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CONTENTS

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Weeds in Soybean *vis-a-vis* other Crops under Climate Change-A Review

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ABSTRACT

Weeds possess wider genetic diversity than field crops. The changes within environment resources due to climate change, caused changes to the biology and competitive abilities of agricultural pests (weeds, insects and pathogen) relative to crops. Weeds with C_3 and C_4 photosynthetic pathways may exhibit differential responses to higher CO_2 levels and temperatures, which can affect the dynamics of crop–weed competition. Weed competition can result in potential crop losses of 34 per cent globally. Weed population will change with climate change and risks of invasiveness may increase. Effectiveness of current management practices may be affected. Most of the research concentrated only on single factor either elevated CO_2 or temperature) therefore research is needed to assess the interactive effects of multiple climate change factors simultaneously to help prediction how weed problems may change in future with changing climate in order to develop flexible integrated weed management practices which are based on a foundation of knowledge of weed biology and ecology. Weeds have been winner and will be winner in future climate change conditions because of more adaptive power and more diversity. In this review, the most of the things illustrated very precisely.

Key words: Climate change, carbon dioxide, temperature, weeds

The mega drivers of agricultural production are environmental (CO_2, temperature, precipitation, sunshine hours, *etc.*), edaphic (physical, chemical and biological properties, *etc.*), genetic potential of crop and agronomic management. Climate change will have significant and generally negative impacts on agriculture and growth prospects in the lower latitudes (Vermeulen *et al.*, 2012; Field *et al.*, 2012; Stocker *et al.*, 2013). As climate prediction models show increased occurrences of drought, flooding and high temperature spells during the crop growing periods (IPCC, 2008; Mittler and Blumwald, 2010). Drought, flooding, high temperature, cold, salinity, and nutrient availability are abiotic factors that have a huge impact on world agriculture and account for more than 50 per cent reduction in average potential yields for most major crops (Wang *et al.*, 2003). By 2050, climate-related increases in water stress are expected to affect land areas twice the size of those areas that will

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experience decreased water stress (Bates *et al*., 2010]. Increased climate variability in the coming decades will increase the frequency and severity of floods and droughts, and will increase production risks for both croppers and livestock keepers and reduce their coping ability (Thornton and Gerber, 2010].

The earth is warmed largely by short-wave radiation (0.15-4.0 µm) emanating from the Sun, which has a high temperature 6000^{0}C). The overall climatic consequences, called '*global warming*', is an enhanced greenhouse effect. Of these gases, CO_2 is the most significant, contributing to about 64 per cent of the effect, followed by CH_4 (19 %), CFCs (11 %) and N_2O (6 %).

Overall, changes to the biology and competitive abilities of agricultural pests (insects, pathogens, weeds) relative to potential crop yield losses have not been well quantified (Scherm, 2004; Gregory *et al*., 2009). This is an important omission as the role of pests on constraining crop production is significant and well recognized. For example, weed competition can result in potential crop losses of, 34 per cent globally, with insect pests and pathogens resulting in additional losses of, 18 and 16 per cent, respectively (Oerke, 2006). Such omissions may reflect the complex challenges in relating atmospheric CO_2 and climate variables to potential reductions in crop production related to increased pest pressures. For example, weed growth and fecundity can be directly affected by increasing atmospheric CO_2 as well as rising temperature; insects and pathogens can also be directly affected by temperature, but indirectly by CO_2 and/or climate induced changes to their weed hosts (Oerke, 2006; Ziska and Runion, 2007). Overall, while a number of pest studies have been conducted, empirical evidence has been eclectic, although it has been suggested that pest pressures will probably increase with climate change (Patterson *et al*., 1999).

Increase in CO_2 to 550 ppm increases yields of rice, wheat, legumes and oilseeds by 10-20 per cent. A 1^{0}C increase in temperature may reduce yields of wheat, soybean, mustard, groundnut, and potato by 3-7 per cent. Much higher losses could be at higher temperatures. Productivity of most crops to decrease only marginally by 2020 but by 10-40 per cent by 2100 due to increases in temperature, rainfall variability, and decreases in irrigation water. The major impacts of climate change will be on rainfed or un-irrigated crops, which **are** cultivated in nearly 60 per cent of crop land. A rise by 0.5^{0}C in winter temperature is projected to reduce rainfed wheat yield by 0.45 tonnes per ha in India (Lal *et al*., 1998). Possibly some improvement in yields of chickpea, *rabi* maize, sorghum and millets; and coconut in west coast. Less loss in potato, mustard and vegetables in north-western India due to reduced frost damage. Increased droughts and floods are likely to increase production variability.

Variations in air temperature, CO_2, and precipitation directly affect soybean yield. Heinemann *et al*., (2006) observed an increase of soybean yield at an elevated temperature and CO_2;

however, the rate of increase in yield was reduced with increased air temperatures in Georgia. Similar results were found when CO_2 concentration was doubled, and soybean yield increased 50 per cent; nevertheless, the positive effect of the CO_2 increase was offset by the air temperature increase of 3°C, and the final combined effect between CO_2 increase and temperature resulted in 36 per cent increase of soybean yield (Lal *et al.*, 1999). Mohanty *et al.* (2017) showed that increasing CO_2 concentrations alone resulted in increased soybean yield in India. Similarly, reduction in rainfall amount indicated negative impact on it. This effect further compounded with increase in temperature and thus, reduced soybean yield. Increasing the temperature with 10 per cent decrease in rainfall declined the soybean yield by 10 per cent. An increase in temperature along with increase in rainfall has also not favored soybean growth. Decreasing the temperature from the base by 1°C and increasing the rainfall by more than 10 per cent benefitted the soybean productivity, whereas increasing the temperature by 1°C with no change in rainfall resulted decline in soybean productivity by 10-15 per cent. Soybean yields in China are predicted to decrease by 5-10 per cent under the slowest warming scenario and by 8-22 per cent under the fastest warming scenario by the end of the century (Chen *et al.*, 2013).

The direct and indirect effects of the global changes on agriculture and natural ecosystems can be summarized as below.

(1) Increased CO_2 concentrations could have a direct effect on the growth-rates of individual crop plants and weeds and also cause vegetation communities to change;

(2) CO_2 induced climate changes may alter temperature, rainfall patterns and amounts of radiation received in different parts of the world; this will influence the productivity of natural ecosystems or agricultural landscapes with significant regional variations; and

(3) Sea level rises, also with regional differences, may lead to loss of productive land, and to increasing salinity of groundwater in coastal zones.

Of the above effects, only the first two are most relevant to weed management. A better understanding of potential changes in both crops and weeds is crucial to enable adapting to future climate changes, and sustain our ability to manage weed populations effectively.

Of the 15 crops, which supply 90 per cent of the world's calories, 12 have the C3 photosynthetic pathway. In contrast, 14 of the 18 'World's Worst Weeds' are C4 plants (Patterson, 1984). The general consensus of the above and other similar studies is that the greater majority of weeds in the world, which are C3 plants, will benefit from increased CO_2 levels under climate change, while most tropical grasses, which are C4 plants, are not likely to show greatly increased growth in higher CO_2. However, because C4 plants are generally more tolerant of heat and moisture stress, the simple notion that climate change will only benefit C3 plants may not be accurate.

A lot of research literature is available on climate change effect on crops, yet, just a few papers cover the effects of climate change on weeds in relation to specific crops (Patterson *et al.*, 1984; Alberto *et al.*, 1996; Tungate *et al.*, 2007).

Principals of weed reaction

The effects of changing climatic conditions impact arable weeds in various ways. In order to persist in a local habitat, species have to respond to the changes of the environment (Woodward and Cramer, 1996). These responses lead to shifts, which act at distinctive scales. Generally, plant species have following three options to avoid extinction (Lavorel and Garnier, 2002; Pautasso *et al.*, 2010).

1. Migration with a favorable climate, which leads to alterations of the distribution of weeds—a process called range shift. For migration, weeds need to possess appropriate propagule dispersion mechanisms. In arable ecosystems, this is often also provided by human actions (Kubisch *et al.*, 2013). Range shifts act at the landscape scale (Jump and Peñuelas, 2005).
2. Acclimation to changes in climate conditions basically refers to the response of species within their phenotypic plasticity without evolutionary adjustments (Pearman *et al.*, 2008). These responses can be divided into tolerance and avoidance of climatic changes that lead to performance beyond the species' ecological optimum (Grime and Hodgson, 1987; Lavorel and Garnier, 2002). As a consequence, the fitness and the competitive ability of the weeds are either reduced or enlarged (Barrett, 2000). Consequently, the realized niche is being altered, which leads to niche shifts. They act at the community scale and can be determined visually as composition shifts.
3. Adaptation to changes in climate conditions, which is often associated with the evolution of new properties or with the optimization of existing ones (Harlan and deWet, 1965; Carroll *et al.*, 2007; Tungate *et al.*, 2007). These individual biological adaptations of weeds, which are driven by natural selection, result in trait shifts. They become apparent at the population scale, but are brought about by morphological, physiological, and genetic processes at the individual plant scale.

Effects of elevated CO_2

CO_2 has risen 33 per cent from a pre-industrial concentration of about 280 µL per L to a current estimate of about 370 µL per L mostly due to population growth, burning of fossil fuels for energy and changes in land use practices, including deforestation (Parry, 1990, 1998; Bunce, 2001). Continuing increases in CO_2 and other trace gases could result in an increase in global surface temperature (IPCC, 1996) and alterations in the Earth's climate.

Consequences of increased atmospheric CO_2 are likely to be felt by plants mainly through direct effects on their physiological processes like photosynthesis and stomatal physiology, resulting in increased growth rates of many plants (Drake *et al.*, 1997). Other consequences are related to increased temperature, which can directly and indirectly affect plant growth and metabolism. Increased CO_2 concentration and temperature will alter a plant's ability to grow and compete with other individuals within a given environment. There is also evidence (IPCC, 1996; Parry, 1998; Bunce, 2001) that increased CO_2 would enable many plants to tolerate environmental stresses, such as drought and temperature fluctuations. Increased tolerance of environmental stress is likely to modify the distribution of weeds across the globe, and their competitiveness, in different habitats.

Photorespiration is one reason why C3 crops (rice, wheat, soybean, barley and sunflower) exhibit lower rates of net photosynthesis than do C4 crops (maize sorghum, sugarcane and millet), at ambient CO_2. However, due to the same reason, C3 species will respond more favourably to elevated CO_2 levels, because CO_2 tends to suppress photorespiration. In C4 plants, the internal mesophyll cell arrangements are different to those of C3 plants, making efficient transfer of CO_2 possible, and this minimizes photorespiration and favours photosynthesis (Drake *et al.*, 1997). Under present CO_2 levels, C4 plants are more photosynthetically efficient than C3 plants. Given that they are already efficient at harnessing CO_2, they are likely to be less affected by further CO_2 increases. It is also possible that in a CO_2 enriched atmosphere, important C4 crops of the world may become more vulnerable to increased competition from C4 weeds.

There is sufficient evidence that increased CO_2 concentration leads to partial closure of stomata through which CO_2 is absorbed and water vapour is released by transpiration. This lowers the water requirements of plants by reducing transpiration per unit leaf area, while promoting photosynthesis. The dual effect of promoting photosynthesis and reducing transpiration is to improve water use efficiency. Kimball and Idso (1983) reported improvement of water use efficiency by 70-100 per cent for both C3 and C4 species.

A doubling of CO_2 concentrations is predicted to cause a 30-40 per cent decrease in the stomatal aperture in both C3 and C4 plants, reducing transpiration losses by as much as 25-40 per cent. Savings in water can be expected, if elevated CO_2 stimulates increase in leaf area index more than it decreases stomatal conductance. In long-term field studies of whole plant responses to elevated CO_2, reviewed by Drake *et al.* (1997), leaf area index did not increase in any species, but evapo-transpiration was reduced compared with normal ambient in all of the species studied.

Differential response of weeds to elevated temperature

Patterson (1995) indicated

significant variations in response to CO_2 both within a species and between species, depending on experimental conditions. While the variability in plant responses is large, C3 weeds generally increased their biomass and leaf area under higher CO_2 concentrations compared with C4 weeds. In view of such results, it could be predicted that C3 weeds, like *Parthenium hysterophorus* L., and *Chromalaena odorata* L. will be much more competitive under raised CO_2 environment, independently of temperature and rainfall effects.

Ziska and Bunce (1997) compared the effect of elevated CO_2 levels on the growth and biomass production of six C4 weeds (*Amaranthus retroflexus* L., *Echinochloa crus-galli* (L.) P. Beauv., *Panicum dichotomiflorum* Michaux, *Setaria faberi* Herrm., *Setaria viridis* (L) P. Beauv., *Sorghum halapense* (L) Pers.) and four C4 crop species (*Amaranthus hypochondriacus* L., *Saccharum officinarum* L., *Sorghum bicolor* (L) Moench, and *Zea mays* L.). Eight of the ten C4 species showed a significant increase in photosynthesis. The largest and smallest increases observed were for *A. retroflexus* (+30%) and *Z. mays* (+5%), respectively. Weed species (+19 %) showed approximately twice the degree of photosynthetic stimulation as that of crop species (+10 %) at higher CO_2, which also resulted in significant increases in whole plant biomass for four C4 weeds (*A. retroflexus, E. crus- galli, P. dichotomiflorum, S. viridis*) relative to the ambient CO_2 condition. Leaf water potentials for three of the species (*A. retroflexus, A. hypochondriacus, Z. mays*) indicated that differences in photosynthetic stimulation were not solely due to improved leaf water status. This study confirmed that C4 plants may respond directly to increasing CO_2 in the atmosphere, and in the case of some C4 weeds (e.g. *A. retroflexus*), the photosynthetic increase could be similar to those published for C3 species.

C3 crop such as rice and wheat, elevated CO_2 may have positive effects on crop competitiveness with C4 weeds (Fuhrer, 2003; Yin and Struik, 2008). C3 weeds like *P. minor* and *A. ludoviciana* in wheat (C3) would aggravate with the increase in CO_2 due to climate change. Elevated CO_2 has been shown to increase growth and biomass accumulation of the C4 weed *Amaranthus viridis* (Naidu and Paroha, 2008). As high temperatures would also create increased evaporative demand, with its high water use efficiency and CO_2 compensation point, C4 photosynthesis is better adapted to high evaporative demand (Bunce, 1983).
The interaction between increased CO_2 concentration and other environmental factors such as water, light intensity, nutrient availability and temperature may also result in differential response to increased CO_2 among weeds and crops (Patterson and Flint, 1982; Bazzaz and Carlson, 1984). Some studies have shown that low or high temperatures reduce or eliminate the high CO_2 growth enhancement (Hofstra and Hesketh, 1975; Idso, 1990; Coleman and Bazzaz, 1992) whereas; others have shown that CO_2 enrichment temperature extremes (Sionit *et al*., 1981; Potvin, 1985; Baker *et al*., 1989).

Based on the differences in temperature optima for physiological processes, it is predicted that C4 species will be able to tolerate high temperature than C3 species. Therefore, C4 weeds may benefit more than the C3 crops from any temperature increases that accompany elevated CO_2 levels. High CO_2 levels have been shown to ameliorate the effects of sub-optimal temperatures (Sionit *et al*., 1987) and other forms of stress (Bazzaz, 1990) on plant growth. Carter and Patterson (1983) and Tremmel and Patterson (1993) have shown that high CO_2 ameliorated the high temperature effects on quack grass (*Elytrigia repens*). Alberto *et al.,* (1996) suggest that competitiveness could be enhanced in C3 crop (rice) relative to a C4 weed (*Echinochloa glabrescens*) with elevated CO_2 alone but simultaneous increases in CO_2 and temperature still favor C4 species. O'Donnell and Adkins (2001) reported that wild oat plants grown at high temperature 23/19^{0}C (day/night) completed their development faster than those grown at normal temperature 20/16^{0}C. If the maturation rate is faster relative to the crop, more seeds may be deposited in the soil seed bank with a consequent increase in the number of wild oat plants. The wild oat plants grown at 480 ppm CO_2 produced 44 per cent more seed than those grown at 357 ppm. As high temperatures would also create increased evaporative demand with its high water use efficiency and CO_2 compensation point C4 photosynthesis is better adapted to high evaporative demand (Bunce, 1983).

The CO_2 enrichment tends to reduce the deleterious effects of drought (Sionit and Patterson, 1985). Due to CO_2 enrichment, the wheat plant could gain biomass against *P. minor.* Under water stress conditions, however, *P. minor* had advantage over wheat with CO_2 enrichment (Naidu and Varshney, 2011). Even under water limited conditions growth enhancement by CO_2 appears to be greater in C3 crops than C4 weeds, if the temperature increase is not as dramatic as predicted (Patterson, 1986). An increase in temperature with accompanying soil moisture stress will offset the growth benefits from CO_2 fertilization; the net effect depends on the level of moisture stress. Plants with C4 photosynthetic metabolism sometimes increase photosynthesis and growth at elevated CO_2 concentration under dry conditions (Patterson, 1986; Knapp *et al*., 1993), when elevated level of CO_2 slows the development of stress.

Nitrogen fixing weeds may especially benefit because growth stimulated by CO_2 will not be constrained by low nitrogen levels (Poorter and Navas, 2003). Under extreme nutrient deficiencies, there may be no response to elevated CO_2 in terms of biomass increase; under moderate limitations more relevant to agricultural situations, the increase in biomass may be reduced but the relative stimulation by elevated CO_2 is often similar (Wong, 1979; Rogers *et al.,* 1993). As in case of water stress reduction in growth caused by nutrient deficiency may reduce the impact of weeds on crop production (Patterson, 1995b), since smaller plants interfere less among themselves.

Crops show substantial differences in the composition and abundance of weed species (Schroeder *et al.*, 1993). The weed species composition is mainly affected by the grown crop besides edaphic factors, the season, altitude and climate (Pysek *et al.*, 2005; Andreasen and Skovgaard, 2009; Cimalova and Lososova 2009; Gunton *et al.*, 2011). Alternate wetting and drying in puddled as well as dry-seeded rice may encourage weeds such as *Leptochloa chinensis*, *Eleusine indica* and *Eclipta prostrata* (Mahajan *et al.,* 2012). Flowering can be faster, slower or unchanged at elevated CO_2, depending on species. Reekie *et al.* (1994) reported that elevated CO_2 delayed flowering in four short day species and hastened it in four long day species.

In their responses to climate change, humans are likely to introduce more weeds and create more opportunities for invasion. Many crops proposed for biofuels, jatropha (*Jatropha curcas*) and giant reed (*Arundo donax*) for example are serious weeds (Low and Booth, 2007).

The invasive weed *Parthenium hysterophorus* had shown tremendous growth response to elevated CO_2 (Naidu and Paroha 2008; Naidu, 2013)

Effects of elevated temperatures

Models of global climate predict that mean surface air temperature of the Earth will rise by 1.5- 4.5^{o}C in the 21st century, due to the doubling of CO_2 concentrations and the enhanced greenhouse effect (IPCC, 2001). Extreme high-temperature events are anticipated to increase in frequency. Plants, in many parts of the world, are thus likely to experience increasing high-temperature stress. However, the effect of increased temperature would be felt in different regions of the world differently. It could be argued that in sub-tropical and tropical regions, an increase of temperature by a few degrees could lead to an increase in evapo-transpiration rates to a point that the growth of some species would suffer, due to moisture deficiency. However, changes in rainfall patterns would offset such species responses, under a changing climate.

Temperature is the dominant factor that controls plant growth at high (above 50^{0}N) and mid- latitudes (above 45^{0}N). At high altitudes, this is due to the influence temperature has on the length of the growing season. Probably the most significant effect of a future increase in temperature in regions where it is the main limiting factor, would be to extend the growing season available for plants. However, the effects of such warming on the length of the growing period will again vary from region to region and from crop to crop.

Under high temperature, plants with C4 photosynthesis pathway (mostly weeds) have a competitive advantage over crop plants possessing the more common C3 pathway (Yin and Struik, 2008) Introduction in 1877 from Central America as a drought tolerant species suitable for afforestation in arid zones of India, *Prosopis juliflora* has invaded nearly 6 million hectares of land contributing for 1.8 per cent of geographical area of the country (Kathiresan, 2005).

It is generally accepted that higher atmospheric CO_2 is likely to stimulate the growth of crops, and C3 plants are the most likely to benefit. The consensus of three decades of research is that a doubling of CO_2 concentrations may cause a 10-50 per cent yield increase in C3 crops like rice, wheat and soybean (Kimball, 1983; Poorter, 1993), the corresponding yield increase expected in C4 crops, such as maize, sorghum and sugar cane, is 0-10 per cent.

Rising minimum temperatures associated with anthropogenic climate change could extend the potential geographic range of pest species and/or alter their demographics, although long-term changes in species diversity are unclear (Bradley *et al*., 2010; McDonald *et al*., 2009). Increases in minimum temperature result in a relatively greater increase in herbicide applied. Once temperature has reached a critical thermal threshold, it is a significant driver of shifts in insect and pathogen demography (Ziska and Runion, 2007; Fuhrer, 2003).

Effect of precipitation

Weeds constrained by rainfall may also find new habitats under new climatic conditions. Annual plant communities are likely to be strongly responsive to altered precipitation regimes because species composition and abundance are driven by germination dynamics that often depend on water availability (Baskin and Baskin, 1998; Lundholm and Larson, 2004). Events early in the growing season can have long-lasting impacts in annual communities (Ross and Harper, 1972; Levine *et al*., 2008). Variation in water availability throughout the growing season may also directly affect plant growth (Novoplansky and Goldberg, 2001; Sher *et al*., 2004). Weeds in row crop agriculture provide a widespread and economically important system dominated by annual plants (Davis *et al*., 2005) to examine the impacts of precipitation variability. In addition, knowledge of how annual weed communities respond to precipitation variability may have important consequences for agricultural management practices.

Lantana camara, for example, could expand if rainfall increased in some areas (McFadyen, 2008). Phyto-sociological survey of floristic composition of weeds in this region reveals that rice fields were invaded by alien invasive weeds *Leptochloa chinensis* and *Marsilea quadrifolia*. These two weed species dominated over the native weeds such as *Echinochloa* species and others by virtue of their amphibious adaptation to alternating flooded and residual soil moisture conditions prevalent during this period in this region (Yaduraju and Kathiresan, 2003; Kathiresan, 2005).

How will 'colonizing species' (weeds) react to changing climate?

Weeds are opportunistic 'colonizing species' or 'pioneers of secondary succession' that are well adapted to grow in locations where disturbances, caused either by humans or by natural causes, have opened up space. Species can become weeds, because they are competitive, adaptable, highly fecund, and are able to tolerate a wide range of environmental conditions, including those in agricultural fields, or disturbed habitats.

In many cases, this opportunity arises because of lack of specific parasites or herbivores *i.e.* 'natural enemies', which gives them an advantage over crops or native flora (Naylor and Lutman, 2002). Thus, in terms of the Darwinian concept of 'struggle for existence', weeds, as a class, are the most successful plants that have evolved on our planet (Auld, 2004).

Weed/crop competition will be altered by climate change

In general, elevated CO_2 levels would stimulate the growth of major C3 crops of the world; the same effect is likely to also increase the growth of both C3 and C4 weeds. Carter and Peterson (1983) found that *Festuca elatior* L., a C3, grass, out-competed *Sorghum halepense* (L.) Pers., a C4, grass, in mixed cultures, under both ambient CO_2 levels and elevated CO_2, even under temperature unfavourable to C3 photosynthesis (between 25 - 40^{0}C). The authors predicted that global CO_2 enrichment would alter the competitive balance between C3 and C4 plants and this may affect seasonal niche separation, species distribution patterns, and net primary production within mixed communities.

Ziska (2000) evaluated the outcome of competition between 'Round-up Ready' soybean (*Glycine max* L.) and a C3 weed (*Chenopodium album L.*) and a C4 weed (*Amaranthus retroflexus*), grown at ambient and enhanced CO_2 (ambient + 250 µL/L). In a weed-free environment, elevated CO_2 resulted in increased soybean growth and yield, compared to the ambient CO_2 condition. However, soybean growth and yield were significantly reduced by both weed species at both levels of CO_2. With *Chenopodium album*, at elevated CO_2, the reduction in soybean seed yield relative to the weed-free control increased from 28 to 39 per cent. Concomitantly, the dry weight of *Chenopodium album* was increased by 65 per cent. Conversely, for *Amaranthus retroflexus*, soybean seed yield losses diminished with increasing CO_2 from 45 to 30 per cent, with no change in weed dry weight. This study suggested that rising CO_2 could alter yield losses due to competition from weeds, and that weed control will be crucial in realizing any potential increase in the yield of crops, such as soybean, as climate change occurs.

Alberto *et al.* (1996) concluded that at elevated CO_2 indicating increased 'competitiveness' of rice. However, under elevated CO_2 level and the higher temperature regime, competitiveness and reproductive stimulation of rice was reduced compared to the lower growth temperature, suggesting that while a C3 crop like rice may compete better against a C4 weed (*Echinochloa glabrescens* L) at elevated CO_2 alone, simultaneous increases in CO_2 and temperature could still favour a C4 species.

Climate change may cause range shifts in weed distribution and abundance

A body of research is emerging (Rosenzweig and Hillel, 1998; Luo and Mooney, 1999; Bunce, 2000), which indicated that elevated CO_2 levels are likely to increase the ability of plants to tolerate both high and low temperatures. However, the responses are linked with moisture availability through modified rainfall patterns, and possibly other factors like nitrogen deposition. Boese *et al*. (1997) established the increased tolerance of low temperatures under elevated CO_2 for several chilling-sensitive plants of tropical or sub-tropical origin. Possible reasons were: improved plant water balance, less severe wilting and less leaf damage under elevated CO_2 compared with ambient levels.

Temperature is recognized as a primary factor influencing the distribution of weeds across the globe, particularly at higher latitudes. Increased temperature and precipitation in some parts of the earth may provide suitable conditions for stronger growth of some species, which are currently limited by low temperatures.

These and other studies (Kriticos *et al*., 2003a, b; 2004, 2006) are indicating significant and increased risks of spread and invasion of new areas by well-known aggressive 'colonisers'. In Australia, species currently restricted to the lowlands, such as Lantana (*Lantana camara* L.) are expected to move into higher altitude areas. Frost-intolerant species such as Rubbervine (*Cryptostegia grandiflora* R. Br.) and *Chromalaena odorata* could also shift their ranges significantly further south (Kriticos *et al*., 2003a and CRC, 2008).

Increased rainfall may also cause range shifts in the distribution of some weeds, which are currently limited to higher rainfall zones. Reduced rainfall will also reduce growth of pastures and crops, increasing bare ground and reducing canopy cover which favours weed invasion. Increased extremes, *e.g.*, long drought periods interspersed with occasional very wet years, will worsen weed invasion, because established vegetation, both native and crops, will be weakened, leaving areas for invasion. More severe cyclones will both disperse weed seeds through wind and floods, and also open up gaps for weed invasion in areas of pristine native vegetation, especially in the wet tropics.

Invasive weeds

There is already a burgeoning concern over our inability to manage the spread of invasive plants (Clements and Catling, 2007; Rew *et al*., 2007), and climate change threatens to make the task more difficult. In fact, the impact of invasive plant species is expected to increase with climate change (Thuiller *et al*., 2006; Vila *et al*., 2007), including increases in species distributions (Kriticos *et al*., 2003b). One example of this cross-border expansion in North America is *Datura stramonium* L., a weed of the solanaceae that causes interference in economically important crops in this region (Weaver and Warwick, 1984; Henry and Bauman, 1991). *Hypericum perforatum* L. exhibits larger leaves in more northern North American latitudes (Maron *et al*., 2004). This short-lived perennial infests areas such as grasslands, old fields or roadsides and has invaded numerous regions worldwide from its original range in Europe, North Africa and Asia (Maron *et al*., 2004). For many weed species, the damage niche (McDonald *et al*., 2009) is showing potential for shifting, whereby the weed species is already present in a region but is in sufficiently small enough populations that it does not have a negative economic impact. *Bromus tectorum* L. (cheat grass) already occurs in Canada, but Valliant *et al*. (2007) demonstrated its large potential to expand to other areas of Canada through the development of weedy genotypes de novo. Indeed, a review by Daehler (2003) demonstrated that invasive species exhibited more phenotypic plasticity than native species occurring in the same region. The role of plasticity versus genetic change continues to be one of the key issues in the study of invasive biology (Richardson and Pysek, 2006). Invasive plants are frequently viewed as harbingers of climate change owing to their potential to cause economic and ecological damage in the process of expanding their ranges. Models are being developed to help predict the range expansion of these plants, based on known tolerance ranges. Success of weeds has often been attributed to an all-purpose genotype, implying a high level of phenotypic plasticity. However, recent work has shown that many species are capable of relatively rapid genetic change as well, enhancing their ability to invade new areas in response to anthropogenic ecosystem modification (Clement and Ditommaso, 2011). Opportunistic weed species possess the ability to track climate change by means of sophisticated dispersal and superior adaptation capabilities (Chapin *et al*., 1996; Bergmann *et al*. 2010; Pautasso *et al*., 2010). For a variety of invasive plant species, the potential for range expansion has been identified but not yet realized.

Implications for weed management

Given the physiological plasticity of many weeds and their greater genetic diversity relative to crops, it is possible that elevated CO_2 could provide an even greater competitive advantage to weeds, with concomitant negative effects on crop production. Therefore, in future decades, when climate change effects are more consistently felt, weed management requirements in agriculture and non-agricultural situations will change. Aggressive growth of C3 or C4 weeds will require more energy and labour intensive management. The abundance of perennial weeds may increase, since elevated CO_2 stimulates greater rhizome and tuber growth. Greater increases in biomass will result in dilution of herbicide applied, making weed control more difficult and costly (Patterson, 1995). Some direct evidence of this scenario comes from the increased glyphosate tolerance at elevated CO_2 shown by different perennial species. However, the C3 species, *C. album* showed significant tolerance of glyphosate at elevated CO_2. In contrast to the ambient CO_2 treatment, the lower glyphosate rate had no effect on *C. album*, and the higher rate only reduced, but did not eliminate the weed, in elevated CO_2. These data indicated that rising atmospheric CO_2 could increase glyphosate tolerance in C3 weeds and this could limit the efficacy of some herbicides.

Increased tolerance of glyphosate was also reported in a perennial C3 weed, quackgrass (*Elytrigia repens*) by Ziska and Teasedale (2000). They also concluded that sustained stimulation of photosynthesis and growth in perennial weeds could occur as atmospheric CO_2 increases, and such changes would reduce the effectiveness of chemical control.

As discussed by Patterson, (1995) growth at elevated CO_2 could result in anatomical, morphological and physiological changes, which alter herbicide uptake, translocation and overall effectiveness. Increasing CO_2 can increase leaf thickness, reduce stomatal number and decrease conductance, possibly limiting the uptake of foliar-applied herbicides. Ziska, (2014) stipulated that increases in pesticide application rates may be a means to maintain soybean production in response to rising minimum daily temperatures and potential increases in pest pressures.

Adapting to climate change

It is clear that both crops and weeds will respond to climate change, but the overall winners of their competition in the field will be the colonizing species, because of their superior adaptations and wide ecological amplitudes. Control of weeds, pests and diseases are all likely to be more difficult and more expensive under climate change.

The agricultural systems in many developing countries are more vulnerable to climate change, because they are dependent on declining natural resource bases, are labour intensive and less capital and technology dependent. The increasing population pressure on natural resources in developing countries is well known; it has already led to pronounced degradation of land and water resources and has increased the risk of hunger. Technically, adapting to climate change will require significant transformation of agriculture production across the globe, by tapping three main sources for growth: (a) Expanding the land area, (b) Increasing the land cropping intensity (mostly through irrigation), and (c) Boosting yields. Experts agree that 80 per cent of increased crop production in developing countries still has to come from intensification of agriculture, which involves: (a) Increased cultivable land; (b) Higher yield crops; (c) Increased crop diversification and multiple cropping; and (d) Shorter fallow periods.

Overall, climate change can be expected to favour invasive plants over established, and slow-growing, native vegetation, especially if accompanied by an increase in extreme conditions, such as droughts alternating with very wet years. Pioneering species with various physiological adaptations and wide ecological amplitudes are better equipped to adapt to new climatic conditions. Weeds generally have excellent propagule dispersal mechanisms, often by human activities or by birds, and are likely to spread rapidly into new areas, quickly exploiting changing climatic conditions that favour their establishment. More effective management solutions will therefore be required to reduce the threat posed by aggressive colonisers, which can make production of food and management of land and water resources much more difficult.

However, climate is not the only factor that will be changing as the 21st century unfolds. Weeds have been winner and will be winner in future climatic conditions because of more adaptive power and more diversity. Weed population will change with climate change and risks of invasiveness may increase. Effectiveness of current management practices may be affected. Most studies evaluated effect of single factor (elevated CO_2) and only few studies have evaluated the interaction of multiple factor of change. Research is needed to assess the interactive effects of multiple climate change factors simultaneously to help prediction how weed problems may change in future with changing climate in order to develop flexible integrated weed management practices which are based on a foundation of knowledge of weed biology and ecology.

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Estimation of Gene Action through Combining Ability in Soybean

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ABSTRACT

Combining ability studies revealed the pre-dominance of additive gene action for the expression of all characters in both the generations with the exception of number of branches per plant and seed yield per plant in F2 generation. It further revealed that NRC 32 was the best general combiner for seed yield and its major components. Crosses JS 95-60 x NRC 12, JS 95-60 x JS 80-21 were identified as a best specific combiners.

Key words: Additive, combining ability, dominance, soybean

The choice of an appropriate breeding procedure for the improvement of the economic productivity of a crop plant depends upon the nature and magnitude of the genetic variation. The exploitation of genetically diverse stock helps to identify promising hybrid combinations and/or to develop superior lines from them. The combining ability analysis is frequently used by breeders to choose such hybrid combinations. In the present study, a combining ability analysis involving six parent of soybean has been conducted to gather information about general combining ability (GCA) of parents and specific combining ability (SCA) for crosses in F1 and F2 generations.

MATERIAL AND METHODS

The present study was conducted at Maharaja Farm, Chhatarpur, Madhya Pradesh during *kharif* 2017. The experimental material consisted of six diverse genotypes of soybean (JS 95-60, JS 335, NRC 12, JS 71-05, JS 80-21 and NRC 32), which were crossed (excluding reciprocals) in a diallel mating system. Parents, F1 and F2 generations were grown during *kharif* 2017 in a randomized complete block design with three replications. A plot for each parent consisted of a single rows (6 m), while for F1 plot consisted of a 6 m long single row spaced 30 cm apart. The seed to seed distance was 10 cm. F2 had three rows of 6 m long and plant to plant 10 cm. Observation were recorded of selected 10 competitive plants from each row on days to 50 per cent flowering, days to maturity, plant height, number of branches per plant, number of pod bearing nodes per plant, number of seeds per pod, number of seeds per plant, seed yield, 100 seed weight and number of pods per plant. The data were subjected to the analysis using method 2 model I as stated by Griffing (1956)

RESULTS AND DISCUSSION

Diallel cross analysis was carried out in know the combining ability of six parents for yield and its components. The combining ability analysis studies in F1 and F2 populations revealed the pre-dominance of additive gene action in the expression of characters with exception of seed yield per plant and number of pods per plant in F1 and number of branches per plant, number of seeds per pod and number of pods per plant in F2 (Table 1 and 2). A study similar to present one was also reported by Rahangdale and Raut (2002). GCA variances were highly significant for all the characters in both the generations with the exception of number of branches per plant, number of seeds per pod, seed yield per plant and number of pods per plant in F2 generation. On the other hand, SCA variances were found significant for all the characters in both the generations except for number of branches per plant, number of seeds per plant, seed yield and number of pods per plant in F1 generation, and number of branches per plant, number of seeds per pod and number of pods per plant in F2 generation. A relative comparison GCA and SCA variances in both populations revealed that all the characters were under the control of additive gene action with exception of number of branches per plant and seed yield per plant in F2 generation. According to Nasim *et al.* (2014), a trait which exhibited higher magnitude of GCA compared to SCA reveals pre-variance of additive type gene action.

The estimation of GCA effects in F1 (Table 3) and F2 (Table 5) population revealed that JS 80-21 appeared to be the best general combiner for seed yield and major components like number of seeds per pod and number of pod bearing nodes per plant. Similarly, JS 95-60 was found to be the best general combiner for early flowering, early maturity, dwarf height and bolder seed size. JS 335 also found good combiner for yield, smaller seed size, early flowering and maturity. NRC 12 was found to be the best general combiner for number of pods per plant and tall plant height. However, this parent was identified as a poor combiner for seed yield and seed size. JS 71-05 was identified as a poor combiner for grain yield, number of pods per plant and days to 50 per cent flowering in F1 and good combiner for grain yield and seed size in F2 population. GCA effects were found to be inconsistent over generations for different characters. Hence, definite conclusion regarding the superiority of one variety over another cannot be made.

An observation of SCA effects in F1 (Table 4) and F2 (Table 6) generations showed that the crosses JS 95-60 x NRC 12, JS 95-60 x JS 80-21 in F1, and JS 95-60 x NRC 12, JS 95-60 x JS 71-05, JS -335 x NRC 32 in F2 generations were identified as a best combiner for seed yield. These crosses also had high magnitude of SCA effects for major yield components like number of seeds per pod and number of pod bearing nodes per plant, in both the

Table 1. Estimation of genetic component of variation in F1

Source of Variation	d. f	Days to 50 % flowering	Days to maturity	Plant height (cm)	Branches (No/plant)	Pod bearing nodes (No/plant)	Seeds (No/ pod)	Seeds No/plant)	Seed yield	100 seed weight	Pods (No/plant)
GCA	5	80.48**	185.92**	17.18**	2.49*	10.41**	0.052**	250.80**	1.72*	!7.8**	57.18**
SCA	15	11.73**	39.91**	7.05**	1.31	5.81*	0.03*	61.18	0.58	2.94**	15.54
Error	40	2.07	3.85	3.30	0.71	2.24	0.013	50.79	0.57	0.52	15.13

Table 2. Estimation of genetic component of variation in F2

Source of Variation	d. f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No of branches /plant	Pod bearing nodes (No/plant)	No of seeds/ pod	Seeds (No/plant)	Grain yield	100 seed weight	Pods (No/plant)
GCA	5	138.45**	!71.29**	13.58**	13.93	7.13*	0.018	139.7*	0.923	21.02**	22.82
SCA	15	27.11**	72.75**	12.78**	20.55	6.19*	0.11	89.13*	1.33*	6.78**	22.29
Error	40	1.06	4.02	2.53	19.36	2.44	0.014	40.22	0.54	0..56	12.88

Table 3. Estimation of GCA effects for yield and its components in F1

Characters	JS 95-60	JS 335	NRC 12	JS 71-05	JS 80-21	NRC 32	SE	C D (P=0.05)	C D (P=0.01)
Days to 50%flowering	-5.347**	3.111**	1.819**	2.069**	0.403	-2.056**	0.216	**0.436**	**0.584**
Days to maturity	-7.625**	5.250**	5.125**	-0.583	-0.208	-1.958**	0.401	**0.810**	**1.084**
Plant height	-2.331**	0.657	1.432**	0.074	1.269**	-1.101**	0.340	**0.687**	**0.919**
Branches (No/plant)	-0.460**	0.374**	0.936**	-0135	-0.189*	-0.526**	0.074	**0.149**	**0.200**
Pod bearing nodes (No/plant)	-2.081**	0.299	0.386	-0.160	1.378**	0.228	0.234	**0.472**	**0.632**
Seeds (No/pod)	0.033**	-0.050**	0.088**	-0.083**	0.092**	-0.079**	0.001	**0.002**	**0.002**
Seeds (No/plant)	-9.169	1.992	1.529	-1.237	7.954	-1.042	5.290	**10.691**	**14.304**
Seed yield (g/plant)	-0.460**	-0.450**	-0.362**	-0.200**	0.796**	0.263**	0.060	**0.121**	**0.162**
100 Seeds weight	2.618**	-1.386**	-1.140**	-0.044	-0.749**	0.701**	0.054	**0.109**	**0.146**
Pods (No/plant)	-4.962**	4.446**	0.567	-0.121	1.871	1.200	1.586	**3.205**	**4.288**

Table 4. Estimation of SCA effects for yield and its components in F1

Crosses	Days to 50 % flowering	Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No/plant)	Seeds (No/pod)	Seeds (No/plant)	Seed yield	100-seed weight	Pods (No/plant)
JS 95-60 x JS335	-2.018	0.375	2.782	-0.863	1.452	0.007	6.571	-0.185	-2.721**	4.779
JS 95-60 x NRC-12	-0.060	3.167	2.307	-1.092	4.448*	.003	10.433	0.961*	-1.033*	5.624
JS 95-60 x JS 71-05	-6.975**	-13.458**	-2.735	0.845	-0.023	0.074**	-3.667	0.532	3.737**	1.655
JS 95-60 x JS 80-21	4.024*	6.167*	1.536	-0.867	0.527	0.465**	7.875	1.356**	1.525**	-0.513
JS 95-60 x NRC 37	-1.851	-12.750**	-4.160	1.437*	-1.611	0.003	-8.529	-0.531	1.658**	-5.409
JS 335 x NRC 12	0.485	1.625	-1.781	0.108	0.202	0.120**	3.179	-0.702	-0.796	-0.751
JS 335 x JS 71-05	-0.101	5.667	-1.056	0.679	-1.169	0.024*	1.987	-0.464	-0.158	-1.330
JS 335 x JS 80-21	-5.101**	-5.375	-0.418	2.333**	2.560	-0.051**	-2.112	-0.127	0.879*	0.512
JS 335 x NRC 32	3.024	1.375	1.486	-0.396	1.277	0.120**	12.050	0.840	-1.140*	3.516
NRC 12 x JS 71-05	3.524*	2.792	3.364	-0.217	-3.307	-0.047**	-10.425	-0.918*	0.596	-6.551
NRC 12 x JS 80-21	1.190	0.417	-3.193	-1.030	0.356	-0.55**	-3.050	-0.448	0.200	-2.109
NRC 12 x NRC 32	-3.351*	-2.167	1.723	-1.259*	1.173	0.215**	5.446	0.219	-1.750**	1.062
JS 71-05 x JS 80-21	1.940	0.125	-0.702	-0.759	-2.315	0.049**	-4.117	-0.810	-1.429**	-3.621
JS 71-05 x NRC 32	4.399*	0.542	2.536	0.212	-0.432	-0.014	-0.754	-0.110	0.413	-0.651
JS 80-21 x NRC 32	-1.268	0.167	2.240	-0.667	2.698	-0.155	-6.112	-0.273	0.258	1.358
SEm (±)	1.633	3.027	2.596	0.560	1.766	0.010	39.900	0.452	0.412	11.960
C D (P=0.05)	**3.300**	**6.117**	**5.246**	**1.131**	**3.560**	**0.021**	**80.630**	**0.909**	**0.832**	**24.171**
C D (P=0.01)	**4.415**	**8.185**	**7.019**	**1.514**	**4.700**	**0.028**	**107.88**	**1.220**	**1.114**	**32.339**

Table 5. Estimation of GCA effects for yield and its components in F2

Characters	JS 95-60	JS 335	NRC 12	JS 71-05	JS 80-21	NRC 32	SE	C D (P=0.05)	C D (P=0.01)
Days to 50% flowering	-6.194**	2.972**	1.931**	2.889**	2.806**	-4.403**	0.111	**0.234**	**0.313**
Days to maturity	-7.806**	5.569**	2.028**	-0.681	2.694**	-1.806**	0.419	**0.846**	**1.132**
Plant height	-2.497**	0.824**	0.969**	0.149	0.757**	-0.201	0.263	**0.531**	**0.711**
Branches (No/plant)	1.536	1.669	0.031	-1.043	-0.747	-1.385	2.017	**4.076**	**5.433**
Pod bearing nodes (No/plant)	1.465**	0.214	0.532*	-0.190	0.976**	0.997**	0.254	**0.513**	**0.686**
Seeds (No/pod)	-0.032**	-0.032**	0.047**	0.049**	0.068**	-0.003**	0.001	**0.002**	**0.002**
Seeds (No/plant)	-6.661	0.522	-1.186	1.231	6.301	-0.207	4.189	**8.465**	**11.327**
Seed yield (g/plant)	0.164**	-0.261**	-0.453**	0.247**	-0.140*	0.443**	0.056	**0.113**	**0.151**
100 Seeds weight	2.378**	-0.885**	1.201**	0.178**	-1.835**	1.365**	0.059	**0.119**	**0.159**
Pods (No/plant)	-3.240**	0.581	0.119	0.185	1.385	1.210	1.341	**2.710**	**3.626**

Table 6. Estimation of SCA effects for yield and its components in F2

Crosses	Days to 50% flowering	Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No/plant)	Seeds (No/pod)	Grains (No/plant)	Grain yield	100-seed weight	Pods (No/plant)
JS 95-60 x JS 335	-4.000**	2.315	2.972	15.231	2.967	0.008	8.650	0.508	-1.099*	3.452
JS 95-60 x NRC-12	-5.625**	-17.143**	-6.174**	-1.802	1.713	0.129**	2.658	1.800**	3.864**	0.385
JS 95-60 x JS-71-05	-4.917	-13.435**	-3.129	-1.257	-1.195	0.058**	3.275	1.733**	2.938**	-0.619
JS 95-60 x JS 80-21	1.167	3.190	0.539	-1.452	-0.995	-0.092**	-9.896	-1.146*	0.849	-1.252
JS 95-60 x NRC 37	1.708*	8.357*	2.130	-1.982	0.684	0.079**	7.379	0.204	-2.616**	2.756
JS 335 x NRC 12	-5.125**	-0.851	-2.028	-2.669	-0.299	0.029**	0.042	-0.342	-0.720	-1.302
JS 335 x JS 71-05	6.583**	7.524**	-0.040	-1.490	-3.208	0.092**	-14.242	-0.275	3.867**	-6.473
JS 335 x JS 80-21	2.667**	1.815	3.582	-0.852	-0.108	0.042**	-1.546	-0.721	-1.720**	0.293
JS 335 x NRC 32	5.792**	-5.351	1.643	1.882	1.605	0.012	8.163	1.096*	0.680	2.302
NRC 12 x JS 71-05	7.625**	9.065**	-2.286	-0.490	2.862	-0.188**	-7.467	-1.217**	-2.416**	-3.340
NRC 12 x JS 80-21	2.375**	5.024	-3.895	-0.550	-2.662	-0.038**	-10.904	-1.162*	-0.370	-6.540
NRC 12 x NRC 3 2	1.583	-2.143	2.064	-0.548	0.484	0.033**	-0.362	0.179	-0.304	0.335
JS 71-05 x JS 80-21	2.750**	4.399	1.960	0.493	-0.804	0.025**	7.279	-0.429	2.416**	-0.244
JS 71-05 x NRC 32	-7.350**	11.768**	-4.249*	1.164	-2.324	0.129**	-10.679	0.354	4.151**	-6,902
JS 80-21 x NRC 32	0.042	-1.143	-0.324	0.435	2.709	0.112**	-9.187	-0.458	2.296**	-3.569
SEm (±)	0.837	3.164	1.991	15.214	1.923	0.011	31.600	0.428	0.447	10.120
C D (P=0.05)	**1.691**	**6.394**	**4.023**	**30.739**	**3.886**	**0.022**	**63.871**	**0.866**	**0.903**	**20.452**
C D (P=0.01)	**2.263**	**8.555**	**5.383**	**41.138**	**5.199**	**0.029**	**85.457**	**1.159**	**1.208**	**27.364**

generations. On the other hand, crosses JS 95-60 x JS 71-05, JS 95-60 x NRC 32 were identified as best specific combiners for days to maturity. Similar observations were also made by Gatut *et al*. (2014) and Shiv *et al*. (2011) in the past.

An overall observation of SCA effects revealed that these were varied from generation to generation. Further, GCA and SCA effects in F1 and F2 population for yield and yield components indicated that the NRC 32 was the best general combiner for seed yield and it also better specific combiner for seed size and yield with NRC 12. Hence, there is every possibility of isolating desirable segregants in the F2 or in advanced segregating generation of cross between JS 335 x NRC 32. Similarly, crosses of JS 95-60 with NRC 12, JS 71-05, and JS 80-21 may also produce desirable segregants in the segregating population. Results on similar lines were also reported by Agrawal and Patil (2005) and Durai and Subbalakshmi (2010).

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Association Analysis in Diverse Populations of Soybean

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ABSTRACT

Association analysis is a basic tool for justifying breeding populations, with the most diverse traits, for their use soybean yield improvement programme. The analysis revealed that none of correlation was found significant in parents. In F_1 population, days to 50 per cent flowering had positive association with days to maturity and 100-seed weight. Plant height versus number of pod bearing nodes per plant, number of seeds per plant and number of pods per plant; number of pod bearing nodes per plant versus number of seeds per plant, number of pods per plant; number of seeds per plant versus seed yield and number of pods per plant had positive associations. Similarly, in F_2 population days to maturity versus plant height; number of pod bearing nodes per plant versus number seeds per plant; number of seeds per plant versus seed yield and number of pods per plant; seed yield versus 100-seed weight and number of pods per plant had positive association.

Path coefficient analysis study in parents, F_1 and F_2 populations revealed the existence of positive direct effect of 100-seed weight, number seeds per plant and number of pods per plant on seed yield. Though, 100-seed weight had substantial positive direct effect, but indirect effect for all the characters was found to be negative. A reciprocal recurrent selection should be followed in order to exploit additive and non–additive genetic improvement of yield in soybean. However, while making the selection, the criteria should be based on major yield components like, number seeds per plant, number of pods per plant and 100-seed weight.

Key words: Correlation, path coefficient, reciprocal recurrent selection, soybean

Yield is a complex quantitative character which has relevant association with various morphological characters. It is essential to know the correlation among yield and other important traits for effective selection. Correlation between two characters is of evolutionary interest mainly due to linkage, pleiotropy and heterozygosity. A positive correlation between desirable characters is helpful to the plant breeder because it helps in synchronized improvement of both the characters. Negative correlation, on the other hand, will suppress the simultaneous expression of both characters.

Path coefficients are standard partial regression coefficient which splits the correlation coefficient into direct and indirect effects. Thus, the correlation and

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path analysis in combination, can give a better insight, into cause and effect relationship between different pairs of characters. Hence, the present study was carried out to study the correlation and path analysis in early generation breeding populations.

MATERIAL AND METHODS

The experimental material consisted of six diverse genotypes of parents, 15 F_1 and 15 F_2 generations which were grown during *kharif* 2017 at Mharajapur farm at Chhatarpur in a randomized complete block design with three replications. A plot for each parent consisted of a single rows, while F_1 plot consisted of a 6 m long single row spaced 30 cm apart. The seed to seed distance was 10 cm. F_2 had three rows of 6 m long and plant to plant 10 cm. Observation were recorded on days to maturity, plant height, number of branches per plant, number of pod bearing nodes per plant, number of seeds per pod, number of seeds per plant, number of pods per plant, seed yield and 100-seed weight on 10 selected competitive plants from each row at days to 50 per cent flowering. The data were subjected to the analysis of Dewey and Lu (1959).

RESULTS AND DISCUSSION

Correlation Coefficient Analysis

Association analysis was carried out to know the behaviour of yield and its components in parent, F_1 and F_2 populations. None of the character showed positive association with yield among themselves. In F_1 population, days to 50 per cent flowering had positive association with days to maturity and negative association with 100–seed weight. Plant height had positive association with number pod bearing nodes per plant, number of seeds per plant and number of pods per plant in F_1 population. These results were buttressed by Malik *et al*. (2007) and Burno *et al.* (2017). Similarly, in F_1 population number pod bearing nodes per plant versus number of seeds per plant, number of pods per plant; number of seeds per plant versus seed yield and number of pods per plant had positive association. Shoktawat and Tyagi (2010) and Chavan *et al.* (2016) also reported similar results. In F_2 population, days to 50 per cent flowering versus days to maturity; days to maturity versus plant height; number pod bearing nodes per plant versus number of seeds per plant and number of pods per plant; number of seeds per plant versus seed yield and number of pods per plant, seed yield versus 100-seed weight and number of pods per plant showed positive association. Based on the association analysis, it could be said that number of seed per plant had substantial contribution towards seed yield followed by number of pods per plant. Barbind *et al.* (1981) reported that days to 50 per cent flowering was positively correlated with plant height and number of pods per plant but negatively correlated with seed yield. Chaudhary and Singh (1974) reported days to maturity had positive association with plant height, number of pods per plant and, number of seeds per pod but had negative association with 100–seed weight. Prraju *et al*. (1982)

Table 1. Genotypic, phenotypic and environmental correlation coefficient of yield and its components in parents

Character		Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No /plant)	Seeds (No /pod)	Seeds (No/plant)	Seed yield	100-seed weight	Pod (No/plant)
Days to 50 % flowering	E	0.4789	0.6603	0.5791	0.4071	-0.1839	0.4767	0.1582	-0.7096	0.4758
	G	0.7990	0.6747	0.3047	0.5205	0.2068	0.4568	0.0923	-0.8669*	0.4758
	P	0.6666	0.6009	0.3391	0.4345	0.1047	0.4257	0.0931	-0.8182*	0.4200
Days to maturity	E		0.2952	0.0336	-0.4196	-0.4241	-0.2103	-0.5930	-0.8114*	-0.1052
	G		0.6011	0.4950	0.3475	0.1537	0.2885	-0.0153	-0.7105	0.4772
	P		0.4556	0.2866	-0.0238	-0.1062	0.0687	-0.3229	-07348	0.1663
Plant height	E			0.1932	0.3740	0.0819	0.6894	0.3880	-0.5459	0.6861
	G			0.7608	0.6543	0.7312	0.6700	0.3567	-0.8600	0.6888
	P			0.4874	0.5102	0.4198	0.6777	0.3710	-0.7194	0.6830
Branches (No/plant)	E				0.5324	-0.1760	0.1945	0.0567	-0.2836	0.1954
	G				0.0554	0.7449	0.1491	-0.0906	-0.3787	0.1746
	P				0.2894	0.3238	0.1694	-0.0093	-0.3380	0.1835
Pod bearing nodes (No/plant)	E					0.3316	0.6885	0.7001	-0.0354	0.5807
	G					0.2685	0.9005	0.7557	-0.8413	0.9607
	P					0.2973	0.7955	0.7183	-0.5071	0.7412
Seeds (No/pod)	E						0.0806	0.2708	0.5702	-0.1697
	G						0.5523	0.4423	-0.4347	0.3606
	P						0.3417	0.3421	-0.0708	0.0751
Seeds (No/plant)	E							0.8772	-0.2014	0.9601
	G							0.9133	-0.8044	0.9287
	P							0.8752	-0.5834	0.9304*
Seed yield	E								0.2268	0.7926
	G								-0.5017	0.8000
	P								-0.1610	0.7951
100-seed weight	E									-0.3457
	G									-0.8531
	P									-0.5935

Table 2. Genotypic, phenotypic and environmental correlation coefficient of yield and its components in F1 population

Character		Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No / plant)	Seeds (No / pod)	No of seeds (No/plant)	Seed yield	100-seed weight	No of pod /plant
Days to 50% flowering	E	0.6260	-0.1905	0.2429	-0.0434	0.0924	0.1610	-0.0107	-0.0657	0.1167
	G	0.8466	0.5037	0.1212	0.0388	-0.0851	0.4411	-0.3844	-0.7369	0.2947
	P	0.8051**	0.2726	0.1509	0.0144	-0.0194	0.3015	-0.2197	-0.6254	0.1972
Days to maturity	E		-0.1799	0.2258	-0.0771	-0.0791	0.1690	0.1327	0.0914	0.1726
	G		0.6780	0.1122	0.3645	0.0816	0.6809	-0.3189	-0.9073	0.5760
	P		0.4487	0.1111	0.2578	0.0373	0.4423	0.1684	-0.8079	0.3624
Plant height	E			0.1044	0.5862	0.1273	0.4386	0.3935	-0.1032	0.4819
	G			-0.2147	0.6798	0.0228	0.7753	0.1961	-0.7197	0.8060
	P			-0.0419	0.6372*	0.0771	0.5861**	0.3000	-0.5115	0.6118**
Branches (No/plant)	E				-0.1269	0.0399	0.1021	0.1559	0.0719	0.0720
	G				0.0079	-0.2833	-0.1240	-0.5310	-0.0066	-0.0761
	P				-0.0602	-0.0923	0.0141	-0.1129	0.0172	0.0173
Pod bearing nodes(No/plant)	E					-0.1406	0.6629	0.5004	-0.2410	0.7263
	G					-0.0284	0.7154	0.3198	-0.4514	0.8685
	P					-0.0831	0.6749**	0.4052	-0.3775	0.7696**
Seeds (No/pod)	E						0.1652	0.1256	0.4140	-0.0325
	G						0.3763	0.4970	-0.1162	-0.1090
	P						0.2506	0.2769	0.0476	-0.0618
Seeds (No/plant)	E							0.6935	0.0908	0.8577
	G							0.3076	-0.7856	0.8308
	P							0.5438*	-0.4254	0.8471**
seed yield	E								0.4571	0.7043
	G								0.2520	0.1615
	P								0.2799	0.5041
100-seed weight	E									0.1524
	G									-0.6827
	P									-0.3259

Table 3. Genotypic, Phenotypic and environmental correlation coefficient of yield and its components in F2 population

Character		Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No/plant)	Seeds (No/pod)	Seeds (No / plant)	Seed yield	100-seed weight	Pod (No/plant)
Days to 50% flowering	E	0.1013	0.1377	0.2028	-0.3592	-0.1765	-0.0459	-0.1280	-0.0618	-0.1545
	G	0.8172	0.3482	-0.2194	-0.3495	-0.2377	-0.0350	-0.7729	-0.7937	0.1624
	P	0.7859**	0.3066	-0.0717	-0.2910	-0.1199	-0.0281	-0.5389	-0.6229	-0.1042
Days to maturity	E		-0.0731	-0.0155	-0.1925	0.1217	0.1604	0.2166	0.2092	-0.0624
	G		0.6633	0.0005	-0.0244	-0.2446	0.1297	-0.8285	-0.7937	0.1624
	P		0.5464*	-0.0027	-0.0468	-0.0648	0.1051	-0.5208	-0.7211	0.0718
Plant height	E			0.1645	0.2503	-0.4216	0.4195	0.2443	0.0289	0.5171
	G			0.1413	0.3878	-0.1841	0.4348	-0.3500	-0.4868	0.5601
	P			0.1336	0.3251	-0.2605	0.3985	-0.1147	-0.3917	0.4792
Branches (No/plant)	E				-0.0465	-0.0044	-0.1214	-0.0750	-0.1104	-0.0312
	G				0.2115	-0.2491	0.1516	0.0989	0.0086	0.1725
	P				0.0447	-0.0499	-0.0378	-0.0136	-0.0259	0.0219
Pod bearing nodes (No/plant)	E					-0.0935	0.5664	0.5566	0.2058	0.6915
	G					0.4796	0.5174	0.1679	-0.0387	0.7290
	P					0.0647	0.5413*	0.3691	0.0201	0.6882**
Seeds (No/pod)	E						0.1685	-0.0856	-0.1872	-0.1195
	G						0.0711	0.1646	0.2242	0.0444
	P						-0.1075	-0.0152	0.0257	-0.0854
Seeds (No/plant)	E							0.8926	0.2456	0.7917
	G							0.1312	-0.4200	0.8344
	P							0.5690*	-0.1824	0.8014**
Seed yield	E								0.4331	0.7840
	G								0.8224	0.0896
	P								0..6351*	0.5166*
100-seed weight	E									0.2623
	G									-0.3737
	P									-0.1173

Table 4. Path- coefficient showing direct and indirect effects of yield components on yield in parents

Character		Days to 50% flowering	Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No/plant)	Seeds (No/pod)	Seeds (No / plant)	100-seed weight	Pod (No/plant)
Days to 50%	G	2.3300	-0.8230	0,2901	0.2163	-0.7286	-0.1551	0.8908	-3.3564	1.4133
flowering	P	0.0879	-0.0423	0.1399	-0.0143	0.0259	0.0174	0.3108	-0.3392	0.1872
Days to	G	1.8617	-1.0300	0.2585	0.3515	-0.4866	-0.1153	0.5626	-2.7497	1.3219
maturity	P	0.5860	-0.0634	-0.1064	0.0126	-0.0014	-0.0177	0.0501	-0.3046	0.0741
Plant height	G	1.5721	-0.6191	0.4300	0.5401	-0.9160	-0.5484	1.3065	-3.3281	1.9080
	P	0.o528	-0.0289	-0.2328	0.0214	0.0304	0.0599	0.4948	0.2982	0.3045
Branches	G	0.7099	-0.5099	0.3271	0.7100	-0.0776	-0.5586	0.2908	-1.4655	0.4835
(No/plant)	P	0.0297	-0.0182	-0.1135	-0.0439	0.0172	0.0539	0.1237	-0.1401	0.0818
Pod bearing	G	1.2127	-0.3580	0.2813	0.0394	-1.4000	-0.1993	1.7559	-3.2558	2.6611
nodes (No/plant)	P	0.0382	0.0015	0.1188	-0.0127	0.596	0.0495	0.5808	-0.2102	0.3304
Seeds	G	0.4818	-0.1583	0.31444	0.5289	-0.3721	-0.7500	1.0770	-1.6882	0.9987
(No/pod)	P	0.0092	0.0067	-0.0977	-0.0142	0.0177	0.1665	0.2495	-0.0294	0.0338
Seeds	G	1.0644	-0.2972	0.2881	0.1059	-1.2607	-0.4142	1.9500	-3.1131	2.5725
(No/plant)	P	0.0374	-0.0044	-0.1578	-0.0074	0.0474	0.0569	0.7301	-0.2481	0.4148
100-seed	G	-2.0196	0.7318	-0.3698	-0.2689	1.1778	0.3260	-1.5686	3.8700	-2.3631
weight	P	-0.0719	0.0466	0.1675	0.0148	-0.0302	-0.0118	-0.4259	0.4146	-2.3631
Pods	G	1.1888	-0.4915	0.2962	0.1239	-1.3450	-0.2706	1.8110	-3.3015	2.7700
(No/plant)	P	0.0369	-0.0105	-0.1590	-0.0080	0.0442	0.0126	0.6793	-0.2451	0.4458

Table 5. Path- coefficient showing direct and indirect effects of yield components on yield in F1population

Character		Days to 50 % flowering	Days to maturity	Plant height	Branches (No/plant)	Pod bearing nodes (No/ Plant)	Seeds (No/pod)	Seeds (No/plant)	100-seed weight	Pod (No/plant)
Days to 50% flowering	G	0.4059	-0.4533	0.1312	-0.0319	0.0102	-0.0362	0.2319	-0.6703	0.0382
	P	-0.0620	0.0527	0.0583	-0.0169	0.0015	-0.0009	0.2040	-0.4456	-0.0108
Days to maturity	G	0.3436	-0.5472	0.1766	-0.0296	0.0958	0.0347	0.3579	-0.8253	0.0746
	P	-0.0499	0.6550	0.0960	-0.0124	0.0270	0.0018	0.2993	-0.5757	0.0199
Plant height	G	0.2044	-0.3710	0.2605	0.0566	0.1787	0.0097	0.4075	-0.6546	0.1043
	P	-0.0169	0.0294	0.2140	0.0047	0.0667	0.0037	0.3965	0.3645	-0.0336
Branches (No/plant)	G	0.0492	-0.0614	-0.0559	-0.2635	0.0021	-0.1204	-0.0652	-0.0060	-0.0099
	P	-0.0094	0.0073	-0.0090	-0.1119	-0.0063	-0.0045	0.0096	0.0122	-0.0010
Pod bearing nodes (No/ Plant)	G	0.0157	-0.1995	0.1771	0.0394	-0.0021	-0.0121	0.3760	-0.4106	0.1124
	P	-0.0009	0.0169	0.1364	0.0067	0.1047	-0.0040	0.4567	-0.2690	-0.0423
Seeds (No/pod)	G	-0.0345	-0.0447	0.0060	0.0746	-0.0075	0.4281	0.1978	-0.1057	-0.0141
	P	0.0012	0.0024	0.0165	0.0103	-0.0087	0.0482	0.1696	0.0339	0.0034
Seeds (No/plant)	G	0.1790	-0.3726	0.2020	0.0327	0.1880	0.1600	0.5257	-0.7146	0.1075
	P	-0.0187	0.0290	0.1254	-0.0016	0.0707	0.0121	0.6766	-0.3032	-0.0465
100-seed weight	G	-0.2991	0.4965	-0.1875	0.0017	-0.1186	-0.0494	-0.4129	0.9097	-0.0884
	P	0.0388	-0.0529	-01095	-00019	-0.0395	0.0023	-0.2878	0.7126	0.0179
Pod (No/plant)	G	0.1196	-0.3152	0.2100	0.0201	0.2283	-0.0463	0.4367	-0.6210	01295
	P	-0.0122	0.0237	0.1309	-0.0019	0.0806	-0.0030	0.5732	-0.2322	-0.0549

Table 6. Path- coefficient showing direct and indirect effects of yield components on yield in F2 population

Character		Days to 50 % flowering	Days to maturity	Plant height	Branches (No/ plant)	Pod bearing nodes (No/ plant)	Seeds (No/ pod)	Seeds (No / plant)	100-seed weight	Pod (No / plant)
Days to 50%	G	-0.0807	0.0150	-0.0467	0.0030	0.0534	0.0198	-0.0185	-0.6861	-0.0321
flowering	P	-0.0757	0.0465	-0.0561	-0.0034	0.0366	-0.0016	-0.0176	-0.4403	-0.0272
Days to	G	-0.0659	0.0184	-0.0889	-0.0000	0.0037	0.0204	0.0685	-0.8190	0.0344
maturity	P	-0.0595	0.0592	-0.0999	-0.0001	0.0059	-0.0016	-0.0175	-0.4403	-0.0272
Plant height	G	-0.0281	0.0122	-0.1341	-0.0019	-0.0592	0.0153	0.2295	-0.5024	0.1187
	P	-0.0232	0.0324	-0.1829	0.0064	-0.0408	-0.0036	0.2488	-0.2769	0.1252
Branches (No/	G	0.0177	0.0000	-0.0189	-0.0138	-0.0323	0.0207	0.0800	0.0089	0.0365
plant)	P	0.0054	-0.0002	-0.0244	0.0480	-0.0056	-0.0007	0.0236	-0.0183	0.0057
Pod bearing	G	0.0282	-0.0004	-0.0520	-0.0029	-0.1527	-0.0399	0.2731	-0.0399	0.1545
nodes (No/ plant)	P	0.0220	-0.0028	-0.0595	0.0021	-0.1256	0.0009	0.3380	0.0142	0.1797
Seeds (No/	G	0.0192	-0.0045	0.0247	0.0034	0.0732	-0.0833	0.0375	0.2313	0.0094
pod)	P	0.0091	-0.0038	0.0477	-0.0024	-0.0081	0.0137	-0.0671	0.0182	-0.0223
Seeds	G	0.0028	0.0024	-0.0583	-0.0021	-0.0790	-0.0059	0.5279	-0.4334	0.1769
(No / plant)	P	-0.0021	0.0062	-0.0729	-0.0018	-0.0680	-0.0015	0.6245	-0.1289	0.2093
100-seed weight	G	0.0536	-0.0146	0.0653	-0.0001	0.0059	-0.0187	-0.2217	1.0319	-0.0792
	P	0.0472	-0.0427	0.0717	-00012	-0.0025	0.0004	-0.1139	0.7069	-0.0306
Pod (No /	G	0.0122	0.0030	-0.0751	-0.0024	-0.1113	-0.0037	0.4405	-0.3856	0.2120
plant)	P	0.0079	0.0043	-0.0877	0.011	-0.0865	-0.0012	0.5005	-0.0829	0.2612

reported positive association for seed yield with days to maturity, plant height, number of branches per plant, number pod bearing nodes per plant, number of seeds per plant, 100-seed weight and number of pods per plant.

Path Coefficient Analysis

Path analysis studies were carried out in parents, F_1 and F_2 generations at genotypic and phenotypic levels. In general, the direct and indirect effects of genotypic path coefficient analysis were higher in magnitude in comparison to phenotypic path coefficient indicating the masking influence of environment in expression of the characters. Though, correlation coefficient for different characters in parents found to be non-significant. Path coefficient analysis studies revealed the very high magnitude of positive direct effect of 100-seed weight followed by number of pods per plant. In F_1 population also 100-seed weight had the highest positive direct effect on seed yield followed by number of seeds per plant, number of seeds per pod and days to 50 % flowering. In F_2 population, 100-seed weight had the high magnitude of positive direct effect followed by number of seeds per plant and number of pods per plant. An overall observation in path coefficient studies in parents, F_1 and F_2 generations showed a substantial contribution of positive direct effect of 100-seed weight and seed yield followed by number of seeds per plant and number of pods per plant. Though, 100-seed weight had positive direct effect for seed yield but indirect effects for all other characters *via* 100-seed weight, which was found to be negative in majority of the cases. However, there is no association between 100-seed weight and seed yield in parents and F_1 population, whereas it had positive association between these two characters in F_2 generation. This further indicated the possibility of improvement of seed size and yield in soybean population. In all three populations the residual effect estimated varied considerably due to unexplainable variation in the yield, which may be due to the effect of cultural practices in conducting the experiment. Hence, it could be concluded from the Path coefficient studies that the number of seeds per plant, number of pods per plant and 100-seed weight should be given weightage as major attributes for improvement of yield in soybean.

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Bio-efficacy of Herbicide of Pre-mix Formulation of Sulfentrazone28 % + Clomazone30 % WP against Weeds of Soybean

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ABSTRACT

An experiment was conducted during kharif 2013 and 2014 to evaluate the bio-efficacy of pre-mix formulation of sulfentrazone + clomazone as pre-emergence herbicide for weed control in soybean. The experiment was conducted in RBD with three replications. The climate of the region is humid with an average rainfall varies from 732-1005 mm. The soil is clay loam with alkaline reaction. The results based on the two years data revealed that the application of herbicides significantly controlled the weeds during the critical period of crop-weed competition. The yield reduction due to weeds was 60.19 per cent. Among the different treatments, hand weeding twice had maximum weed control efficiency (91.02,) which reflected in higher soybean yield. Among herbicidal treatments, the maximum weed control efficiency and highest yield was with pre-mix formulation of sulfentrazone + clomazone @ 870/725 g a. i. per ha and remained at par with imazethapyr @ 100 g a. i. per ha applied as post-emergence. All the herbicides tested in the study were better than control and realized higher seed yield of soybean.

Keywords: Soybean, weed, weed control efficiency and yield

Soybean [*Glycine max* (L.) Merrill] is a leading oilseed crop of the world and India. Its productivity has been oscillating between 1.0 to 1.7 t per ha in last decade as compared to other major soybean growing countries (2.7 t/ha). Soybean is an important rainy season crop grown in more than 0.92 mha in south-eastern parts of Rajasthan, mainly in Kota, Bundi, Baran and Jhalawar districts producing 0.75 mt with average productivity of 811 kg per ha, which is very low as compared to national productivity of 1,153 kg per ha (Anonymous, 2017). One of the major reasons for lower productivity is abiotic and biotic factors encountered during rainy season. Among the biotic factors, weed is the most crucial which reduces yield to the tune of 20-77 per cent depending on the type of soil, season and intensity of weed infestation

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(Billore *et al*., 1999; Kuruchania *et al*., 2001). Soybean suffers from heavy weed competition especially in the early stages of growth. Although, a number of pre-plant incorporation (PPI), pre-emergence (PE) and post-emergence (PoE) herbicides are recommended for weed management of soybean, it shall be appropriate to test new molecules and make additional options available to farmers. Hence, the present investigation was carried out to study the bio-efficacy of new molecule of herbicides for weed management in soybean.

MATERIAL AND METHODS

An experiment was conducted during *kharif* 2013 and 2014 at research farm of Agricultural Research Station, Ummedganj Farm, Kota, south-eastern part of Rajasthan state, lies between 23^0 45′ and 26^0 38′ North latitude and 75^0 37′ & 77^0 26′ East longitude at an altitude of up to 275 mean sea level. To evaluate the bio-efficacy of sulfentrazone + clomazone (Pre-mix) as PE for weed control in soybean. The experiment consisted of eleven treatments involving three levels of pre-mix sulfentrazone + clomazone @ 580, 725 and 870 g a. i. per ha as PE; sulfentrazone @ 360 g a. i. per ha as PE and check herbicides, namely clomazone @ 375 and 1000 g a. i. per ha and pre-mix pendimethalin + imazethapyr @ 960 g a. i. per ha as PE, and imazethapyr @ 100 g a. i. per ha as PoE along with hand weeding twice at 20 and 40 days after sowing and a weedy check (Table 1). These treatments were replicated thrice in randomized block design. Soybean variety "JS 335" was sown on 17^{th} and 20^{th}, July 2013 and 2014 and harvested on 20^{th} and 27^{th}October, 2013 and 2014, respectively. Soil of the experimental field was clay loam, alkaline in reaction (pH 7.6), low in organic carbon (0.42 %), medium in available nitrogen (385.5 kg/ha), potassium (295.5 kg/ha) and low in available phosphorus (20.5 kg/ha) and sulphur (15.0 kg/ha). All the PE herbicides were applied just after sowing of soybean while the PoE herbicide was applied after 15-20 days after sowing (DAS) using 500 litres of water per ha. Soybean was raised according to recommended package of practices. The maximum and minimum temperature was 38.78 and 36.63 and 16.97 and 20.67, relative humidity 75.31 and 62.27 and total rainfall received was 1129.7 and 784.6 mm during *kharif* 2013 and 2014, respectively. Weed count and their dry biomass were recorded at 30 and 45 days after sowing, weed control efficiency of each treatment was determined by using the standard formula. Yield and all the yield attributes were recorded at the time of harvesting. The data were pooled over the years as per standard procedures.

RESULTS AND DISCUSSION

During the study period, soybean was infested mainly with *Acalypha indica, Commelina* spp., *Digera arvensis* Forsk., *Chorchorus* spp., *Euphorbia* spp. and *Alternanthera* spp. among broad leaf weeds and *Dinebra Arabica* (syn of *D. retroflexa)* Jacq.), *Echinocloa* spp., *Digitaria sanguinalis* (L.) Scop. and *Cynodon dactylon* (L.) Pers. among grassy weeds and *Cyperus rotundus* L. (sedges).

All the weed control treatment substantially reduced the weed count and their dry matter at 30 and 40 DAS growth stages as compared to weedy check. The highest weed control efficiency was observed with hand weeding twice (20 and 40 DAS).The weed control efficiency of the sulfentrazone + clomazone at both the growth stages were higher than check herbicide pendimethalin + imazethapyr (Pre-mix) and remained higher than with imazethapyr. The higher weed control efficiency might be due to effective control of weeds as indicated by lower weed count and their dry matter contents (Table 1).

The variation in weed count and their dry matter and weed control efficiency might be due to the differences in effectiveness of herbicides against different weeds in the field. The effectiveness of PE and PoE herbicides was found to be equally effective (Billore *et al*., 1999). Many researchers have reported lower weed densities in soybean with the use of herbicides like sulfentrazone (Niekamp *et al.,* 2001; Krausz and Young, 2003), pendimethalin (Nayak *et al.,* 2000; Raskarand Bhoi, 2002, Chauhan *et al.,* 2002), clomazone (Werling and Bhuler, 1988), imazethapyr (Meena *et al.,* 2011), weed management (Meena *et al.,* 2012) and pendimethalin 30 per cent EC + imazethapyr 2 per cent SL (Meena *et al.,* 2018).

As far as the growth/yield attributes are concerned, plant height and branches per plant remained unaffected due to various treatments (Table 2). However, marginally lower plant height and branches per plant were recorded in sulfentrazone @ 360 g a. i. per ha as PE and imazthapyr @ 100 g a. i. per ha as PoE, respectively. The maximum pods per plant were observed with two hand weeding and showed non-significant differences with sulfentrazone + clomazone @ 870 and 725 g a. i. per ha, imazethapyr @ 100g a. i. per ha. The highest value of seed index (11.23) is with Pri-mix Sulfentrazone + Clomazone @ 870 (450+420) g a. i. per ha as PE. If weeds were not managed by hand weeding twice, the yield reduction was to the extent of 60.17 per cent. All the treatments showed higher yield over control (un-weeded) as well as clomazone @ 375 g a. i. per ha. The yield enhancement due to weed control treatments was between 37.51-151.09 per cent over un-weeded control. The significantly highest seed yield was recorded with two hand weeding and remained at par with sulfentrazone + clomazone @ 870 g a. i. per ha as PE and imazethapyr @ 100 g a. i. per ha as PoE. Among the herbicides, however, the lower level of sulfentrazone + clomazone @ 725 g a. i. per ha was equally effective at its higher level and imazethapyr @ 100 g a. i. per ha. All the three levels of sulfentrazone + clomazone produced higher yield than check herbicides, namely pendimethalin + imazethapyr Pre-mix @ 960 g a. i. per ha, clomazone @ 375 g a. i. per ha as PE and sulfentrazone @ 350 g a. i. per ha as PE. More or less a similar pattern was also recorded in straw yield. The harvest index remained unchanged due to different treatments.

The yield enhancement in weed control treatment might be due to the

Table 1. Effect of herbicides on total weed count, dry matter and weed control efficiency in soybean (Pooled data of 2 years)

Treatment	30 DAS			45 DAS		
	Count (m^2)	Dry matter (g/m^2)	WCE (%)	Count (m^2)	Dry matter (g/m^2)	WCE (%)
Un-weeded control	4.31(17.61)	3.53(11.45)	-	4.75(21.61)	5.22(26.20)	-
Pri-mix Sulfentrazone + Clomazone @ 580 (300+280) g a. i./ha as PE	3.39(10.5)	2.12(3.48)	69.27	3.99(14.89)	3.33(10.08)	61.59
Pri-mix Sulfentrazone + Clomazone @ 725 (375+350) g a. i./ha as PE	2.44(4.94)	1.53(1.34)	88.15	2.77(6.67)	2.34(4.47)	83.00
Pri-mix Sulfentrazone + Clomazone @ 870 (450+420) g a. i./ha as PE	2.33(4.45)	1.44(1.09)	90.37	2.63(5.94)	2.21(3.87)	85.31
Clomazone 50 EC @ 375 g a.i./ha as PE	3.77(13.23)	2.22(3.93)	65.60	4.33(17.72)	3.61(12.03)	54.19
Sulfentrazone 48% SC @ 350 g a. i./ha as PE	3.59(11.89)	2.22(3.93)	65.22	4.12(15.94)	3.36(10.32)	60.64
Clomazone 50 EC @ 1000 g a. i./ha as PE	3.54(11.50)	2.16(3.66)	67.70	4.12(16.01)	3.38(10.43)	60.51
Sulfentrazone 48% SC @ 360 g a. i./ha as PE	3.45(10.89)	2.16(3.68)	67.53	4.08(15.62)	3.36(10.30)	60.72
Pri-mix Pendimethalin 30% EC + Imazethapyr 10% SL @ 960 g a. i./ha as PE	3.89(14.12)	2.40(4.74)	58.42	4.29(17.39)	3.63(12.18)	53.43
Imazethapyr 10% SL @ 100 g a. i./ha as PoE	2.48(5.17)	1.58(1.49)	87.02	2.73(6.45)	2.33(4.43)	83.08
Hand weeding twice at 20 and 40 DAS	2.36(4.56)	1.36(0.75)	93.41	2.35(4.5)	1.83(2.36)	91.02
SEm (±)	0.071	0.045		0.056	0.053	
CD (P = 0.05)	0.205	0.135		0.170	0.165	

Square root transformed value $\sqrt{x+1}$ *of weed count used for statistical analysis,Data in parenthesis are original values of weed counts and dry weight*

Table 2.Effect of herbicides on soybean growth, yield attributes and yield (Pooled data of 2 years)

Treatment	Plant height (cm)	Branches (No/ plant)	Pods (No/ Plant)	Seed index	Seed yield (kg/ha)	Straw yield (kg/ha)	HI (%)
Un-weeded control	87.50	2.40	24.90	10.59	869	1460	37.29
Pri-mix Sulfentrazone + Clomazone @ 580 (300+280) g a. i./ha as PE	75.50	3.70	33.50	10.64	1558	2550	37.92
Pri-mix Sulfentrazone + Clomazone @ 725 (375+350) g a. i./ha as PE	74.00	3.50	37.10	11.10	1905	3110	37.98
Pri-mix Sulfentrazone + Clomazone @ 870 (450+420) g a. i./ha as PE	72.50	3.90	37.70	11.23	1974	3200	38.15
Clomazone 50 EC @ 375 g a. i./ha as PE	81.00	2.70	28.70	10.98	1195	2007	37.30
Sulfentrazone 48% SC @ 350 g a. i./ha as PE	78.00	3.50	31.90	10.84	1440	2375	37.75
Clomazone 50 EC @ 1000 g a. i./ha as PE	79.50	3.50	31.50	11.11	1359	2262	37.52
Sulfentrazone 48% SC @ 360 g a. i./ha as PE	77.00	3.30	32.40	10.88	1490	2450	37.81
Pri-mix Pendimethalin 30% EC + Imazethapyr 10% SL Premix @ 960 g a. i./ha as PE	81.00	2.70	28.70	10.92	1260	2050	38.06
Imazethapyr 10% SL @ 100 g a. i./ha as PoE	73.50	3.20	37.30	11.13	1927	3135	38.07
Hand weeding twice at 20 & 40 DAS	69.75	4.10	38.90	10.96	2182	3525	38.25
SEm (±)	1.83	0.11	0.69	0.57	94.20	241.14	0.77
CD (P = 0.05)	5.45	0.32	2.10	NS	277.90	696.90	NS

effective control of weeds which offers less competition between crop and weeds during the critical period of crop-weed competition. The similar results were also reported by Singh *et al.* (2004) and Mishra and Singh (2009).

Based on the results of two years experimentation, it could be concluded that the application of sulfentrazone + clomazone (Pre-mix) @ 870 followed by 725 g a. i. per ha as PE was found to be as effective as imazethapyr @ 100 g a. i. per ha as PoE and was superior to pendimethalin and clomazone as PE. However, hand weeding twice is better option, if feasible.

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Weather-Based Forewarning Model to Predict Semilooper Population in Soybean

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ABSTRACT

Semilooper (Gesonia gemma) is a major soybean insect-pest, causing high yield losses up to 46 per cent due to high incidence from reproductive stage to pod filling stage. The incidence is prevailed by the favourable weather conditions, which causes the semilooper to become a dreaded pest of soybean. Hence, the present study was carried out to assess the relevant weather variables which directly influence the semilooper incidence and the suitable period of infestation. Therefore, survey data on semilooper infestation during 2010-2015 were collected under Crop Pest Surveillance and Advisory Project (CROPSAP) from 20 districts of Maharashtra state. The study was carried out to analyze the effect of weather parameters on the incidence of semilooper in soybean to develop the forewarning model. Training dataset from 2010-2013 have been used for correlation and regression analysis to develop the forewarning model and the dataset for 2014 and 2015 used to validate the model. The infestation of semilooper started from 1st week of July and continued till maturity. The semilooper population had significant and negative correlation with maximum and minimum temperature of current and previous two weeks, whereas relative humidity and rainfall (all three weeks) had positive correlation. Weather based prediction model with rainfall (1st and2nd lag weeks); and second order minimum temperature (current week) explained 28.58 per cent variability in semilooper population build-up. The congenial weather conditions favourable for semilooper infestation were maximum temperature, minimum temperature, relative humidity and rainfall ranging from 27.43 - 31.65^{0}C, 21.36 - 24.36^{0}C, 86.20 - 93.23 per cent and 14.83 - 119.18 mm respectively, with low rainfall in previous weeks but high in current week.

Key words: *Gesonia gemma* (Semilooper), prediction, soybean, validation, weather variables

Soybean [*Glycine max* (L.) Merrill], popularly known as golden bean, is the premier oilseed crop of India and the World. Although, the crop has shown unparallel growth in area and production in past five decades, the productivity still hovers around 1 t per ha. Among various constraints for low productivity (Joshi and Bhatia, 2003; Tiwari, 2014), many biotic and abiotic stresses during different crop growth stages obstruct to attain the realization of the yield

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potential at farmers fields. Amid these, climate change induced increase in insect-pest infestation is the major one, which reduces the realized yield of the crop (Punithavalli *et al.*, 2014). It has been reported that nearly 380 insect species attack soybean worldwide and around 273 have been reported in India. Among the total insects infesting soybean, about 14 insect damage seeds, seedlings and roots, 10 on stems, 126 attacks leaves, 6 infests flowers and pods, 72 were sucking and 6 storage pests (Patil *et al.*, 2014). About a dozen insect-pests are major ones which can cause 20-100 per cent yield losses (Sharma *et al.,* 2014) in India. Babu *et al.* (2015) reported that in Rajasthan, semilooper was the major insect-pest infesting soybean. Further, abiotic stresses in soybean have been reported to cause about 26.4 per cent losses worldwide (Patil *et al.*, 2014). Semilooper (*Gesonia gemma*), a major soybean insect, causes high yield loss due to higher defoliation during the reproductive stage of the crop (Babu *et al.*, 2017), or flower initiation and pod filling stages (up to 46 per cent) of crop growth (Singh and Singh, 1991). The economic threshold level for green semilooper estimated at 3 larvae per meter row length (mrl) during flower initiation stage and 2 larvae per meter row length at pod filling stage of the crop (Singh and Singh, 1991).

For managing the insect-pests effectively and its advance planning by early detection of the incidence, it is highly imperative to understand and investigate the effect of weather parameters on the incidence of semiloopers that plays a significant role in their infestation. There is very scanty information available on the prediction of infestation and incidence of semiloopers on soybean. For developing effective integrated pest management (IPM) and timely management of the pest, it is vital to develop prediction model. The information of insect attack predicted by the model is to be disseminated to the soybean growers as a forewarning insect advisory so as to enable them to timely manage their crop from insect attack. Hence, this paper aims to delineate the pre-disposing weather factors responsible for semilooper infestation in soybean.

MATERIAL AND METHODS

In the present study, daily survey data of semilooper population per meter row were collected from the villages of 20 districts of Maharashtra under the Crop Pest Surveillance and Advisory Project (CROPSAP) and district-wise daily weather data which included maximum temperature, minimum temperature, rainfall and relative humidity were maintained. The data were collected for the main soybean cultivation period - 27th - 39th standard meteorological weeks (SMW), *i.e.* from 1st week of July to September end. The data were collected from Ahmednagar, Akola, Amravati, Aurangabad, Buldhana, Chandrapur, Jalgaon, Kolhapur, Nagpur, Nanded, Nasik, Osmanabad, Parbhani, Pune, Sangli, Satara, Solapur, Wardha, Washim, Yeotmal districts. This daily village level data was transformed to weekly (SMW wise) at district level, as the data on weather variables were available at the district level. The data transformation was done by taking mean of the variables (except rainfall) and total of rainfall based on SMWs using excel. The data were used to develop and train the prediction model and to validate the model developed.

The correlation analysis was used to assess the extent of relationship and step-wise regression analysis to study the cause and effect relationship between the semilooper population on soybean crop and weather variables. Regression analysis was attempted using panel data model and mean data model. Mean data model was found to be statistically best fit and hence used to predict the semilooper incidence on soybean crop and its pre-disposing conditions. In mean model, weekly mean of all variables over the years for each district was calculated, whereas in panel model weekly, all the data points for all years and districts were used for the analysis. In panel model, variability was retained over the years and across the districts but in mean model the variability of the data was retained across the districts only. For the analysis, data from the initiation of the incidence to the attainment of the first peak of the incidence (27^{th} to 36^{th} SMW) were used (Patel, *et al.*, 2019). Curvilinear equations were fitted using multiple regression technique to identify the variables which were influencing the occurrence and severity; and for predicting the semilooper incidence in soybean crop. The present study was carried out by using SAS Enterprise Guide version 4.3. In the regression model, semilooper population was taken as response variable and weather variables of current and previous two weeks as explanatory variables. Training dataset from 2010-13 was used to build the model and the data sets from 2014 to 2015 were used validate the model (Akashe *et al.*, 2014).

The training dataset was processed to remove the outliers and influential points using cook's D statistics and student residuals. The pest-weather prediction model was evaluated by coefficient of determination (R^2), Root Mean Square Error (RMSE), Predicted Residual Error Sum of Square (PRESS) Statistics. The minimum Akaike Information Criterion (AIC) and RMSE were used to select the best fit model among the models. For validating the models, cross-validation (LOOCV – Leave One Out Cross-Validation) i.e. R^2_{Pred} using independent dataset (2014-15), methodology was used (Montgomery *et al.*, 2011; Patel, *et al.*, 2019). The observed and predicted values were compared using two sample t-test, standardized residuals, RMSE, mean absolute error (MAE), and validation-R^2 of predicted values fitted with observed values. In cross-validation approach, there is no need to explicitly use independent dataset or validation dataset and is useful when it is not possible to take independent dataset. The PRESS statistics is used to work out the predicted coefficient of determination (R^2_{Pred}).

RESULTS AND DISCUSSION

Correlation studies

The incidence of semilooper

(*G. gemma*) was found to be severe in the year 2010 (Fig. 1) as compared to other years. Therefore, year 2010 was considered as high incidence year (Vannila *et al.*, 2011). The data analysis and expert knowledge revealed that peak incidence of the semilooper was near 36th SMW but the insect attained 2-3 peaks during crop season and continued to infest the crop till maturity. Also the peaks were fluctuating mainly from 32nd to 37th week in different years. Similarly, Babu *et al.*, (2017) also reported a minor deviation than other years in 2014, and peak infestation was seen in early September (around 36th SMW). Netam *et al.* (2013) has also reported that maximum population of semilooper in soybean was during last week of August (around 35th SMW). These deviations in peak incidence were mainly because of the weather variations in different years and in different districts.

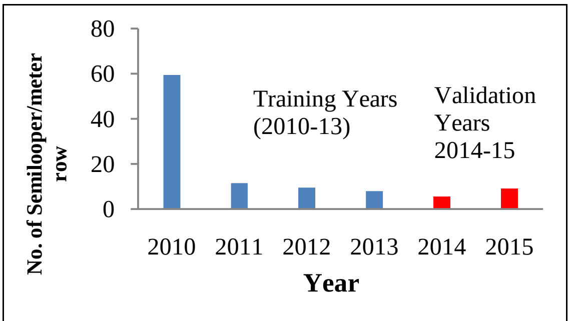

Fig 1. Normal and high incidence year

The degree of relationship between agro-meteorological parameters of current and previous two weeks; and semilooper population has been analyzed from 27th-36th SMW for the period 2010-13 (Table 1). From the correlation analysis it was found that there was a significant correlation between semilooper and maximum temperature (current and 1st lag week); minimum temperature (current week) at 5 per cent level of significance; and rainfall (1st & 2nd lag week) at 1 per cent level of significance. Maximum temperature ($TMax_0$: r = -0.22*, $TMax_{-1}$: r = -0.24*), minimum temperature ($TMin_0$: r = -0.24*) were significantly and negatively correlated whereas rainfall (RF_{-1}= 0.28* and RF_{-2}= 0.35*) had significant positive effect on semilooper population in soybean (Table 1). Correlation studies by Babu *et al.* (2017) revealed that morning relative humidity was positively and significantly correlated whereas evening relative humidity and sunshine hours had significant negative correlations with semilooper population.

Development and validation of prediction model

The effect of weather parameters (of current, 1st and 2nd lag weeks) on the incidence of the semilooper larval population on soybean were analyzed using step-wise multiple regression methodology. The pest-weather prediction models were developed using four years (2010-13) survey data collected from 20 districts of Maharashtra as training dataset to fit the model. The fitted models and other statistics presented in table 2 revealed that in mean model, rainfall of 1st and 2nd lag weeks (RF_{-1} and RF_{-2}) and second order minimum temperature of current week ($TMin_0^2$) were the significant variables influencing incidence of semilooper population and the model explained

Table 1. Correlation coefficient between semilooper (*Gesonia gemma*) larva and weather variables on soybean (2010-13)

Year (2010-13)	$TMax_0$	$TMin_0$	RH_0	RF_0	$TMax_{-1}$	$TMin_{-1}$	RH_{-1}	RF_{-1}	$TMax_{-2}$	$TMin_{-2}$	RH_{-2}	RF_{-2}
Pooled (n=86)	-0.22*	-0.24*	0.04	0.13	-0.24*	-0.21	0.03	0.28**	-0.17	-0.16	0.06	0.35**

*Note: **, * Significant @ 1 per cent and 5 per cent, respectively. $TMax_0$, $TMax_{-1}$, $TMax_{-2}$ represents Maximum temperature for current week, 1st and 2nd lag week, respectively and similarly for other weather variables.*

28.58 per cent variability (coefficient of determination-R^2). Whereas in panel model, minimum temperature and relative humidity of current week; maximum temperature (1st and 2nd order) of 1st lag week; and relative humidity (1st and 2nd order) of 2nd lag week were found to be the significant factors responsible for insect incidence and the model explained 21.34 per cent variability in the semilooper population. Prabhakar *et al.*, (2008) also reported that the regression model for predicting the semilooper larvae incidence in castor could explain 31 per cent in the semilooper population. In mean model, the effect of rainfall (RF_{-1} and RF_{-2}) on semilooper population was found to be positive and significant, while minimum temperature ($TMin_0^2$) had significant negative effect on the semilooper population on soybean in the study area. In panel model, $TMin_0$, RH_0, RH_2 and $TMax_1^2$ were found to be significant and negatively affecting the semilooper population; while the effect of $TMax_1$ and RH_2^2 was positive and significant. All the variables included in the model were significant at 5 per cent level of significance. The validation of developed prediction models was carried out using cross-validation methodology (LOOCV – Leave One Out Cross-Validation), *i.e.* R^2_{Pred} = 22.59 per cent (mean model) and R^2_{Pred} = 15.88 per cent (panel model). Comparison of predicted and observed values using two years independent dataset (2014-15) were carried out by two sample t-test which revealed no significant difference between predicted and observed values (mean model: p=0.1103 > 0.05; panel model: p=0.096 > 0.05). The fitting of predicted against observed values of semilooper population from 2014 to 2015 explained 29.73 per cent (mean model) and 3.15 per cent (panel model) variability of predicted values (Fig. 2). Standardized residuals of observed and predicted values were between +3 and -3, signified the suitability of the model (Akashe *et al.*, 2016). Other statistical measures are mean absolute error (Mean Model: MAE=0.35; Panel Model: MAE=0.39) and root mean square error (Mean Model: RMSE=0.42; Panel Model: RMSE=0.47) (Duraimurugan, 2018). Thus, the mean model is found to be the best fit model based on the validation statistics and useful to forewarn the incidence of the semilooper two weeks prior to the incidence.

Pre-disposing weather conditions

In the present study, average pre-disposing weather conditions for the semilooper infestation has been worked

Table 2. Prediction Models for Semi-looper (*Gesonia gemma*) incidence

Mean Model	$SL = 4.11 + 0.007 \times RF_{-1} + 0.01 \times RF_{-2} - 0.01 \times TMin_0^2$	$R^2 = 28.58$ %, $R^2_{Adj} = 25.96$% $R^2_{Pred} = 22.59$%, SE = 0.79, N=86
Panel Model	$SL = 27.57 - 0.049 \times TMin_0 - 0.024 \times RH_0 + 1.27 \times TMax_{-1} - 0.97 \times RH_{-2} - 0.02 \times TMax_{-1}^2 + 0.006 \times RH_{-2}^2$	$R^2 = 21.34$%, $R^2_{Adj} = 18.36$% $R^2_{Pred} = 15.88$%, SE = 0.33, N=165

SL- Semilooper; , SE- Standard error; and N- No of observations

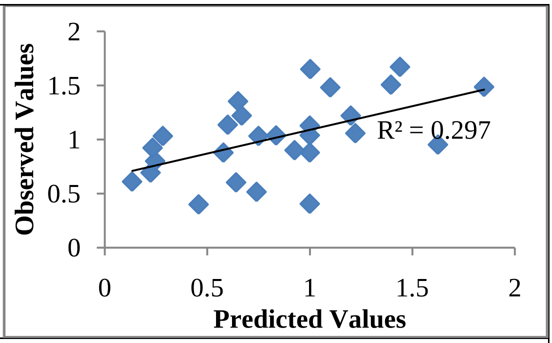

Fig 2. Mean model: observed and predicted semilooper population

out to know the congenial environmental conditions for their incidence. Based on the best fit regression model validated for forecasting accuracy, the weather conditions favourable for higher incidence of the semilooper in soybean are presented in table 3. The results revealed that the conditions for infestation of semilooper (*Gesonia gemma*); average maximum temperature from 27.43 to 31.65 °C, minimum temperature from 21.36 to 24.36 °C, relative humidity from 86.2 to 93.23 per cent and the total rainfall of weekly average were ranging from 14.83 to 119.18 mm with low rainfall in previous weeks followed by high rainfall in the current week were favourable for semilooper infestation.

In the present study, in all the 6 years, the commencement of the semilooper incidence was seen from29th SMW (mid July) rarely in 27th or 28th SMW and persisted till end of the soybean growing season (September last). This period coincided with the flowering to maturity stages of the crop. The semilooper harboured on many other crops besides the soybean season too. The severe incidence was observed during 35th – 36th SMW, but generally attained 2-3 peaks during the cropping season. Correlation analysis indicated that

Table 3. Average weather condition during semilooper incidence

Current Week		**1st Previous Week**		**2nd Previous Week**	
Weather Factors	**Range**	**Weather Factors**	**Range**	**Weather Factors**	**Range**
$TMax_0$	27.54-31.65	$TMax_{-1}$	28.36-31.47	$TMax_{-2}$	27.43-30.25
$TMin_0$	21.56-24.36	$TMin_{-1}$	21.52-24.97	$TMin_{-2}$	21.36-24.36
RH_0	86.20-93.33	RH_{-1}	86.31-93.23	RH_{-2}	87.93-93.29
RF_0	28.22-119.18	RF_{-1}	14.83-76.38	RF_{-2}	16.45-78.27

RF_{-1} & RF_{-2} were significant and positively correlated whereas $TMax_0$, $TMax_{-1}$, & $TMin_0$ were negatively correlated with the semilooper population. The developed pest-weather prediction mean regression model could explain 28.58 per cent variation in semilooper population. It is important to mention that apart from weather parameters natural enemies also significantly influence the population of semiloopers in the crop (Prabhakar *et al.*, 2008). The results of validation techniques showed no significant difference between observed and predicted values and the mean model was found to be best fit model than panel model. The favourable weather conditions for the semiloopers infestation (27th - 36th SMW) were maximum temperature in the range of 27.43 to 31.65 °C, minimum temperature 21.36 to 24.36 °C, relative humidity 86.2 to 93.23 per cent and rainfall 14.83 to 119.18 respectively with low rainfall in previous weeks but high in the current week. These weather ranges have been worked out as the pre-disposing conditions congenial for semilooper incidence. Thus, the satisfactorily validated mean model can be utilized two weeks prior to the infestation to disseminate the insect advisory with the objective to forewarn the soybean farmers well in advance to take preventive measures to protect the crop from semilooper damage.

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Impact of Better Management Practices on Performance of Soybean in Madhya Pradesh

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ABSTRACT

Soybean is a major kharif oilseed crop in Malwa region of Madhya Pradesh. Although, the state has maximum area under the crop, the yield levels do not commensurate with the varietal yield potential and available of improved production technology. To enhance the yield level at farmer fields, twenty-eight Krishi Vigyan Kendras (KVKs) implemented the cluster approach in conduct of frontline demonstration in soybean crop. Main objective of this study was to assess the varietal vis-a-vis *economic performance and relationship of independent variables with selected dependent variables. Further, this study examines the impact of technological interventions* viz., *use of improved variety, sowing method, seed treatment, seed inoculation, spacing, balance nutrient application, weed management and plant protection measures on performance of soybean crop at selected farmers' fields. The results showed that maximum yield comes under variety JS 97-52 and sowing on broad-bed and furrow (BBF) system was most appropriate technology for enhancing the productivity of the crop. Evaluation of agro-climatic wise performance of soybean brought out that maximum average yield was registered in Malwa plateau under improved technology. The B:C ratio as well was second higher in this agro-climatic region. Other zones which supports profitable crop of soybean are Satpura Plateau, Nimar Valley and Gird zone in that order.*

Key words: Cluster approach, economic performance, frontline demonstrations, soybean, yield

The soybean is a crop of global importance and one of the most frequently cultivated crops worldwide. Since, this is the most important oilseed crop in central region of the India with potentials of supplementing edible oil and increasing earnings through export of soy meal, it needs special focus on improving national productivity hovering at 1 ton per ha at present. In view of the positive impact of frontline demonstrations in increasing the seed

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yield of soybean, the present study deals with evaluating the impact of frontline demonstrations encompassing improved technological interventions in different agro-climatic zones of Madhya Pradesh on soybean productivity and economic viability.

MATERIAL AND METHODS

Frontline Demonstrations were conducted employing cluster approach at farmers' fields by 28 Krishi Vigyan Kendras of central region during *kharif* season of 2015, where soybean is a major oilseed crop. The technological interventions imparted were use of improved variety, seed treatment, seed inoculation, recommended spacing, balanced nutrient incorporation, weed management and plant protection measures. Planting on changed land configurations (BBF, Ridge and Furrow were a part of demonstration depending on the facility available with the farmers. The economic evaluation was carried out in terms of net returns and B:C ratio following the standard producers. The correlation between the improved practices and yield was also worked out.

RESULTS AND DISCUSSION

Varietal performance

The performance of three varieties (JS 93-05, JS 97-52 and JS 95-60) under frontline demonstrations revealed that their performance varied from location to location. The mean seed yield of soybean variety JS 93-05 grown on nearly 44 ha by KVKs at Dhar and Satana districts ranged from 1,286 to 2,024 kg per ha, with a mean of 1,655 kg per ha. JS 97-52 was demonstrated by 8 KVKs (Indore, Jhabua, Khandwa, Rajgarh, Ratlam, Sehore, Shajapur and Tikamgarh) covering about 242 ha and the yield varied from 1,224 to 2,230 kg per ha with a mean of 1,633 kg per ha. The performance of JS 95-60 demonstrated by nineteen KVKs (Ashoknagar, Betul, Bhopal, Chhindwada, Damoh, Dewas, Durg, Guna, Harda, Hoshangabad, Jabalpur, Khargone, Mandsaur, Narsinghpur, Rajnandgaon, Sagar, Satna, Sheopur and Ujjain) covering about 624 ha showed the variation in seed yield between 569 kg per ha and 2,274 kg per ha with a mean of 1,401 kg per ha (Table 1). Overall performance of varieties was in order: JS 97-52> JS 93-05 > JS 95-60. The lower performance of JS 95-60 is justified as it is early maturing (85 days) as compared to JS 93-05 (95 days) and JS 97-52 (110 days). The varieties with longer maturity duration are able to accumulate higher quantity of photosynthetes and their translocation to seeds (Egli, 1998; Dogra *et al.*, 2015). The observed variable yield pattern in each of these varieties at distant locations are expected on account of climatic conditions and rainfall pattern experienced during cropping season (Billore *et al.*, 2018).

Sowing method

Out of the four sowing methods demonstrated covering sizable area, planting soybean on BBF culminated on highest average seed yield, which was about 34 per cent higher over flat bed sowing. Sowing on raised bed and ridges and furrows also led to enhanced seed yield by about 26 and 21 per cent respectively, over flat bed sowing.

Table 1. Varietal performance at varied locations under frontline demonstrations

Krishi Vigyan Kendra	Varieties					
	JS 93-05		JS 97-52		JS 95-60	
	Area covered (ha)	Average seed yield (kg/ha)	Area covered (ha)	Average seed yield (kg/ha)	Area covered (ha)	Average seed yield (kg/ha)
Dhar	30.0	2024	-	-	-	-
Satna	14.4	1286	-	-	-	-
Mean	-	**1655**	-	-	-	-
Indore	-	-	30.0	1616	-	-
Jhabua	-	-	30.0	1470	-	-
Khandwa	-	-	30.0	1645	-	-
Rajgarh	-	-	30.0	2230	-	-
Ratlam	-	-	30.0	1661	-	-
Sehore	-	-	30.0	1636	-	-
Shajpur	-	-	32.0	1575	-	-
Tikamgarh	-	-	29.6	1224	-	-
Mean			-	1633	-	-
Ashoknagar	-	-	-	-	30.0	1452
Betul	-	-	-	-	60.0	1784
Bhopal	-	-	-	-	29.6	826
Chhindwada	-	-	-	-	45.2	1173
Damoh	-	-	-	-	31.6	569
Dewas	-	-	-	-	40.0	1855
Durg	-	-	-	-	30.0	1500
Guna	-	-	-	-	30.0	1537
Harda	-	-	-	-	30.0	1854
Hoshangabad	-	-	-	-	30.0	1671
Jabalpur	-	-	-	-	29.6	1355
Khargone	-	-	-	-	30.0	1193
Mandsaur	-	-	-	-	30.0	1664
Narsinghpur	-	-	-	-	40.0	920
Rajnandgaon	-	-	-	-	30.2	1154
Sagar	-	-	-	-	30.0	1054
Satna	-	-	-	-	15.6	1252
Sheopur	-	-	-	-	30.0	1525
Ujjain	-	-	-	-	32.0	2274
Mean	-	-	-	-	-	**1401**
Total area (ha)	**44.4**	-	**241.6**	-	**623.8**	-

Increase in soybean seed yield by planting on changed land configuration and consequent mitigation of water stress has been reported by several workers (Table 2) (Anonymous. 2007-08; 2008-09; Lakpale *et al*., 2012; Ramesh *et al*., 2007; Chattopadhayay *et al*., 2016; Motwani and Ashish, 2018).

Table 2. Sowing methods used in soybean

Sowing method	Total area covered (ha)	Seed yield (kg/ha)	% increase over flat bed sowing
BBF	60.00	1784	34.03
Ridge and Furrow	329.6	1617	21.49
Raised bed	109.6	1679	26.15
Flat bed sowing	410.6	1331	-
Mean	**-**	**1603**	
Total area (ha)	**909.8**	**-**	

Soil test based fertilizer application

All the demonstrations (*kharif*, 2015) covering 909.8 ha area received tailored recommended fertilizer dose based on soil test values. The average yield level achieved was 1,510 kg per ha as compared to that achieved in farmers' practice (1,160 kg/ha), which was 34.80 per cent higher. Role of balanced fertilization in elevating the yield of soybean has amply been brought out by other workers (Timothy *et al*., 2018)

Zone-wise performance of soybean in Madhya Pradesh

In view of variable performance of soybean varieties from one location to other, the data was organized based on the ten agro-climatic zone of the Madhya Pradesh. In this exercise the demonstrations covering about 876 ha were considered. The grouping of average seed yield performance brought out that soybean performed best on the Malwa plateau (1,807 kg/ha), which was 15.32 per cent higher than Gird zone (1,567 kg/ha) next in order. Vindya plateau, Bundelkhand region and Chhattishgarh plain offered lower values of 1,027, 1,250 and 1,260 kg per ha, respectively. The seed yield of remaining zones ranged between 1,356 and 1,550 kg per ha. Malwa plateau excels in soybean production due to more suitable agro-climatic conditions. However in most of the zones, the yield levels were much higher than the national average for the year 2015 (757 kg/ha) (http://eands.dacnet.nic.in/PDF/Glance-2016.pdf) and can be attributed to adoption of improved technology. Similar observations revealing the impact of improved technology were made by other workers in the past (Patil *et al*., 2003; Singh, 2002, Singh *et al*., 2014; Mukherjee, 2003;; Tomar *et al*., 2003; Singh *et al*., 2013).

Correlation of yield with different technology use for cultivation

Correlation studies between selected variables (Table 4) revealed

Table 3. Yield performance of soybean in various agro-climatic zone in Madhya Pradesh

Agro-climatic zones	Area (ha)	Average seed yield (kg/ha)
Bundelkhand region	29.6	1250
Central Narmda Valley	99.2	1550
Chhattisgarh plain	60	1260
Gird zone	90	1567
Jhabua hills	30	1470
Kymore plateau	30	1356
Malwa plateau	282	1807
Nimar valley	60	1421
Satpura plateau	105	1478
Vindhya plateau	90	1027
Mean Yield	**-**	***1419***
Total area (ha)	**875.8**	**-**

that the yield is positively co-related with crop duration, seed rate, sowing method, seed treatment and soil test, whereas negatively co-related with area, variety and source of seed. Negative association of variety with the yield may be explained as all the three varieties used in the demonstrations were improved ones. Crop duration is positively correlated with the yield because longer duration allows the crop to accumulate more photosynthetes and their translocation to seed to improve yield. The positive association of seed rate is justifiable as for optimum plant population and desirable growth is essential to culminate into higher yield. Since soybean is cultivated as rainfed crop, the water stress during crop growth duration becomes important. This is the reason, planting soybean on changed land configuration mitigates the effect of water stress (deficit as well as excess) (Ramesh *et al.*, 2007; Chattopadhayay *et al.*, 2016; Motwani and Ashish, 2018) and hence the correlation is positive. Positive correlation between seed treatment and yield is as well justified in view of protection of plants from initial diseases and pests and avoids death of seedlings leading to lower population. On considering source of seed, the entire quantity of quality seed was procured from Beej Nigam and hence negative correlation with the yield. Application of tailored recommended nutrients dose based on soil test values provides balanced nutrition to soybean crop and is being expressed in yield and therefore positive correction is observed with respect to yield.

Economic evaluation

Economic evaluation of performance of soybean in different agro-climatic zones (Table 5) showed that overall net returns were Rs 26,761 per ha with B:C ratio of 2.28 under frontline

Table 4. Relationship between yield and production factors of soybean

Production Factors	Area	Variety	Crop duration	Seed rate	Sowing method	Seed treatment	Source of Seed	Soil test	Rainfed/ Irrigated	Yield
Area	1.00									
Variety	0.09	1.00								
Crop duration	0.07	0.32	1.00							
Seed rate	0.04	0.17	-0.13	1.00						
Sowing method	0.02	0.07	0.60	-0.24	1.00					
Seed treatment	0.01	-0.02	0.02	0.01	-0.01	1.00				
Source of seed	-0.10	-0.12	0.07	-0.09	-0.33	0.01	1.00			
Soil test	-0.04	-0.18	0.14	-0.40	0.08	-0.01	0.10	1.00		
Rainfed/Irrigated	0.03	0.06	-0.02	0.09	-0.06	-0.05	0.04	-0.08	1.00	
Yield	-0.12	-0.28	0.01	0.05	0.36	0.04	-0.21	0.12	-0.04	1.00

Table 5. Economic performance of soybean crops under cluster approach for frontline demonstrations

Agro climatic region	Farmer's ptactice				Frontline demonstrations			
	Gross cost (Rs/ha)	Gross returns (Rs./ha)	Net Returns (Rs/ha)	B:C Ratio	Gross cost (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
Bundelkhand Region	15000	30666	15667	2.04	22000	50000	28000	2.27
Central Narmada Valley	22167	30344	10400	1.37	20067	44300	21633	1.96
Chhattisgarh Plain	14175	32125	17950	1.79	16325	40325	24000	1.97
Gird Zone	17114	35591	16473	2.14	33222	47123	26109	2.26
Jhabua Hills	21200	37406	16206	1.76	22175	45580	23405	2.06
Kymore-Plateau	15500	23500	8000	1.52	18600	40700	22100	1.19
Malwa Plateau	21584	43878	22294	2.26	22923	55350	32427	2.63
Nimar Valley	16318	40248	23930	2.47	18225	45401	27177	2.50
Satpura Plateau	16950	34070	17120	2.11	20550	53150	32400	2.71
Vindhya Plateau	15187	24028	9316	1.46	17677	33279	15602	1.83
Grand Total	**18676**	**35898**	**17300**	**1.97**	**21932**	**47640**	**26761**	**2.28**

demonstrations, which was higher than in farmers'practice (Rs 17,300/ha and 1.97, respectively). As the cost of cultivation differed from zone to zone, the net returns ranged from Rs 21,633 (Central Narmada Valley) to Rs 32,427 (Malwa Plateau), whereas B:C ratio from 1.19 (Kymore Plateau) to 2.71 (Satpura Plateau). Other zones which supports profitable crop of soybean are Satpura Plateau, Nimar Valley and Gird zone in that order. The yield variation is observed in various zones due to differential micro-climate, adaphic factors followed by the farmers' technology with their own perception. This also warrants identifying and refining the existing present technology for adoption and development of zone specific improved varieties for low performing zones to make soybean cultivation more profitable.

Frontline demonstration encompassing improved technology including improved varieties, irrespective of locations or agro-climatic zones, are effective in convincing farmers to adopt proven technology and switch over to improved varieties. The planting of soybean on changed land configuration (BBF and Ridges and Furrow system) has added advantage over flat land planting by way of mitigating adverse effect of moisture stress and thereby improving the yield levels of soybean. The improvement in performance of crop and monetary benefit can be harnessed by the farmers by adaptation of improved technology and varieties.

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Adoption of Soybean Production Technology by the Farmers in Malwa Plateau of Madhya Pradesh

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ABSTRACT

Soybean had played a pivotal role in socio-economic transformation of majority of small and marginal farming community of central India and continued to contribute significantly to the oil economy of India. The average productivity of soybean presently is staggering around one ton per ha, which is a matter of concern. A study, therefore, was conducted in three major soybean growing districts namely, Indore, Dewas and Dhar of Madhya Pradesh of Malwa Plateau with a prime objective to assess adoption of package of agronomical practices by the farmers. The data were collected from 280 soybean growers belonging to different villages in the study area using semi-structured interview schedule containing 25 agronomic practices belonging to six categories. The responses of soybean growers were recorded and measured by adoption index score. The data were analyzed using statistical tools like percentage, mean, standard deviation, and correlation. Majority of the respondents belonged to middle age group, with education up to middle school, having medium income level with semi-medium land holdings (2-4 ha) and medium socio-economic status. The village level rural agricultural extension officer (RAEO) was found to be most important link of technology outreach as reflected in the extension contact of the farmers. However, their participation in extension activities organized in the area was found to be very less. It was observed that majority of the farmers have medium adoption level of the soybean production technology. Further, an analysis of practice-wise adoption revealed that full adoption was found with respect to land preparation, use of improved varieties, sowing time, weeding as well as storage of seed. However, majority of the farmers did not adopt the practices like, germination test, seed treatment and use of bio-inoculation, maintaining seed rate, plant population, spacing, plant nutrition, disease management and time of threshing. Further, the plant protection practices like, use of chemicals weed control and insect management were partially adopted by most of the farmers although they do not follow the recommended spray concentration.

Key words: Adoption index, correlation, extension participation index, soybean

Soybean [*Glycine max* (L.) Merrill], a crop of socio-economic prosperity for millions of small and marginal farmers of central India, has continued to occupy

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premier position in the oilseed scenario of the country. Malwa plateau of Madhya Pradesh has been the epicenter of soybean development, both in terms of its horizontal spread as well as growth and development of soy-based industries (Tiwari *et al.*, 1999). Soybean in the state of Madhya Pradesh is mainly grown as rainfed crop during rainy season *(kharif)* by the farmers who presently are fascinated to grow only short duration varieties in order to minimize yield losses due to long dry spells/terminal drought and climatic adversities experienced since last decade. ICAR-Indian Institute of Soybean Research (ICAR-IISR), which was established at Indore in 1987, is continuously engaged in development, dissemination and technical backstopping of location-specific technologies directly and through the nation-wide centres of All India Coordinated Research Project on Soybean (AICRPS). The soybean research and development (R&D) system in India has developed more than 112 improved varieties so far as well as agronomic practices suiting to various agro-climatic regions and clientele groups. The state agriculture department of Madhya Pradesh, which is main extension agency, has major responsibility to provide extension services and to disseminate technological knowledge to the farming community at village level. Though, the crop exhibited a phenomenal growth in area, production and productivity initially up to 1990s, the average productivity of soybean in the country is hovering around one ton per ha till last few years (Sharma *et al.*, 2018). Frontline demonstrations which were conducted in the area, have successfully demonstrated the production potential (up to 2.5 t/ha) of soybean varieties grown with improved technologies (Billore *et al.,* 2005). Thus, there exists yield gap indicating scope of increasing the productivity by enhancing level of technology adoption by the farmers. A recent study conducted by Sharma *et al.* (2018) has also pointed out a significant yield gap in soybean and explored considerable scope to enhance soybean yield and thereby, farmer's income through adoption of research emanated recommended package of practices. The earlier study (Dupare *et al.,* 2011) also revealed that most of the soybean growers had low to medium range of adoption level indicative of partial/non-adoption or over adoption in case of some of the major agronomic practices. With this backdrop, it was considered appropriate to analyze status of farmers' adoption of recommended agronomic practices *vis-a-vis* their socio-economic background, information flow *etc.*, which could lead to suggest remedial measures for increasing the soybean productivity.

METHODOLOGY

The present study was conducted in three major soybean growing districts of Madhya Pradesh, namely Indore, Dewas and Dhar which are popular for soybean revolution in the Malwa plateau region. The sample for the study consisting 280 soybean growers drawn randomly from selected six villages (two villages from each selected district). To collect the data, a pre-tested interview schedule containing basic information about the farmers, sources of information and their utilization along with list of various recommended practices to know their adoption level was utilized. The information gathered through the semi-structured interview schedule was numbered, coded and scored using standard procedures. The adoption behavior was calculated considering 25 recommended practices starting from land preparation to harvesting and threshing as recommended by soybean R&D system (Table 6). The responses of the respondents were scored as 2 for full adoption of a recommended practice. A score 1 was assigned to partial adoption whereas, non-adoption of a practice was scored zero. The extension participation index and technology adoption index of selected soybean farmers were worked out as below.

The extent of contact of a farmer with different extension agencies and their participation in various extension activities or programmes were considered for constructing Extension Participation Index (EPI).

$$EPI = \frac{\text{Actual total score obtained by respondent}}{\text{Maximum obtainable score}} \times 100$$

The extent of the adoption of the recommended crop production technology was ascertained by Technology Adoption Index (TAI_i) constructed using the scores of 2, 1 and 0 for full, partial adoption and no adoption, respectively, of different package of practices (Table 6) and assigning equal weights to each practice (Dupare, 1995; Sharma *et al*, 2018).

$$TAI_i = (S_{oi}/S_{max}) \times 100$$

Where, TAI_i is the index of adoption of technology by i^{th} farmer, S_{oi} is the total technology adoption score obtained by i^{th} farmer, and S_{max} is the maximum obtainable technology adoption score by the i^{th} farmer.

Respondents were grouped into three categories (high, medium and low) on the basis of mean ± standard deviation of the index. The data obtained were analyzed using standard statistical tools like, mean, standard deviation, percentage and correlation coefficients.

RESULTS AND DISCUSSION

A. Background profile of soybean growers

Majority of the respondents (67.14%) belonged to middle age group (32-58 years) with an average age of about 45 years. Regarding their annual income from all the sources, most of the respondents (40.7%) had average annual income ranging from INR 1.44 to 2.68 lacs (one lacs = INR 100 thousand) followed by 35.7 per cent farmers having annual income of less than INR 1.43 lacs, while the income level of remaining 23.6 per cent of the respondents was more than INR 2.69 lacs. As far as their land holding category is concerned, most of the respondents (37.1%) belonged to semi-medium category, *i.e.* those having land between 2.1 to 4 hectares followed by25 per cent of the small and marginal farmers with holdings of 1 to 2 ha. Another 20.0 per cent farmers with land holding up of 4.1-10 hectares belonged to medium category whereas remaining a group of farmers (17.8%) constituted large category. Majority of them (62%) had medium to small and marginal land holdings ranged between 1 and 4 ha (Table 1).

It was observed that the farmers had sufficient educational background with only 7.8 per cent of them being illiterate or functionally literate, who can only read and write. Out of 280 respondents, most of them (42.8%) studied up to middle school level followed by 32.1per cent who acquired education up to high school and remaining 17.8 per cent were with education level up to college/graduate level. Majority of the respondents (90%) were found to manage their livelihood separately from their parents as nuclear family and only 10 per cent of them were maintained their livelihood affairs jointly with their parents and siblings (Table 1).

Table 1. Background profile of soybean growers

Characteristic	No of respondents (N=280)	Percent
Age (Mean-45.21, SD-14.18)		
High (above 59 yrs)	38	13.6
Medium (32-58 yrs)	188	67.1
Low (below 31 yrs)	54	19.3
Education		
Illiterate/functionally literate	22	7.86
Up to middle school level	120	42.86
Up to high school level	90	32.14
College/graduate	48	17.14
Farming category		
Marginal and small (<2ha)	70	25.0
Semi-medium (2.1-4.0 ha)	104	37.14
Medium (4.1-10.0 ha)	56	20.00
Large (above 10.1 ha)	50	17.86
Annual incomeMean-2.06, SD-0.63		
High (above INR 2.69 lac)*	66	23.6
Medium (INR 1.44-2.68 lac)	114	40.7
Low (below INR 1.43 lac)	100	35.7
Average family size	*3.87*	
Family type		
Nuclear	252	90.0
Joint	28	10.0

One lacs = INR 100 thousand

B. *Socio-economic status of soybean growers*

Socio-economic status refers to position of an individual with reference to prevailing average standard or cultural position, effective income, material possession and participation in group activities of the community. An effort made to know the socio-economic profile of soybean growers revealed that majority of soybean growers (54.28%) belonged to medium socio-economic category, followed by 28.57 per cent had low socio-economic status and only 17.14 per cent had high socio-economic status (Table 2). Soybean crop had contributed significantly to the socio-economic transformation of small and marginal farmers. The earlier studies on soybean also documented improvement in the socio-economic condition of farmer's post-soybean introduction in the region (Dupare *et al.,* 2009; Badal *et al.,* 2000; Gadge, 2003; Sharma *et al.,* 2016).

Table 2. Socio-economic status levels of respondents

SES score (Mean-20.17, SD-3.81)	No. of respondents (N=280)	Percent
High (above 23)	48	17.14
Medium (17-22)	152	54.28
Low (Below 16)	80	28.57

C. *Extension Contact and Extension participation*

The extension contact is the degree to which contacts were made by an individual farmer with extension personnel for seeking advice and information related to farming. The frequency of contacts made with different types of extension agencies was used for calculating the extension contact. To study the information seeking behavior of soybean growers, two major activities followed by the farmers, namely contacts with extension agencies and their participation in extension activities conducted in their area, were considered. It can be noted that the Rural Agricultural Extension Officer (RAEO) is the most important link between the farming community and the department of agriculture of Madhya Pradesh (Table 3). About 51.42 per cent of the farmers kept contact with RAEO on regular basis whereas 30.72 per cent of the respondents consulted the RAEO as per the need. However, surprisingly rests of the farmers (17.85%) had no contact with the RAEO. Moreover, only few farmers had their contact with higher officials of department of agriculture and the KVK/ICAR scientists located in their area.

Extension participation denotes herein that the participation of soybean growers in various extension activities conducted in the study area and was worked out on the basis of regularity. A very dismal picture of the farmers' participation in extension activities emerged out. It was observed (Table 3) that majority of the farmers (78.58%) had

Table 3. Extension contact and participation

Extension professionals / Program	Frequently/ Always	Sometime	Never
Extension contact			
1. RAEO/Gram Sewak	144(51.42)*	86 (30.72)	50(17.86)
2. Officers of department of agriculture	6(2.14)	34(12.14)	240(85.72)
3. Scientists of KVK/ICAR Institute	2(0.71)	16 (5.71)	262(93.58)
Extension participation			
4. Farmers' Training Program	36 (12.85)	24 (8.57)	220 (78.58)
5. *Krishi Mela*	68 (24.28)	28 (10.00)	184 (65.72)
6. Group Meetings	20 (7.14)	4 (1.43)	256 (91.43)
7. Field Day/ Demo visit	6 (2.14)	22 (7.86)	252 (90.00)

**Figures in parentheses shows percentage*

never attended any agricultural training programmes, 65.72 per cent did not attend any farm exhibition, 91.43 per cent did not attend any meeting/programme organized by agricultural department, 90 per cent did not attend any field days and almost all of them did not see any crop-specific demonstration programmes organized for them. But, few progressive farmers mostly participated in such programmes (training, *krishi mela*, field days, demonstrations, meetings, *etc*) and got benefited in terms of knowledge or technical know-how related to new technologies and practices, which could be used in their current farming practices.

D. Extension Participation

The sum total of scores received by the respondents for their extension contact as well as extension participation was considered to work out the extension participation index (Table 4). Majority of the respondents (70%) had medium extension participation followed by 19 per cent had high extension participation and only 11 per cent had low extension participation. This situation warrants improvement through modern IT tools as well as through extension outreach so as to make the farmers aware of new agricultural technologies and practices in order to motivate them to adopt those in the field and increase the yield potential.

E. Magnitude of adoption of recommended soybean production technology

The data (Table 5) related to adoption levels of respondents related to recommended soybean production technology revealed that majority of soybean growers (65%) had medium level of adoption of the recommended practices. Only 7.9 per cent of the respondents adopted the technologies at high level, whereas, only 27.1 per cent farmers had low level adoption, which is a major concern for the development.

Table 4. Extension Index score of the soybean growers

Level of participation Index	No. of respondents (N=280)	Percent	Average index value
High	54	19.29	0.576
Medium	196	70.00	0.283
Low	30	10.71	0.112

Table 5. Distribution of respondents according to their technology adoption index

Adoption level	No. of respondents	Percent	Average Index value
High (>78%)	22	7.85	0.839
Medium (35-77%)	182	65.0	0.644
Low (< 34%)	76	27.15	0.285

F. *Practice-wise adoption of recommended agronomic practices*

Since, the categories of adoption as mentioned above do not provide actual picture of the practices being fully or partially adopted or not adopted by the farmers. Therefore, an effort was made to study all the 25 recommended agronomic practices-wise adoption (Table 6) for drawing the meaningful conclusions and suggestions for farmers and extension professionals for updating the technical know-how of the farmers.

Sharma *et al.* (2006) reported that there was 36 per cent gap in adoption of improved soybean production technology in Madhya Pradesh leading yield realization up to 48 per cent compared to that with full package. Thus, adoption of full package of practices for soybean resulted in 48 per cent higher yield over farmers practices. Yield loss due to weed infestation was estimated to the extent of 77 per cent (Tiwari and Kurchania, 1990), while the adoption of weed management practices by farmers was only 26 per cent (Dupare *et al.*, 2011). Merely, 16 per cent farmers adopted intercropping soybean. Sulphur is important nutrients to be included in nutritional schedule for optimizing soybean productivity, and about three-fourth of the farmers did not use this nutrient. Since, most of the farmers were following mono-crop system (soybean-wheat/gram) over time and even did not adopt intercropping and integrated approach for nutrient management, the soil fertility level had declined significantly and crop also became more prone to diseases and pest infestation (Dupare *et al.*, 2010). For long-term sustainability and enhancement in yield levels, varietal/crop diversification is to be promoted. Three cycles of soybean-wheat cropping systems over nine years had revealed that inclusion of maize in each cycle in place of soybean led to higher profitability (*Vyas et al.,* 2013). Also, there was partial adoption of integrated approach for insect-pest management and many farmers did not use even recommended pesticides at appropriate time and doses.

Table 6. Practice-wise adoption of recommended soybean production technology (N=280)

Package of practices	Non-adoption	Adoption
Tillage and land preparation		
1. Deep summer ploughing	44 (15.72)*	236 (84.28)
2. Criss-cross harrowings	30 (10.72)	250 (89.28)
3. Planking	30 (10.72)	250 (89.28)
Variety, germination and treatment		
4. Improved variety	8 (2.85)	272 (97.14)
5. Germination test	122 (43.58)	158 (56.42)
6. Seed treatment	120 (42.86)	160 (57.14)
7. Seed inoculation	122 (43.58)	158 (56.42)
Sowing and plant geometry		
8. Seed rate	244 (87.14)	36 (12.85)
9. Plant population	160 (57.14)	120 (42.86)
10. Row to row spacing (cm)		
35	76 (27.14)	-
35-40	84 (30.00)	-
45		120 (42.85)
11. Plant to Plant spacing		
1-3 cm	218(77.86)	
3-5 cm		62(22.14)
12. Intercropping	248 (88.58)	32 (11.42)
Weed control		
13. Chemical control (herbicides)	12 (4.28)	268 (95.72)
14. Hoeing for weed mgt	32 (11.42)	248 (88.58)
15. Manual weeding	190 (67.86)	90 (32.14)
Plant Nutrition		
16. Application of FYM	106 (37.86)	174 (62.14)
17. Optimum NPKS	118 (42.14)	162 (57.86)
18. Application of sulphur	234 (83.57)	46 (16.42)
Plant protection		
19. Management of green semilooper	116 (41.42)	164 (58.58)
20. Management of Heliothis and tobacco caterpillar	44 (15.72)	236 (84.28)
21. Management of girdle Beetle	100 (35.72)	180 (64.28)
22. Disease management	252 (90.00)	28(10.00)
23. Use of bio-pesticide	252 (90.00)	28 (10.00)
Harvesting and threshing		
24. Harvesting time	-	280(100.00)
25. Threshing	238 (85.00)	42 (15.00)

**Figures in parentheses shows percentage to each practice*

The low level of adoption of improved production technology was mainly due to various socio-economic constraints faced by the farmers, such as non-availability of quality inputs, high cost of inputs, lack of access to capital, lack of knowledge, poor extension support and poor marketing facilities (Sharma, *et al.,* 2006; Dupare, *et al.* 2011; Kumar *et al.,* 2012; Singh *et al.,* 2013). Singh and Singh (2013) reported that lack of knowledge about improved soybean production technology was high particularly regarding seed treatment (62% knowledge gap), weed control (35.6%) and plant protection measures (30%).

Tillage and land preparation

It is very heartening to note that out of 25 agronomic practices recommended by the soybean R&D system; majority of the respondents (84.28%) adopted the practice of deep summer ploughing once in 3-4 years. Further, even more numbers of the respondents (89.28%) adopted the practice of two criss-cross harrowing for seed bed preparation. Similarly, the same numbers of farmers adopted the practice of planking to make the field ready for sowing after the arrival of monsoon.

Variety, germination and treatment

It was good to learn that majority of the farmers (97.14%) used relatively new improved soybean varieties, which includes, JS 95-60, JS 93-05 and JS 20-34. The farmers preferred these short duration varieties (85-95 days) in order to avoid the risk of yield loss due to early withdrawal of monsoon and long dry spells during cropping season being experienced during last few years. However, only 56.42 per cent of the soybean growers carried out germination test for their available seed before sowing in order to ensure the ideal plant population. Remaining farmers (about 43%) did not adopt the practice. Germination test ensures the quality of seed and helps to optimize seed rate to achieve recommended plant population for harnessing better yield level. Interestingly, it was found that about 57 per cent farmers only followed seed treatment practice with recommended fungicide as well inoculation with *Bradyrhizobium japonicum* and PSB (phosphate solubilizing bacteria) culture before sowing. The farmers (43%) did not adopt these practices. Similarly, seed treatment with fungicide is recommended in order to avoid the yield losses due to diseases, which otherwise are very difficult to manage at later stage and likely to increase the cost of cultivation. Also, seed inoculation with cultures like *Bradyrhizobium japonicum* helps for biological fixation of atmospheric nitrogen, whereas with phosphate solubilizing bacteria which helps in solubilization of fixed soil phosphorus facilitating its availability to crop. Therefore, the soybean R&D system recommended these practices for ensuring the efficient utilization freely available atmospheric nitrogen and soil available soil nutrients and for avoiding the yield losses due to diseases. Non-adoption of these practices is a matter of concern and requires concerted efforts to motivate farmers to take up the practices to raise and sustain the productivity.

Sowing and plant geometry

Seed rate: It is very disappointing to know that only 12.85 per cent of the farmers adopted the recommended seed rate for sowing of the crop. Instead, majority of the soybean growers (87.14%) used very high seed rate. The R&D system have recommended the seed rate of 60-85 kg per ha based-on seed size and minimum germination of 70 per cent, which is optimum to ensure optimum plant population thereby realized yield. Some of them used very high seed rate as 125-130 kg per ha with narrow plant spacing than recommended. After further enquiry, it was learnt that they used higher seed rate to manage the weed population. However, this practice of crowding the plants not only expose the crop for competition for natural resources, but also results in higher incidence of pest and diseases, lowering the yield and net income.

Plant population: It was observed that only 42.86 per cent of the respondents maintained the recommended plant population (4.5 to 6.0 lacs/ha) depending on the varietal architecture. It is again a matter of a great concern that majority of them (57.14%) did not bother to follow this practice to ensure recommended plant population. As majority of the farmers used their farm saved seed for sowing without carrying out its germination test obviously, there was doubt about its germinability. Moreover, they were using higher seed rate

Weed management

resulting in higher plant population which resulted in to poor yield.

Spacing: It is very disheartening to know that farmers, even after successful cultivation of soybean crop during last 4-5 decades, were not following the recommended practice of row to row/plant to plant spacing. In this regard, only 42.85 per cent farmers followed the recommended row spacing of 45 cm. Remaining farmers (30%) followed either sowing the crop at 35-40 cm or even less than 35 cm (27.14%). Farmers generally believed that dense planting of soybean suppresses the weed population. Similarly, majority of the farmers (77.86%) were not able to maintain plant to plant spacing of 3-5 cm. Only 22.14 per cent were maintained this practice. The non-adoption of spacing could be one of the reasons for not being able to achieve the potential yield of newly introduced high yielding varieties. This sometimes leads to the problem of non-podding in soybean, which was experienced in the region during last decade.

Intercropping: Though, intercropping of soybean with suitable companion crop is monetarily profitable and remunerative, it was adopted by only 11.42 per cent of the farmers. Majority of the farmers had not adopted the intercropping with maize/sorghum/pigeon pea mainly for the reason that they did not have suitable intercrop seed drill and possible delay insowing of subsequent *rabi* crops (potato, onion and garlic).

For weed management, a serious concern for major *kharif* season crop like, soybean, the R&D system has recommended variety of approaches namely, manual, cultural and chemical methods for containing weeds during initial critical 45 days after sowing. This included manual weeding, intercultural operations like, hoeing (*dora/kulpa*) and three groups of recommended herbicides, both for minimizing the infestation of monocot/dicot weeds. However, it was observed that the farmers now-a-days had, by and large, dispensed with the use of pre-plant incorporation (PPI) herbicides, except a few started using diclosulum (PE-pre-emergence). In the study area, majority of the farmers (95.72%) used post-emergence herbicide (PoE) like, Imazethapyr, which they sprayed at 15-20 days after sowing. In addition to use of PoE herbicide, the farmers (88.58%) were found resorting to the intercultural operation of *dora/kulpa* as per its suitability during dry spell. The practice of manual weeding was practiced by a few farmers (32.14%), especially, those had small land holdings.

Plant nutrition

Being a leguminous crop, soybean is also contributing to enrich the soil by way of biologically fixing the atmospheric nitrogen added with residue recycling, which is available for soybean and subsequent crop in rotation. Field trials on soybean-wheat cropping systems brought out the contribution of 35-40 kg nitrogen per ha of soybean crop to next wheat crop in rotation (Saxena and Tilak, 1975). Therefore, the soybean R&D system has recommended resorting to nutrient management in soybean utilizing integrated approach. This involves use of biofertilizers, application of Farm Yard Manure @ 10 t per ha or Poultry Manure @ 5 t per ha or through Vermi-Compost @ 2.5 ton per ha before sowing. Subsequently prior to sowing, incorporation of 20:60:20:20 kg NPKS per ha is considered sufficient enough to get adequate soybean yield. This agronomic recommendation of fertilization can further be tailored on the basis of soil test values or can be modified on the basis of targeted yield concept. But, it is equally necessary to incorporate all the basic nutrition in balanced quantity. The effort made to know the status of nutrient application and its adoption by the farmers brought out that majority of them (62.14%) applied organic manure through FYM, but, on rotational basis as the recommended quantity of FYM was either not available at their doorstep or too expensive. The unavailability of the FYM is major constraint now-a-days due to mechanization of most of the farm operations which forced the farmers to get rid of their draught animals. Remaining group of farmers (37.86%) had not applied the FYM as was not affordable due to heavy cost. Most of them viewed that the nutrition applied to the *rabi* crop, particularly potato/onion/garlic suffices the requirement of subsequent soybean crop grown during *kharif*. Further, only 57.86 per cent farmers had adopted the recommended dose of fertilizers partially either through DAP (lacks K and S) or complex fertilizer (12:32:16) (lacks S).

Balanced incorporation of both the elements is necessary for the oilseeds for optimizing yield and quality of produce. Moreover, the soils of Malwa region are deficient in zinc and required to be included in fertilizer schedule. The study revealed that almost three-forth (76.42 %) respondents did not apply the carriers for these two essential elements. Non-inclusion of potassium, sulphur and zinc in fertilizer schedule curtails the yield level and quality of grains in terms of seed lusture and reduced oil content. Potassium is associated with quality of produce (Dev, 1995) and also known to provide protection against moisture stress, insect-pests/disease and lodging .

Plant Protection

Plant protection is the one of the most important aspects of crop management. Of late, soybean crop is being infested by four major insects, *viz.* green semi-looper, *Heliothis armigera*, tobacco caterpillar and girdle beetle. Consequent to their attack experienced during last two decades, the R&D system of soybean has recommended management measures which included cultural and mechanical measures and number of optional insecticides including bio-pesticides, which can be used, if needed. The query on prevailing plant protection with respondents revealed that they used to apply 2-3 sprays of recommended insecticides earlier, but now applying 3-4 sprays during crop season. It also came out that the spraying of insecticide was ritual irrespective of the incidence of pest. Majority of the farmers (58.58%) applied first spray after 3 weeks of sowing for protection from green semi-looper. Even sizable number of the farmers (84.28 %) sometime applied 2 sprays of insecticide during 4-5th week to control insects like, *Heliothis armigera* and tobacco caterpillar. Similarly, more than 64.28 per cent of the respondents adopted management practices to control girdle beetle.

Apart from the insects, viral disease like yellow mosaic virus (YMV) is also found affecting on soybean resulting in considerable yield loss, if not managed in time. But, only 10 per cent of the farmers were attentive to control it. Few of them, believed that the fungicidal seed treatment carried out during sowing would protect the crop from all sort of diseases. Therefore, there is need to educate the farmers about importance of seed treatment and also for control of white fly, a vector for spreading YMV. As far as application of bio-pesticides is concerned, the adoption was found to be merely 10 per cent. The bio-pesticides show their efficacy only if the insect is identified at its initial stage and also needs repetitive sprays on community basis, which has discouraged the farmers for their adoption. Only those farmers engaged in organic soybean production and associated with some corporate only adopted locally prepared bio-pesticides using plant-based sources in soybean crop.

Harvesting, threshing and storage

The best time for harvesting of soybean crop is decided based-on change in pod color (ICAR-IISR, 2015); when 90-95 per cent pods change color form green. In the study area, the practice of right stage of harvesting was adopted by all the farmers. The harvesting of soybean earlier was mostly carried out manually using human labor using sickle. The harvested soybean is collected and kept in the field itself for 2-3 days for sun drying after which the same is shifted to a threshing floor in the form of heap. But now-a-days, large and commercial farmers started using combine harvesters, which are available on rent and this practice is becoming popular in the area.

The threshing is the most important operation for soybean particularly for keeping the viability of seed and maintaining the quality. Therefore, threshing of soybean is recommended using motorized thresher with 350-450 rpm. It is very disappointing to know that majority of the farmers (85%) had not adopted the threshing technique. Only 15 per cent of them who had large land holdings and associated with seed business had adopted this practice. With regard to storage of soybean for seed is concerned, majority of the farmers were using gunny bags as recommended.

Relationship between adoption and characteristics of soybean growers

In order to ascertain the relationship between characteristics of soybean growers, a correlation analysis was carried out with the adoption index score of individual respondent (Table 7). The analysis revealed that age of soybean grower and soybean production technology index were found to be negatively and significantly correlated. It implied thereby that young farmers were more inclined towards taking risk and that decreases with the increase in age, therefore, young farmers were more likely to adopt technologies. Education of the head of household was found to be positively and significantly correlated with the technology adoption index. It is obvious that with the increase in education, the knowledge on crop production technologies increases and thus, the level of adoption of technologies.

Since adoption levels of majority of the farmers in the present study are found only up to medium level and most of the agronomic practices are either adopted only partially and few of them had not adopted, it is imperative that more number of trainings, awareness programmes may be executed for motivating soybean growers to enhance adoption of recommended production practices. Further, they should be convinced practically by way of

Table 7. Correlation of technology adoption index with farm characteristics

Variable	Correlation	Significance
Age (years)	-0.381*	<.0001
Education level	0.196*	0.001
Land holding (ha)	-0.141**	0.018
Family income (INR Lacs)	-0.112	0.061
No. of family members	0.186*	0.007
Mobile phone	-0.071	0.2395

** and ** denotes significance at 1% and 5% level of significance, respectively.*

organizing large number of on farm demonstrations and more exposure to be given to them by conducting field tours to KVKs/ICAR institutes or wherever extension programmes like, exhibitions, practical demonstrations are organized. The state agriculture department should plan a sound strategy highlighting these issues in their programmes and sincere efforts should be made for their execution.

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Yield Potentials of Soybean on Altered Land Configuration

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ABSTRACT

Demonstrations conducted for two years (2017-2018) on Vertisols and associated soils in Mandsaur and Neemach region of Madhya Pradesh revealed that planting soybean on altered land configuration (broad bed furrow system) enhances the productivity by 21.19 per cent as compared to farmers practice of flat bed planting. The higher additional returns (Rs 10,444/ha) were achieved over farmer's practice in case of former. The benefit cost ratio of (3.00) in broad bed furrow system was also higher than farmer's practice (2.64). Later maturing variety (JS 93-05) gave higher yield (1,921 kg/ha) and additional returns (Rs 10,995/ha) as compared to early maturing JS 95-60 (1,840 kg/ha and Rs 10,179/ha). Comparison additional yield between flat bed planting (167 kg/ha) and broad bed furrow planting (323 kg/ha), both with improved technology brought out that change in planting method led to 103 per cent increase in additional yield in the latter case, suggesting that serious attempts to be made to popularise this technology to realise higher yield and monitory returns to farmers.

Key words: Broad bed and furrow system, improved production technology, soybean

Concerned with low national productivity of soybean in the country, M/s Sonic Biochem Extractions Pvt. Ltd, as a stakeholder in soybean value chain, has been making its efforts to transfer the research emanated production technology to farmers of Mandsaur and Neemach region of Madhya Pradesh. The interventions are aimed at improving soybean productivity and in turn farmers' socio-economic status. Since 2016, the demonstration programme was initiated at modest scale and has further been expanded in subsequent years. During past three years, a total of 481 demonstrations were laid out. The soybean is, by and large, cultivated under rainfed regime in the country and its productivity is invariably affected by uncertainty and erratic distribution of rainfall during the cropping season. Research in the past has brought out that planting the crop on changed land configuration using broad bed and furrow or ridge and furrow systems can provide salutary soil environmental conditions for growth and mitigate the adverse effect of water stress caused during the crop season culminating in higher yield (Ramesh *et al*., 2006; Ravinder *et al*., 2017)). In view of above, in addition to demonstrate advantage of

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improved production technology, 20 demonstrations each in 2017 and 2018were laid out using improved production technology with planting the crop on broad bed and furrow (BBF) system and compared with 40 demonstrations using improved technology with planting on flat bed in view of popularising planting soybean on BBF system with improved technology and the results are reported in this paper.

MATERIAL AND METHODS

For all the demonstrations including the ones laid out on altered land configuration were organised on carefully selecting the responsive soybean growers prior to each cropping season and educating them about the intricacies of the programme by organising training programmes. Exclusive staff, trained at the ICAR-Indian Institute of Soybean Research Indore, Madhya Pradesh, was assigned to execute and monitor the programme and to resolve the problems encountered during the cropping season by liaisoning with subject matter specialists. The farmers were supplied with the quality seed of improved soybean varieties (JS 95-60 and JS 93-05) and facilitated with the BBF machine (Singh *et al.,* 2011) procured from ICAR-Indian Institute of Soybean Research, Indore for planting the crop. The employed BBF machine is capable to plant four rows of soybean on bed with 30 cm deep furrow on both the side of broad bed. The set of 40 demonstrations with improved production technology with planting on BBF was compared with 40 demonstrations from the same locations with improved technology with flat sowing, which is *in vogue* with farmers. The farmers were also facilitated to use quality agro-chemicals as per recommendation.

The seed yield (kg/ha) from each demonstration (0.4 ha) was recorded and compared with same size plot under farmer's practice at each location. Data with improved practices with flat planting and improved practices with BBF system was also compared with equal number of demonstration from same area.

All these demonstrations were on Vertisols and associated soils of Mandsaur and Neemach region.

Economic evaluation, taking the prevailing rates of inputs and outputs, was carried out and discussed.

RESULTS AND DISCUSSION

The results of 40 demonstrations during two consecutive years revealed that resorting to planting soybean using BBF system with improved production technology as compared to flat planting practiced by the farmers could enhance the average seed yield of soybean by 323 kg per ha, which was higher by 21.19 per cent. During 2017 and 2018, the additional seed yield achieved over flat bed planting was 303 and 343 kg per ha; which was 19.45 and 22.94 per cent higher (Table 1). It may be noted that irrespective of the crop planted using BBF machine (1,866 kg/ha) or on flat bed (1,544 kg/ha), the yield levels are much higher than the national average yield of soybean (1,000 kg/ha). The higher level of seed yield in farmers practice also reflected that they have partially adopted improved production technology on account of constant association with the programme during past three years. Better performance of planting soybean with improved production practices using BBF machine was reported by earlier workers (Ramesh *et al.*, 2006; Lakhpale and Tripathi, 2012; Chhattopadhyay *et al.*, 2016; Ravinder *et al.,* 2017; Motwani and Ashish, 2018). The variation in each year might be on account of varietal potential (variety used were JS 95-60 and JS 93-05) and prevailing climatic conditions. The average rainfall in the study region during cropping season (June to August) recorded during 2017 and 2018 was 635.1 and 731.4 mm, respectively. Since the crop is grown under rainfed conditions, even higher rainfall is capable to enhance the seed yield of soybean and this is reflected in the yield levels recorded during both the years.

The adoption of improved soybean varieties (Table 2) also led to variable yield differences. The seed yield of JS 93-05 under BBF planting with improved production technology (1,921 kg/ha) and flat sowing (1,582 kg/ha) was higher than JS 95-60 (1,840 and 1,525 kg/ha, respectively) during two years. This can be accounted for the maturity duration of these two varieties (JS 95-60: 80-85 days; JS 93-05: 90-95 days). Late maturing varieties get extended period for accumulation of photosynthetes and partitioning into seed yield. This statement gets strength from higher yielding potential of JS 93-05 (2000 -2500 kg/ha) than JS 95-60 (1800-2000 kg/ha).

On an average basis, in case of BBF planting with improved production technology an expenditure of Rs 20,046 per ha could produce gross returns of Rs 60,193 per ha with benefit cost ratio of 3.00. As compared to this, the farmers practice with flat bed sowing involved an expenditure of Rs 18,847 per ha generating gross returns of Rs 49,749 per ha with benefit cost ratio of 2.64. The average additional returns by adoption of planting on BBF with improved

Table 1. Performance of soybean planted using BBF machine during 2017 and 2018

Year	Yield (kg/ha)		Increase in yield over FP		Gross returns (Rs/ha)		Cost of cultivation (Rs/ha)		Additional returns over FP (Rs/ha)	B:C Ratio	
	BBF + IP	FP	(kg/ha)	%	IP	FP	IP	FP		IP	FP
2017 (20)*	1863	1560	303	19.45	56806	47580	19220	18089	9226	2.96	2.63
2018 (20)	1870	1527	343	22.94	63580	51918	20873	19605	11662	3.05	2.65
Overall (40)	1866	1544	323	21.19	60193	49749	20046	18847	10444	3.00	2.64

**No of demonstrations; BBF- Broad bed and furrow system; IP- Improved production technology; FP- Farmer's practice* technology over farmer's practice on flat bed s owing were Rs 10,444 per ha (Table 1). The incremental cost benefit ration worked out for 40 demonstrations was 1.27, indicating 1.27 fold increases in returns over farmer's practice. The gross returns (Rs 61,995 and Rs 59,326 in 2018 and 2017, respectively) were higher than farmer's practice (Rs 49,147 and Rs 50,978, respectively) (Table 2).

Table 2. Performance of soybean varieties planted using BBF machine during 2017 and 2018

Year	Variety	Yield (kg/ha)		Increase in yield over FP		Gross returns (Rs/ha)		Cost of cultivation (Rs/ha)		Additional returns over FP (Rs/ha)	B:C Ratio	
		BBF + IP	FP	(kg/ha)	%	IP	FP	IP	FP		IP	FP
2017 (27)*	JS 95-60	1840	1525	315	21.04	59326	49147	19998	18817	10179	2.77	2.61
2018 (13)	JS 93-05	1921	1582	339	21.50	61995	50978	20146	18910	10995	3.08	2.70

**No of demonstrations; BBF- Broad bed and furrow system; IP- Improved production technology; FP- Farmer's practice*

Table 3. Performance of soybean flat planting during 2017 and 2018

Year	Yield (kg/ha)		Increase in yield over FP		Gross returns (Rs/ha)		Cost of cultivation (Rs/ha)		Additional returns over FP (Rs/ha)	B:C Ratio	
	IP	FP	(kg/ha)	%	IP	FP	IP	FP		IP	FP
2017 (20)*	1634	1461	174	11.63	49843	44546	19200	18100	5297	2.60	2.46
2018 (20)	1653	1492	161	11.02	56185	50720	20850	19600	5466	269	2.58
Overall (40)	1644	1477	167	11.32	53096	47712	20046	18869	5384	2.65	2.52

****No of demonstrations; IP- Improved production technology; FP- Farmer's practice***

Demonstrations on flat sowing with improved production technology was also compared with farmer's practice, which revealed that improved production technology could result in an additional seed yield of 167 kg per ha (11.32 % increase) and additional returns of Rs 5,384 per ha. In these demonstrations as well the yield levels in improved practices (1,644 kg/ha) and farmer's practice (1,477 kg/ha) were above national productivity of soybean. This indicated partial adoption of improved production technology by the farmers on account of constant association with the programme. The benefit cost ratio was higher in improved practices (2.65) than farmer's practice (2.52) (Table 3). The above results are in conformity with earlier reports (Joshi *et al.* 2004; Billore *et al.* 2005; Mankar *et al.*, 2014)

Comparison of data on improved practices in case of BBF planting (Table 1) and flat plating demonstrations (Table 3) showed that the additional seed yield by former was higher by nearly 103 per cent. Similarly, additional returns were higher by 94 per cent even when there was negligible difference in cost of cultivation.

Demonstrations for two years on Vertisols and associated soils suggest that adoption of improved production technology can help farmers to obtain higher seed yield and returns from soybean cultivation. With change from flat planting with improved technology to planting on broad bed and furrow system with improved technology can remarkably enhance the seed yield as well as returns, therefore there is need to popularise the planting of soybean on broad bed and furrow system.

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Regional Analysis of the Response of Soybean to Planting Date

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ABSTRACT

Results of field experiments conducted in different agro-climatic zones during 2015 to 2017 to study the effect of planting date on soybean yield revealed that timely planting (onset of monsoon) of soybean had noticeable impact on seed yield; produced higher yield to the tune of 24.67 to 120.35 per cent across the zones. The maximum and minimum yield enhancement due to timely planting was in North Hill and Southern zones, respectively. The yield penalty due to delayed planting of soybean was to the extent of 21.15 to 44.45 kg per ha per day across the zones. The higher yield variability over the years was observed under timely planting in North Hill, North Eastern Hill and Central zones, while higher variability with late planting was in North plain, Eastern and Southern zones. Invariably, the timely planting was associated with higher sustainable yield index than late planting. Timely planting showed less than average stability in North Hill, North Eastern Hill and Central zones, while the remaining zones where late planting indicated less than average stability. The timely planting (onset of monsoon) is the most important least expensive option for augmenting the soybean productivity.

Key words: Planting date, soybean, stability, sustainable yield index, yield variation

Crop yield is mainly influenced by climatic conditions throughout the growing season, especially under rainfed conditions. The yield gaps can be reduced with better crop management, which include resorting to sowing during appropriate time period. It is known that planting date influences soybean [*Glycine max* (L.) Merrill] growth stages, due to variation in photoperiod (Han *et al*., 2006; Kumudini *et al*., 2007), air temperature (Chen and Wiatrak, 2010), and rainfall distribution and amount during the crop cycle (Hu and Wiatrak, 2012). In another study, Meotti *et al*. (2012) observed that 77 per cent of soybean yield variability was associated with the climatic conditions induced by the sowing dates.

Planting soybean too early has been shown to decrease yields (Steele and Grabau, 1997). Environmental conditions associated with late sowing affect crop features related to the capture of radiation and portioning of crop resources. These lead to lower reproductive nodes (Board *et al*., 1999), and shortening of the reproductive phases (Kantolic and Slafer, 2001). Consequently, planting soybean early allows longer vegetative and

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reproductive periods (Hu and Wiatrak, 2012), which can reduce insect and disease pressures and circumvent late-summer drought (Salmeron *et al*., 2014).

On the other hand, delayed sowing generally shifts reproductive growth into less favorable conditions with shorter days and lower radiation and temperature (Egli and Bruening, 2000). Accordingly, planting date is one of the most important and least expensive production decisions affecting soybean seed yields and quality, so it still receives considerable attention from soybean researchers (Egli and Cornelius, 2009; Hu and Wiatrak, 2012). Ultimately, Battisti and Sentelhas (2014) classified planting suitable date when actual yield overcomes the production cost in more than 80 per cent of years and mean air temperature ranges between 20 and 30 °C. But if actual yield overcomes the production cost only between 60 and 80 per cent of the years and mean air temperature does not remain between 20 and 30 °C, the planting date is classified as marginal. Planting date is considered as unsuitable if actual crop yield overcome the production cost in less than 60 per cent of the years. Therefore, sowing soybean on the best dates offer the best climatic conditions to obtain high seed yield. The aim of this study was to evaluate the effect of planting dates on yield in different agro-climatic zones of India.

METHODS AND MATERIALS

Field experiments were conducted in different agro-climatic zones, namely north hill zone (Imphal and Medziphema), north plain (Delhi, Pantnagar and Ludhiana), eastern (Raipur, Ranchi and Bhawanipatna), north eastern hill (Imphal and Medziphema), central (Kota, Sehore, Amaravati) and southern (Dharwad, Bangaluru, Coimbatore, Adilabad, Pune) during 2015 to 2017. Soybean crop was planted on the onset of monsoon (timely planting) and **[**20 days after timely planting (late planting)**]**. The crop was raised with recommended package of practices for respective zones. The data were collected from the AICRP on Soybean (Anonymous, 2015; 2016; 2017) and pooled over the locations within zone and over years. The pooled data were subjected to analyses for coefficient of variation (CV), sustainable yield index (SYI) and stability index (b). Sustainable yield index was determined as per Singh *et al*. (1990). Stability was estimated as per the procedure suggested by Finley and Wilkinson (1963). The type of stability is decided on regression coefficient (b) and mean values. If ‘b’ is equal to unity, the treatment is considered to have average stability (same performance in all the environments). If ‘b’ is more than unity, it is suggested to have less than average stability (good performance under favorable environments) and if ‘b’ is less than unity, it is reported to have more than average stability (good performance under poor environment).

RESULTS AND DISCUSSION

Results accrued over the centres and years revealed a perceptible variation in soybean yield in all the agro-climatic regions of India as reported below.

North hill zone

The maximum yield was observed during 2016 followed by 2017 and least in 2015. The delayed planting of soybean decreased the yield by 120.35 per cent as compared to normal planting (Table 1), which indicated the yield loss of 44.35 kg per ha per day. The yield variability over the years was less in case of late planting than timely planting. Timely planting showed higher sustainability over the late planting indicating minimum guaranteed soybean yield will be 56 per cent of the maximum yield achieved over the years. Timely planting did well under favourable environments as evidenced from the stability index which was more than unity.

North plain zone

The highest yield was recorded during 2015 and closely followed by 2017. The magnitude of yield diminution was 30.31 per cent over late planting and indicated a yield reduction of 22.75 kg per ha per day. Soybean yield variation was found to be higher under delayed planting than timely planting. The maximum sustainability yield index was associated with timely planting; the minimum guaranteed yield will be 73 per cent of maximum yield achieved during the three years. Timely planting performed very well under unfavorable environments while late planting did well under favourable environments.

North eastern hill zone

The congenial weather conditions during 2015 resulted in the maximum soybean yield as compared to 2017 and 2016. Timely planting produced higher yield (25.09 %) over late planting, which resulted in yield reduction of 27.25 kg per ha per day. The higher yield variation was observed under timely planting than late planting. The minimum guaranteed yield will be 61 per cent under timely planting as compared to late planting (47 %) as evidenced from the sustainable yield index. Timely planting showed average yield stability over the years, while late planting performed very well under unfavourable environments.

Eastern zone

The maximum yield was noted in 2016 followed by 2017 and 2015. Delayed planting showed a yield loss of 46.85 per cent as compared to timely planting and indicated a yield penalty of 28.65 kg per ha per day. The difference in yield variation between two planting dates was found to be negligible. Timely planting possessed higher sustainability yield index than late planting. Late planting showed average stability indicating that the yield performance was uniform over the years, while timely planting performed very well under unfavourable environments.

Central zone

The highest yield was recorded during 2016, while yield performance was more or less the same during remaining two years. The timely planting of soybean produced higher yield by of 83.08 per cent, which indicated a yield loss of 35.35 kg per ha per day due to late planting by 20 days. The yield variation under timely planting was higher than late planting. Timely planting was more sustainable than late planting and

Table 1. Impact of planting date on soybean productivity in different agro-ecological zones

Planting date	Year			Mean	Coefficient of variation	Sustainable yield index	b
	2015	2016	2017				
North Hill Zone							
Timely	1128	2059	1686	1624	39.67	0.56	1.70
Late	657	811	742	737	6.53	0.32	0.27
Mean	**893**	**1435**	**1214**	**1181**			
North Plain Zone							
Timely	2130	1542	2197	1956	20.84	0.73	0.85
Late	1883	965	1654	1501	27.64	0.47	1.13
Mean	**2007**	**1254**	**1926**	**1729**			
North Eastern Hill Zone							
Timely	2709	1838	1901	2149	25.11	0.61	1.03
Late	2218	1332	1604	1718	23.47	0.47	0.96
Mean	**2464**	**1585**	**1753**	**1934**			
Eastern Zone							
Timely	1407	2105	1876	1796	23.56	0.68	0.97
Late	970	1648	1052	1223	24.51	0.41	1.01
Mean	**1189**	**1877**	**1464**	**1510**			
Central Zone							
Timely	1347	1801	1525	1558	19.00	0.74	1.58
Late	898	925	730	851	8.78	0.41	0.48
Mean	**1123**	**1363**	**1128**	**1204**			
Southern Zone							
Timely	1952	2334	-	2143	13.99	0.80	0.96
Late	1518	1919	-	1719	14.68	0.61	1.01
Mean	**1735**	**2127**	**-**	**1931**			

Timely- onset of monsoon, Late- 20 days after normal

indicated that the minimum guaranteed yield will be 74 per cent of the maximum achievable yield over the years. Timely planting with higher stability index than unity indicated that soybean performed very well under favourable environments, while late planting performance was better under harsh environments.

Southern Zone

The experiment was conducted for two years only (2015 and 2016). The maximum yield was recorded in 2016.

Timely planting produced higher yield to the extent of 24.67 per cent and delayed planting caused a yield reduction of 21.15 kg per ha per day. Late planting showed higher yield variation than timely planting. The maximum sustainable yield index was associated with timely planting indicating a minimum guaranteed yield will be 80 per cent of the maximum yield achieved over the years. Late planting indicated average stability means performed well under all the environments, while timely planting performed very well under unfavourable environments.

Different soil properties and weather conditions at the different locations might have contributed to the differences in seed yield among the six agro-climatic zones under consideration. Environmental conditions can change the yield in the same sowing date in different years; therefore, just one field experiment cannot bring conclusive results for choosing the best sowing date (Egli and Cornelius, 2009).

With planting delay the growth period becomes short, while high temperature during flowering decreases the seed yield and yield components of soybeans planted early. No doubt, the duration of the vegetative stage, reproductive stage, and total growing period were extended by early planting, compared with those in timely planting. Early planting extended the duration of the reproductive stage more than that of vegetative stage (Chen and Wiatrak, 2010).

On the other hand, the planting delay decreased the yield (Kane *et al*., 1997; Board *et al*., 1999; Egli and Bruening, 2000; Kantolic and Slafer, 2001). Yields decreased at a faster rate after the optimal planting date, primarily because of decreased vegetative and reproductive growth that reduced the number of branches and pods, decreased plant height, and reduced photosynthesis (Popp *et al*., 2002; Pedersen and Lauer, 2003; Bastidas *et al*., 2008; De Bruin and Pedersen, 2008). Similar results were also reported by Billore *et al*., (2000, 2009) and Billore and Srivastava (2013).

On the basis of foregoing results it could be concluded that the timely planting of soybean is a best least expensive option for achieving the sustainable higher yield.

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Monetary Benefits of Integrated Pest Management in Soybean [*Glycine max* (L) Merrill] Cultivation

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ABSTRACT

Results of the Participatory Rural Appraisal (PRA) conducted in four selected villages in Mhow Tehsil of Indore district revealed that the lower soybean productivity was associated with incidence of insect-pests, in general, and girdle beetle in particular. Based on this information, interventions of integrated pest management (IPM) were evaluated for a period of four years. The results revealed that manual removal of girdle beetle infested plants on initiation of infestation at weekly interval is an effective intervention for resource poor farmers. Adoption of IPM package [soil incorporation of phorate 10 G (@ 10 kg/ha) at sowing, use of seed treated with Bt (3 g/kg seed) and Trichoderma viridae (3 g/kg seed), installation of pheromone traps (5-6/ha) and need based spray of triazophos (0.8 l/ha)] enhanced seed yield (ranged between 40 and 24 %), net income (between 49 and 27.5 %) during year 3 and 4, respectively over farmers' practice. The adoption of IPM practices increased the average yield between from 1.65 t per ha to 2.40 t per ha with percentage increase from 24.16 to 26.73, during the four years of experimental trails.

Keywords: Economics, girdle beetle, , IPM, seed yield, soybean

Soybean [*Glycine max* (L.) Merrill] is a major oilseed crop of the country grown predominantly during the rainy (*kharif*) season in the Central India. The crop is primarily popular among millions of small and marginal farmers and has been instrumental in bringing socio-economic transformation in the farming community of Madhya Pradesh (Dupare, 2009). It is popularly known as 'Soy State' because of its significant share in area (>51%) and production (>55%) in the country (Nahatkar *et al.,* 2017). However, the average productivity of soybean is hovering around 1 ton per ha since last decade. Among the major constraints, biotic stress particularly infestation with insect-pests warrants serious efforts on their management to optimize productivity.

Among the insect-pests infesting soybean and causing yield loss, girdle beetle (*Obereopsis brevis*) alone has been reported to damage the crop plants

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between 3.5 to 15 per cent (Bhosale *et al*., 2014). More *et al*. (2014) reported that at 10 per cent level of girdle beetle infestation, the losses in seed weight per plant varied from 3.17 to 5.26 and 35 to 56 per cent at 35 and 56 days of growth, respectively. In Maharashtra, Ramesh Babu *et al.* (2018) reported the yield losses in different soybean varieties up to 45 per cent due to insect-pests. ICAR-Indian Institute of Soybean Research has carried out pertinent number of technological interventions in its adopted villages namely Borkhedi, Ambachandan and Katkatkhedi in Mhow block, Indore district through its outreach programme and results are reported in this paper.

MATERIAL AND METHODS

The IPM interventions in soybean were identified based on Participatory Rural Appraisal (PRA) technique. The IPM practices were evaluated in selected Bhagora, Borkhedi, Ambachandan and Katkatkhedi villages in Mhow tehsil of Indore district (Madhya Pradesh) for consecutive four years during *kharif* seasons. The number of selected of farmers was 55, which was 10 more than as suggested by Choudhury (1999). Through PRA, the problem-cause analysis for low yield of soybean was assessed and it was recorded through matrix ranking. The matrix ranking was prioritized the problems faced by the farmers and used to analyze the possible causes for those problems with the help of team of scientists from research institutes. It was conceived that the low yield of soybean harnessed by the farmers are due to the following.

Problem	Rank
Increased incidence of pest and diseases	01
Non availability of seed of improved varieties	02
Lack of technical know-how on the improved package of practices	03

The incidence of girdle beetle, stem fly and other pests constituted the major culprits, which is due to non-adoption of proper pest management measures and mono-cropping of soybean. Accordingly, three practices of IPM module were evaluated to manage girdle beetle during first two *kharif* seasons and subsequently during next two *kharif* seasons, covering 55 farmers (2001-30 Nos; 2002 – 10 Nos, 2003-5 Nos; 2004–10 Nos). During first two *kharif* seasons, the three practices included were (i) two sprays of quinalphos on incidence of pest as per prevailing farmers' practice, (ii) soil incorporation of phorate 10 G (@ 10 kg/ha) at sowing followed by triazophos (@ 0.8 l/ha) at flowering, and (iii) manual removal of girdle beetle infested plant/plant parts twice at weeks interval soon after the infestation was observed. During subsequent two years, the two interventions were (i) two sprays of quinalphos at incidence of the pest as per prevailing farmers' practice, and (ii) soil incorporation of phorate10 G (@ 10 kg/ha) at sowing, use of seed treated with *Bacillus thuringiensis*- Bt (3 g/kg seed) and *Trichoderma viridae (*3 g/kg seed), installation of pheromone traps (5-6/ha) and need based spray of triazophos (0.8 l/ha).The volume for the spray of the insecticides used was 500 litre per ha. The farmers of the identified village depend only on indiscriminate use of chemical insecticide to control of insect-pests without much consideration of appropriate recommended insecticide, quantity and dilution. It was recorded that two sprays of quinalphos during the pest incidence was practiced by the farmers. The rainfall received during 1, 2, 3 and 4 years of intervention was 675.6 mm, 585.5 mm, 700 mm and 680 mm, respectively.

For economic evaluation of the interventions, the prevailing rates of inputs, farm operations and the cost of produce were utilized. The incremental cost benefit ratio (ICBR) was calculated as follows (Bang and Zhao, 2016).

ICBR = Additional income (Rs/ha)/Cost of intervention (Rs/ha)

The cost of cultivation was worked out for both, prevailing farmers' practices and implemented IPM practices. The cost of seeds, fertilizers, pesticides and other inputs were added as input cost. Similarly, the return of income received from through sale of soybean grains were calculated as gross returns. The cost of expenditure on inputs was deducted from gross returns to obtained net returns. Benefit cost ratio was worked out by dividing total gross income with total cost of cultivation. Further, the scientifically validated and approved interventions under IPM for soybean were implemented during *kharif* 2003 and 2004 and compared with prevailing farmers' practice.

RESULTS AND DISCUSSION

Impact of intervention conducted during first two *kharif* seasons revealed (Table 1) that increase in seed yield of soybean due to chemical pest management over farmers' practice was 11.46 per cent, whereas in case of mechanical removal of girdle infested plant/plant parts twice at weeks interval was 34.2 per cent. The lower seed yield during second year (*kharif*) than first year (*kharif*) was on account of lower rainfall and its ill distribution during cropping season. Manual removal of girdle infested plants/plant parts twice in a weeks' interval was also effective in curtailing yield loss, whereas marginally higher yield than this treatment was observed in soil incorporation of phorate followed by spray application of triazophos at flowering. The two intervention also led to higher net income (Rs 1,283 and 873/ha; Rs 3,020 and 3,335/ha) and ICBR (2.86 and 3.18; 4.48 and 7.65) during first year and second year. The results indicated that mechanical removal of girdle beetle infested plant/plant parts twice at weeks' interval soon after the infestation was an effective strategy for resource poor farmers.

During the subsequent two *kharif* seasons, the IPM intervention such as soil incorporation of phorate10 G (@ 10 kg/ha) at sowing, use of seed treated with Bt (3 g/kg seed) and *Trichoderma viridae (*3 g/kg seed), and need based spray of triazophos (0.8 l/ha) and installation of pheromone traps (5-6/ha) led to 40 and 24 per cent increase in seed yield over the farmers' practice during

Table 1. Performance of IPM practices on seed yield and economics of soybean during first two *kharif* seasons (2001 and 2002)

Intervention	Seed yield (t/ha)		Increases yield over farmers' practice (%)		Cost of intervention (Rs/ha)		Additional income (Rs/ha)		Net income (Rs/ha)		ICBR	
	***Kharif* 1**	***Kharif* 2**	***Kharif* 1**	***Kharif* 2**	***Kharif* 1**	***Kharif* 2**	***Kharif* 1**	***Kharif* 2**	***Kharif* 1**	***Kharif* 2**	***Kharif* 1**	***Kharif* 2**
Two sprays of quinalphos on incidence of pest as per prevailing farmers' practice	**1.44**	0.84	-	-	-	-	-	-	-	-	-	-
Soil incorporation of phorate 10G (@ 10 kg/ha) at sowing followed by triazophos (@ 0.8 l/ha) at flowering	**1.64**	1.13	**13.89**	**34.52**	**690**	**867**	**1973**	**3887**	**1283**	**3020**	**2.86**	**4.48**
Manual removal of girdle beetle infested plant/plant parts twice at weeks interval as soon as the infestation was observed	1.57	1.13	**9.03**	**34.52**	**400**	**500**	**1273**	**3825**	**873**	**3335**	**3.18**	**7.65**

Table 2. Impact of IPM application on seed yield and economics of soybean during subsequent two *kharif* seasons (2003 and 2004)

Intervention	Seed yield (t/ha)		Cost of cultivation (Rs/ha)		Gross income (Rs/ha)		Net income (Rs/ha)		B:C ratio	
	***Kharif* 3**	***Kharif* 4**	***Kharif* 3**	***Kharif* 4**	***Kharif* 3**	***Kharif* 4**	***Kharif* 3**	***Kharif* 4**	***Kharif* 3**	***Kharif* 4**
Two sprays of quinalphos on incidence of pest as per prevailing farmers' practice	**2.0**	**1.95**	**7000**	**7000**	**33400**	**32398**	**26400**	**25398**	**4.77**	**4.62**
Soil incorporation of phorate10 G (@ 10 kg/ha) at sowing, use of seed treated with Bt (3 g/kg seed) and *Trichodermaviridae* (3 g/kg seed), installation of pheromone traps (5-6/ha) and need based spray of triazophos (0.8 l/ha)	**2.8**	**2.42**	**7874**	**7874**	**47096**	**40253**	**39222**	**32379**	**5.98**	**5.11**

third (*Kharif*) and forth (*Kharif*) year, respectively. The net income due to IPM application was higher and ranged between Rs 32,379 and Rs 39,222 as compared to farmers' practice (Rs 25,398 to 26,400) for year 3 and 4. The incremental benefit:cost (B:C) ratio as well followed a similar trend.

The results of the interventions brought out that manual removal of girdle beetle infested plant/plant parts twice at weeks' interval soon after the infestation was observed to effectively manage the losses due to infestation of girdle beetle, particularly for resource poor farmers with small and marginal holdings. Adoption of IPM package encompassing soil incorporation of phorate 10 G (@ 10 kg/ha) at sowing, use of seed treated with Bt (3 g/kg seed) and *Trichoderma viridae (*3 g/kg seed), installation of pheromone traps (5-6/ha) and need based spray of triazophos (0.8 l/ha) was found effective and helpful in managing the girdle beetle and other pests. It could optimize productivity and profitability of farmers addressing the environmental concerns as well.

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Effect of Different Plant Growth Regulators on Morpho-physiological Traits and Productivity of Soybean [*Glycine max* (L.) Merrill]

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The role of plant growth regulators is well established in improvement of morpho-physiological attributes of the crop plants. Gibberellic acid promotes cell elongation and increases size of leaf, flower and fruit. Gibberellins play an essential role in many aspects of plant growth and development such as seed germination (Haba *et al*., 1985). The morphological and yield contributing characteristics of soybean could be modified by GA_3 at all development stages (Kalyankar *et al*., 2008). The plant normally produces large number of flowers but most of them abscise, which is controlled by many factors. The use of growth regulators proved better to increase the crop yields (Upadhyay and Ranjan, 2015).

A field experiment was carried out in Research Farm, R A K College of Agriculture, Sehore (Madhya Pradesh) during *kharif* 2018. The soil of the experimental site was medium black with clay loam in texture. It analyzed: pH (7.6), available nitrogen (205 kg N/ha), available phosphorus (14.75 kg P_2O_5/ ha), available potassium (438 kg K_2O/ha) and available sulphur (15.6 kg/ha) and had fairly uniform topography and homogeneity. The experiment was laid out in a Randomized Block Design with three replications. The treatments evaluated were comprised of water spray, two levels each of gibberellic acid (@ 100 and 150 ppm), naphthalene acetic acid (@ 40 and 60 ppm), chlormequat chloride (@ 200 and 300 ppm) and salicylic acid (@ 50 and 100 ppm). These growth regulators were sprayed at pre-flowering (42 days after sowing, DAS) and pod initiation stage (64 DAS) of crop. The gross and net plot size was 6.00 m x 3.60 m and 5 m x 2.70 m; respectively. Sowing of soybean variety RVS 18 was done on 3rd July 2018 with spacing 45 cm x 5 cm.

The observations on plant height, number of branches per plant, pods per plant and dry weight of plant was recorded on randomly selected 3 plants at harvest. Leaf area index was recorded at 35, 55 and 75 days after sowing. Net assimilation rate was worked out at

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35-55 and 55-75 days interval. Seed index was worked out by weighing 100 seeds. The seed and straw yield was taken for each plot and expressed as kg per ha. The statistical analysis was done as described by Fisher (1967).

Application of all the growth regulators led to significantly or numerically higher values of growth/yield attributes, and seed and straw yields over control. Among the four growth regulators evaluated, gibberellic acid followed by naphthalene acetic acid at both the levels was superior to control in enhancing these traits. However, spray of gibberellic acid @ 150 ppm recorded maximum plant height (47.33 cm), number of branches (5.56), plant dry weight (18.27 g), leaf area index (5.87) and net assimilation rate (0.00027 g cm^{-2} day^{-1} at DI 35-55 **g cm^{-2} day^{-1}** and 0.00015 **g cm^{-2} day^{-1}** at 55-75 days interval) and differed significantly over control and rest of the treatments. The rate of increase in plant height and number of branches was higher in between 55-75 days after sowing. The dry weight per plant was observed higher at harvest. Leaf area index recorded was maximum at 55 days after sowing and net assimilation rate was observed maximum 35-55 days interval. Similar results were reported by earlier workers (Jadhav, 2000; Sarkar *et al*., 2002; Emongor, 2007).

All the four growth regulators recorded significantly higher seed yield over control. Gibberellic acid and naphthalene acid at both the levels recorded significantly higher seed yield over control and other two growth regulators. However, the seed yield achieved by them was on par with each other. Maximum seed yield (1,722 kg/ha) was recorded in case of spray of gibberellic acid @ 150 ppm). Straw yield as well was significantly or numerically higher in case of spray of gibberellic acid and naphthalene acid at both the levels; the highest was with gibberellic acid @ 150 ppm (1,961 kg/ha. Harvest index was not affected significantly by the treatments. The higher seed and straw yield by the spray of growth regulators could be on account of enhancement of growth and yield attributes of soybean. The above results are in conformity with those reported by Rahman *et al*. (2004), Sapkal *et al*. (2011) and Kothule *et al*. (2003).

The results of the study suggested that the spray of all the four growth regulators evaluated led to either significantly or numerically higher values of growth/yield attributes, and seed and straw yields of soybean over control. However, spray of gibberellic acid (100 and 150 ppm) and naphthalene acid (40 and 60 ppm) showed an edge over spray of chlormequat chloride (200 and 300 ppm) and salicylic acid (50 and 100 ppm) at pre-flowering and pod initiation stage of soybean. Among the four evaluated growth regulators, spray of gibberellic acid @ 100 or 150 ppm is superior over others in promotion of growth/yield attributes and yield of soybean.

Table 1. Effect of different growth regulators on growth, yield attributing traits, net assimilation rates and yield of soybean

Treatments	Plant height (cm)	Branches (No/ plant)	Pods (No/ Plant)	Dry weight (g/ plant)	Seed index	Leaf area index	Net assimilation rate (g cm^{-2} day^{-1})		Seed yield (kg/ ha)	Straw yield (kg/ ha)	Harvest index (%)
							35-55 DI*	55-75 DI			
Water spray	38.05	3.89	26.27	12.44	9.20	4.39	0.00016	0.000078	1236	1527	44.73
Gibberellic acid @ 100 ppm	46.67	5.22	31.78	16.88	11.58	5.70	0.00025	0.00012	1688	1935	46.61
Gibberellic acid @ 150 ppm	47.33	5.56	32.16	18.27	11.84	5.87	0.00027	0.00015	1722	1961	46.90
Naphthalene acetic acid @ 40 ppm	43.22	4.73	31.16	15.94	11.18	5.41	0.00023	0.00011	1592	1814	46.71
Naphthalene acetic acid @ 60 ppm	45.77	4.74	31.72	16.83	11.36	5.60	0.00024	0.00011	1619	1908	45.98
Chlormequat chloride @ 200 ppm	40.34	4.77	27.33	14.05	10.56	5.23	0.00020	0.000096	1443	1679	46.23
Chlormequat chloride @ 300 ppm	40.22	4.78	27.55	14.33	10.63	5.28	0.00020	0.000098	1483	1739	46.03
Salicylic acid @ 50 ppm	40.77	4.22	27.00	12.77	10.12	4.81	0.00017	0.000085	1396	1553	47.33
Salicylic acid @ 100 ppm	41.22	4.25	27.22	13.37	10.33	5.12	0.00018	0.000091	1438	1612	47.14
SEm (±)	1.13	0.26	0.44	0.89	0.42	0.28	0.000016	0.000016	49	83	1.21
CD (P = 0.05)	**3.40**	**0.79**	**1.32**	**2.68**	**1.26**	**0.84**	**0.000047**	**0.000050**	**149**	**250**	**NS**

**DI – Days interval*

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Performance of Soybean under Different Management Systems

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Solidaridad, South and South East Asia, is functional in Madhya Pradesh to develop sustainable soy-value chain by developing linkage between all the stakeholders. The targeted group involves small and marginal farmers. During past three years, as one of the activity, the front line demonstration programme India funded by Ministry of Agriculture and Farmers Welfare, Government of India through ICAR-Indian Institute of Soybean Research is being continued. During *kharif* 2018, a total of 100 front line demonstrations with improved and sustainable technology were organised. In view of experienced water stress during crop growth stages resulting in yield erosion (Bhatia *et al.,* 2008) and use of excessive pesticides without integrated approach, three management systems as described in methodology below have been attempted keeping 12 trials in each system. In the present paper, the results from these trials have been compared with prevailing farmer's practice and also among the three management systems. These management systems are the part of 100 front line demonstrations organised in Agar and Dewas regions on Vertisols and associated soils of Madhya Pradesh.

Of the 100 front line demonstrations, 36, 12 each under three management systems, were conducted under real farm conditions on farmers' fields on Vertisols and associated soils in Agar and Dewas districts located on Malwa Plateau of Madhya Pradesh. Soybean growers, belonging to small and medium land holding category were carefully selected based on their response to adopt the sustainable production technology. The three management systems, each with 12 demonstrations, encompassed planting on flat bed with improved production technology, planting on broad bed and furrow land configuration with improved management technology and flat land planting with improved management technology with pest management using non-chemical measures. At each location, the demonstration plot performance was

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compared with farmer's practice. The improved technology involved early maturing improved soybean variety JS 95-60, seed germination test, optimum seed rate, seed treatment with recommended fungicides and inoculation with biofertilizers (*Bradyrhizobium japonicum* @ 5g/kg seed and PSB @ 5 g/kg seed), planting on appropriate crop geometry, application of recommended fertilizers, recommended integrated pest and disease management including use of pheromone traps (10 No/0.4 ha) for both *Spodeptra litura* (Fabricius) and *Helicoverpa armigera* (Hübner), use of yellow sticks for controlling sucking pest (10 No/0.4 ha) and erecting bird perches (15 No/ha) in the field, harvesting and threshing as per recommendations. In the first two management systems, spray of *das parni ark* four times at interval of 15 days for pest management was done. The third set of 12 demonstrations differed from other two sets in terms of use of pesticides. For these demonstrations, *Trichoderma viride* with bio-culture PSB and Rhizobium were used for seed inoculation and neem oil sprayed once after 40 days of sowing and locally prepared botanical bio-pesticide (*das parni ark*) was sprayed four times at interval of 15 days for pest management in a crop season in addition to pheromone traps and bird perches. In other two management systems, the seed was treated with carbendazim + thiram (2:1) @ 3g per kg seed.

Botanical pesticide was locally prepared by farmers by using neem leaves, custard apple leaves, cow urine, fresh water, cow dung, pongamia leaves, datura leaves, *cascabela thevetia* leaves, bilva leaves, tobacco, chilli and garlic. For preparation of *das parni ark*, 200 litre water was taken in a drum, then 2 kg of crushed leaves of neem, custard apple, pongamia, datura, *cascabela thevetia*, Bilva each, and 10 litre cow urine was added and mixed using a wooden stick. Next day 500 g tobacco, 500 gram chilli, 500 gram garlic was added and again mixed using wooden stick. The solution was covered with cotton cloth and kept for 40 days. The mixture was stirred every morning. After 40 days the solution was filtered and used for spraying by preparing spraying solution of 5-8 litres of *das parni ark* with 200 litres of water.

The farmers' practice had the components of non-use of biofertilizers, no seed treatment, higher and unbalanced doses of fertilisers and chemical pesticides, higher seed rate than recommended, close spacing between row-row, flat sowing method and a monotonous repeated use of same pesticides for pest management. The yield recorded for each demonstration was expressed as kg per ha.

The demonstrations under different management systems were economically evaluated and expressed in terms of net returns and B:C ratio. For working out the gross returns, the prevailing market price of soybean was considered. Similarly for working out cost of cultivation, the prevailing rates of inputs and agricultural operations were taken into consideration.

The seed yield under flat sowing with improved technology varied between 1,228 and 1,640 kg per hammm (average 1,375 kg/ha), whereas in farmer's practice it was between 950 and 1,313 kg per ha (average 1,160 kg/ha). On an average basis the yield enhancement was 19.43 per cent (215 kg/ha). The net returns varied around Rs 25,358 per ha for improved practices and were higher than farmer's practice (around Rs 20,085/ha) by 26.25 per cent. The average benefit cost ratio as well was higher in former (2.19) than later (2.05) (Table 1).

As compared to flat sowing with improved technology, sowing on broad bed and furrow system with improved technology invariably resulted in higher seed yield. The seed yield in demonstrations with sowing on broad bed furrow with improved technology ranged from 1,273 to 1,731 kg per ha (average 1,466 kg/ha), which was higher than farmer's practice (1,025 to 1,313 kg/ha; average 1,175 kg/ha). On an average basis the yield increment was 24.73 per cent (291 kg/ha). Economic evaluation revealed that in these demonstrations, improved practice with sowing on broad bed furrow systems led to higher net returns (Rs 29,095/ha) than farmer' practice (Rs 21,496/ha) by 35.35 per cent. The benefit cost ratio was 2.41 and 2.17, respectively (Table 2).

The third system, wherein, flat sowing with improved technology without the use of chemical pesticide was adopted, the seed yield variation was between 896 and 1,423 kg per ha (average 1,169 kg/ha) against farmer's practice between 625 and 1,188 kg per ha (average 916 kg/ha). The yield levels were, in general, lower than other two systems. The average net returns and benefit cost rationas well were higher (Rs 20,039/ha; 2.02) over farmer's practice (Rs 14,530/ha, 1.88) (Table 3).

The performance of soybean variety JS 95-60 revealed that the seed yield and returns turned to be higher in improved production technology, irrespective of adoption of flat bed sowing or sowing on broad bed and furrow system. However, it is more advantageous to plant soybean on broad bed furrow system to mitigate the moisture stress due to on-setting climatic change. In spite of proven utility of planting soybean on broad bed and furrow systems (Ramesh *et al*., 2006, 2007; Lakpale and Kumar, 2012; Chattopadhyay *et al.,* 2016; Motwani and Ashish, 2018) in increasing yield and profitability of soybean, the farmers' still go for flat planting. The improvement in seed yield and profit of soybean by adoption of recommended improved technology is continuously being demonstrated from past thirty year (Anonymous, 2018-19) to motivate farmers for adoption and popularised over years on farmers' fields. The outcome of planting on broad furrow system in this paper and also in research done by others offers an opportunity to further increase the productivity and profit and help in dealing with moisture stress on account of climatic change. It has been reported that limited soil moisture availability during the cropping season of soybean could culminate in 28 per cent yield reduction in soybean (Bhatia *et al*., 2008). In order to popularise eco-friendly approach for pest management (Gupta, 2010), the third

Table 1. Flat sowing with improved production technology

S. No.	Name of farmer	Yield (kg/ha)		Per cent increase over FP	Gross Returns (Rs/ha)		Cost of Cultivation (Rs/ha)		Net returns (Rs/ha)		BC ratio	
		IP	FP		IP	FP	IP	FP	IP	FP	IP	FP
1	Bherulal	1455	1313	10.88	49479	44625	20873	19358	28606	25268	2.37	2.31
2	Gabbusingh	1522	1200	26.86	51760	40800	25093	22443	26667	18358	2.06	1.82
3	Surajsingh	1640	950	72.63	55758	32300	26628	21193	29131	11108	2.09	1.52
4	Narayansingh	1475	1250	18.01	50154	42500	24598	21738	25556	20763	2.04	1.96
5	Bherusingh	1337	1150	16.23	45448	39100	20128	18193	25320	20908	2.26	2.15
6	Gangaram	1277	1200	6.40	43413	40800	18758	18368	24656	22433	2.31	2.22
7	Rustam Khan	1390	1225	13.50	47272	41650	22008	20113	25265	21538	2.15	2.07
8	Raju khan	1284	1100	16.69	43641	37400	19338	18078	24304	19323	2.26	2.07
9	RamjaniKhan	1277	1150	11.06	43424	39100	19548	18193	23876	20908	2.22	2.15
10	Ajjij khan	1362	1138	19.74	46310	38675	20128	17808	26183	20868	2.30	2.17
11	Modsingh	1247	1125	10.81	42383	38250	19698	18083	22686	20168	2.15	2.12
12	Atmaram	1228	1113	10.38	41752	37825	19705	18453	22047	19373	2.12	2.05
	Mean	***1375***	***1160***	***19.43***	***46733***	***39419***	***21375***	***19335***	***25358***	***20085***	***2.19***	***2.05***

Table 2. Sowing on broad bed with improved production technology

S. No.	Name of farmer	Yield (kg/ha)		Per cent increase over FP	Gross Returns (Rs/ha)		Cost of Cultivation (Rs/ha)		Net returns (Rs/ha)		BC ratio	
		IP	FP		IP	FP	IP	FP	IP	FP	IP	FP
1	Kailash	1617	1313	23.23	54991	44625	20423	17975	34569	26650	2.69	2.48
2	Mohanlal	1577	1275	23.71	53629	43350	19173	16770	34457	26580	2.80	2.58
3	Arajun Singh	1533	1275	20.23	52120	43350	20048	18203	32072	25148	2.60	2.38
4	Mansingh	1273	1025	24.23	43295	34850	21168	18573	22128	16278	2.05	1.88
5	Ghansyam	1310	1075	21.83	44527	36550	20553	18678	23974	17873	2.17	1.96
6	Manklal	1290	1075	20.04	43874	36550	20035	18295	23839	18255	2.19	2.00
7	Jagdish	1297	1075	20.65	44096	36550	20048	18658	24049	17893	2.20	1.96
8	Jagadish	1401	1175	19.25	47639	39950	20793	19258	26846	20693	2.29	2.07
9	Babulal	1538	1188	29.51	52292	40375	21649	19193	30643	21183	2.42	2.10
10	Lakshminarayan	1731	1300	33.15	58852	44200	21474	17415	37378	26785	2.74	2.54
11	Mukesh	1525	1125	35.56	51853	38250	22841	18850	29012	19400	2.27	2.03
12	Keilash	1504	1200	25.37	51151	40800	20974	19585	30177	21215	2.44	2.08
	Mean	***1466***	***1175***	***24.73***	***49860***	***39950***	***20765***	***18454***	***29095***	***21496***	***2.41***	***2.17***

Table 3. Sowing on flat bed with improved production technology without the use of chemical pesticides

S. No.	Name of farmer	Yield (kg/ha)		Per cent increase over FP	Gross Returns (Rs/ha)		Cost of Cultivation (Rs/ha)		Net returns (Rs/ha)		BC ratio	
		IP	FP		IP	FP	IP	FP	IP	FP	IP	FP
1	Gokulsingh	1182	863	37.07	40195	29325	19105	15350	21090	13975	2.10	1.91
2	Radheshyam	848	625	35.70	28836	21250	20525	17025	8311	4225	1.40	1.25
3	Bhagwati Prasad	1032	875	17.91	35079	29750	20380	17400	14699	12350	1.72	1.71
4	Rajendra	1265	1050	20.48	43010	35700	19105	16693	23905	19008	2.25	2.14
5	Rod Singh	1340	1138	17.84	45573	38675	19255	16595	26318	22080	2.37	2.33
6	Arju Singh	1008	863	16.83	34261	29325	20420	18720	13841	10605	1.68	1.57
7	Sriram	896	700	28.00	30463	23800	19395	17150	11068	6650	1.57	1.39
8	Amar Singh	1268	1188	6.79	43114	40375	19445	17275	23669	23100	2.22	2.34
9	Bheru Yadav	1423	1000	42.26	48370	34000	19835	16213	28535	17788	2.44	2.10
10	Mangi Lal	1220	875	39.45	41487	29750	19545	15188	21942	14563	2.12	1.96
11	Bane Singh	1204	863	39.53	40918	29325	19545	15855	21373	13470	2.09	1.85
12	Naggu Singh	1343	950	41.40	45673	32300	19960	15750	25713	16550	2.29	2.05
	Mean	**1169**	**916**	**28.61**	**39748**	**31131**	**19710**	**16601**	**20039**	**14530**	**2.02**	**1.88**

management system was demonstrated. The utility of use of botanicals (Das, 2014; Sharma *et al.,* 2018) and neem based products (Bajwa and Ahmed, 2012) for non-chemical management of pests has been reported and hence, used in the third management system. The adoption of production technology without the use of seed treatment chemicals and insecticides in this management system could not take the yield levels to other two management systems, may be on account of partial management of diseases and pests. Probably isolated use of the third management system may not be fully effective till the system is adopted on community basis.

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