Similarly, increasing sole soybean plant density from 50 to 100 per cent increased plant height by 11.23 and 13.39 per cent and seed yield per ha by 69.12 and 72.08 per cent in 2016 and 2017 seasons, respectively.

Soybean varieties differed significantly for plant height, number of pods per plant, seed yields per plant and per ha in 2016 and 2017 seasons (Tables 5 and 6). Intercropped soybean, *cv*. Giza 111 had the highest number of pods per plant, seed yields per plant and per ha as compared with the other varieties in 2016 and 2017 seasons. Meanwhile, intercropped soybean, *cv*. Giza 21 produced the tallest plants in comparison to the others in 2016 and 2017 seasons. Also, sole soybean, *cv*. Giza 111 had the highest number of pods per plant, seed yields per plant and per ha as compared with other varieties in 2016 and 2017 seasons.

Interaction between soybean plant density x soybean varieties had significant effects on seed yield per ha in 2016 and 2017 seasons; plant height, number of pods and seed yield per plant remained uninfluenced. The highest seed yield per ha was obtained by growing soybean, *cv*. Giza 111 in high plant density (100 %) under intercropping or sole culture in 2016 and 2017 seasons. Meanwhile, converse was true with soybean, *cv*. Giza 21 in low plant density (50 %) under intercropping or sole culture in 2016 and 2017 seasons.

VI. Insect incidence

Susceptibility of the tested soybean varieties to the infestation with aphids varied statistically according to soybean plant density (Tables 7, 8). The population density of aphids for intercropped soybean, *cv*. Giza 21 differed significantly among soybean plant densities in the 1st and 2nd weeks in 2016 season and in the 1st, 2nd, 4th and 5th weeks, as well as, mean of 2017 season.

Also, the population density of aphids for intercropped soybean, *cv*. Giza 82 differed significantly among soybean plant densities in the 1st and 2nd weeks in 2016 season and in the 1st, 2nd and 6th weeks, as well as, mean of 2017 season. Moreover, the population density of aphid**s** for intercropped soybean, *cv*. Giza111 differed significantly among soybean plant densities in the 2nd week only in 2016 and 2017 seasons.

Population density of aphids for sole soybean, *cv*. Giza 21 differed significantly among soybean plant densities in the 2nd week only in 2016 season, but there were no significant differences for the remaining weeks in the same season. Meanwhile, the population density of aphids for sole soybean, *cv*. Giza 21 differed significantly among soybean plant densities in the 2nd week and mean of 2017 season (Tables 7, 8). Also, the population density of aphid**s** for sole soybean, *cv*. Giza 82 differed significantly among soybean plant

Table 7. Effect of soybean plant densities and soybean varieties on the population density of aphids under intercropping and sole cultures in 2016 season

Treatments	Mean number of aphids /plant /week						Mean
	1st week	2nd week	3rd week	4th week	5th week	6th week	
Intercropped soybean, cv. Giza 21							
50% soybean + 100% maize	2.0±2.0	2.0 ±1.7$_b$	1.6±1.0	1.0±1.0	0.0±0.0	0.0±0.0	1.2±0.9
75% soybean + 100% maize	1.0±1.0	1.0±1.0$_b$	1.5±1.3	0.5±0.3	0.5±0.3	0.0±0.0	0.8± 0.3
100% soybean + 100% maize	1.0±1.0	7.0±1.0$_a$	1.3±1.1	1.3±0.5	0.0±0.0	0.0±0.0	2.1±0.5
F test	0.48	13.4	0.041	0.85	3.0	-	2.580
P<0.05	**0.65**	**0.017**	**0.96**	**0.496**	**0.16**	**-**	**0.191**
L.S.D. (P=0.05)	**-**	**3.5**	**-**	**-**	**-**		**-**
Intercropped soybean, cv. Giza 82							
50% soybean + 100% maize	0.0±0.0$_b$	0.0±0.0$_b$	1.7±0.6	0.0±0.0	0.6±1.2	0.0±0.0	1.3±0.3
75% soybean + 100% maize	3.0±1.7$_a$	3.7±0.6$_a$	2.3±0.6	1.0±1.0	1.0±1.0	0.0±0.0	2.2±0.5
100% soybean + 100% maize	4.0±0.0$_a$	3.0±1.0$_a$	1.6±1.1	1.6±1.5	0.0±0.0	1.6±1.5	1.6 ±0.4
F test	9.750	18.727	0.727	5.200	1.750	3.571	3.564
P<0.05	**0.029**	**0.009**	**0.538**	**0.077**	**0.284**	**0.129**	**0.129**
L.S.D. (P=0.05)	**2.617**	**1.772**	**-**	**-**	**-**	**-**	**-**
Intercropped soybean, cv. Giza 111							
50% soybean + 100% maize	4.3±1.5	0.5±0.33$_c$	1.0±1.0	0.0±0.0	0.0±0.0	0.0±0.0	1.2 ±0.1
75% soybean + 100% maize	6.3±3.2	5.7±1.2$_b$	1.3±0.6	0.6±1.1	0.5±0.33	0.0±0.0	2.9±0.9
100% soybean + 100% maize	4.3±3.5	7.3±1.2$_a$	0.5±0.3	0.7±0.6	0.0±0.0	0.0±0.0	2.5±0.6
F test	0.381	90.25	2.000	1.000	1.000	-	5.321
P<0.05	**0.706**	**0.000**	**0.250**	**0.444**	**0.444**	**-**	**0.075**
L.S.D. (P=0.05)	**-**	**1.511**	**-**	**-**	**-**		**-**

Table 7-Contd

Sole soybean, cv. Giza 21							
50% soybean	2.0±2.0	2.0 ±1.7$_b$	1.6±1.0	1.0±1.0	0.0±0.0	0.0±0.0	1.2±0.9
75% soybean	1.0±1.0	1.0±1.0$_b$	1.5±1.3	0.5±0.3	0.5±0.3	0.0±0.0	0.8± 0.3
100% soybean	1.0±1.0	7.0±1.0$_a$	1.3±1.1	1.3±0.5	0.0±0.0	0.0±0.0	2.1±0.5
F test	0.48	13.4	0.041	0.85	3.0	-	2.580
P<0.05	**0.65**	**0.017**	**0.96**	**0.496**	**0.16**	**-**	**0.191**
L.S.D. (P=0.05)	**-**	**3.5**	**-**	**-**	**-**		**-**
Sole soybean, cv. Giza 82							
50% soybean	1.9±1.5$_b$	4.5±0.0$_b$	2.0±1.0	0.6±1.1	0.5±0.33	0.5±0.3	2.3±0.5$_b$
75% soybean	5.3±1.5$_a$	11.7±3.1$_a$	0.0±0.0	0.3±0.0	0.5±0.33	0.0±0.0	3.5±0.5$_a$
100% soybean	5.7±1.2$_a$	8.0±0.0$_a$	2.3±2.5	0.0±0.0	0.0±0.0	0.0±0.0	3.4±0.8$_a$
F test	8.971	22.964	2.457	2.000	0.400	-	17.200
P<0.05	**0.033**	**0.006**	**0.201**	**0.25**	**0.694**	**-**	**0.011**
L.S.D. (P=0.05)	**3.22**	**3.99**	**-**	**-**	**-**		**1.095**
Sole soybean, cv. Giza 111							
50% soybean	3.3±1.5	2.3±1.5$_c$	1.0±1.0	0.5±0.33	0.5±0.33	0.0±0.0	1.5±0.3
75% soybean	3.0±2.8	4.6±1.5$_a$	3.2±1.8	0.5±0.33	0.5±0.33	0.0±0.0	2.3±1.1
100% soybean	2.3±0.6	3.6±1.9$_b$	2.0±1.7	0.0±0.0	0.0±0.0	0.0±0.0	1.8±0.5
F test	0.554	172.00	1.181	0.400	0.400	-	2.138
P<0.05	**0.614**	**0.00**	**0.395**	**0.694**	**0.694**	**-**	**0.234**
L.S.D. (P=0.05)	**-**	**0.33**	**-**	**-**	**-**		**-**

Note: Means followed by the different letters are significantly different from each other at P<0.05 and followed by a least significant difference (L.S.D)

Table 8. Effect of soybean plant densities and soybean varieties on the population density of aphids under intercropping and sole cultures in 2017 season

Treatments	**Mean number of aphids /plant /week**						**Mean**
	1st week	**2nd week**	**3rd week**	**4th week**	**5th week**	**6th week**	
Intercropped soybean, cv. Giza 21							
50% soybean + 100% maize	$3.3\pm0.6_a$	$1.7\pm0.6_a$	2.0 ± 0.0	$1.7\pm0.6_a$	$2.0\pm0.0_a$	0.0 ± 0.0	$1.6\pm0.2_a$
75% soybean + 100% maize	$0.7\pm0.6_b$	$0.0\pm0.0_b$	1.0 ± 0.0	$0.0\pm0.0_b$	$0.3\pm0.6_b$	0.0 ± 0.0	$0.9\pm0.1_b$
100% soybean + 100% maize	$4.0\pm1.0_a$	$3.7\pm2.1_a$	2.0 ± 2.0	$0.0\pm0.0_b$	$0.0\pm0.0_b$	0.0 ± 0.0	$1.9\pm0.4_a$
F test	14.000	7.000	0.750	25.000	31.00	-	17.500
P<0.05	**0.016**	**0.049**	**0.529**	**0.005**	**0.004**	**-**	**0.011**
L.S.D. (P=0.05)	**1.851**	**2.724**	**-**	**0.756**	**0.756**		**0.478**
Intercropped soybean, cv. Giza 82							
50% soybean + 100% maize	$0.3\pm0.6_b$	$1.0\pm0.0_b$	1.7 ± 0.6	1.1 ± 0.0	1.1 ± 0.0	$0.0\pm0.0_b$	$1.0\pm0.3_b$
75% soybean + 100% maize	$3.0\pm1.7_a$	$5.0\pm1.7_a$	2.3 ± 0.6	1.0 ± 1.0	1.0 ± 1.0	$0.0\pm0.0_b$	$2.1\pm0.5_a$
100% soybean + 100% maize	$4.0\pm0.0_a$	$3.7\pm1.0_a$	1.3 ± 1.5	1.7 ± 1.5	1.5 ± 0.5	$1.6\pm0.6_a$	$2.3\pm0.5_a$
F test	8.435	14.250	1.273	1.310	1.310	8.036	20.967
P<0.05	**0.037**	**0.015**	**0.373**	**0.365**	**0.365**	**0.004**	**0.008**
L.S.D. (P=0.05)	**2.562**	**2.617**	**-**	**-**	**-**	**1.199**	**0.590**
Intercropped soybean, cv. Giza 111							
50% soybean + 100% maize	2.3 ± 1.5	$0.3\pm0.6_b$	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.1
75% soybean + 100% maize	4.0 ± 1.0	$5.7\pm1.1_a$	1.3 ± 0.6	1.3 ± 1.1	0.3 ± 0.6	0.0 ± 0.0	2.5 ± 0.3
100% soybean + 100% maize	4.3 ± 1.5	$5.7\pm2.5_a$	0.3 ± 0.6	0.6 ± 0.6	0.3 ± 0.6	0.0 ± 0.0	1.9 ± 0.9
F test	1.319	7.877	1.000	2.000	0.400	-	5.858
P<0.05	**0.363**	**0.041**	**0.444**	**0.250**	**0.694**	**-**	**0.065**
L.S.D. (P=0.05)	**-**	**4.307**	**-**	**-**	**-**		**-**

Table 8-contd

Sole soybean, cv. Giza 21							
50% soybean	2.0±1.7	$8.0\pm0.6_{a}$	1.3±1.1	1.3±1.1	1.3±1.1	0.3±0.6	$2.7\pm0.7_{a}$
75% soybean	1.3±1.1	$2.0\pm0.8_{b}$	1.0±1.0	1.0±1.0	1.0±1.0	0.0±0.0	$1.3\pm0.5_{b}$
100% soybean	1.3±0.6	$5.7\pm2.1_{a}$	1.7±1.1	0.7±0.6	0.7±0.6	0.7±0.6	$2.1\pm0.9_{ab}$
F test	0.571	24.86	0.200	0.286	0.286	2.000	7.279
P<0.05	**0.605**	**0.006**	**0.826**	**0.766**	**0.766**	**0.250**	**0.046**
L.S.D. (P=0.05)	**-**	**2.368**	**-**	**-**	**-**	**-**	**1.022**
Sole soybean, cv. Giza 82							
50% soybean	$2.3\pm1.5_{b}$	$2.7\pm0.6_{b}$	$2.73\pm1.5_{a}$	2.0±1.0	1.0±0.0	1.6±0.1	$2.5\pm0.7_{b}$
75% soybean	$5.7\pm1.2_{ab}$	$12.7\pm3.1_{a}$	$0.63\pm0.3_{b}$	1.7±1.0	0.6±0.3	1.0±0.0	$3.7\pm0.8_{a}$
100% soybean	$9.0\pm2.6_{a}$	$7.7\pm2.3_{ab}$	$3.7\pm1.5_{a}$	0.7±0.6	1.6±0.2	1.6±0.2	$4.1\pm0.7_{a}$
F test	8.465	9.174	15.026	2.005	1.000	2.000	10.580
P<0.05	**0.037**	**0.032**	**0.014**	**0.249**	**0.444**	**0.250**	**0.025**
L.S.D. (P=0.05)	**4.433**	**6.352**	**1.575**	**-**	**-**	**-**	**1.648**
Sole soybean, cv. Giza 111							
50% soybean	2.0±1.0	5.0±1.7	1.3±0.6	0.6±0.3	$1.0\pm0.0_{a}$	0.6±0.3	2.3±0.2
75% soybean	3.7±1.4	5.0±1.0	3.7±2.8	0.6±0.3	$0.0\pm0.0_{b}$	0.6±0.3	2.6±0.5
100% soybean	3.3±1.5	3.7±0.6	2.0±1.7	0.6±0.3	$0.7\pm0.6_{ab}$	0.6±0.3	1.6±0.7
F test	1.463	1.231	0.839	-	7.000	-	4.375
P<0.05	**0.333**	**0.383**	**0.496**	**-**	**0.049**	**-**	**0.098**
L.S.D. (P=0.05)	**-**	**-**	**-**		**0.756**		**-**

Note: Means followed by the different letters are significantly different from each other at P<0.05 and followed by a least significant difference (L.S.D)

densities in the 1st and 2nd weeks, as well as, mean of 2016 season and in the 1st, 2nd and 3rdweeks, as well as, mean of 2017 season. Furthermore, the population density of aphid**s** for sole soybean, *cv*. Giza 111 differed significantly among soybean plant densities in the 2nd week only in 2016 season and in the 5th week only in 2017 season. Generally, these results revealed that the population density of aphid**s** in all intercropped soybean varieties was lower than sole soybean varieties. It was observed that the population density of aphids for plants of soybean, *cv*. Giza 21 decreased gradually and was maximum during the first week under intercropping culture or the second week under sole culture after 45 days from planting in the two growing seasons.

On the other hand, the population density of aphids for plants of soybean, *cv*. Giza 82 decreased gradually and was maximum during the first and the second week in the first and second seasons, respectively, under intercropping culture or the second week under sole culture in the two growing seasons after 45 days from soybean planting. However, the population density of aphids for plants of soybean, *cv*. Giza 111 decreased gradually and was maximum during the second week under intercropping or sole culture after 45 days from soybean planting in the two growing seasons. Host plant genotype is an important factor influencing probing activity of aphids (Atiri *et al*., 1984). Moreover, it seems that aphids appeared to be more active before pod filling on all soybean varieties and the aphid's population was found to be significantly higher at higher population densities.

Intercropped soybean, *cv*. Giza 21 had the lowest population density of aphids by increasing soybean plant density in 2017 season, meanwhile there was hardly any significant effect of soybean plant density on population density of aphids in 2016 season (Tables 7, 8). Also, intercropped soybean, *cv*. Giza 82 had the highest population density of aphids by increasing soybean plant density from 50 to 75 per cent in 2016 season and 50 to 100 per cent in 2017 season. Meanwhile, increasing soybean plant density from 50 to 100 per cent did not affect significantly the population density of aphids for intercropped soybean, *cv*. Giza 111 in 2016 and 2017 seasons. On the other hand, sole soybean, *cv*. Giza 21 had the lowest population density of aphids by increasing soybean plant density in 2017 season, whereas there was no significant effect on it in 2016 season. However, sole soybean, *cv*. Giza 82 had the highest population density of aphids by increasing soybean plant density from 50 to 100 per cent in 2016 and 2017 seasons. Meanwhile, increasing soybean plant density from 50 to 100 per cent did not affect significantly the population density of aphids for sole soybean, *cv*. Giza 111 in 2016 and 2017 seasons.

It seems that this insect does not present a high damaging potential to the crop of soybean, *cv*. Giza 21 by increasing plant density at the sixth week which is reflected positively on the maturity stage of this variety than soybean, *cv*. Giza 82 under intercropping or sole culture. It is important to mention that soybean, *cv*. Giza 21 had the highest water consumptive use by decreasing plant density from 100 to 50 per cent, while the reverse was true for soybean, *cv*. Giza 111 under intercropping or sole culture in 2016 and 2017 seasons (Table 3). These results showed that soybean, *cv*. Giza 111 was tolerant to aphid's infestation, which reflected positively on seed yield per plant under intercropping or sole culture compared to the other varieties regardless of plant density (Tables 7, 8). Soybean, *cv*. Giza 111 had the longest pubescence and highest density (Table 1), and the lowest leaf N content (Table 2), which formed biological barrier for dispersal of the aphids compared with the others. Certainly, leaf trichomes influenced patterns of insect herbivory and insect abundance for a variety of plant species (Southwood, 1986). Successful feeding and nutrient uptake by aphids requires adequate plant cell turgor pressure (Archer *et al*., 1995), which is mediated by plant water content (Taiz and Zeiger, 2002). It appear that soybean, *cv*. Giza 82 was susceptible to aphid's infestation by increasing plant density from 50 to 100 per cent, which served as vector for transmission of SMV that was low during the growth period on the other varieties under intercropping or sole culture (Table 4). It seems that aphid's dispersal depended on soybean variety under intercropping or sole culture more than plant density of this variety.

Population density of white fly for intercropped soybean, *cv*. Giza 21 differed significantly between soybean plant densities in the 1st, 3rd and 4th weeks in 2016 season and in the 1st week only in 2017 season (Tables 9, 10). Also, intercropped soybean, *cv*. Giza 82 differed significantly between soybean plant densities in 1st, 2nd, 3rd, 5th and 6th weeks, as well as, mean of 2016 season and in 1st, 2nd, 4th and 5th weeks, as well as, mean of 2017 season. Moreover, intercropped soybean, *cv*. Giza 111 differed significantly between soybean plant densities in 1st, 2nd, 3rd and 4th weeks, as well as, mean of 2016 season and in 1st, 2nd and 4th weeks, as well as, mean of 2017 season. However, the population density of white fly for sole soybean, *cv*. Giza 21 differed significantly between soybean plant densities in the 1st and 6th weeks, as well as, mean of 2016 season and in the 1st, 2nd and 3rd weeks, as well as, mean of 2017 season. Moreover, the population density of white fly for sole soybean, *cv*. Giza 82 differed significantly between soybean plant densities in the 1st, 3rd and 6th weeks, as well as, mean of 2016 season and in the 1st, 2nd and 3rd weeks, as well as, mean of 2017 season. Furthermore, the population density of white fly for sole soybean, *cv*. Giza 111 was differed significantly between soybean plant densities in the 1st, 2nd, 3rd and 6th weeks, as well as, mean of 2016 season and in the 1st, 2nd, 3rd and 4th weeks, as well as, mean of 2017 season. It was observed that the population density of white fly for plants of soybean, *cv*. Giza 21 decreased gradually and was maximum during the first week under intercropping or sole culture after 45 days from soybean planting in the two growing seasons. On the other hand, the population density of white fly for plants of soybean, *cv*. Giza 82 decreased gradually and was maximum during the second week under intercropping culture or the first week under sole culture in the two growing seasons after 45 days from soybean planting. However, the population density of white fly for plants of soybean, *cv*. Giza 111 decreased gradually and was maximum during the first week under intercropping or sole culture after 45 days from soybean planting in the two growing seasons. It seems that white fly appeared to be more active before reproductive stage on all soybean varieties. In other words, white fly appear earlier in the season and therefore was unlikely to be included in our late season samples under intercropping or sole culture.

Increasing soybean plant density from 50 to 100 per cent did not affect significantly the population density of white fly for intercropped soybean, *cv*. Giza 21 in 2016 and 2017 seasons (Tables 9, 10). However, intercropped soybean, *cv*. Giza 82 or Giza 111 had the highest the population density of white fly by increasing soybean plant density from 50 to 100 per cent in 2016 and 2017 seasons. Also, sole soybean, *cv*. Giza 21 or Giza 111 had the highest population density of white fly by increasing soybean plant density from 50 to 100 per cent in 2016 and 2017 seasons. Moreover, sole soybean, *cv*. Giza 82 had the highest population density of white fly by increasing soybean plant density from 50 to 100 per cent in 2016 season, but decreasing soybean plant density from 100 to 50 per cent increased the population density of white fly in 2017 season.

It is expected that whiteflies secreted abundant honeydew containing metabolized sugars which formed a suitable medium for the development of a dark sooty mold, and thereby adverse effects on photosynthetic process of soybean. However, infestation of whiteflies usually heaviest during flowering period and cannot cause severe yield reductions of intercropped soybean, *cv*. Giza 21 even with the highest plant density compared to the other treatments. These results probably attributed to maize plant integrated positively with soybean, *cv*. Giza 21 to form biological barrier to dispersal of the white fly regardless plant density compared with the other treatments. It is important to mention here that water consumptive use of sole soybean was lower than that of intercropped soybean, which lead to intercropped fields to have higher vegetation diversity than monocultures and this has been shown to reduce insect pests by barrier crops that obstructed pest movement (Perrin and Phillips, 1978). Accordingly, traits of secondary crop species should be screened to determine key elements that affect pest and predator abundances and ultimately resulted in improved yield (Landis *et al*., 2000).

Table 9. Effect of soybean plant densities and soybean varieties on the population density of white fly under intercropping and sole cultures in 2016 season

Treatments	Mean number of white fly /plant /week						Mean
	1st week	**2nd week**	**3rd week**	**4th week**	**5th week**	**6th week**	
Intercropped soybean, cv. Giza 21							
50% soybean + 100% maize	3.6±2.0$_{b}$	2.0±1.0	1.0±1.0$_{b}$	0.5±0.3$_{b}$	1.3±1.5	0.3±0.3	1.4±0.9
75% soybean + 100% maize	5.0±2.0$_{b}$	1.1±0.7	5.2±0.3$_{a}$	2.3±0.7$_{a}$	2.0±0.0	1.0±1.0	1.9±1.0
100% soybean + 100% maize	8.7±3.2$_{a}$	2.0±1.0	0.7±0.3$_{b}$	0.5±0.3$_{b}$	1.3±0.6	1.0±1.0	2.3±0.8
F test	13.923	2.909	63.129	71.008	0.471	4.000	3.765
P<0.05	**0.016**	**0.166**	**0.001**	**0.001**	**0.655**	**0.111**	**0.120**
L.S.D. (P=0.05)	**2.724**	**-**	**1.198**	**0.583**	**-**	**-**	**-**
Intercropped soybean, cv. Giza 82							
50% soybean + 100% maize	5.0±1.0$_{b}$	4.7±2.5$_{b}$	2.6±0.6$_{b}$	1.5±0.0$_{b}$	0.0±0.0$_{b}$	0.0±0.0$_{b}$	2.1±0.4$_{b}$
75% soybean + 100% maize	5.3±2.3$_{b}$	4.6±1.5$_{b}$	4.8±1.0$_{a}$	1.5±0.7$_{a}$	0.5±0.3$_{b}$	1.7±1.0a$_{b}$	3.4±0.3$_{ab}$
100% soybean + 100% maize	9.0±1.0$_{a}$	10.6±2.1$_{a}$	2.3±0.6$_{b}$	1.7±0.6	1.3±0.6$_{a}$	3.0±1.7$_{a}$	4.6±1.1$_{a}$
F test	15.647	7.360	7.047	3.684	14.000	8.621	10.368
P<0.05	**0.013**	**0.046**	**0.049**	**0.124**	**0.015**	**0.035**	**0.026**
L.S.D. (P=0.05)	**2.203**	**4.956**	**2.010**	**-**	**0.680**	**1.990**	**1.545**
Intercropped soybean, cv. Giza 111							
50% soybean + 100% maize	4.0±2.0$_{b}$	2.3±1.5$_{b}$	1.7±0.6$_{a}$	3.6±1.1$_{a}$	1.7±1.1	1.3±1.1	2.4±0.6$_{b}$
75% soybean + 100% maize	7.0±2.6$_{ab}$	1.0±1.0$_{b}$	0.7±0.0$_{b}$	2.0±0.6$_{b}$	1.7±1.0	1.7±1.0	2.3±0.3$_{b}$
100% soybean + 100% maize	14.7±4.6$_{a}$	8.0±0.5$_{a}$	2.0±1.0$_{a}$	2.0±1.0$_{b}$	0.0±0.0	0.0±0.0	4.4±0.8$_{a}$
F test	7.708	13.321	31.000	46.594	0.098	0.690	7.517
P<0.05	**0.042**	**0.017**	**0.004**	**0.002**	**0.907**	**0.553**	**0.044**
L.S.D. (P=0.05)	**7.779**	**3.998**	**0.756**	**0.537**	**-**	**-**	**1.522**
	9.0±4.3$_{b}$	3.0±1.8	3.0±1.8	5.7±2.5	2.0±1.0	1.6±0.6$_{b}$	4.1±0.6$_{b}$

Table 9-contd

Sole soybean, cv. Giza 21							
50% soybean							
75% soybean	6.7±2.5$_{b}$	2.7±1.5	2.0±1.0	3.3±2.5	3.3±2.5	2.3±1.0$_{a}$	3.4±0.6$_{c}$
100% soybean	21.0±6.0$_{a}$	6.7±1.5	5.3±1.5	1.0±1.0	1.0±1.0	2.3±1.0$_{a}$	6.2±0.5$_{a}$
F test	16.989	1.822	1.436	0.942	2.846	18.429	67.13
P<0.05	**0.011**	**0.274**	**0.339**	**0.462**	**0.170**	**0.010**	**0.001**
L.S.D. (P=0.05)	**7.325**	**-**	**-**	**-**	**-**	**0.346**	**0.678**
Sole soybean, cv. Giza 82							
50% soybean	11.3±2.3$_{ab}$	4.0±2.0	1.7±0.6$_{b}$	1.7±0.5	1.7±0.6	1.3±0.7$_{b}$	3.6±0.8$_{ab}$
75% soybean	7.3±1.1$_{b}$	2.3±1.5	0.7±0.6$_{b}$	1.7±0.7	1.0±1.0	4.0±1.0$_{a}$	2.8±0.1$_{b}$
100% soybean	15.3±4.6$_{a}$	3.0±2.0	5.7±2.5$_{a}$	2.3±0.5	1.7±2.1	1.3±0.7$_{b}$	4.9±0.5$_{a}$
F test	10.907	0.442	10.500	1.062	0.143	8.889	7.742
P<0.05	**0.024**	**0.671**	**0.026**	**0.427**	**0.871**	**0.034**	**0.042**
L.S.D. (P=0.05)	**4.954**	**-**	**3.205**	**-**	**-**	**1.990**	**1.511**
Sole soybean, cv. Giza 111							
50% soybean	5.3±1.5$_{b}$	4.3±1.5$_{b}$	1.3±1.1$_{b}$	1.7±0.6	1.7±0.6	1.3±0.6$_{b}$	2.6±0.2$_{b}$
75% soybean	8.7±2.0$_{ab}$	2.3±0.6$_{b}$	5.0±1.8$_{a}$	2.7±1.2	2.7±1.1	1.0±0.0$_{b}$	3.7±1.4$_{b}$
100% soybean	13.3±2.9$_{a}$	10.7±2.1$_{a}$	6.0±2.0$_{a}$	1.7±0.6	1.7±0.6	6.0±1.0$_{a}$	6.6±1.0$_{a}$
F test	7.927	16.300	8.579	0.750	0.750	84.400	93.767
P<0.05	**0.041**	**0.012**	**0.036**	**0.529**	**0.529**	**0.001**	**0.000**
L.S.D. (P=0.05)	**5.603**	**4.138**	**3.293**	**-**	**-**	**1.195**	**0.858**

Note: Means followed by the different letters are significantly different from each other at P<0.05 and followed by a least significant difference (L.S.D)

Table 10. Effect of soybean plant densities and soybean varieties on the population density of white fly under intercropping and sole cultures in 2017 season

Treatments	Mean number of white fly /plant /week						Mean
	1st week	2nd week	3rd week	4th week	5th week	6th week	
Intercropped soybean, cv. Giza 21							
50% soybean + 100% maize	$1.0±1.0_b$	2.0±1.0	1.0±1.0	0.7±0.6	1.3±0.7	0.6±0.3	1.7±0.3
75% soybean + 100% maize	$4.3±0.6_a$	1.1±0.6	1.1±0.6	2.3±1.5	1.7±0.6	1.7±0.6	2.2±0.5
100% soybean + 100% maize	$1.0±1.0_b$	2.0±1.0	1.1±0.6	0.3±0.6	1.3±0.6	1.0±1.0	1.3±0.1
F test	11.765	6.400	0.918	1.938	0.927	1.273	4.353
P<0.05	**0.021**	**0.057**	**0.087**	**0.258**	**0.077**	**0.373**	**0.099**
L.S.D. (P=0.05)	**2.203**	**-**	**-**	**-**	**-**	**-**	**-**
Intercropped soybean, cv. Giza 82							
50% soybean + 100% maize	$3.3±1.5_c$	$3.3±1.5_b$	4.0±2.6	$0.0±0.0_b$	$0.0±0.0_b$	0.0±0.0	$2.1±0.6_c$
75% soybean + 100% maize	$5.3±2.3_b$	$0.6±0.3_c$	0.3±0.6	$0.3±0.3_b$	$0.3±0.3_b$	0.3±0.3	$3.4±0.8_b$
100% soybean + 100% maize	$13.7±2.1_a$	$14.0±1.7_a$	1.3±1.1	$1.6±0.6_a$	$1.6±1.6_a$	0.6±1.1	$5.3±0.9_a$
F test	324.400	348.250	0.839	7.000	7.000	0.500	30.947
P<0.05	**0.000**	**0.000**	**0.496**	**0.049**	**0.049**	**0.640**	**0.004**
L.S.D. (P=0.05)	**1.195**	**1.511**	**-**	**1.309**	**1.309**	**-**	**1.141**
Intercropped soybean, cv. Giza 111							
50% soybean + 100% maize	$9.0±1.1_b$	$0.3±0.3_b$	1.3±1.1	$4.3±1.1_a$	1.6±2.1	1.0±0.0	$3.5±0.5_b$
75% soybean + 100% maize	$7.7±1.5_b$	$1.0±1.0_b$	0.0±0.0	$1.3±0.6_b$	2.7±0.6	1.0±0.0	$2.5±0.5_b$
100% soybean + 100% maize	$14.7±2.6_a$	$4.0±1.0_a$	3.7±2.5	$3.0±1.0_a$	2.0±0.0	1.7±0.0	$5.2±1.2_a$
F test	8.135	68.800	3.250	13.857	0.934	3.063	25.566
P<0.05	**0.039**	**0.001**	**0.145**	**0.016**	**0.069**	**0.156**	**0.005**
L.S.D. (P=0.05)	**4.596**	**1.195**	**-**	**1.999**	**-**	**-**	**1.278**

Table 10-contd

Sole soybean, cv. Giza 2							
50% soybean	9.0±4.3$_{b}$	6.0±2.5$_{ab}$	2.0±1.1$_{b}$	5.0±3.6	2.3±1.1	1.6±1.0	4.6±1.5$_{b}$
75% soybean	9.0±4.5$_{b}$	2.7±1.5$_{b}$	5.0±1.5$_{ab}$	0.3±0.3	0.3±0.2	1.0±1.0	3.7±0.9$_{c}$
100% soybean	23.3±3.2$_{a}$	9.0±2.6$_{a}$	7.0±1.0$_{a}$	1.0±1.0	1.0±1.0	0.6±1.0	8.4±0.6$_{a}$
F test	10.388	9.679	10.364	4.300	4.000	1.000	151.536
P<0.05	**0.026**	**0.029**	**0.026**	**0.101**	**0.111**	**0.444**	**0.000**
L.S.D. (P=0.05)	**10.08**	**3.998**	**3.069**	**-**	**-**	**-**	**0.800**
Sole soybean, cv. Giza 82							
50% soybean	13.0±2.6$_{a}$	11.3±2.1$_{a}$	10.3±1.5$_{a}$	3.6±3.1	3.6±3.1	1.3±1.5	8.5±0.9$_{a}$
75% soybean	6.0±2.0$_{b}$	4.0±1.7$_{b}$	5.7±0.6$_{b}$	1.0±1.0	3.7±2.5	1.0±1.0	4.5±0.2$_{c}$
100% soybean	13.0±5.6$_{a}$	6.0±1.0$_{b}$	5.7±2.5$_{b}$	1.7±2.1	2.0±1.0	1.7±2.1	6.0±1.0$_{b}$
F test	10.138	32.846	63.100	0.832	0.407	1.000	30.844
P<0.05	**0.027**	**0.003**	**0.001**	**0.499**	**0.691**	**0.444**	**0.004**
L.S.D. (P=0.05)	**4.983**	**2.724**	**2.389**	**-**	**-**	**-**	**1.932**
Sole soybean cv. Giza 111							
50% soybean	**8.3±1.5$_{b}$**	**4.3±1.5$_{b}$**	**1.3±1.1$_{b}$**	**1.3±0.6**	**1.7±0.6**	**1.7±0.3**	**3.1±0.6$_{b}$**
75% soybean	7.3±0.6$_{b}$	3.3±2.5$_{b}$	3.0±1.0$_{b}$	1.3±0.6	3.3±2.5	1.3±0.6	3.2±0.9$_{b}$
100% soybean	28.0±8.5$_{a}$	8.0±1.7$_{a}$	7.7±1.5$_{a}$	6.0±1.2	0.7±0.3	0.7±0.3	8.5±0.9$_{a}$
F test	15.806	13.938	19.400	49.000	3.769	1.750	30.951
P<0.05	**0.013**	**0.016**	**0.009**	**0.002**	**0.120**	**0.284**	**0.004**
L.S.D. (P=0.05)	**11.508**	**3.022**	**2.926**	**1.511**	**-**	**-**	**2.635**

Note: Means followed by the different letters are significantly different from each other at P<0.05 and followed by a least significant difference (L.S.D)

Population density of lima bean pod borer for intercropped soybean, *cv*. Giza 21 differed significantly between soybean plant densities in the middle and end 2016 and 2017 seasons (Table 11). However, the population density of lima bean pod borer for intercropped soybean, *cv*. Giza 82 differed significantly between soybean plant densities in the middle, end and mean of 2016 and 2017 seasons. Also, the population density of lima bean pod borer for intercropped soybean, *cv*. Giza 111 differed significantly between soybean plant densities in the middle 2016 season, but it differed significantly in the first, middle and end 2017 season. On the other hand, the population density of lima bean pod borer for sole soybean, *cv*. Giza 21 differed significantly between soybean plant densities in the first, middle and end 2016 and 2017 seasons. Sole soybean, *cv*. Giza 82 had the same trend of sole soybean, *cv*. Giza 21 in 2017 season, but it differed significantly between soybean plant densities in the end 2016 season. The population density of lima bean pod borer for sole soybean, *cv*. Giza 111 differed significantly between soybean plant densities in the middle and end 2016 and 2017 seasons. Generally, it was observed that the population density of lima bean pod borer for all soybean varieties increased gradually and was maximum during the end of season under intercropping or sole culture in the two growing seasons. It seems that lima bean pod borer appeared to be more active during the maturity stage on all soybean varieties.

Intercropped soybean, *cv*. Giza 21 had the highest population density of lima bean pod borer by decreasing soybean plant density from 100 to 50 per cent in 2017 season only (Table 11). Also, intercropped soybean, *cv*. Giza 82 had the highest population density of lima bean pod borer by decreasing soybean plant density from 100 to 50 per cent in 2016 and 2017 seasons. Moreover, intercropped soybean, *cv*. Giza 111 had the highest population density of lima bean pod borer by decreasing soybean plant density from 100 to 50 per cent in 2016 season only. It is likely that increase in plant density of all intercropped soybean varieties from 50 to 100 per cent led to reduced insect incidence levels below the economic threshold level by the presence of maize. However, sole soybean, *cv*. Giza 21 or Giza 111 had the highest population density of lima bean pod borer by increasing soybean plant density from 50 to 100 per cent in 2016 and 2017 seasons. Meanwhile, increasing soybean plant density from 50 to 100 per cent did not affect significantly the population density of lima bean pod borer for sole soybean, *cv*. Giza 82 in 2016 and 2017 seasons. It is likely that most plants of soybean, *cv*. Giza 82 were at the maturation stage when lima bean pod borer did not present a high damaging potential to the crop, especially soybean, *cv*. Giza 82 as it is early maturing variety as compared to the others. Restriction of feeding to mature leaves may represent a phenological adaptation enabling these insect species to avoid pubescent leaves (Epstein, 1988).

Soybean varieties of sole culture differed significantly for insect assemblages; aphids, white fly and lima

Table 11. Infestation percentage of lima bean pod borer on soybean varieties pods under intercropping and sole cultures in the two seasons (2016 and 2017)

Soybean variety	**First season (2016)**				**Second season (2017)**			
	First	**Middle**	**End**	**Mean**	**First**	**Middle**	**End**	**Mean**
Intercropped soybean, cv. Giza 21								
50% soybean + 100% maize	13.7±4.5	30.0±5.0$_{a}$	44.4±3.5$_{a}$	29.4±4.3$_{a}$	20.1±4.9	45.0±8.0$_{a}$	43.3±3.2$_{b}$	36.1±5.4
75% soybean + 100% maize	5.0±5.0	16.7±3.1$_{b}$	34.8±4.0$_{c}$	18.8±4.1$_{b}$	12.5±2.5	33.3±2.5$_{ab}$	35.1±4.3$_{c}$	26.9±3.1
100% soybean + 100% maize	15.0±2.9	28.0±2.0$_{a}$	38.2±3.0$_{b}$	27.1±2.7$_{a}$	12.1±2.1	27.6±2.5$_{b}$	48.2±3.5$_{a}$	29.3±2.7
F test	3.082	11.868	290.680	11.045	3.542	8.656	623.339	3.295
P<0.05	**0.155**	**0.021**	**0.000**	**0.024**	**0.130**	**0.035**	**0.000**	**0.143**
L.S.D. (P=0.05)	**-**	**8.172**	**1.133**	**6.980**	**-**	**11.906**	**1.030**	**-**
Intercropped soybean, cv. Giza 82								
50% soybean + 100% maize	5.0±3.0	33.4±2.5$_{a}$	44.2±1.9$_{a}$	27.5±2.5$_{a}$	25.3±3.1$_{a}$	38.1±2.1$_{a}$	50.0±4.9	37.8±3.4$_{a}$
75% soybean + 100% maize	4.0±2.0	33.7±2.1$_{a}$	41.6±2.1$_{a}$	26.5±2.1$_{a}$	26.0±2.0$_{a}$	35.8±2.4$_{a}$	46.2±2.0	36.0±2.1$_{a}$
100% soybean + 100% maize	8.1±2.8	16.0±3.0$_{b}$	26.8±4.9$_{b}$	16.9±3.6$_{b}$	15.0±5.0$_{b}$	16.0±3.9$_{b}$	45.5±6.0	25.5±4.9$_{b}$
F test	1.281	31.198	113.263	9.730	7.040	34.425	0.558	14.226
P<0.05	**0.372**	**0.004**	**0.000**	**0.029**	**0.049**	**0.003**	**0.611**	**0.015**
L.S.D. (P=0.05)	**-**	**7.206**	**3.462**	**7.555**	**9.100**	**8.091**	**-**	**7.286**
Intercropped soybean, cv. Giza 111								
50% soybean + 100% maize	0.0±0.0	26.1±2.0$_{a}$	46.2±2.1	24.1±1.4	16.6±1.5$_{a}$	35.8±3.0$_{a}$	56.6±2.0$_{a}$	36.3±2.3$_{a}$
75% soybean + 100% maize	0.0±0.0	12.5±5.5$_{b}$	45.2±2.4	19.3±2.6	5.0±2.9$_{b}$	37.5±2.5$_{a}$	52.1±1.1$_{b}$	31.5±2.2$_{ab}$
100% soybean + 100% maize	5.0±5.0	12.0±3.5$_{b}$	45.0±1.0	20.7±3.2	10.0±2.0$_{b}$	28.2±3.1$_{b}$	50.0±1.0$_{b}$	29.4±2.1$_{b}$
F test	3.000	8.036	0.424	3.681	13.154	8.582	14.726	7.312
P<0.05	**0.160**	**0.040**	**0.681**	**0.124**	**0.017**	**0.036**	**0.014**	**0.046**
L.S.D. (P=0.05)	**-**	**10.728**	**-**	**-**	**5.999**	**6.687**	**3.462**	**5.333**

Table 11-contd

Sole soybean, cv. Giza 21								
50% soybean	0.0±0.0$_{b}$	20.0±2.0$_{b}$	67.2±2.9$_{a}$	29.1±2.0$_{b}$	10.0±2.0$_{b}$	45.5±4.7$_{c}$	75.0±10.0$_{b}$	43.5±5.6$_{b}$
75% soybean	0.0±0.0$_{b}$	25.0±3.0$_{b}$	61.5±1.8$_{b}$	28.8±1.6$_{b}$	12.0±2.0$_{b}$	48.1±2.8$_{b}$	68.2±2.8$_{b}$	42.8±2.5$_{b}$
100% soybean	15.0±5.0$_{a}$	50.0±3.0$_{a}$	71.5±1.7$_{a}$	45.5±3.2$_{a}$	30.0±5.1$_{a}$	69.6±3.8$_{a}$	89.0±3.6$_{a}$	62.8±4.2$_{a}$
F test	27.000	137.903	13.182	40.778	29.514	702.413	23.930	13.607
P<0.05	**0.005**	**0.000**	**0.017**	**0.002**	**0.004**	**0.000**	**0.006**	**0.016**
L.S.D. (P=0.05)	**6.543**	**7.286**	**5.698**	**5.685**	**7.960**	**1.963**	**8.581**	**11.994**
Sole soybean, cv. Giza 82								
50% soybean	15.0±3.5	36.5±3.1	53.2±2.8$_{b}$	34.9±3.1	25.0±5.0$_{b}$	45.1±2.0$_{b}$	70.0±5.0$_{b}$	46.7±4.0
75% soybean	10.0±3.0	40.0±5.0	65.4±5.1$_{a}$	38.5±4.3	30.0±2.0$_{a}$	61.7±2.9$_{a}$	68.3±2.6$_{b}$	53.3±2.5
100% soybean	15.0±5.0	30.0±2.0	71.8±2.9$_{a}$	38.9±3.3	22.4±1.9$_{b}$	55.0±3.8$_{a}$	88.4±2.6$_{a}$	55.3±2.8
F test	1.493	4.529	35.458	0.883	14.920	14.402	122.230	5.025
P<0.05	**0.328**	**0.094**	**0.003**	**0.481**	**0.014**	**0.015**	**0.000**	**0.081**
L.S.D. (P=0.05)	**-**	**-**	**6.067**	**-**	**3.926**	**8.662**	**3.911**	**-**
Sole soybean, cv. Giza 111								
50% soybean	10.0±2.0	37.9±2.6$_{a}$	62.7±2.1$_{b}$	36.9±2.2$_{a}$	15.0±3.0	40.3±4.0$_{b}$	84.3±4.1$_{b}$	46.5±3.7$_{b}$
75% soybean	10.0±1.9	23.1±3.1$_{b}$	60.3±4.0$_{b}$	31.1±3.0$_{b}$	10.0±2.0	36.4±4.9$_{b}$	84.3±4.1$_{b}$	43.6±3.7$_{b}$
100% soybean	10.0±5.0	20.8±1.8$_{b}$	76.7±2.6$_{a}$	35.8±3.1$_{a}$	15.0±3.0	63.7±10.0$_{a}$	89.5±2.0$_{a}$	56.1±5.0$_{a}$
F test	-	30.622	16.836	8.851	1.493	60.587	20.280	13.930
P<0.05	**-**	**0.004**	**0.011**	**0.034**	**0.328**	**0.001**	**0.008**	**0.016**
L.S.D. (P=0.05)	**-**	**6.641**	**8.584**	**3.663**	**-**	**7.351**	**2.617**	**7.555**

Note: Means followed by the different letters are significantly different from each other at P<0.05 and followed by a least significant difference (L.S.D), then T test (0.05).

bean pod borer in 2016 and 2017 seasons (Table 12). The data belonging to aphids infestation revealed that sole soybean, *cv*. Giza 82 had the highest total richness of aphids; 3.27±0.67 in the first and 3.43±0.71 in second season in comparison to that of sole soybean, *cv*. Giza 21 (1.37±0.56 in 2016 season and 2.03±0.83 in 2017 season) and sole soybean, *cv*. Giza 111 (1.87±1.06 in 2016 and 2.23±0.47 in 2017 seasons). With regard to white fly or lima bean pod borer infestation, the susceptibility of the tested soybean varieties to insect assemblages did not differ under sole culture in 2016 and 2017 seasons. Generally, it was observed that soybean, *cv*. Giza 21 and Giza 111 appeared to be more tolerant to aphids infestation than white fly or lima bean pod borer infestation. These results probably due to soybean, *cv*. Giza 82 had shortest pubescence compared with the other cultivars (Table 1). It is known that the effect of pubescence may be positive, negative or nonexistent, depending on the leaf hair type (glandular or non-glandular), density and length (Andres and Connor, 2003).

Soybean varieties of intercropping culture differed significantly for the insect assemblages; aphids, white fly and lima bean pod borer in 2016 and 2017 seasons (Table 12). With regard to white fly infestation, intercropped soybean, *cv*. Giza 82 had the highest total richness of white fly; 3.67±0.60 in 2016 season and 3.60±0.80 in 2017 season in comparison to that of intercropped soybean, *cv*. Giza 111 (2.96 ±0.56 in 2016 and 3.56±0.70 in 2017 seasons) and intercropped soybean, *cv*. Giza 21 (1.87±0.60 in 2016 and 1.73±0.30 in 2017 seasons). However, the susceptibility of the tested soybean varieties to aphids or lima bean pod borer was not differed under intercropping culture in 2016 and 2017 seasons.

The insect assemblages; aphids, white fly and lima bean pod borer differed between cropping systems in 2016 and 2017 seasons (Table 12). With respect to aphids infestation, intercropping soybean with maize reduced susceptibility of the tested soybean varieties to the insect assemblages compared to those of sole soybean. Total richness of aphids was significantly higher in sole soybean (*cvs*. Giza 21 and Giza 111) than that of intercropping culture by 39.04 and 25.98 per cent, respectively in 2017 season only without any significant differences in 2016 season. Meanwhile, it reached to 92.35 per cent in 2016 season and 87.43 per cent in 2017 season for sole soybean, *cv*. Giza 82. These results indicated that aphids caused significantly less damage in intercropped soybean than those of sole soybean. These results may be attributed to intercropping soybean with maize producing less favourable habitat for aphid**s** than sole soybean. It is likely that aphids preferred the taller crop as maize than shorter crop as soybean when shaded by the taller crop in intercropping. These results are parallel to those observed by Gad El-Rab (1997), who reported that aphid density was higher in sole soybean and lower in intercropped soybean with maize. Also, Hasibuan and Lumbanraja (2012) indicated that intercropping soybean with maize reduced the population

Table 12. Comparisons among all soybean varieties for insect-pests assemblage under intercropping and sole cultures in 2016 and 2017 seasons

Soybean variety	First season (2016)			Second season (2017)		
	Intercropping culture	Sole culture	T test $0.05_{2.77}$	Intercropping culture	Sole culture	T test $0.05_{2.77}$
			Aphids			
Giza 21	$1.84\pm0.55_{a}$	$1.37\pm0.56_{b}$	-0.865	1.46±0.23	$2.03\pm0.83_{b}$	1.128
Giza 82	$1.70\pm0.45_{aB}$	$3.27\pm0.67_{aA}$	2.92	$1.83\pm0.43_{B}$	$3.43\pm0.71_{aA}$	2.848
Giza 111	$2.22\pm 0.89_{a}$	$1.87\pm1.06_{b}$	-0.591	1.77±0.43	$2.23\pm0.47_{b}$	0.664
F test	0.355	16.418	-	0.335	18.429	-
P<0.05	**0.721**	**0.000**	**-**	**0.734**	**0.010**	**-**
L.S.D. (P=0.05)	**-**	**0.97**	**-**	**-**	**0.692**	**-**
			White fly			
Giza 21	$1.87\pm0.60b_{B}$	$4.57\pm0.6_{A}$	3.066	$1.73\pm0.3_{bB}$	$5.60\pm1.0_{A}$	4.02
Giza 82	$3.367\pm0.60_{a}$	3.77±0.46	0.423	$3.60\pm0.8_{aB}$	$6.33\pm0.7_{A}$	4.08
Giza 111	$2.967\pm0.56_{a}$	4.33±0.86	-0.921	$3.56\pm0.7_{aB}$	$6.47\pm0.8_{A}$	2.79
F test	8.014	0.917	-	15.674	1.373	-
P<0.05	0.039	0.470	-	0.013	0.352	-
L.S.D. (P=0.05)	1.071	-	-	1.050	-	-
			Lima bean pod borer			
Giza 21	24.67±3.7	34.00±2.3	1.444	$30.67\pm3.7_{B}$	$49.00\pm4.1_{A}$	2.868
Giza 82	$23.3\pm2.7_{B}$	$37.53\pm3.6_{A}$	4.118	$33.00\pm3.5_{B}$	$51.33\pm3.1_{A}$	3.960
Giza 111	$21.0\pm2.4_{B}$	$34.33\pm2.8_{A}$	5.714	$32.00\pm2.2_{B}$	$48.33\pm4.2_{A}$	3.673
F test	1.192	0.374	-	0.118	0.318	-
P<0.05	0.393	0.710	-	0.892	0.745	-
L.S.D. (P=0.05)	-	-	-	-	-	-

Note: Means followed by the different letters are significantly different from each other at P<0.05 and followed by a least significant difference (L.S.D), then T test (0.05).

density of soybean aphids significantly.

The data belonging to the white fly infestation showed that intercropping soybean with maize reduced susceptibility of the tested soybean varieties to the insect assemblages compared to those of sole soybean. Total richness of white fly was significantly higher in sole soybean, *cv*. Giza 21 than that of intercropping culture by 144.38 per cent in 2016 season and 223.69 per cent in 2017 season. Meanwhile, it reached to 12.20 per cent in 2016 season and 75.83 per cent in 2017 season for sole soybean, *cv*. Giza 82. Whereas, it reached to 81.74 per cent in 2017 season for sole soybean, *cv*. Giza 111 without any significant differences in 2016 season. These results show that white fly caused significantly less damage in intercropped soybean than those of sole soybean. These results probably attributed to maize interfered with the movement of this insect on the soybean surface, thereby; reducing its access to leaf epidermis and this biological effect was enhanced according to pubescence density in each soybean variety.

With respect to lima bean pod borer infestation, intercropping soybean with maize reduced susceptibility of the tested soybean varieties to insect assemblages compared to those of sole soybean. Total richness of lima bean pod borer was significantly higher in sole soybean, *cv*. Giza 21 than that of intercropping culture by 37.81 per cent in 2016 season and 59.76 per cent in 2017 season. Meanwhile, it reached to 61.07 per cent in 2016 season and 55.54 per cent in 2017 season for sole soybean *cv*. Giza 82. However, it reached to 63.47 per cent in 2016 season and 51.03 per cent in 2017 season for sole soybean, *cv*. Giza 111. These results revealed that lima bean pod borer caused significantly less damage in intercropped soybean than those of sole soybean. These results could be due to maize disrupted the ability of this insect to attack soybean plants.

It could be concluded that with proper selection of soybean varieties and intercropping soybean with maize at appropriate plant density, infestation of aphids, white flies and lima bean pod borer could be reduced appreciably.

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Genetic Divergence Analysis on Some Soybean Genotypes

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The soybean is a papilionoid legume that has a fairly wide range of adoption involving a wide array of climatic, soil and growth condition through it is mostly grown on rainfed condition. For a successful breeding programme, the presence of genetic diversity and variability play a vital role. Genetic diversity is essential to meet the diversified goals of plant breeding such as breeding for increasing yield, wider adaptability, desirable quality, and pest and disease resistance. Genetic diversity has been considered as an important factor discriminating the genotypes for selecting genetically diverse parents for obtaining high yielding lines for efficient and successful hybridization programme. Genetic diversity plays an important role in plant breeding either to exploit heterosis or generate productive recombinants. The choice of parents is of paramount importance in breeding program me.

Thus, the knowledge of genetic diversity and relatedness in the germplasm is a pre-requisite for crop improvement programmes. Reduction in genetic variability makes the crop increasingly vulnerable to diseases and adverse climatic changes. So, precise information on the nature and degree of genetic diversity present in soybean introductions from principal areas of cultivation would help to select parents for evolving superior varieties. The aim of study was to identify genetically divergent soybean parents with desirable traits for hybridization, particularly for yield. A number of workers (Ganesamurthy and Seshadri, 2002; Ramgiry, 1998; Todesse and Sentayhu, 2015) have used this approach in the selection of parents in soybean. Therefore, an attempt was made to identify the diverse genotypes and their implication in the breeding programme aimed at the development of desirable idotypes of soybean using D^2 analysis.

Thirty three nationally released and introduced genotypes of soybean from diverse locations were used in the experiment (Table 1). The experiment was conducted at Maharaja College of Chhatarpur, Madhya Pradesh during 2015 in a simple lattice design with two replications. Each plot was with 4 rows at 30 cm width and 5 m row length. Sowing was done by hand drilling at a seed rate of 70 kg per ha. The spacing between

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plots and replication were 0.4 m and 1 m, respectively. The observations were recorded on randomly tagged ten plants for days to maturity, plant height (cm), number of branches per plant, number of pods per plant, number of seeds per pod, 100 seed weight (g) and seed yield per plant (g). Wicks criterion was used to test the significance of difference in mean values of all the characters. Genetic diversity was studied using Mahalanobis D^2 statistics based on the genetic distance ($d=\sqrt{D^2}$), cluster distance was applied for estimating genetic distances between genotype. The genotypes were grouped in to number of cluster by Tochers method as described by Rao (1952). Intra-inter clusters distances and mean performance of the clusters for the characters were also computed.

Table 1. List of soybean genotypes and their source of origin in the present study

S. No	Genotype	Source
1	JS 20-34, JS 95-60, JS 20-89, JS 20-98, JS 93-05, JS 20-53, JS 97-52, JS 335, JS 20-29, JS 20-79 (10)	JNKVV, Jabalpur
2	RVS 24, RVS 2000-4, RVS 2002-19, RVS 2001-18, RVS 2002-22, RVS 2001-4 (6)	RVSKVV, Gwalior
3	NRC 98, NRC 111, NRC 97, NRC 96, NRC 117, NRC 107 (6)	IISR, Indore
4	MACS 1419, MACS 1410, MACS 1420 (3)	ARI, Puna
5	MAUS 613, MAUS 5616 (2)	VNMKV, Parbhani
6	DSB 25, DSB 23-2 (2)	UAS, Dharwar
7	PS 1543, PS 1539 (2)	GBPUA&T, Pantnager
8	DS 3050 (1)	IARI, NewDelhi
9	SL 995 (1)	PAU, Ludhaina

Table 2. Distribution of 33 genotypes into different cluster

S. No.	Cluster no.	No. of genotype	Name of genotype
1	I	8	JS 20-34, NRC 98, SL 995, JS 95-60, DSB 23-2, RVS 24, JS 20-89, MACS 1419
2	II	11	JS 20-98, JS 93-05, JS 20-53, DS 3050, PS 1543, RVS 2000-4, RVS 2002-19, MAVS 613, MAVS 5613, NRC 96, RVS 2001-18
3	III	5	JS 97-52, NRC 111, DSB 25, PS 1539, NRC 97
4	IV	6	RVS 2002-22, JS 335, MACS 1410, MACS 1420, NRC 117, JS 20-29
5	V	2	NRC 107, JS 20-79
6	VI	1	RVS 2001-4

Results of analysis of variance showed significant differences among the genotypes suggesting the presence of sufficient genetic variability in the genotypes selected for the study. Based on the degree of divergence, thirty three genotypes of soybean were grouped in to six cluster using D^2 value in such a way that the genotypes with in a cluster had smaller D^2 values than those in other clusters. The clustering pattern of the genotypes was based on the degree of divergence between the parents. Composition of different cluster with their corresponding genotypes included in each cluster has been given (Table 2). Cluster II had maximum eleven genotypes in each group followed by cluster I, IV, III, V and VI which had eight, six, five, two and one genotypes, respectively.

Perusal of inter- and intra-cluster D^2 values (Table 3) indicated that the highest inter-cluster distance was between cluster I and VI (70.250) followed by between V and VI (68.287) and III and VI (64.505), respectively. Average intra- and inter-cluster D^2 values among thirty three genotypes revealed that the cluster II showed maximum intra-cluster D^2 values (4.170) followed by cluster I (3.820) and cluster III (2.609) indicating presence of diversity in these cluster. The inter-cluster D^2 values ranged from 70.250 to 5.376. The maximum inter-cluster D^2 value 70.250 was observed between cluster I and II. The intra-cluster distances varied from 1.221 to 4.170. Though, the genotypes selected for study were of diverse locations (Table 3), but location diversity did not contribute any direct association with genetic diversity.

Table 3. Average intra- and inter-cluster D^2 values of 33 genotypes of soybean

Cluster	I	II	III	IV	V	VI
I	3.802	6.425	5.376	23.372	8.170	70.250
II	-	4.170	10.157	12.250	9.898	33.952
III	-	-	2.609	18.779	7.387	64.505
IV	-	-	-	1.221	28.712	35.82
V	-	-	-	-	2.062	68.287
VI	-	-	-	-	-	0.00

The average cluster mean for six characters (Table 4) revealed that genotypes included in cluster V were early maturity habit. Cluster V genotypes had minimum plant height and shorter duration for maturity, however, genotypes included in cluster I, II and III were of average plant height. For yield character, the genotypes included in the cluster VI showed the highest value for number of branches per plant (3.57), number of pods per plant (115.6), number of seeds per pod (2.76), 100 seed weight (12.61) and seed yield per plant (18.01). This cluster has one genotype RVS 2001-4. Selection of genotypes from this cluster for these characters may yield desirable results.

Table 4. Mean values of characters for six clusters in 33 genotypes of soybean

Traits	I	II	III	IV	V	VI
Days of maturity	113.05	111.01	116.51	114.3	99.5	110.9
Plant height (cm)	60.3	70.5	69.67	85.4	58.8	84.3
Branches(No/plant)	3.13	3.47	3.01	5.47	2.74	3.57
Pod (No/plant)	38.83	60.1	35.4	70.1	36.01	115.6
Seed (No/pod)	2.04	2.18	2.54	2.61	2.40	2.76
100 seed weight (g)	11.28	12.54	11.09	12.17	12.09	12.61
Seed yield (g/plant)	8.63	12.61	6.85	10.02	8.48	18.01

The results revealed that maximum range of variability was observed for number of pods per plant (35.4 to 115.6). Besides, most of the yield component *viz.*, number of branches per plant, number of seeds per pod, 100 seed weight also contributed remarkably. Meena *et al.* (2017) reported maximum diversity by plant height, pods per plant, seed yield and branches per plant. Variability was observed for number of branches per plant, plant height, days to maturity, and number of seeds per plant while, Sharma (2000) reported that plant height, number of branches per plant, 100 seed weight contributed more to words total genetic divergence. The diversity among the genotypes which was measured by inter-cluster distance was adequate for improvement by hybridization and selection. Kumar and Nadrajan (1994) reported 100 seed weight followed by pods per plant contributed high while, seeds per pod contributed minimum towards total genetic divergence. In the present study the crosses made between the genotypes of cluster separated by large inter-cluster distance likely to show high heterosis. Similar findings were also reported by Meena *et al.* (2007) and Ramgiry (1998). Minimum inter-cluster D^2 values was observed between cluster I and III (5.376) indicating the close relationship among the genotypes included in these two clusters.

Based on the *per se* performance and inter-cluster distance, three genotype RVS-2001-4, NRC-107 and JS-20-79 have been identified as the best genotypes within the clusters for most of the yield attributes. Maximum inter-cluster distance was observed between cluster I and VI and cluster V and VI for number of branches per plant, number of pods per plant, number of seeds per pod and 100 seed weight. Genotype belonging to cluster VI (RVS-2001-4) appeared to the promising for seed yield and other traits and hence, may be intermated with the genotypes cluster V and VI for the identification of promising desirable strains by testing their combining ability using appropriate mating design like diallel analysis. This will give new combinations of desirable genes in gene pool from distant sources. The outcome of such studies will not only generate the genetic variability in crop like soybean, but will be useful in the identification of genetically diverse parents for the inclusion in the intensive hybridization programme aimed at the development of suitable idotypes of soybean. The selection of best genotypes based on *per se* performance and combining ability test and their further studies of segregating material handled by Pedigree method may useful in isolation of some of the transgressive segregants leading to the development of suitable genotypes with desirable gene recombination's for distant sources.

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Performance of Soybean Planted on Broad Bed Furrow System under Real Farm Conditions

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Solidaridad, India has been supporting soybean growers of Madhya Pradesh by way of transferring the research emanated production technology, establishing their linkages with financial agencies and soybean industries through its stake holders. The organisation has also been successfully conducting front line demonstration on soybean funded by Ministry of Agriculture and Farmers Welfare, Government of India through ICAR-Indian Institute of Soybean Research during past two years. In view of uncertainty of monsoon and its uneven distribution particularly during the current decade on account of global climatic change, to mitigate water stress to crop, the measures like broad bed furrow planting were implemented on limited scale in these demonstrations. Under climate change through elevated temperature and CO_2 concentration in atmosphere, the soil moisture plays a crucial role to sustain the productivity of crops. Bhatia *et al*. (2008), while analysing the impact of climate change, reported that soil moisture availability during cropping season of soybean is a limiting factor and leads to a 28 per cent reduction in yield due to adverse soil moisture conditions. Planting soybean on Broad Bed Furrow System saves the crop from moisture stress in the event of long dry spell through storing moisture from rainwater in furrows, and also helps in removing excess rainwater through draining out through furrows and saves the crop from water logging. Therefore, the results of planting soybean on broad bed furrow and flat planting with improved production technology has been compared with the production practices followed by the farmers in this manuscript.

During *kharif* seasons of 2016 and 2017, a total of 115 and 150 front line demonstrations were organised on farmers' fields of Malwa plateau of Madhya Pradesh respectively. For these demonstrations only small farmers, who are responsive to adopt improved technology were selected and updated on the various aspects by organising training programmes prior and during the cropping period. To support them during the demonstration, the technical staff of stakeholders and trained farmer leaders (lead farmers) was made responsible. Out of these demonstrations, in 2016 and 2017, at 12 and 7 locations of Agar block

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of Agar Malwa, Madhya Pradesh the planting of soybean was done on broad bed furrow system along with the components of improved production technology. From the same location, for comparison the results of trials with improved production technology with flat planting were used. Both of the above systems were compared with farmer's practice to visualise the effect of improved production technology, when soybean was planted on broad bed furrow and flat land. For farmer's practice, the comparable data under broad bed furrow and flat planting was averaged out. The soil of demonstrations belonged to Vertisols and associated soils. The soybean variety in all these comparison is early maturing JS 95-60. The rainfall during 2016 and 2017 was 1236.9 mm (44 rainy days) and 815.5 mm (39 rainy days), respectively. Monsoon season rainfall pattern during the study years revealed that during critical crop growth stages (August) there was 100 per cent excess rainfall in 2016 whereas 36 per cent less than normal rainfall in 2017 (Table 1).

Table 1. Monsoon season rainfall in Agar Malwa District during study years

Months	2016		2017	
	Rainfall	% Departure	Rainfall	% Departure
June	123.4	29	107.9	13
July	491.3	64	309.9	4
August	633.8	100	201.8	-36
September	76.7	-53	195	20

Source: IMD

The economic evaluation was done in terms of net returns and benefit cost ratio (B:C ratio) for broad bed and furrow and flat plantings with improved technology and farmer's practice. For working out gross returns, the prevailing market price of soybean and for cost of cultivation, the cost involved in raising the crop and input at the prevailing market rates was considered. The B:C ratio was worked out by dividing gross returns with cost of cultivation.

The maximum average seed yield of soybean under broad bed furrow planting was 1,832 kg per ha (range 1,533-2,228 kg/ha) in 2016 and 1,964 kg per ha (range 1,668-2,128 kg/ha) in 2017, whereas it was 1,571 kg per ha (range 1,488-1,675 kg/ha) and 1,810 kg per ha (range 1,625-1,957 kg/ha), respectively in case of flat planting. In comparison to these two the seed yield in farmer's practice was 1,475 kg per ha (range 1,319-1,694 kg/ha), respectively. The comparison of broad bed and furrow planting and flat planting with farmer's practice showed an increase of 22.71-24.05 per cent and8.34-16.62 per cent, respectively (Table 2). This showed the impact of improved technology on productivity, which was further accentuated in broad bed and furrow

Table 1. Performance of soybean planted on BBF in comparison to flat sowing and farmers practice in front line demonstrations at Agar Block of Agar Malwa district of Madhya Pradesh

Number of locations	Seed yield (kg/ha) BBF	Flat	FP	Per cent increase in BBF over Flat	FP
			2016		
1	1791	1488	1463	20.36	22.42
2	1787	1548	1491	15.44	19.85
3	1533	1387	1319	10.53	16.22
4	1866	1547	1488	20.62	25.40
5.	1982	1575	1395	25.84	42.08
6	1875	1638	1563	14.47	19.96
7	1703	1596	1408	6.70	20.95
8	1662	1630	1398	1.96	18.88
9	2115	1582	1500	33.69	41.00
10	1745	1509	1475	15.64	18.31
11	2228	1672	1694	33.25	31.52
12	1691	1675	1510	0.96	11.99
Average	**1832**	**1571**	**1475**	**16.62**	**24.05**
			2017		
1	1668	1659	1388	0.54	20.17
2	1734	1625	1287	6.71	34.73
3	2267	1857	1940	22.08	16.86
4	1839	1750	1457	5.09	26.22
5.	1988	1866	1632	6.54	21.81
6	2128	1957	1788	8.74	19.02
7	2122	1953	1766	8.65	20.16
Average	**1964**	**1810**	**1608**	**8.34**	**22.71**

planting. This clearly brought out that the significance of conserved moisture by planting soybean in broad bed and furrow system, which is effective in mitigating the water stress in the event of excessive as well as water stress during cropping season. The results of earlier reports (Ramesh *et al.*, 2006, 2017; Lakpale and Tripathi, 2012; Chattopadhayay, *et al.*, 2016) also showed that the planting of soybean on changed land configuration (broad bed and furrow system) with improved technology leads to higher productivity than flat planting with improved technology and farmer's practice.

Economic evaluation

The average gross returns in case of broad bed and furrow planting (Rs 56,777 and 59,893 per ha during 2016 and2017, respectively) were higher than flat planting (Rs 48,284 and 55,424/ha) as well as farmers' practice. The gross returns were lesser in farmer's practice (Rs 45,804 and Rs 49,058/ha). Net returns followed a similar trend that of gross returns. It is interesting to note that the

Table 2. Economic analysis of soybean planted on BBF in comparison to flat sowing and farmers practice in front line demonstrations

Number of locations	Gross Returns (Rs/ha)			Cost of cultivation (Rs/ha)			Net returns (Rs/ha)			Additional returns (Rs/ha) over FP		BC ratio		
	BBF	**Flat**	**FP**	**BBF**	**Flat**	**FP**	**BBF**	**Flat**	**FP**	**BBF**	**Flat**	**BBF**	**Flat**	**FP**
							2016							
1	55521	46128	45353	23548	19528	19537	31973	26660	25817	6156	843	2.36	2.36	2.32
2	55397	47988	46206	21383	18635	18280	34014	29353	27926	6088	1427	2.59	2.58	2.53
3	47523	42997	40889	21833	19832	18797	25690	23165	22092	3598	1073	2.17	2.17	2.18
4	57846	47957	46113	21495	19160	24040	36351	28797	22073	14278	6724	2.69	2.50	1.92
5	61442	43989	43245	23183	19785	18503	38259	24204	24743	13516	-539	2.65	2.22	2.33
6	58125	50778	48438	19148	21010	19792	38977	29768	28646	10331	1122	3.04	2.42	2.45
7	52793	49476	43633	22380	20088	19106	30413	29388	24527	5886	4861	2.36	2.46	2.28
8	51522	50530	43323	18360	19363	16401	33162	31167	26922	6240	4245	2.80	2.61	2.64
9	65565	49034	46500	24130	20481	20049	41435	28553	26451	14984	2012	2.72	2.39	2.32
10	54095	46779	45725	25495	25275	23801	28600	21504	21925	6675	-421	2.12	1.85	1.92
11	69068	51832	52514	22995	18534	19963	46073	33980	32551	13522	1429	3.00	2.79	2.28
12	52421	51925	47709	19505	19528	17645	32916	32397	30065	2851	2332	2.69	2.66	2.70
Average	**56777**	**48284**	**45804**	**21955**	**20102**	**19660**	**34822**	**28245**	**26145**	**8677**	**2100**	**2.60**	**2.42**	**2.32**
							2017							
1	50874	50600	42336	20691	23383	19731	30183	27217	22606	7577	4611	2.46	2.16	2.15
2	52887	51188	39254	23742	21094	19299	29145	20020	19955	9190	65	2.23	1.86	1.96
3	69144	56639	59171	21062	19637	18909	48082	37002	40262	7820	-3260	3.28	2.88	2.45
4	56090	53375	44424	21136	20327	18125	34954	33048	26299	8655	6749	2.65	2.63	2.45
5	60634	56913	49776	26777	23867	22596	33857	33046	27180	6677	5866	2.26	2.38	2.20
6	64904	59689	54580	20269	21815	19311	44635	37874	35269	9366	2605	3.20	2.74	2.83
7	64721	59567	53863	21472	24700	20709	43249	34867	33155	10094	1712	3.01	2.41	2.60
Average	**59893**	**55424**	**49058**	**22164**	**22118**	**19811**	**37729**	**31868**	**29247**	**8483**	**2621**	**2.73**	**2.44**	**2.38**

additional returns in broad bed and furrow planting was higher (Rs 8,677 and 8,483/ha) over farmer's practice than flat planting (Rs 2,100 and 2,621//ha) in 2016 and 2017, respectively (Table 3). The possible reason is that the farmers in soybean cultivation in the region are for almost four and half decade and they have already adopted some of the improved practices with time and thus the net additional returns in improved practice are not high. However, the working out of benefit cost ratio was in decreasing order: broad bed and furrow planting with improved technology (2.60 and 2.73 for 2016 and 2017) < flat sowing with improved technology (2.42 and 2.44) < farmer's practice (2.32 and 2.38).

The study suggested that for higher production and profitability of soybean cultivation, planting on broad bed and furrow system in imperative and farmers are required to be motivated to adopt it to mitigate the losses due to climate change.

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References: References should be cited by authors and year: Ansari (2000) or Ansari and Sharma (2000) in the text. References should be arranged in alphabetical order and listed at the end of the paper as follows:

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

Joshi O P, Billore S D, Ramesh A and Bhardwaj Ch . 2002. Soybean-A remunerative crop for rainfed forming. *In*: Agro technology for dry land forming, pp 543-68. Dhopte AM (Eds.). Scientific Publishers (India), Jodhpur. **(Book chapter)**

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

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LIABILITIES	AMOUNT	ASSETS	AMOUNT
Capital Fund		**Fixed Assets**	
Opening Balance	4,771,861	Computer & Printer	114
Add : Life Membership	14,000	Less :- Depreciation	46
Add : Surplus of the year	68,217		68
	4,854,077		
		Furniture & Fixture	13,468
		Less :- Depreciation	1,347
			12,121
		Investments	
		Fixed Deposit	1,048,078
		Mutual Fund (in Canara Bank)	3,660,000
		Current Assets	
		TDS Recievable	62,277
		Bank Balance - Canara Bank	71,533
TOTAL ₹	**4,854,077**	TOTAL ₹	**4,854,077**

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED ON 31.03.2018

EXPENDITURE	AMOUNT	INCOME	AMOUNT
Printing of Soybean Research	18,375	Membership Fees	11,600
Web Designing Expenes	6,500	Sale of Publications	8,750
Legal & Professional Fees	4,720	Interest Received	
		- On Fixed Deposit	76,301
Depreciation	1,392	- On Saving Account	2,553
Excess of Income over Expenditure	68,217		
TOTAL ₹	**99,204**	TOTAL ₹	**99,204**

For SOCIETY FOR SOYABEAN RESEARCH AND DEVELOPMENT

President　　　Treasurer

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DATE : 08/08/2018

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