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Raising the Yield Ceilings in Soybean – An Indian Overview*

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ABSTRACT

Besides Green Revolution, Indian agriculture is studded with several sizeable revolutions which include the soybean revolution of India. Covering an area of over 10 million hectares, it is an amazing saga as to how soybean traversed from being a marginal and traditional crop to become a major cash/oilseed crop in India. Besides the outcome of contributing towards socio-economic well-being of central Indian farmers, soybean has established some models such as futures exchange, foreign exchange earnings and global trade facilitation, use of ICTs (esp. ITC's 'e-Choupals') towards technology adoption and domestic trade etc. *that are worth emulating. Soybean production increase in India is mainly due to area expansion but productivity enhancement, although not vividly recognized, has also gradually and consistently contributed towards production. Potential and actual yields as revealed by nation-wide frontline demonstrations at farm level have elucidated a sizeable yield gap (YG II) of about one t per ha. Technology adoption should continue to further bridge YG II but the situation warrants that the potential yield has also to be simultaneously increased so that YG 1 ceiling moves up. The concurrent increase in genetic yield potential is imperatively needed more so as the yield gap cannot be fully bridged in a rainfed crop like soybean. Soybean is not an easy option for raising the genetic potential for yield. Under Indian conditions, another major limitation is the short growing period particularly in the predominant soybean belt of central India. Nevertheless, studies at the Directorate of Soybean Research (DSR, India) have shown an appreciable genetic gain in seed yield. There is a need for an amalgam of conventional and new plant breeding techniques particularly molecular breeding towards hauling in genes for productivity and associated characters like favourable physiological traits. Concurrent efforts in promoting new agronomy along with suitable farm machinery, management of biotic stress, enhancing biological nitrogen fixation and enhancing seed availability are also imperative. Environmental and sustainability concerns in soybean are discussed in regard to (i) climate change, (ii) new agronomy, organic farming and BNF, and (iii) GMOs/transgenics. Domestic utilization of de-oiled cake is increasing, yet food uses are scanty. India now has several varieties/lines that have been developed for food uses. Proper utilization strategy is, however, needed to promote/facilitate (i) soy-products and specialty soybeans, (ii) related entrepreneurship/job-creation through secondary and tertiary agriculture, and (iii) development of niche markets for various soy-products nationally and globally. Breeding strategies along with other research and developmental strategies to surmount the challenges are presented that could potentially ensure a secured supply and enhanced utilization of soybean.*

Key words: Soybean, soybean breeding, soybean revolution of India, soybean trend and market drivers, yield gap, yield potential

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Soybean is a unique role-model of consortium approach and the harbinger of the Technology Mission on Oilseeds, which was set up in May 1986, which led to a breakthrough in oilseed production that was christened as "Yellow Revolution" in Indian agriculture. Oilseed production was, then, doubled from 10.8 million tonnes in 1985-86 to 21.5 million tonnes in 1993-94. Rapeseed/mustard, soybean and sunflower had made significant contribution towards this spurt of growth in oilseeds. However, 'soy-revolution' had commenced much earlier than this.

1. The saga of success: 'Soy-revolution' of India

Soy-revolution of India is a landmark achievement. In India, soybean had been grown for ages in the northern hills esp. on the borders of North West Frontier provinces and in Mirpurkhas in Sindh, in north-east and in Nepal. In those days, it was used as forage and as a food crop. It is great to remember that Father of the Nation Mahatma Gandhi nurtured the journal, "Harijan" in which an article on soybean was published. It described soybean and its use mainly black, yellow and other colours of grain and recommended mixing of soy-flour with wheat-flour for making Indian bread, 'chapaties' ("Harijan", November, 1935; Kale, 1936). The advent and renaissance of soybean in India has been depicted by Tiwari *et al.* (1999). This saga of success shows as to how a traditional and marginal plant eventually became a major cash/oilseed crop (Fig. 1).

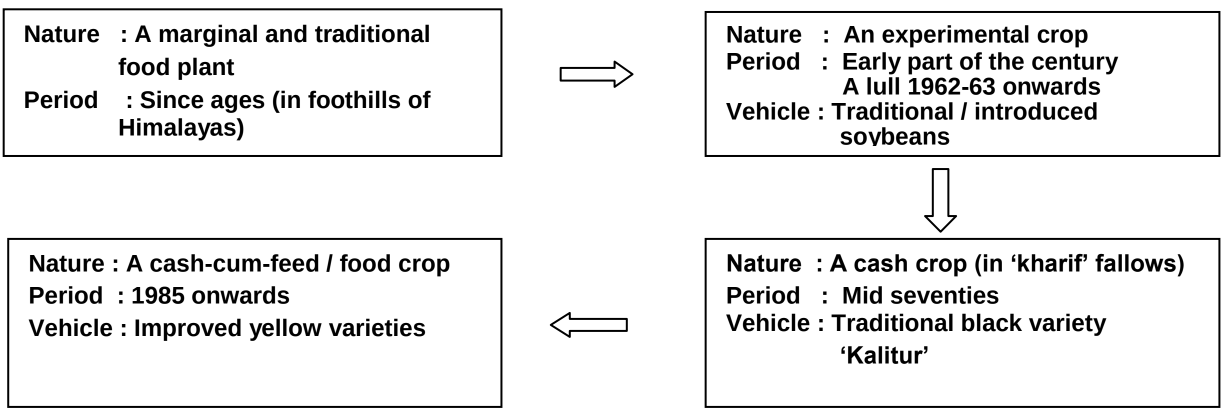

Fig. 1. The summarized success story of soybean in India

Soy-revolution does not pertain to a parochial section and it came about by encompassing the large plurality and breadth of the agricultural-related system of India. The entrepreneurship of certain risk-taking Indian businessmen who realized the prospect of huge monetary profit through the export of the soybean de-oiled cake (DOC) and the ingenuity of farmers of 'Malwa' region of central India to take up this new crop in large areas in fallow land were the crucial factors in initiating the process of 'soy-revolution' with Indore (in Malwa region of Central India) as its epicentre. In fact, the 'soy-revolution' was initiated with indigenous ingredients including the indigenous black-seeded variety and human resource *viz*., farmers, industrialists/ business-men and scientists. Eventual commercial success of soybean owes much to the concurrent development of the soy-industry which provided remunerative market to the growers. Soybean, particularly in its early years of spread, largely occupied the available rainy season ('*kharif*') fallow land. It, thus, fulfilled a developmental need of central India. The estimates given by Williams *et al.* (1974) were exceeded by actual soybean coverage area. This resulted in an enhancement in the cropping intensity and an increase in the unit area profitability from the land use. Fortuitously, the epicentre of this revolution geographically did not have much latitudinal span otherwise soybean, being a highly photosensitive crop, could have felt early problems in its cultivation. The Indian R&D set up in case of soybean revolution was ahead of its time. The Indian Council of Agricultural Research (ICAR) started the All India Coordinated Research Project[2] on Soybean (AICRPS) in 1967 when hardy any area of significance was under the crop. Eventually, ICAR established the National Research Centre for Soybean (now Directorate of Soybean Research) at Indore in Central India in 1986 when soybean covered only about 1.5 million hectares (ha), about one seventh of the present coverage of over 10.5 million hectares.

Soybean, despite its short stay as a crop (1970s and thereafter) in India, has served as a base in establishing some models such as futures exchange, global trade facilitation, use of ICTs towards technology adoption and domestic trade etc. that are worth emulating. The distinctive model of new approach using information and communication technology in the form of 'ITC's Soy-choupals" or "e-Choupals" is well known (Rao, 2007; Tiwari, 2008). Soybean cultivation has largely brought about socio-economic upliftment of farmers (Badal *et al.,* 2000). The crop continues to significantly contribute towards agrarian economy and farm-prosperity. At this juncture, we have to (i) defend the gains made, (ii) extend the gains to potential areas yet uncovered, and (iii) make new gains on sustainable basis.

2. **Production and productivity trends**

Yield increase in crops could result either from genetic modification of the plant and/or crop management. Often complementary changes in both these two realms are required and realized as in case of Indian green revolution (Gaud, 1968; Swaminathan, 2013) and also during post-green revolution periods in the world (Duvick and Cassman, 1999). Development of improved varieties and management practices are the starting desiderata following which yield increase in farmers' fields is realized only when the new technology is adopted by farmers otherwise a gap remains between potential and actual yield at farm level. This process of adoption also needs facilitated input availability, conducive and enabling policy and favourable economic environment.

Production increase in soybean in India over the last four decades could largely be attributed to the rapid area expansion under the crop (Fig. 2).

Productivity enhancement, although not vividly recognized, has gradually but consistently contributed towards production. Barring the aberrations caused by weather in some years, effect of increased productivity is

[2]*All India Coordinated Research projects, with nation-wide coverage through several to many centres in individual crop commodities and on other focused themes, coordinate research activities including multi-location trials and are the distinct characteristic of the National Agricultural Research System of India.*

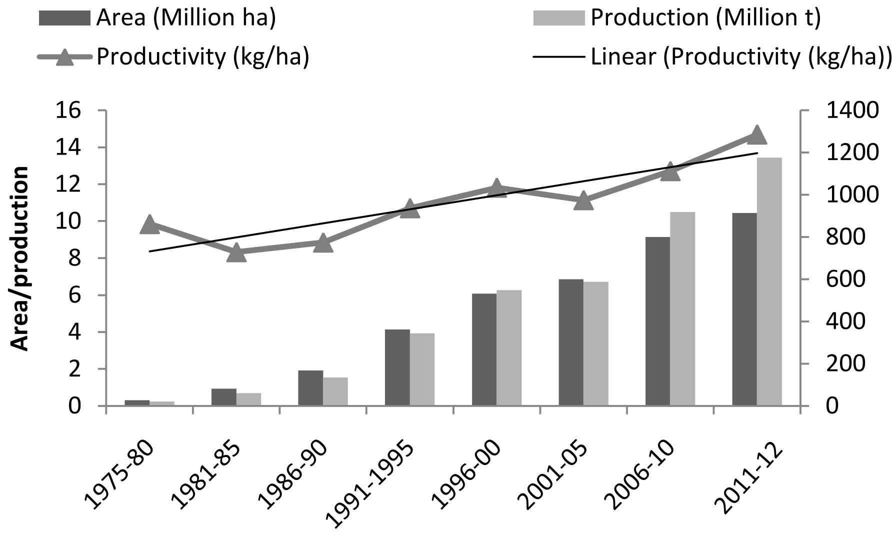

Fig. 2. Soybean area, production and productivity in India (5-yearly basis)

now becoming apparent in the recent years (Fig. 3). In 2012, the area was 10.69 million ha, production was 14.67 million tonnes and producti-vity was 1.37 t per ha, a never before high figure. This indicates that productivity is slowly on the rise although this trend gets blurred owing to abnormal weather conditions in some years affecting the productivity adversely.

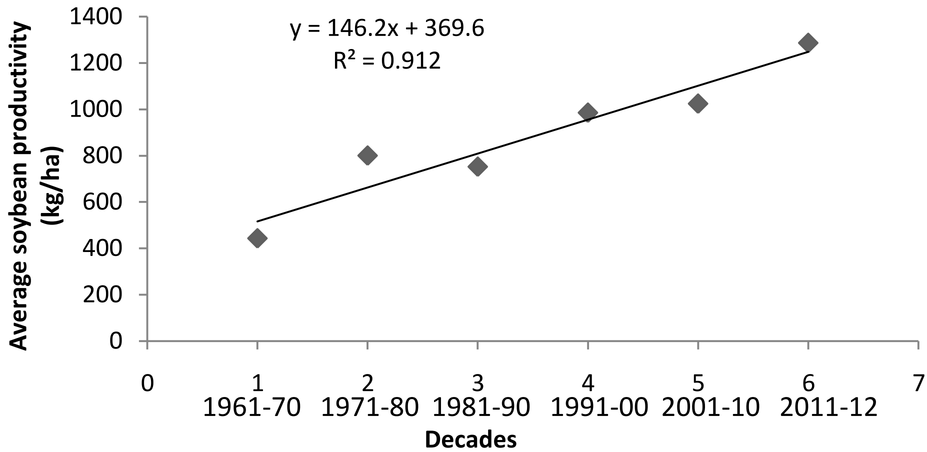

Fig. 3. Decade wise productivity trends of soybean in India

In XI plan period (2007-2012) the area, production and productivity increased by 17, 38 and 16 per cent, respectively The major soybean growing states are Madhya Pradesh(5.81 m ha; 54.35 %), Maharashtra (3.21 m ha; 30.03 %), Rajasthan (0.99 m ha; 9.26%), Karnataka (0.20 m ha), Andhra Pradesh (0.19 m ha) and Chhattisgarh (0.15 ha). All India total area is 10.69 m ha(year 2012). The crop is fast spreading in southern and northern states. Punjab is looking for diversification from rice-wheat. The state has longer duration (120 days) and hence higher expected yield (~ 2.5 t/ha). This indicates the effect of favourable niches. Whether or not such niches could be claimed for soybean is a matter of medium or long-term strategy. It is to be noted that when chickpea was taken to Andhra Pradesh, higher yields were obtained. There could be high- and low-yield environments depending mainly upon the length of growing season and also high-input and low-input conditions that determine the yield realizations. For example, in USA the states namely Iowa, Illinois, and Indiana produce relatively high yields when compared with Kentucky, Tennessee and Missouri that produce lower yields (Egli, 2008b). In China, productivity differs in northern and southern China. In India, latitudinal differences are presently less as soybean area is concentrated in central region but states like Punjab and Himachal Pradesh have longer growing period than central and southern regions. Also, there are low-input and high-input areas. Some eye-opening district averages are from Jalgaon, Kolhapur, Sangli, Satara and several others that have started yielding often exceeding 2 t per ha probably due to early planting and high input conditions. Strategically, low-yielding districts could be specifically targeted for yield-increase by input management.

3. Eating away the reserve (yield gap II)

In case of soybean in India, the productivity increase has mostly come from bridging the yield gap II whereas the upper limit of yield gap I has almost remained static. Yield gap I (YG I) is the difference between potential and achievable yield. It is estimated by simulation models or commonly by difference between experiment station and potential yields at the farm level. Gap I is conditioned by irreducible environmental factors. Though, YG I cannot be abridged in totality, it gives an indication of upper limits of achievable productivity in a given environment. Yield Gap II (YG II) is the gap existing between potential yield at farm level and actual yield at farm level. It is estimated by the difference between the achievable and average farmers' yields. YG II deals with the biological and socio-economic constraints. Amelio-ration of these constraints could largely lead to the realization of the production potential. Thus, YG II is manageable as it is mainly due to the difference in the management practices and extent of input use.

National average yield in India is presently about 1.3 t per ha (year 2012) but yields of 2.5 to 3.5 t per ha are not uncommon in farmers' fields in some districts of Maharashtra state and Malwa plateau of central India. Simulation studies have revealed climatic potential of 3 to 3.5 t per ha while rainfed potential is 2 to 2.5 t per ha (Bhatia *et al.*, 2008). Front Line Demonstrations (FLDs represent-ing real farm situations) showed sizeable yield gap between that obtained by adopting improved technology (IT) and that under farmers' practices. Average rainfed potential of 2000 kg per ha has been reported (Bhatnagar and Tiwari, 1989; Bhatnagar and Tiwari, 1997a; Billore *et al.*, 2004).

Several abiotic, biotic and socio-economic factors responsible for poor productivity have been identified (Tiwari 2001a; Joshi and Bhatia, 2003). The identified constraints to Indian soybean production and productivity comprise a relatively short stay of soybean as a crop, limited genetic diversity, narrow genetic base of Indian soybean varieties, short growing period available in Indian latitudes, almost stagnant genetic potential for yield, hindered agronomy/availability of inputs at farm level, rainfed nature of crop and water scarcity at critical stage(s) of plant growth, insect-pests and diseases, quality improvement problems, poor seed longevity and mechanical damage to soybean seed, inadequate mechanization and partial adoption of technology by farmers (Tiwari, 2001a). Some major issues and strategies including the developmental ones to overcome the constraint have also been suggested (Tiwari, 2009b).

There are now reports which indicate that yield increases may be ending in some environments, with plateaus noted for soybean in some countries (Nafziger, 2004). On the contrary, Egli (2008a) observed that there is no evidence of declining growth rates or the appearance of plateaus. Also, there is no clear evidence through 2005 that increases in soybean yields in some areas like the mid-western United States are ending (Wennblom, 1978; Nafziger, 2004). In case of India, it appears that, of late, the yield gap II is being bridged faster than ever before. Sadly, the potential yield at farm level has remained stagnant at about 2 t per ha.

Both yield and extent of yield gap is also dependent upon the input conditions. It has been observed (Bhatia, 2008) that potential and actual yields are higher under high moisture availability and *vice versa* (Table 1).

The gap in yields was very large at locations with low rainfall and it narrowed considerably with the increase in rainfall (Bhatia *et al.*, 2008). Up to about 850 mm of rainfall, water deficiency appears to be the main cause for reduction in yield. The authors have suggested that, as soybean is mainly a rainfed crop, bridging this yield gap would require (i) rainfall conservation technologies, (ii) cultivars tolerant to drought conditions, (iii) efficient use of available water through adoption of improved watershed management and land treatment

Table 1. Potential (simulated; CROPGRO Model) and actual yields (kg/ha) (Years: 2001-2003)

Water	Potential	Actual	Gap
Non-limiting	3020	2020	1000
Limiting	2170	1000	1170

Data extracted from Bhatia et al. (2008)

incorporating conservation tillage (broad bed-and-furrow, ridge-and-furrow, reduced tillage, residue recycling and mulching), along with water harvesting technologies.

These studies also show narrowing of not only YG II but also YG I especially under good rainfall and input conditions. There is a need to worry. First of all, the Yield Gap II can never be fully bridged in a rainfed crop like soybean. Even in case of cereals under best production systems, it has been observed that annual improvement in national crop yield shows a decline and ceases once the crop reaches about 80 per cent of the potential productivity as established by the nation's very best producers (Cassman, 1999). In Louisiana, the typical soybean farmer produces an average yield that is 70 per cent of that expected, if recommended production practices were followed (Louisiana Agric. Ext. Serv., 2009). Similar yield potential studies in other parts of the world show yields ranging from 60 to 80 per cent of the optimal level (Foulkes *et al.*, 2009). Recent reports confirm this in soybean also (Singh *et al.*, 2013; Table 2). Secondly, increasing technology adoption should continue to bridge YG II but the potential yield has also to be simultaneously increased so that YG 1 ceiling moves up.

The narrowing of YG II indicates that a gradual increase in soybean productivity with improved management under rainfed situation is being achieved, obviously so in recent years. Narrow YG I, as estimated through several studies and in the obvious present soybean scenario in India, indicates the need to further refine the production technology including development of varieties that can perform still better in a predominant rainfed environment. In view of increasing technology adoption, narrowing yield gap and stagnant ceiling of potential yield at farm level, technological innovations are needed to be continually injected into the soybean farming. We have to raise the yield ceilings in Indian soybeans.

Table 2. Narrowing extension gap in realizing soybean yield at farm level

Year	Extension Gap Demonstration yield-Farmers' yield (kg/ha)	Technology Gap Potential yield-Demonstration yield (kg/ha)	Technology Index Tech Gap / Potential yield x 100 (%)
2007	1040	210	32.1
2008	980	240	29.3
2009	520	220	35.1
2010	190	310	9.5

Source: Singh et al. (2013)

4. Raising the yield ceilings

Yield potential is built up by progressive assembling of productivity genes as against simultaneous progress in assembling genes for quality, resistance to insect-pests and diseases, and environmental stresses. The distinction at the genetic level is between the genes increasing yield potential, the 'productivity genes' and the genes conferring resistance to the various stresses. Evans (1993) defined yield potential as the yield of a cultivar when grown in environments to which it is adapted; with nutrients and water non-limiting; and with insect pests, diseases, weeds, lodging and other stresses effectively controlled. Evans and Fisher (1999) suggested that 'potential yield' should be used for the maximum yield that could be obtained in a crop as determined by simulation models whereas 'yield potential' should be used mainly for majored comparison of cultivars. This also means that 'potential yield' should be used for comparison between different crops and different environment as well as for estimating plausible future limits to crop yields.

It is to be noted that high soybean yields are dependent on high solar radiation and cool temperature as per Spaeth *et al.* (1987). On the other hand, Bhatia *et al*. (2008) studied locations in India and found that the maximum and minimum temperatures did not show any significant association with simulated yields indicating that most of the variability in potential yield was accounted for by the variability in the solar radiation.Yield comparisons across latitudes and across countries need adjustment for length of growing season available and, therefore, achievable goals of productivity enhancement under short duration of Indian conditions are to be fixed and viewed accordingly (Tiwari, 2003).

Productivity increase may be through:

- Area expansion by claiming favourable niche
- Productivity enhancement by
  - Narrowing/ bridging the YG II (crop management using agronomy, input supply, seed, extension etc. and policy therefor),
  - Raising the genetic potential or pushing the ceiling of YG I (crop improvement) through
    - Genetic insulation against abiotic and biotic stresses
    - Assembling productivity genes (yield *per se*)
    - Genetic improvement of photosynthesis and related physiological traits
    - Improvement of quality traits/development of specialty soybeans (for farm prosperity and health)

4.1. Soybean: Not an easy option for raising the genetic potential for yield

The aim hereunder is not to draw attention to general yield-limiting constraints, that have already been enumerated earlier in this article, but to recognize biological intricacies of soybean esp. (i) high energy requirement for oil and protein synthesis, (ii) non-availability of secondary gene pool (GP-2, after Harlan and de Wet, 1971), (iii) available solar radiation and/or length of growing period for this highly photo-sensitive crop under Indian conditions, (iv) phenological adjustments for high yield etc.

Soybean, unlike C_4 maize, is a C_3 legume that produces modest yields of seeds with high levels of oil and protein, while requiring fewer production inputs. Being an oilseed and proteinseed crop, it requires more energy as the production value for each unit of glucose is 0.83 for carbohydrate, 0.40 for protein and 0.33 for lipid.

Both members of the sub-genus *Soja viz.,* the cultigen [*Glycine max (*L.*)* Merrill; 2n = 40] and the wild progenitor *G. Soja* Sieb and Zucc. (2n = 40) are included in GP-1. Much to the dismay of soybean breeders, soybean does not have a GP-2. A host of wild perennial species, belonging to the sub-genus *Glycine*, constitute the GP-3 that is difficult to exploit.

Under Indian conditions, another limitation is the short growing period particularly in the predominant soybean belt of central India. A duration of 90 to 100 days is preferred in major central Indian region. We require soybean genotypes, which flower in ~37 days, mature in ~90 days and have seed fill duration of ~38 days that would give the optimum yields under rainfed production system of central India (Bhatia and Ramesh, 2009).

Long juvenility is lacking in Indian germplasm and has probably to be differently understood under Indian conditions. Studies show that assimilate-supply during seed filling period is more important than harvest index. Some worrying trends indicated that improvement in yield through breeding of high yielding short season cultivars could be associated with undesirable characteristics *viz*., greater seed size, poorer seed quality, less protein and more oil (Voldeng *et al*., 1997). Also, there could be a biological ceiling for yield. Although some higher estimates are globally stated, maximum yield under simulated conditions in India has been estimated to be 3,850 kg per ha (Bhatia *et al*., 2008).

As stated earlier, in crops like soybean, yield increase and also bridging the yield gap II, slows down and ceases once the crop reaches about 80 per cent of the potential productivity as established by the best producers/demonstrations. It means that YG I has also to be continuously kept rising in order to maintain good pace of bridging the YG II.

There is a need to enhance the genetic potential for yield as, all said and done, greater yield potential is yet not well-pursued in soybean under Indian conditions. As stated earlier, this is different from and is in addition to checking the yield erosion due to insect-pests and diseases, shattering loss *etc*. This also differs from minimising the yield gap - II through adoption of package of practices, input supply including seed *etc*. Gai (1999) has summarised the approaches for genetic improvement for soybean yield as (i) assembling positive yield genes, (ii) to support yield genes with plant architecture genes as their genetic background, (iii) utilising hybrid vigour, and (iv) to ensure the yield potential realization through genetic control of negative factors like biotic and abiotic stresses. Broadening the present narrow genetic base of the soybean cultivars, suitable improvisation of breeding methods, use of biotechnology and molecular breeding in combination with conventional breeding, and precision agriculture are important future media for yield enhancement and its realization. Some of these are briefly discussed below.

4.2. No neglect rather reorientation of conventional breeding

Most of the present Indian soybean varieties are the result of conventional approaches in crop improvement. Tiwari *et al*. (1999) have summarized that the present Indian soybean varieties represent different groups based on their breeding history. Broadly, there are (1) indigenous soybean varieties, (2) varieties representing direct introductions and/or selection in them, (3) varieties developed through hybridization and largely pedigree selection, and (4) varieties developed through mutation breeding. Most of the Indian varieties were developed through hybridization and pedigree selection (Tiwari, 2001b; Tiwari and Raut, 2004). Early generation testing has been used in a limited way particularly to develop high oil lines at MACS, Pune (c.f. Tiwari and Raut, 2004). Limited back-crossing has also been useful in soybean improvement in India. A line, 'PK 515' having introgressed resistance to yellow mosaic and a moderate degree of resistance to Bihar hairy caterpillar was developed by effecting BC_1 i.e. (*G. formosana* (*soja*) x Bragg) x Bragg and then the resultant progeny were routed through pedigree method (Ram *et al*., 1984). Varietal blends have also been evaluated in India. Bhatnagar *et al*. (1994) evaluated 15 varietal blends resulting from combi-nations of 6 Indian pure varieties. The differences in yield among blends and varieties were highly significant but none of the blends proved significantly higher in yield than the highest yielding component. Other methods of breeding like bulk method, recurrent selection, backcrossing *etc*. as also the modern techniques such as marker-assisted selection (MAS) and development of transgenics have either not been used or have not yet resulted in a commercial variety in India. Breeding efforts and information on genetics/inheritance of different traits of soybean have been reviewed by Prabhakar and Tiwari (1991), Tiwari (2001b), Tiwari and Raut (2004) and Tiwari *et al*. (2004).

Indigenous soybean varieties are land

races or selections from them and have been known since long. These represent (a) pool of black-seeded indigenous varieties such as 'Bhat'/'Bhatmas' which represent the habitat of northern hill region but were also cultivated in scattered pockets of central India under the names such as 'Kalitur' and 'Kala Hulga', (b) yellow-seeded pool of northern-hill / Tehri-Garhwal region presently represented by 'JS 2', and (c) a pool of indigenous varieties with yellow coloured small seeds such as those represented by 'Type 49'. The variety 'Punjab 1', although a selection from exotic 'Nanking' variety, is also known to have adapted to Indian conditions and to an extent represents endemic variability. Besides the indigenous varieties and selections from them, early soybean varieties of India resulted from direct introductions mainly from U S A. For example, the varieties, Bragg, Lee, Clark-63, Davis, Hardee, Improved Pelican, KM-1 (Introduced from AVRDC Taiwan) and Monetta were released after direct introduction. Soybean varieties released and notified in India have been listed and updated with their pedigree and characteristics from time to time by NRCS/DSR (Bhatnagar and Tiwari, 1990; Agarwal *et al.,* 2010).

In mid-seventies when 'soy-revolution' was experienced, the variety 'Kalitur' ruled in and around Malwa plateau in central India. It is to be noted that it was not the yellow but traditional black-seeded indigenous variety 'Kalitur' that was the vehicle of 'soy-revolution'. It was at a later stage when the indigenous and introduced yellow-seeded varieties came handy for consolidation of early gains. 'Kalitur' was and still recognized for high seed longevity, tolerance to a degree of water-logging, a general resilience to change in weather *etc*. However, soon farmers started realizing its inherent defects such as a high degree of pod-shattering and not so high yield as desired. Yellow-seeded varieties replaced 'Kalitur' and the problem of shattering in 'Kalitur' was, thus, overcome. Promising soybean varieties were identified as early as early seventies by Saxena and Pandey (1971), Lal and Mehta (1972), Lal *et al*. (1974) and Singh and Saxena (1975). In years to come, plant breeders could develop improved varieties which alleviated the defects of pod-shattering and poor seed germinability prevalent in many initially bred varieties. Selection criteria for these characters, rapid screening methods and needed management practices and production technology were also developed (Tiwari and Bhatnagar, 1989, 1991a,b and 1993; Prabhakar *et al*., 1992; Tiwari and Bhatia, 1995; Tiwari and Bhatnagar, 1997; Tiwari and Hariprasad, 1997).

Soybean continued to spread and large number of trials were undertaken to identify suitable varieties particularly for non-traditional regions of India (various AICRPS Reports; Tiwari *et al.* 1994). Besides NRCS/DSR (Indore), JNKVV (Jabalpur and Sehore) and GBPUA&T University (Pantnagar), there are about 20 centres spread all over the country that have contributed towards development of present Indian soybean varieties. Out of a total of over 100 varieties, about 30 remain in the active seed chain every year. Mega-varieties *viz*., JS 335, JS 93-05, JS 95-60 and JS 97-52 are predominantly covering majority of the area but other regionally adapted varieties, although covering small area, are serving the cause of diversity and claiming new non-traditional niches of soybean coverage.

Mutation breeding has also resulted in some Indian soybean varieties (Bhatnagar and Tiwari, 1997b et seq.) such as Ahilya 1 (NRC 2), Ahilya 2 (NRC 12), Birsa Soy 1, Aarti (MAUS 1), VL Soya 1, Pusa 97-12 and TAMS 98-21. Yellow seeded mutants were obtained from black seeded indigenous cultivar, Kalitur (Raut *et al.*, 1982; Patil *et al.*, 1981 and 1985; Bhatnagar *et al.*, 1990). The mutants with higher seed germinability were utilized in the development of elite cultivars such as MACS 450 which is developed from a cross Bragg x MACS 111, where MACS 111 was a mutant from Kalitur. Misra *et al.* (1981) reported shattering resistant mutants. Bhatnagar *et al.* (1989) have developed high germinability genotype from the cultivar Bragg through mutation. Bhatnagar *et al.* (1992) were able to break the negative association between oil content and protein content through mutagenesis. Rani *et al*. (2012) reported an early maturing mutant, 'NRC 107' (parent variety 'NRC 37').

Conventional breeding has given successively ruling mega soybean varieties like Gaurav (JS 72-44), JS-335, JS 93-05, JS 95-60 and others and has served the nation well. When a developmental need occurred for early soybean varieties to suit the highly system-efficient sequence of "short duration soybean – potato - late sown wheat" cropping pattern of Malwa plateau, conventional breeding gave varieties such as NRC 7, JS 93-05, JS 95-60 and others including an early maturing variety 'Samrat' developed by farmers. NRC-7 is such an early maturing variety whose notification period is over but it is still the favourite of farmers in and around Dhar district in central India. Using conventional breeding approach, several private seed companies have also developed soybean varieties that have spread to an extent.

Four-seeded pods obtained as transgressive segregants were reported in the cultigen by Tiwari and Bhatnagar (1994) borne in plants with characteristic narrow/lanceolate leaves. It is interesting to note that the short duration varieties developed later (JS 90-41, JS 93-05 and JS 95-60) have this somewhat new plant type different from earlier bred Indian soybean varieties in possessing some four-seeded pods along with characteristic lanceolate leaves (Shrivastava, 2011). As the genes controlling four-seededness and number of pods are apparently independent, appropriate hybridization may produce genotypes combining these two desirable characters.

It has been estimated that during the years 1969 to 1993, the annual genetic gain in seed yield of soybean varieties has been about 22 kg per ha (Karmakar and Bhatnagar, 1996). A strikingly similar recent study has also shown that the annual genetic gain in seed yield of soybean varieties released in India was approximately 23 kg per ha during the years from 1969 to 2008; the seed yield gain, thus, amounted to 103.5 per cent or 2.6 per cent per year during the studied span of 39 years (Ramteke *et al*., 2011). This achievement of soybean breeders in India is noteworthy especially in view of the relatively short stay of soybean as a crop in this country.

So, conventional breeding is not to be neglected. Even modern approaches like molecular breeding also thrive on the base built through conventional breeding. First of all, sincere efforts are to be made to increase yield *per se*. This is distinct and different than insulating varieties against stresses which also has to continue. Secondly, conventional breeding has to be reoriented with use of discreetly chosen parents and pre-bred diverse material in the crosses, sizeable F_2 populations (presently we suffer from finite populations and limited number of crosses), combination breeding, two/three-way and further complex crosses and development of multi-parent intercross populations, gene stacking, simultaneous development of mapping populations preferably immortal ones using single seed descent (Brim, 1966) or other suitable methods, improved methods of testing performance, development of hot-spots and screening/phenotyping facilities, at least two off-season nurseries dedicated to soybean with built-in phenotyping, rust-averting and other measures, and free flow of parents and segregating material. Fortunately, research and development is in progress in several of these areas at DSR (Indore) and other centres. All India Coordinated Research Project on soybean (AICRPS) has many centres in the country which should be more involved than before in this regard.

4.3. Associated characters –Improvement and incorporation

The yield potential can be enhanced by increasing the contribution of yield components along with physiological characters. Substantial genetic gain in yield may be achieved if breeders are able to develop cultivars with physiological characters such as faster growth rates and greater yet appropriate biomass at maturity. Genetic improvement in soybean yield has been found to be associated with assimilate supply during seed filling period but not so much with changes in harvest index. There appeared to be little change in soybean harvest index (Frederick and Hesketh, 1994). Association and regression analysis in a large sample of Indian soybean genotypes has shown that 'pods per plant' is the main determinant of seed yield (Prabhakar and Tiwari, 1993). In view of short duration varieties or otherwise as well, it would be pertinent to measure per day productivity and base the selections on it. Rubisco (ribulose 1, 5 biphosphate carboxylase / oxygenase) content and photosysnthesis are reported to be linearly releated. In sulphur (S)-defecient plants, the decline in the ratio of rubisco/soluble protein implies that other housekeeping enzymes become more important than Rubisco for survival (Sexton *et al.*, 1997). Therefore, S-application is needed so that a linear increase in yield may be obtained by enhanced nitrogen application. Along with photosynthate supplied to sinks, changes in some other traits namely more pods, lodging resistance, greater N_2 fixation and greater stress tolerance have also been, more or less, responsible for yield improvement (Specht *et al.*, 1999). In India, screening for several of these characters has been undertaken and varieties, that possess desirable physiological and morpho-anatomical characters (such as high leaf photosynthesis, specific leaf weight, leaf-thickness and palisade-thickness), have been identified for use as donors in breeding programmes (Bhatia *et al.*, 1996). An upcoming/ experimental method *viz.*, spectral analysis uses the electromagnetic radiation coming from plants and other objects to facilitate large scale screening for early detection of substantial or large (and not small) differences in yield as experimented in Kansas State University, USA. It determines the level of photosynthetic activity of vegetation in many different situations enough to cull out lines having a low yield potential at an early stage of evaluation.

As experimented in case of rice, one current target for molecular modification of photosynthesis is to introduce the precursor pathway for organic acid fixation of CO_2 (C4 pathway) into C3 species. Sinclair *et al.* (2004), however, have argued that even if the putative advantage of increasing the leaf photosynthetic rate was achieved by completely converting a C3 soybean plant to C4 photosynthesis, in view of the complex hierarchy of carbon assimilation and the yield, there is no guarantee that grain yield would increase. The efforts could, however, continue.

Globally some success has been achieved for hauling in physiological characters for productivity. Eight soybean germplasm lines and cultivar 'Jackson' have been identified as having greatly enhanced tolerance of nitrogen fixation to soil drying (Serraj and Sinclair, 1997; Sall and Sinclair, 1991; Sinclair, 2004; Sinclair *et al*., 2000; Sinclair *et al*., 2004). Two rare slow-wilting genotypes, PI 416937 and PI 471938, have been identified for drought tolerance. Several QTLs for slow wilting and associated characters have also been identified. PI 471938 has 3 QTLs for slow wilting, each contributing to a 136 kg per ha yield increase under drought. Breeding lines derived from these sources have shown excellent yield potential (University of Arkansas). Such elite lines should be procured for Indian soybean improvement.

Thus, in addition to the apparent and direct contributors to yield such as pods per plant, several other parameters like water use efficiency, specific leaf weight, efficient and high nodulation and biological nitrogen fixation, photosynthetic efficiency with better translocation and partition-ing, delayed leaf senescence, relative water content, and root conductivity, drought resistance, slow wilting etc., should also be measured and incorporated selectively as per need.

Most soybean varieties are highly sensitive to changes in latitude or planting date because of their responsiveness to variations in photoperiod. Sources of photoperiod insensitivity have been identified *viz*., MACS 330, EC 325097, EC 333897, EC 34101, EC 325118, EC 390977 and EC 538822. The short photoperiod of the tropics caused most soybean germplasm to flower and mature too rapidly for adequate growth and yield. The use of long juvenility trait was the solution found by soybean breeders particularly in Brazil. This trait was attempted to be incorporated in the Indian soybean varieties by the DSR scientists but studies showed that the effects are different and the long-juvenility has also to be understood in terms of earliness needed under central Indian conditions. Most of the area is under early varieties maturing in 90-95 days, which needs different phenology rather than increasing the period taken to flower alone. Planting date also affects the varietal performance greatly (Bhatia *et al*., 1999). It appears that high yields of some districts of Maharashtra are due to early planting of the crop.

4.4. **Utilization** *of diverse germplasm for soybean yield improvement*

In case of agro-biodiversity, soybean has both endemic and exotic variability that has been utilized and the so-called "founder-effect" has been avoided. A review of soybean introductions in India is available (Tiwari, 2006a). It will be interesting to know that during the first two decades of the 19^{th} century, new soybean accessions were introduced from India and China into the USA by USDA plant explorers Charles V Piper and Frank N Meyer, respectively (cf. Hymowitz and Bernard, 1991). Some indigenous material from India is well documented and, interestingly, USA imported some of it from India. For example, the USDA Germplasm Collection Inventory (1989) records that USA introduced 258 accessions from India during the years 1945 to 1985. Further, it also records to have imported, in USA, 54 PI numbers *i.e.* serially from 374.154 to 374.207 collected from central India which were all black-seeded and belonged to the maturity groups VIII and X. Later in sixties, soybean varieties and lines started to be introduced largely from USA and to some extent from Taiwan to India. Presently, directed soybean introductions of specific nature are needed in India but it is sadly noted that sometimes even those purely plant breeding needs that do not necessarily require new introductions are also inappro-priately contrived to be germplasm needs. Tiwari (2006a) has elucidated this point by subtly differentiating between plant breeding needs and germplasm needs *sensu stricto*.

Results of pedigree analysis and diversity analysis in soybean have indicated narrow genetic base of cultivated varieties. Studies in major soybean growing countries like USA (Delannay *et al*., 1983; Manjarrez-Sandoval *et al.,* 1997; Kisha *et al.,* 1998; Thompson and Nelson, 1998), Brazil (Hiromoto and Vello, 1986; Vello *et al*., 1988), and China (Gai, 1999) have indicated that up to now breeders have used only a small part of available genetic resources and the soybean varieties have a very narrow genetic base. Indian soybean cultivars also have a narrow genetic base as shown by studies on fairly large sample of soybean varieties through ancestral analysis (Karmakar and Bhatnagar, 1996; Satyavathi *et al*., 2003), coefficient of parentage (Bharadwaj *et al*., 2002) and genetic diversity assessment using molecular markers (Satyavathi *et al*., 2006). Although moderately high genetic diversity was observed in Indian soybean varieties with AFLP analysis, it was due only to 12 varieties in 3 diverse clusters (Satyavathi *et al*., 2006). Most of the Indian soybean varieties have been derived from a limited number of common ancestors. About 73 per cent of the genetic contribution of the present soybean varieties comes from as few as 10 ancestors. Varieties *viz*., Bragg, Improved Pelican, Punjab-1, Hardee, CNS, JS-2, Kalitur and Lee have been used frequently as parents of the released varieties. Out of these, Bragg has been most frequently used and occurred as a direct parent in 15 pedigrees. This repeated use of a few parents for breeding has led to narrow genetic base in soybean (Bharadwaj *et al*., 2002, Satyavathi *et al*., 2003). Out of more than 100 varieties released in India, only 10 have been developed through direct utilization of germplasm as against use of varieties themselves as parents. Germplasm enhancement and pre-breeding are needed. There is a need to strengthen the activities in this aspect by resorting to crossing between unadapted genotypes (cultivated)/alien species especially *Glycine soja* Sieb et Zucc., and elite cultivars. Base broadening measures were suggested and adopted to an extent (Tiwari, 2001c).

Genetic potential of wild can now be feasibly unlocked using new techniques and the old paradigm of 'looking for the phenotype' has given way to the new paradigm of 'looking for the genes' (Tanksley and McCouch, 1997). The tools of genome research are now available that may finally unleash the genetic potential of our wild and cultivated germplasm resources for the benefit of society (Tanksley and McCouch, 1997). There are confirmed reports that intro-gression of diverse germplasm into the current soybean [*Glycine max* (L.) Merr.J genetic base could increase genetic variability and lead to greater gains from selection (Thompson and Nelson, 1998; Singh and Hymowitz, 1999). Many of the high-yielding lines have been found to be more diverse. The increased genetic diversity and resultant yield provide the evidence that exotic germplasm can contribute genes for high yield. Elite lines derived from other species such as *G. tomentella* - derived elite diploid lines (Riggs *et al*., 1998: Singh and Hymowitz, 1999) may also be introduced and utilised in India.

Potential of exotic germplasm for yield has been shown earlier also but recent studies using modern techniques have led to definite genes/QTLs. QTLs for yield have been identified in *max* x *soja* (Li *et al*., 2008a). Despite the question of limited adaptability of the *soja* yield-QTL across genetic backgrounds, the studies demonstrate the potential of exotic germplasm for yield enhancement in soybean. Concibido *et al*. (2003) identified a QTL for yield in *Glycine soja* and transferred it (PI 407305 haplotype) to cultivated soybean using molecular markers.

To strengthen efforts in genetic resource conservation, enhancement and use in soybean in India we should undertake:

- Introductions particularly directed introductions needed (presently a meagre collection of about 4500 of the cultigen *G. max* accessions and about 70 accessions of GP-3 wild relatives and annual wild progenitor, *G. soja,* in India);
- Bi- or multi-lateral agreements for exchange of germplasm particularly with Brazil, China and Japan, may be on *quid pro quo* basis, as soybean is not covered under the multi-lateral access under the Annex-I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA);
- Secondary declaration (comprising items *a* to *h*) needed for soybean introductions should not mar germplasm acquisition; post-entry quaran-tine should take care of the concerns. Presently, import of all soybean germplasm needs a phytosanitary certificate from the exporter declaring that the material exported is free from specific diseases (06), viral infections (12) and insect-infestations (01);
- Targeted exploration of germplasm (particularly land-races) that are well-adapted to characters like drought stress in soybean to augment the existing indigenous and exotic collections;
- Molecular characterization of the genetic resources with phenotypic contrast using both genic SSRs and even SNP markers as feasible, facilitated use of such molecular markers in pre-breeding, germplasm genomics;
- Allele mining (gene polymorphisms) and association analysis of the selected genetic resources for identification of favourable alleles in the targeted trait-specific candidate genes;
- Genotyping and phenotyping of the material to be used in breeding, intensive morpho-physiological phenotyping of selected genotypes under biotic stresses, drought stress and excess water stress conditions under specifically developed facilities such as rain-out shelter, environmental chambers, control plots etc. and also including screening for diseases and insects at different locations/hot-spots such as Dharwad and Ugarkhurd for rust, Ludhiana (or Delhi) for yellow mosaic virus, Jabalpur for *Rhizoctonia* root rot etc.; collaboration with National Institute of Biotic Stress Management (ICAR) for this purpose;
- Repatriation of Indian soybean germplasm;
- Pre-breeding or genetic enhancement among gene pool; development of polygenic trait-specific genepool/set/sub-set and development of multi-parent intercross populations as a specific gene-resource for crop improvement;
- Use of core collections developed by DSR, development of sub-sets of core collection;
- Conservation should be in terms of

diversity and not in terms of accessions; facilitating utilization of soy GRs should be integral part; supply of even core collections and reference collections to breeders in India.

4.5. *Need for an amalgam of conventional and molecular breeding: MAS and use of quantitative trait loci (QTLs) for hauling in productivity genes in soybean*

Conventional breeding has given admirable output in India. Still, technologies being used need to be improved. It is not meant here to quickly take up the so-called new plant breeding techniques *viz*., Oligonucleotide Directed Mutagenesis (ODM), Zinc Finger Nuclease Technique (ZFN), Cisgenesis (comprising Cisgenesis and Intragenesis), RNA-dependent DNA Methylation (RdDM), Reverse Breeding, Synthetic Genomics, *etc*. We may not yet be ready for it but certainly conventional breeding has to be combined with some new plant breeding techniques that can be feasibly resorted to. For example, we should quickly incorporate yellow mosaic virus resistance and other desirable characters in our already available mega varieties by using MAS. Depending upon number of genes for a character, the suitable version of MAS breeding method may be used. A designated off-season nursery is a must to speed up the process.

For Single gene traits –MA Back Crossing

For Oligogenic traits – Gene pyramiding and F_2 enrichment

For Polygenic traits – MA Recurrent Selection and Genomic Selection; Recurrent selection combined with high throughput genotyping of minor genes/QTLs using techniques such as microarray.

Conventional soybean breeding techniques are to be integrated with the next generation high throughput genomics and phenomics technologies for discovery of new genes or QTLs for yield, mining favourable alleles and incorporating them for designing soybean with higher per day and per unit productivity. We may undertake linkage mapping of QTLs for yield and its components employing mapping populations and use the source germplasm for development of mapping populations. The QTL mapping strategy would comprise QTL detection, QTL localization and QTL fine mapping. Markers linked to the gene of interest (GOI) need to be identified. Once this tagging of GOI and the marker is done, the linked marker could be utilised for marker assisted selection (MAS) unaffected by the environmental effects to a great degree. Novel approaches for discovery of new QTLs or genes employ (i) association mapping including genome-wide association studies, (ii) nested association mapping, (iii) next generation sequencing-based approaches for mapping genes and QTLs *viz*., novel high throughput DNA sequencing, MutMap (combining DNA sequencing and EMS induced mutagenesis), BSR-Seq–RNA-Seq using bulked segregants RNA-sequencing, *etc*. Some of these may be taken up eventually when we have requisite material and trained scientists. Phenotyping facilities for traits are also imperative and have to be created. Facilities creation and specific training/HRD are urgently needed in these areas.

QTLs for yield and closely related characters have been mapped in soybean (Mansur *et al*., 1993, 1996; Maughan *et al*., 1996; Mian *et al*., 1996; Panthee *et al*., 2007; Li *et al*., 2008b; Soybase, 2012). Bobby *et al.* (2008) identified four QTL for pod number (qPN001-qPN004) on chromosomes 2, 6, and 8 (2 QTLs), respectively; two QTL for seed number (qSN001 and qSN002) on chromosomes 5b and 11b, respectively; five

QTL for 100-seed weight (qSW001 to qSW005) on chromosomes 5a, 6, 8, 9, and 11c, respectively, and two QTL for total seed weight (qTSW001 and qTSW002) identified on chromosomes 5b and 17c, respectively. The QTLs identified could be introduced in breeding programs to develop soybean cultivars with high yield potential. A more or less comprehensive list of QTLs of agronomic importance in soybean is given by Hu *et al*. (2011).

Further, meta-QTL analysis is being carried out in soybean that can be taken advantage of. Meta-analysis is an important tool in linkage analysis to optimize QTL, shrink the Confidence Interval (CI), and improve the accuracy and validity of QTL position (Löffler, 2009). It is of particular relevance for the validation of known QTL. QTL location is so affected by many factors, including genetic background, population size and analytical method that a single study can only be taken as suggestive, unless it is based on a large enough set of experiments. Where the CI is large, it is difficult to distinguish between the presence of a single locus and the presence of two (or more) loci. The meta-analysis approach, as developed by Goffinet (2000) *et seq*. (particularly Goffinet and Gerber), however, does provide a means to alleviate the extent of this uncertainty, since it improves the capacity to identify the true number of QTL present, and the precision of their location by reducing their associated CI. In soybean, Hu *et al*. (2011) for the first time made comprehensive efforts in this direction wherein (i) published QTLs were collected, (ii) a consensus map of published maps with a reference map was created, (iii) consensus QTLs were acquired by the meta-analysis approach, (iv) genes were mined using bioinformatics tools, and (v) markers of consensus QTLs with high effects and small CIs were provided for MAS.

Methods are now available to lead to desired precision mapping and to reduce the number of genes in an identified QTL. Reducing the number of candidate genes in QTLs can also be achieved by a combination of QTL mapping and micro-arraying that has been successfully attempted in case of ovariole number in Drosophila as a new approach to candidate gene identification (Wayne and McIntyre, 2002) and since followed in many crop plants as well. Moving from traits to genes is required.

New technologies for assaying genotypes for SNP allele type are expected to make SNP markers the replacement for the currently used SSR marker systems (Hyten *et al*., 2008). A particularly important advantage of the illumina-based SNP allele detection over the SSR marker allele detection is the elimination of the tedious gel-based marker allele visualization required for the latter. Further, populations and maps have been developed that can be used. For example, several studies have used the SNP-based genetic linkage map developed by Kassem and his group to map QTLs (Bobby *et al*., 2008; Kassem *et al*., 2012).

In India, QTLs have been identified for several characters such as high seed longevity (Satt 538, Satt 285, Satt 600 and Satt 434; Singh *et al*. 2008), high oil and protein content. One of the two genes responsible for YMV resistance in soybean was found to be linked to markers Satt 322 and GMAC 7 present on C2 linkage group. Fertile transgenic plants have been recovered via *Agrobacterium tumefaciens* – mediated transformation in Indian soybean variety, 'JS 335' (Rani *et al*., 2012).

With the advent of soybean genomic information and bioinformatics tools, finding consensus QTL intervals in the corresponding physical map would be made easier, particularly for mining candidate genes.

Bioinformatics tools are important in the process leading from QTL to the quantitative trait gene, or QTG and gene-silencing. A whole realm of computational biology has sprung up for facilitating genetic improvement.

4.6. Stress resistant / tolerant varieties

4.6.1. Disease resistance

Soybean diseases such as rust, yellow mosaic, *Sclerotium* blight/collar rot, *Rhizoctonia* aerial blight, *etc*. are collectively causing significant yield losses in soybean. Of late, diseases like rust, *Rhizoctonia solan*i rot and some other diseases have become more serious than before. Yellow mosaic disease, earlier confined to northern India, is now occurring in the predominant soybean belt of central India. Fortunately, sources of genic resistance are available in adapted genetic background that have 'PI 171443' (UPSM 534) in their pedigree as their main source (Singh *et al*. 1974 a,b; Ram *et al*., 1981).

Since the year 1993, soybean rust caused by the fungus *Phakopsora pachyrhizi* is almost regularly damaging the soybean crop in parts of Maharashtra, Karnataka and north-eastern states. Recently, the rust has also spread to several parts of central India. Predominant rust isolates *viz*., India 73-1, Taiwan 72-1 and Taiwan 80-2 and resistance genes are well reported. Each of the soybean genotypes PI 200492, PI 230970 and PI 462312 (Ankur) had a major gene, *i.e.* \`$Rpp_1$', \`Rpp_2' and \`$Rpp_3$' respectively conferring specific resistance to each one soybean rust isolates (Hartwig and Bromfield, 1983). The line PI 459075 carries a single (the fourth) dominant gene *i.e.*, \`Rpp_4' for resistance to all the three rust isolates (Hartwig, 1986). So far, six genes have been globally reported to govern soybean rust. Although the known resistance sources are being tapped in India, there seems to be difference in the isolates and the corresponding resistance sources reported elsewhere and those in India. Molecular marker analysis to re-establish the type/nature of isolates/biotypes or otherwise is urgently warranted to give a sound scientific footing to rust resistance endeavours in India. Apart from host-resistance genes, assessment of fungal gene expression during distinct phases of the host-pathogen interaction is warranted. R*abi*/summer crop of soybean should either not be taken or taken with due care to check the build-up of inoculum and its spread. Of late, two germplasm lines *viz*., EC 241778 and EC 241780, the latter in particular, have been identified to possess a high degree of resistance to rust both under field and epi-phytotic conditions. Using these as parents, varieties *viz*., Phule Agrani (KDS 344) from MPKV (ARS, Kasbe Digraj), KS 103 and DSb 21 (from UAS, Dharwad) possessing field resistance to rust have been developed and released.

Basic and strategic research on diseases, incorporation of resistance and comprehensive management of diseases including use of bioagents are to be taken up as thrust. Molecular characterization of pathogens and their variants/races is needed. New technology such as small interfering RNA (siRNA) or micro RNA (miRNA) are now being used for genetic improvement of crop plants for various characters including disease and pest resistance (Katoch and Thakur, 2013). Recently, this technology is being applied towards host-induced gene silencing (HIGS) to suppress the growth of invading pathogens through the expression of silencing constructs in host plants. This has emerged as a powerful strategy to control fungal diseases (Nunes and Dean, 2012). It is high time to make use of such new tools of science for disease management.

4.6.2. Resistance to insect-pests

Management of insect-pests is also to be taken up on priority. In the predominant soybean growing area in Central India, green semi-loopers (*Gessonia gemma*, *Chrysodeixis acuta* and *Diachrysia orichalcea*), girdle beetle (*Obereopsis brevis*), stemfly (*Melanagromyza sojae*) and blue beetle (*Cneorane sp.*) are the major insect pests. Tobacco caterpillar (*Spodoptera litura*) is a sporadic but serious pest of soybean and there had been its outbreaks in Madhya Pradesh, Rajasthan and Maharashtra. Some other pests like leaf miner (*Bilobata subsecivella*) in Marathwada region, Bihar hairy caterpillar (*Spilosoma obliqua*) in parts of northern plains and Terai region and a few others are also becoming serious. Although some successful attempts of developing resistance sources and breeding lines such as those having gene for resistance to Bihar hairy caterpillar introgressed from *Glycine soja* (Ram *et al.*, 1984, 1989) were made earlier, breeding for insect-pests resistance is now receiving the impetus it deserves. Sources for resistance against girdle beetle (TGX 863x26E, TGX 302-2A, TGX 849-249D, TGX 814-35E, SREC 56A) and against semi-loopers (EC 333902 and VP 1165) have been identified at DSR. These sources possess other desirable traits of high yield and/or early maturity also and have been used in hybridization programmes. Some of the advanced breeding lines *viz.*, G4 P15 (3,585 kg/ha; 94 days), G4 P17 (3,022 kg/ha; 94 days) and G5 P22 (2,636 kg/ha; 84 days) possess insect resistance along with good yield potential and early maturity (Sharma, 2011). On the basis of leaf feeding by *Spodoptera litura* larvae, segregants selected from some crosses *viz.*, PK 416 x TGX 855-53D, JS 335 x TGX 855-53D and PK 472 x EC 34500 exhibited higher degree of resistance than their respective parents (Bhardwaj *et al.,* 2004). Although *Bacillus* spp. containing *cry* genes have been much researched upon and produced expected results, there are already reports of development of resistance against them (Tabashnik *et al.*, 2013). It will be, therefore, appropriate to tap the potential of other insecticidal genes available in diverse sources. Vegetable Insecticidal Proteins (VIPs), cowpea trypsin inhibitors (CpT1), *etc* could be such sources.

RNA interference technology could become a powerful tool in insect management albeit some specialists fear that releasing such gene-silencing agents into fields could harm beneficial insects, particularly among organisms that have a common genetic makeup.

Plant based insecticides (botanical insecticides) have great potential in insect-pest management particularly for resource-poor farmers. Several plant species have appreciable insecticidal properties (Raheza, 1998; Singh, 2000; Sundararajan and Kumuthakalavalli, 2000). Leaf extracts of *Acacia arabica*, *Annona squamosa* and *Datura stramonium* have larval mortality potential as high as 76.6 per cent, 83.3 per cent and 93.3 per cent, respectively (Rajguru and Sharma, 2012). Relatively low efficacy of seed extracts of these plants can be enhanced by exploiting synergistic behaviour of their combinations with *Bacillus thuringiensis* subsp. *kurstaki* (Btk) (Rajguru *et al.*, 2011a). Histological studies of cadavers reveal that *Acacia arabica*, *Annona squamosa*, *Datura stramonium*, *Eucalyptus globulus* and *Ipomoea carnea* exhibit contact action while *Lantana camara*, *Nicotiana tabacum*, *Pongamia pinnata*, *A. arabica* seed, *A. squamosa* seed and *D. stramonium* show stomach action against *Spodoptera litura* larvae (Rajguru *et al.*, 2011b).

In order to rationalize use of pesticides and promote alternative management practices, Integrated Pest Management (IPM) is now gaining desired momentum. Based on component-wise recommendations, the GOI finalized an IPM package for soybean (TMOP, 1998). The package was further updated and refined in 2013 in collaboration with NCIPM (Gupta *et al.,* 2013). ICT is being used for pest surveillance and monitoring to facilitate timely assessment of extent of incidence and faster dissemination of suitable management strategies, thereby avoiding Pestilence situations. The "Crop Pest Surveillance and Advisory Project (CROPSAP) for soybean, cotton, paddy, pigeonpea and chickpea" launched by Government of Maharashtra in 2009, subsequent to severe outbreak of and losses due to *Spodoptera litura*, has brought about much needed awareness among the farmers about adoption of IPM and rational use of chemical pesticides. The entomopathogenic nematodes (EPNs) *viz*., *Steinernema carpocaspae* and *Heterorhabditis indica* could be ideal candidates for inclusion in soybean IPM (Sharma *et al*., 2011).

Climate change has now become an additional determinant in pest management and could significantly impact upon and even reduce the effectiveness of current IPM strategies leading to higher crop losses. Therefore, better knowledge and understanding of pest behaviour under different projected scenarios of climate change is required in order to accordingly adopt and develop new IPM technologies. Available resistant varieties and management practices including botanicals should be adopted by farmers in order to raise the present ceiling of realized yield at farm level. Losses due to pod-shattering and post-harvest handling are also to be minimised.

4.6.3. Resistance to drought / abiotic stress

Soybean suffers from drought and also excess water conditions (the latter especially in and around Hoshangabad district in central India). For improved and stable yields, it would be desirable to develop soybean varieties to cope with drought and excess water stresses prevalent in target environments. In India, soybean cultivars have not been specifically developed for drought and excess moisture stress conditions although tolerance in some lines is reported for these. Variety 'JS 97-52' has, however, been reported to be tolerant to excessive soil moisture. These stress traits are genetically complex and exhibit high G x E interactions. Conventional breeding for these traits is slow and laborious. Systematic efforts are, therefore, needed for identifying sources of tolerance and associated physiological characters. Molecular characterization and allele mining for important genes associated with stress resistance/tolerance should also be undertaken. Some reports are specifically available on drought resistance in soybean.

Selection of genotypes capable of enhanced productivity under drought conditions can be effective in breeding drought resistant varieties (Rosielle and Hamblin, 1981). Accordingly, Joshi and Bhatia (2003) have studied and classified Indian soybean varieties based on their yield potential and drought resistance (Table 3).

Several morphological, physio-logical and biochemical characters have been associated with drought resistance in soybean. Sloane *et al*. (1990) reported that soybean line PI 416937 was less sensitive to drought than currently grown cultivars. The genotype had larger and thicker leaves and was superior in the ability to maintain leaf turgor, transpiration and net C-exchange rates under severe drought stress. Canopy temperature depression, canopy growth and per cent growth cover at early stage (aided by image/ camera / photographic analysis) have also been found useful in several crops. Singh *et al.* (1973) and Sarkar *et al.* (1991) suggested some criteria for identification of

Table 3. Classification of soybean varieties based on yield potential and drought resistance

Category	Varieties
High yielding and resistant to drought	NRC 8, NRC 7, PK 327, PK 564, Hardee, JS 71-05
High yielding and Susceptible to drought	JS 335, PK 308, PK 416, MACS 13, PK 472, Durga. NRC 2, PK 262, Pusa 20, JS 75-46
Low yielding and Resistant to drought	Pusa 24, Kalitur
Low yielding and Susceptible to drought	Pb 1, KHSb 2, JS 80-21, Bragg, Monetta, Gaurav, MACS 58, Pusa 40, Pusa 22, MACS 124, Pusa 16, NRC 1

Source: Joshi and Bhatia (2003)

drought resistance. Characters such as root density, ability to maintain turgor in the tissues, frequent closer of stomata, nitrate-reductase enzyme stability, rate of protein synthesis, heat shock proteins, proline accumulation and lesser increase in abscisic acid are suggested to be used as measure(s) of resistance to drought. Genetic variability for some of these characters directly or indirectly contributes to drought resistance or tolerance in soybean (Shivkumar and Shaw, 1978; Brown *et al.*, 1985; Sarkar *et al.*, 1991). Bhatia *et al*. (2014) have comprehensively reviewed drought resistance and related phenomena and traits in respect of soybean under Indian conditions.

Besides measures of drought-postponement and –avoidance, drought resistance should be aimed at for consistent minimization of yield loss. Resistance mainly rests on yield components *viz*., yield variation in terms of traits affecting water use (WU), water use efficiency (WUE) and harvest index (HI) (Turner *et al*., 2001), as represented by equation Y = WU x WUE x HI (Passioura, 1977). Deep rooting, osmotic adjustment and early vigour leading to early ground cover are the traits associated with WU. A view has been expressed in several studies that the higher WUE is generally achieved through reduction in stomatal conductance which can be counter-productive in terms of accumulation. Therefore, from the agricultural point of view, it is essential to increase WUE without compromising transpiration and, then, such improved genotypes would possess superior mesophyll efficiency to assimilate CO_2 (Udaykumar *et al*., 1998).

Recently, Line EC 538828 has also been identified to have a degree of drought resistance. Variety 'Jackson' and related material including slow wilting genotypes with identified QTLs, as mentioned earlier, are also available that should be made use of. Multi-trait stacking / pyramiding of genes for stress resistance is now facilitated by the availability of molecular markers and QTLs. Breeding methods such as intermating segregants / generations from different bi-parental crosses, use of multi-parent intercross populations, marker assisted recurrent selection (MARS) and others may be employed for hauling in number of quantitative genes and multi-trait QTLs against stress.

Breeding strategy for drought-prone environments has been excellently presented by Reynolds and Tuberosa (2008). The components comprise considering and combining (i) drivers of yield such as water uptake (WU), water use efficiency (WUE) etc., (ii) associated proxy genetic markers such as carbon-isotope discrimination for WUE, canopy temperature for WU etc., (iii) molecular markers associated with relevant QTLs, and finally all these eventually to be translated into (iv) improved cultivars. The challenge is to translate vast molecular and phenotypic data into improved cultivars and practices that are more resilient to drought and other vagaries caused by climate change, by carrying out what the authors call "the translational research" for the benefit of farmers (Collins *et al*. 2008; Reynolds and Tuberosa, 2008). Conservation agriculture and other proven technology/ system should also be used in overall strategy for drought-prone environments.

4.7. Developing specialty soy-beans and special / niche markets

There is a market-driven need to breed and develop specialty soybeans. Soybean unlike other food crops is complex in being an agro-industrial venture. Farm and industry both are needed for production and value addition. Soybean and its products have both direct consumers and industrial users.

Significant achievements have been made in India in identification and development of food product-specific soybean varieties. Varieties suitable for organoleptic acceptance and yield of soy-paneer or 'tofu' have been identified (Bhatnagar *et al*., 1991). Indian soybean varieties have been reported to contain trypsin inhibitor in the range of 35-115 mg per g soy meal (Kumar *et al*., 2001). Lines *viz*., 'NRC 101' and 'NRC 102' have been developed using PI 542044 (a source of null allele) at Directorate of Soybean Research (DSR, Indore) which are devoid of 'kunitz' trypsin inhibitor (KTI). Besides, 'Satt 409' marker tightly linked with 'Ti' locus has been validated and is being used for marker-assisted selection for developing KTI-free soybean varieties (Rani *et al*. 2011). Gene specific marker has recently been deployed in the development of KTI-free variety in the background of a high yielding soybean cultivar *viz*., JS 97-52 (Kumar *et al*., 2013a).

Varieties with comparatively low levels of lipoxygenases *viz*., Pb 1 and Shilajeet have been identified (Kumar *et al*., 2002). Genotypes carrying null alleles for lipoxygenases have been procured from USDA and introgre-ssion of the null alleles into Indian varieties is underway. A new simple sequence repeat (SSR) marker tightly linked to lipoxygenase 1 (Rani *et al*., 2013) and lipoxygenase 2 gene (Kumar *et al*., 2014) was recently identified. Soybean genotypes free from lipoxygenase 2 (principal contributor towards beany flavour) have been developed using marker-assisted forward breeding (Kumar *et al*., 2013b). Marker assisted pyramiding of null-alleles of lipoxygenase 2 and 'kunitz' trypsin inhibitor in the background of high yielding variety 'JS 97-52' is underway.

Genotype 'SL 525' having comparatively low levels (3.5 m moles/100g) of raffinose family oligosaccharides has been identified (Kumar *et al*., 2008). Oligosaccharides in soybean seed were found to be influenced by growing locations but the differences were genotype-dependent (Kumar *et al.* 2010); cooler locations were suggested to be better suited for processing soy-food products with improved taste and flavor. The food-industry has interest in soybean due to different concentrations and compo-sitions of flavonoids in seeds. There, however, is a conflict of interest as soymilk for babies should be low in flavonoid concentration whereas soymilk produced for adults should have a desirable high concentration of flavonoids. At DSR, low isoflavones content genotype *viz*., 'Kegone' (a table variety) and high isoflavones content varieties *viz*., Hardee and ADT 1 have been identified. RNAi silencing construct has been developed at IARI (New Delhi) for inducing seed specific silencing of gene IPK2. This gene, targeted for silencing, is responsible for formation of immediate substrate of phytic acid in soybean that limits phosphorus bioavailability in both livestock and humans.

Lines *viz*., 'Co Soya2' followed by 'Ankur' have been identified at DSR to possess high concentration of tocopherols (Rani *et al*. 2007). Concentration of α-tocopherol was the highest (27.0 %) in 'Ankur' followed by that in 'MACS 124' (26.2 %) while concentration of gamma tocopherol was the highest in 'VLS 1' (69 %) followed by that in 'MACS 13' (67 %). Lines with comparatively high level of oleic acid (>40 %) and low levels of linolenic acid (about 4 %) have been identified. 'VLS 59' has been identified for comparatively low linolenic acid while 'IC 210', 'EC241811' and 'NRC 106' (selection from 'EPS 472') have been identified for high oleic acid.

The two lines *viz*., 'NRC 102' which is free from 'kunitz' trysin inhibitor and 'IC 210', an indigenous line, which has high oleic (42 %), are ready for commercialization. This develop-ment probably also makes it the first laudable step towards promoting specialty soybean and carving a new commercial niche market in India as an Indian corporate body has validated the claims of DSR for these traits and signed a pre-MoU for the procurement of these two lines.

Vegetable soybean is a type of soybean harvested as fresh or frozen vegetable at near R-7 growth stage while the pod is still green and the seed fill is about 80 - 90 per cent. It provides similar protein content, milder flavor, nuttier texture, and is easier to cook when compared with grain soybeans. However, there is no apparent trend to utilize immature soybean as vegetable in India although some vegetable-type lines are available. Variety 'Harit Soya' (Himso, 1563) was released for culinary purpose in 2001 for northern hills of India. Some vegetable-type soybean lines were procured from AVRDC. Selection, 'NRC 105', has also been made in the segregating material at the DSR, Indore. Further, Ranchi and Bangalore centres have also used AVRDC germplasm lines and varieties *viz*., 'Swarna Vasundhara' and "Karune' have been developed and state-released. Nevertheless, exhaustive plant breeding programme, identification of suitable locations for raising vegetable - type soybean, opti-mization of agronomic practices, *etc*. is needed. QTLs for major quality traits in soybean such as oil content, protein content, fatty acids, amino acid content, isoflavone content, *etc*. are well documented and even subjected to meta-analysis (Hu *et al*., 2011). Now in India also, research on identification/validation of major genomic regions associated with oleic acid trait is underway.

Fortunately, there is a growing trend of using DoC (de-oiled cake) in Indian domestic markets that principally spells away the lurking danger of otherwise absolute export-dependence of soybean cultivation and industry. Yet, a lot has to be done for maintaining quality including good agronomic practices (GAP). Indian soybean breeding centres lack awareness and facilities to screen varieties and segregating material for needed parameters of quality. Both strengthening of chosen centres for needed facilities and training to human resource are needed in this regard. It is hoped that sponsored research, sponsored by industry particularly soy-food ventures, will start and gain momentum in this aspect. All said and done, specialty soybean production is presently about 12 per cent globally. In India, food use is about 5 to 7 per cent. Specialty market is small but has a definite niche and is growing. Aggregate demand strategy vs. segregated demand building will give needed resilience to specialty soybean market. Going from commodity to specialty soybean may have a yield drag and would need premium to compensate for yield penalty and risk. Even insurance cover may be needed. Premiums through (i) open market (~20 %), (ii) local cash bid (>50 %), (iii) future price, and (iv) other means, *e.g.* premium as in US/Canada could be the means to promote specialty soybeans. Contract farming for specialty soybean, *e.g.* high oleic acid, low linolelnic, 'tofu', non - GMO, low saturated fat, clear hilum, organic, seed soybean, etc. could also be helpful. Promotion of soy-products and specialty soybeans and also development of niche markets for various soy-products will bring about nutritional security nationally and globally. It will also result in sizeable job-creation through related secondary and tertiary agriculture.

4.8. Hybrid soybean

Soybean is a self-pollinated crop. Still, enhancing the yield and other characters through hybrid vigour appeared to be a realisable possibility in this crop. For posterity, blue sky or long term projects are essential. Hybrid soybean development is one of them. There have been three major obstacles in developing hybrid soybean *viz*., (i) lack of effective ways to avoid self-pollination of female parent, (ii) less information/data on heterosis and low level of hybrid vigour, (iii) difficulty in pollen transfer from male to female parent. Most of these have now been overcome by Huan Sun and his colleagues in China (Soybean Research Center, Jilin Academy of Agricultural Sciences, Changchun, China).

The earlier attempts of using genetic male sterility have recently been replaced by a better option of tapping cytoplasmic male sterility. The first report of cytoplasmic male sterility in soybean came through a USA patent taken by Davis (1985). He used 'Elf', 'Bedford' and 'Braxton' as parents to create a cytoplasmic-nuclear male-sterile line. Later, since 1993, several sources of nuclear-cytoplasmic male sterile lines and their maintainers and restorers were reported in China by Sun *et al*. (1997) and Sun *et al*. (1999) such as 035x167, NJCMS1A and NJCMS1B, W931A and W931B, and FuCMS series. The former one was developed from an interspecific cross, and the latter three were developed from crosses between cultivated parents. In addition, a photoperiod-sensitive male sterile line was also reported to have potential for hybrid seed production. Vectors such as bees and thrips have also been tried for pollination by some researchers. These sources were used in breeding hybrid soybean in China and as a result, the first hybrid "HybSoy 1" was released (Sun, 2009). About 20 per cent realizable heterosis for yield has been documented in soybean. Supplementary measures such as pollinating insect population have been found useful in hybrid seed production.

Although identification of desirable cross combinations giving significantly higher seed yield combined with the use of male sterile lines and methods of producing large quantities of hybrid soybean seed have not yet reached the desirable level of commercial acceptability, India should have preparedness to eventually benefit from hybrid soybean. We may note, as a necessary step, extent of hybrid vigour (as done by Raut *et al*., 1988) in all crosses we make and attempt to improve it. We should introduce the needed sources of cytoplasmic-nuclear male sterility, if needed on *quid pro quo* (something for something, something in return) basis.

5. Environmental and sustaina-bility concerns vis-à-vis yield-centric endeavours in soybean

We need to expand single-minded yield-centric approach to address environmental and sustainability concerns. Manifestation of genetic potential of yield is needed through sustainable means and ways as no development should be fraught with degraded resources and long-term vulnerability. Soybean has certain intrinsic virtues in regard to environmental and sustainability aspects. Soybean is a crop which has advantages of fixing atmospheric nitrogen through biological nitrogen fixation (BNF) and, therefore, needs less nitrogenous chemical fertilizers. Soybean is relatively better poised for climate change particularly CO_2 increase than other vulnerable crops. Soybean yet has no GMOs in India. Organic farming and conservation agriculture are gaining momentum in soybean. Let us briefly look at these aspects with reference to soybean.

5.1. Climate change and soybean

Global climate change is already under way as evident from the increased frequency of occurrence of climate change related events which have tremendous potential and some realized impacts on Indian agriculture. For Indian region (south Asia), the IPCC has projected 0.5 to 1.2^{0}C rise in temperature by 2020, 0.88 to 3.16^{0}C by 2050 and 1.56 to 5.44^{0}C by 2080, depending on the scenario of future development (IPCC, 2007). Despite the beneficial effects of higher CO_2 on several crops, associated increase in temperatures, increased variability of rainfall, resultant variation in length of crop-growing season available, changes in the incidence, distribution and overall dyanamics of pests and pathogens, soil degradation, quality deterioration in produce and other such related direct and indirect effects may impact adversely on crop productivity/production and quality. Although temperature rise will cause a shift in planting dates, which may change the length of growing season yet benefit some areas, the variability in rainfall is seen as a potentially greater management challenge. Agricultural systems are managed eco-systems and are dynamic in nature. As such, the extent of loss may vary but rainfed crops like oilseeds, owing to less availability of water, inputs and overall management may be rendered more climatically-challenged than other high input receiving and well-managed crops.

In the backdrop of climate change, soybean could be a crop of relatively and somewhat better choice. If soybean alternatively occupies such upland areas where rice could be cultivated, a concurrent reduction in methane production could be potentially achievable. Several studies have shown soybean crop to be different from others in some parameters of climate change. Although rising concentration of atmospheric CO_2 is estimated in some studies to possibly have some positive effect on soybean yields (Waggoner, 1984; Allen *et al.*, 1987; Specht *et al.*, 1999), there are reports that indicate a broad range of likely impact on yield varying from positive to negative figures (Adams *et al.* 1998). It is, nevertheless, implied that collateral improvement in the photosynthesis / transpiration ratio (*i.e.*, water use efficiency) would certainly offset some of the negative effects of global warming particularly for a C_3 species like soybean that is often exposed to water stress. Farquhar (1997) even went on to state that: "…doubling the CO_2 concentration is almost like doubling the rainfall…". However, sub-tropical climate of India and the likely effect of climate change may not allow us to bask in the findings reported elsewhere regarding beneficial effects of increased CO_2, *etc*.

Studies conducted in India using CROPGRO-soybean model indicate that present temperatures are within the optimum range of soybean growth, development and yield and do not impede the productivity of the crop (Bhatia *et al*., 2008). Looking at the future climate scenarios, the simulation studies have projected increased yield due to doubling of CO_2 in central India (Lal *et al*., 1999, Mall *et al*, 2004). However, a 3^0 C rise in surface air temperature almost offsets the positive effects of doubling of CO_2 concentration. Soybean rainfed yield increase ranging from 8 to 10 per cent have been projected under different scenarios of climate change in India using InfoCrop-soybean model (Table 5) depending on certain parameters such as demography, technology development, dependence on fossil fuel or other alternative sources, *etc*. The rainfed yield increase has been mainly associated with projected increase in rainfall in the major soybean growing region of central India (MoEF, 2012).

Table 5. Simulated yield estim-ates for soybean under climate change scen-arios

	1961-90 (Current baseline)	2021-50 (A1B)	2071-2100 (A1B)
Yield (kg/ha)	2244	2480	2432
Increase in yield	-	10.5%	8.4%

Source: MoEF, 2012.

Simple adaptation strategies such as change in planting dates and varieties could help in reducing impacts of climate change to some extent (Mall *et al*., 2004). Screening of germplasm for climate-change related adaptation needs to be taken up on a sizeable scale. Crop improvement and varietal deployment strategy would, then, be to use such identified elite lines and cultivars, analyse them genetically and simultaneously go for assembling desired multi-trait genes and identified QTLs in new improved varieties using a suitable breeding method like development and use of multi-parent intercross populations and marker assisted recurrent selection. Besides development of climate resilient genotypes, additional strategies for increasing our adaptive capacity may include development of land-use systems, providing value-added climatic risk-management services to farmers, and improved land-use policies and risk management through early warning system and crop-weather insurance.

5.2. GMO vs non-GMO debate in soybean

There is a very strong demand of Indian soybean DOC in European market due to its non-GMO status. Some countries are paying premium for non-GMO soybean but premium is also available for organic soybean and organic soy-products! As is evident and also elucidated in a review of regulatory and operational mechanisms as related to agro-biodiversity (Tiwari, 2006b), the present commercial concerns of the country make us cautious and do not facilitate development of GMOs/transgenics in crops / commodities where our international trade may be affected such as Basmati rice, soybean or Darjeeling Tea. Nevertheless, regulation is not a static activity and it needs continuous re-visiting based on increased knowledge and experience. Efforts are being made in ICAR towards development of experimental events in soybean for resistance against YMV and insects, as it is felt that the country should be ready with the technology and eventually harness the benefits whenever there is change in market forces and national strategy. Techniques for regeneration of popular and high yielding soybean varieties *viz*., JS 335, NRC 7, NRC 37 and JS 93-05 from three different types of explants (embryonic axis, cotyledonary node and half seed explants) have been standardized (Verma et al., 2009 and 2011). Two gene constructs "antisense replicase" and "Cry 1 F" are being utilized for transformation using *Agrobacterium tumefaciens* carrying pBinAR Vector has been standardized (Rani *et al*., 2012b).

As stated earlier, GMOs in Indian soybean is a debated issue. Between having GMOs and not having GMOs, probably a co-existence model could also be considered in future, if situation then so demands, where desiderata comprising segregation, identity preservation and certification of non-GMO versus GMO product are put in place in this largely export-based crop driven by foreign preference of non-GMO product by some importing countries. There is an additional cost involved in doing this but that could be paid off in the long run. This system of segregation, identity preservation and certification of non-GMO versus GMO products would allow both kinds to co-exist and be accepted, albeit by different groups of growers, buyers and consumers. However, promoting conservation agriculture and organic farming appear suitable under present conditions.

5.3. *New agronomy and organic farming for sustainability and farm-prosperity*

New agronomy is to be developed and promoted to meet the present challenges of yield instability due to stress and climate change, increasing cost of cultivation *etc*. There has been a plant type change in soybean. Short duration, 4-seeded pods and other characteristics have now been introduced in new varieties. New plant types need new agronomy and *vice versa* in order to enhance/manifest the yield potential of soybean. Narrow rows in USA, narrow/paired rows in India, broad bed and furrow, sowing on ridges, conservation agriculture *etc*. have been found to be beneficial. Reducing seed rates using quality enhanced seed to the extent of 50 kg/ ha with row to row distance of 45 cm on ridge planting has already been found promising in some parts of central India. Automated systems and precision agriculture need a pilot experiment and demonstration in suitable areas and conditions. The methods of application of rhizobial inoculants need to be improved by appropriately adopting (i) directly mixing liquid inoculants with seeds before sowing, and/or (ii) in-furrow inoculation i.e. liquid inoculants in furrow as is being done mostly in the occidental countries. Farm machines for land treatment, related sowing, in-furrow inoculation etc. are needed and those have been developed to a sizeable extent for Indian conditions. Some of these new agronomical practices are partially adopted in India, but a lot remains to be done. There is a need to explore the possibility of using nano-technology particularly use of nano-particles in enhancing resource/energy use efficiency. A multidisciplinary project on nano-technology in soybean needs to be initiated in DSR in collaboration with other lead institute like TNAU (Coimbatore), CAZRI (Jodhpur), IISS (Bhopal) etc.

While embracing new technologies, we should also retain and refine farmers' traditional practices and Indigenous Technical Knowledge (ITK). Farmers of Malwa region in central India, where soybean is predominantly grown, have traditional practices such as seed-priming *i.e.* pre-soaking hydration *viz*., soaking of chickpea seed in water before sowing in post

-rainy season, weeding between rows by using bullock (now tractor) -drawn hoe i.e. 'dora' or 'kolpa' and such other useful practices (Tiwari *et al.* 1999; Vinaygam *et al.* 2006). It is this rational clinging to traditions that conservation agriculture and particularly organic farming, in selected crops and situations, is flourishing in Madhya Pradesh. In fact, organic farming and conservation agriculture along with BNF/biofertilizers are intrinsically suited and particularly relevant to soybean to make it a pillar of sustainability in central India.

5.3.1. *Organic farming*

Organic farming is a potent system to provide sustainability to soybean production and resilience to climate change through both mitigation and adaptation as elucidated by Scialabba and Müller-Lindenlauf (2010). The authors point out that the highest mitigation potential of organic agriculture lies in carbon sequestration in soils and in reduced clearing of primary ecosystems. The emission reduction potential is owing to abstention from mineral fertilizers. Organic farming comprises careful management of nutrients and, therefore, leads to reduction in N_2O emissions from soils. On the adaptation side, organic agriculture systems dwell in building resilient production systems in the face of climate change and other uncertainties, through farm diversification and enhancing inherent soil fertility through organic matter (Scialabba and Müller-Lindenlauf, 2010).

It will not be wise to sunder organic farming and precision farming making them exclusive of each other. There is an entire realm of 'precision conservation' or development and use of conservation-oriented precision agricultural systems (Berry *et al.*, 2003; Kitchen *et al.*, 2005). With suitable modification in regard to ingredients to be included (modern automated irrigation systems) or excluded (*e.g.* GMOs), the advanced technology could be applied to organic farming.

Area to be brought under organic farming should be carefully identified rather than abruptly claiming established high yielding regions. Presently there appears a little decrease in soybean productivity under organic farming but such decreases in several other crops in India have been found to be largely compensated by premium price (Ramesh *et al.*, 2008; Ramesh *et al.*, 2010). Such reported decrease in soybean yield under organic farming has to be overcome by adopting suitable organic technology and assured enhanced profitability in the form of premium price, if organic farming is to be sizeably realised in soybean.

Madhya Pradesh, the soybean state, is apparently one of the leading states of India in organic farming on an overall basis. Soybean crop cultivation is conducive to organic farming but the crop still needs a fillip in so far as organic farming is concerned in order to ward-off ill effects of climate change at large, provide for sustainable agriculture and bring increased profit and prosperity to soybean farmers.

5.3.2. *Biological nitrogen fixation (BNF) in soybean*

It is obvious that there are enormous economical and environmental benefits resulting from replacing N fertilizer by BNF. Global estimates show that the BNF contribution averages at about 100 kg N per ha at a soybean grain yield of ~ 2.0 Mg (2.0 t) per ha. Difference of N-removal by inoculated and un-inoculated soybean crop has shown that an additional N uptake of about 15 kg N per ha came from inoculation, along with resultant grain yield increase of 10.1 per cent (Rawat *et al.*, 2013). Initially *Bradyrhizobium japonicum* strain USDA 110 (in formulation *viz*., Nitragin which also contained USDA 6 and USDA 122) was introduced in India from USA probably in late sixties. Present isolates bear significant similarity to this strain (Ansari *et al., 2014).*

Extant strains (or evolved and naturalized group therefrom) may have high competitiveness and occupancy but may not be efficient. Since soils cropped with soybean have high bacterial populations from previous inoculations, more efficient and competitive strains have to be identified and selected (mostly from the existing population) and used for 're-inoculation'. Success of Brazil is worth emulating in this regard where the four strains authorized presently for the production of commercial inoculants in Brazil are efficient and can compete against naturalized population (Hungria *et al*., 2006b). BNF research in Brazil comprises continuous selection for both rhizobial strains and soybean cultivars and has led to yields as high as 5,000 kg ha^{-1} without any top-dressing with N-fertilizer, and rates of BNF exceeding 300 kg of N per ha. The research recommends that the inoculant should be applied to the seeds to allow a population of 1.2 million cells per seed (Hungria *et al*., 2006a). Brazil again has a strong inoculant legislation to guarantee a good contribution of BNF at the field level. In India, Schedule III Part – A of the Fertilizer (Control) Order 1985 gives specifications of biofertilizers to ensure and enforce the quality of biofertilizers.

If there are no efficient and competitive strains made available by selection, then genetic incorporation of promiscuity for nodulation as reported by Pulver *et al*. (1985) and Dashiell *et al.* (1986) could result in efficient nodulation and nitrogen fixation with wide range of available bacterial strains for the ultimate outcome of enhanced yield with high stability.

It is to be noted that in northern and central China, BNF alone apparently cannot meet the N requirement for maximum yield and best results were obtained with top dressing of N fertilizer (50 kg/ha) at V2 (second node stage), and especially at R1 (beginning bloom) stage (Gan *et al.*, 2002, 2003). Unlike Brazil, this may be true for most other countries as well. N-fertilizer application may lead to inhibition of nodulation and nitrogen fixation. N-application, if so required, would then necessitate the use of such super-nodulating genotypes of soybean that have been shown to display a nitrate-tolerant symbiosis in the presence of fertilizer-N at 40 and 180 kg of N per ha (Eskew *et al*., 1989; Song *et al*., 1995).

In order to obviate the incompatibility between inoculation and other agro-chemicals used in seed treatment, pest management and micro-nutrient deficiency etc., there is a need to search for new inoculation practices and/or compatible chemicals that will not hinder rather maximize the BNF process under field conditions. In-furrow inoculation i.e. liquid inoculants in-furrow has been used in Brazil as an attractive alternative, although higher doses of liquid inoculants are required.

Besides enhancing BNF efficiency, augmentation of application of native plant growth promoting micro-organisms (PGPM) is also required. Plant growth promoting rhizobacteria when co-inoculated with *Bradyrhizobium* have resulted in increased nodulation and nitrogen fixation in soybean (Zhang *et al.,* 1996). Also, there is a need to study and take advantage of the mutualistic tripartite symbiosis formed by arbuscular mycorrhizal fungi (AMF), rhizobia and legume plants (Antunes and Goss, 2005). Tripartite symbiosis formed by indigenous AMF, *Bradyrhizobium japonicum* and soybean has been specifically well established under field conditions also in view of the fact that nodule development was enhanced by greater amount of AMF root colonization (Antunes *et al.*, 2006). Further research under Indian conditions with a cropping system approach is needed for identifying desirable strains and host combinations under site-specific conditions and also in regard to (i) tillage, (ii) soil P (as both tillage and high soil P conditions may impede AMF colonization and also nodule formation/N_2 fixation), and (iii) technical difficulties due to obligate biotrophy of AMF.

Thus, there is a need to go beyond rhizobia and develop microbial consortia, biofertilizers rather bio-inoculants and related practices for large scale application in raising the soybean yield ceilings at farm level.

6. Policy, new initiatives and enableing environment

6.1. Market drivers and trend

- Production intensification rather than area increase will be the principal means of meeting future demand i.e. increased soybean production through improved yields and agronomic practices.
- In India, maize could be a competitor for soybean from a viewpoint of yield, profitability, myriad uses and increasing export possibility. Globally, the demand for corn ethanol is the reason for competition between soybeans and corn for acreage in the US and other countries.
- Organic farming in soybean, particularly in central India, may increase if premium price is assured; it could provide for sustainability, farm-prosperity and environment- friendliness; Madhya Pradesh to emerge as the predominant organic-farming state if all other crops/produce are accounted for; demand for related products like lecithin from organically produced soybean will increase.
- Ecosystem Approach, CA, IPM and GAP will be increasingly taken as concepts and elements of sustainable intensification and also for facilitating foreign trade
- Public sector guidelines such as Codex Alimentarius will remain important to ensure food safety, while private sector standards such as Global Gap may become increasingly significant; Expanding Asian markets including India may embrace these guidelines.
- Industry-sponsored research, unlike as in other countries, will remain minuscule in India. Nevertheless, development of specialty soybean and GAP related research may be sponsored by industry, particularly by soy-food ventures, and gain momentum in this aspect. A distinctive niche market for specialty soybean and organic products will keep on gradually expanding.
- Future demand for non-GMO and ID-preserved produce/ products will continue and may increase in some regions like EU.
- GM soybean appears to continue as unacceptable and unfeasible in near future; Madhya Pradesh, the predominant soybean growing state, promotes organic farming.
- Competition between soybean meal, used in animal feed, and the meal/feed from other protein sources could increase. The impact of global demand for biodiesel could also result in development of alternative feedstocks.

- Canola and palm oil (palm oil mainly from Malayasia and canola from northern US and Canada) will continue to give competition to soyoil globally and regionally.
- The development of trans-fat-free soybean oils appears to have the potential to achieve reasonable market share

6.2. Conducive and enabling policy

The oilseed sector suffers from huge import bill, pertaining mostly to edible oil. Easy import of oil (soy-oil from Brazil and Argentina and palm oil from Indonesia and Malaysia) has made the domestic production vulnerable. Import duty on vegetable oils was withdrawn in 2008 when there was apparent price inflation. At present, crude oil can be imported duty-free while refined oil attracts duty. These measures keep on changing on regular reviews. Concerns have been raised that a duty cut (or zero-import duty) on oil may not necessarily help reduce consumer price as the foreign suppliers could jack-up export prices accordingly. Heavy palm oil exports could lower domestic oilseed crushing and result in higher carry-over stocks as has happened in case of soybean in some years (2008-09 when compared with 2007-08). Reviewing the situation and imposition of an appropriate duty is needed which could generate additional revenue without affecting consumers and could boost the confidence of the farmers in expanding the area under oilseeds. Allowing remunerative returns to growers and cross-subsidize edible oil prices for low-income populace may also be considered. The revenue/export earnings from soybean produce/products are huge in value and a part of it could be utilised for soybean development programme appropriately and probably through a Soybean Development Board which may be established.

Indian soybean presently has sizeable export particularly of soymeal which earlier was to the tune of about 5 million tonnes and is presently (year 2012-13) about 3.5 million tonnes, worth about ₹ 10,0000 million. About the same quantity of soymeal is consumed domestically mainly as livestock, poultry and aqua feed. Human soy-food consumption as soy-flour, -nuggets, -lecithin, *etc*. is less than a million ton. A futures exchange, NBOT, also exists. A study conducted by the IIM, Ahmedabad has indicated that the performance of the Indian commodity futures markets, in general, is varied and can be further improved (cited from DAC, 2000). Further, cooperatives should be promoted but these should not be parastatal in nature but should belong to the farmers or select group in real terms. Related legislation, like seed legislation, and other regulatory and operational mechanisms need a relook. Some of these may not be exclusive to soybean. Enforcement of existing laws, for example adhering to label claim in case of pesticides and ensuring quality in bio-fertilizers under Fertilizer (Control) Order, is also important.

Logistics and trans-portation need to be streamlined or else India may lag behind because:

- The crushing industry of Argentina is strategically located on the Port of Rosario and Argentina leads in soymeal and oil production and is placed third in grain exports;
- Brazil and China already have and also have further plan to put new mass transportation system for soy produce/products in place;
- China is providing large concrete bins/silos and bulk transportation for six main route through railways and bulk truck transportation through road is underway;
- Brazil maintains that logistics need more investment both from public and private sector; will get repaid in 3-4 years;

- Leading soybean producing countries are making sizeable investments in these areas and putting needed policies in place. Chinese Govt., for example, (i) exempted all agricultural taxes since 2006, (ii) provided subsidies to the farmers, and (iii) invested heavily in R&D and logistics.

Trade policy and MSP do not fully support soybean. Market price is often higher than MSP. There is no systematic direct procurement from farmers. There is minimum support price (MSP) system in place but supply and demand should be taken into account for fixing of MSP. Provision of procurement should especially be made in new soybean areas.

Direct marketing through SHGs or informal groups, NGOs, cooperatives, Farmers' Associations, Companies, partnership, joint ventures may also be encouraged through various policy back-up and related programmes. Direct marketing by farmers to the consumers was experimented through 'Apni Mandis' in Punjab and Haryana. The direct marketing concept also got popularized in some crop-groups viz., vegetables through Rythu Bazars in Andhra Pradesh and Uzhavar Santhaigal in Tamil Nadu. At present, these markets are being run with the help of State Govt./agencies to inculcate habit of marketing without the help of middlemen by the small and marginal producers of fruit and vegetables. Madhya Pradesh has done a lot to improve procurement and 'mandi' functioning. It will be a welcome feature if, besides grain, green soybean pods and other soy-products like 'tofu' are also sold through direct marketing in India as those are sold in soy-countries of the orient. Unemployed youth could be involved in direct marketing for procurement of orders and supply of graded and packed products to different city dwellers. Involvement of the youth, agri-business related HRD, and needed financial assistance from the public sector to such ventures would generate entrepreneurship and provide profitable employment to the younger generation. Entrepreneurs and industrialists intending to establish new ventures like value addition units/plants particularly for specialty soybeans should have capital availability and needed facilitation. Standards for different soy-based products should be in place and be adhered to. In case of export of oilseeds/DOCs, the need for India is to become more quality conscious and upgrade the processing units in compliance with global particularly EU requirements.

6.3. New initiatives and re- orientations

Although soybean provides oil and other edible products and has great untapped potential, development and promotion of the crop for higher productivity and its products to alleviate mal-nutrition has been far from sufficient. Specific target setting and funding through specific initiatives are needed.

6.3.1. Creation of large teams and robust research platforms

National Agricultural Research System (NARS) has been evolving continually (Tiwari, 1998). In my view, one of the greatest changes in Indian agricultural research has been in the mode of research so as to tap the plurality and breadth of the system. Closure of small individualistic ad-hoc cess fund projects and embarking on mega-projects like those on seed and hybrids, with which I had the fortune of having intimate association, and later NATP are some of the landmarks of this change which eventually led to NAIP and a number of network projects in ICAR. This reform has paid off well in terms of both output and outcome.

In case of soybean, it is high time to form large teams and create robust research platforms for two or three major challenges such as drought, soybean quality and enhancing genetic potential of seed yield *per se*. For example, we may have 'Team Drought Defiance" involving persons across institutes and agencies. We may have at least two robust research platforms - one at DSR (ICAR) and one at a chosen SAU. The platforms will have needed specific genotypes for major challenges, recently developed genetic material (*e.g.* slow-wilting genotypes and material derived therefrom having QTLS for drought resistance from University of Arkansas), specific facilities for research (*e.g.* for drought resistance, for quality in soybean), facilities for phenotyping / phenomics and related field and laboratory facilities, networking and tie-ups to make available national (such as micro-array) and global facilities and expertise, bench-space provision for a small duration in leading laboratories, critical human resource assembled from across institutes/agencies for the coveted purpose, ICT facilities for frequent dialogues, provision for needed HR training in India and abroad and an effective monitoring system having an outsider member also (e.g. economist, social scientist). We may aim to simulate putting researchable issues on a conveyor belt of robust research platform to quickly and smoothly reach the destination of output and outcome in order to carry out "translational research" (terminology after Collins *et al*. 2008; Reynolds and Tuberosa, 2008). As is prevalent in some major soybean countries, the research sponsored by private sector should increase in India also.

6.3.2. Pilot project on soybean production and utilization

A Development Research Project on combining soybean development, soy-product utilization and entrepreneurship development for soy-based secondry agriculture would be very helpful in augmenting productivity, production and utilization of soybean. It could specifically cover low yielding-high potential districts in major soybean producing states such as Madhya Pradesh, Maharashtra, Karnataka, and Rajasthan. After identifying the needs and developing location-wise soybean-based farm-models, the thrust should be on overall enabling of the farmers rather than transfer of a component of technology. Availability of inputs such as suitable improved varieties (as soybean is highly photo-sensitive), seed, fertilizer, pesticide, machineries, *etc*., could be facilitated at appropriate / subsidized rate. Trained extension personnel with good knowledge about improved production technology shall be deployed at block level to guide and monitor the programme. Now, India has several food-product specific soybean varieties. These may be specifically included in the project. Domestic use of soy-protein and related cottage industries (secondary and tertiary agriculture) may be promoted using these specialty soybeans. For implementation of the programme, appropriate support from the centre may be given and a separate planning, coordinating and monitoring cell may be created in the nodal department of the concerned Ministry.

Also, each soybean R&D centre or sub-centre in the country should adopt at least one and preferably three villages for promoting soybean-based overall farm-prosperity. Much can be learnt from the Institute Village Linkage Programme (IVLP) of ICAR in this regard.

6.3.3. Creation of National Soybean Development Board

Presently, soybean is covered under agencies/bodies which deal with agricultural produce and products or at the most oil and oilseeds in general viz., Indian Oilseeds and Produce Export Promotion Council (IOPEPC; formerly IOPEA), Agricultural and Processed Food Products Export Development Authority (APEDA), and the National Oilseeds and Vegetable Oils Development Board (NOVOD). There are also national apex bodies viz., the Central Organisation for Oil Industry and Trade (COOIT) and the Soybean Processors Association of India (SOPA) pertaining to soybean industry that are playing significant role. Soybean is largely a commercial crop and an agro-industrial venture. Soybean production, processing, value addition and utilization have national as well as global intricacies that rest on farmer-industry – buyer - consumer confluence. The crop and its produce and products have shown phenomenal growth necessitating an exclusive body to deal with it nationally and globally. Thus, soybean is a suitable candidate and a need is felt to establish National Soybean Development Board. This board will take care of forward and backward linkages including popularization of varieties and production technologies, supply of critical inputs, procurement, processing/value addition, marketing, trade, export *etc*. to promote the cause of soybean growers, industry and consumers. The Board may also have a Soybean Development Fund under it to take care of strategic R&D needs geared towards promotion of soybean-related commerce for both domestic use and export.

6.3.4. Dissemination of seed of improved varieties through inclusive formal and informal approaches

Seed broadly includes planting/ propagating material or production resources of all living forms. In recent times, seed has also emerged as an important carrier of a combination of inputs. The seed, then, besides being a seed and propagule, could also carry with it the seed treatment chemicals, nutrients, bacterial (*Rhizobium*) culture, protective coating, proprietary marks of identification for product authentication etc. (Tiwari, 2009a). Supply of seed is specifically challenged in case of soybean (Bhatia *et al.*, 2002) as it is 'least storable' and is delicate in nature. Besides being a high volume-low value crop for the purpose of seed, soybean is self-pollinated and, unlike hybrids, its seed may be retained and used by the farmers. As such, private seed companies may be less interested in it than in the crops where hybrid technology is in vogue that necessitates seed change every season/year.

Availability of seed of improved varieties may be augmented using integrated seed supply systems using formal and informal agencies/partners. Barring some mismatch in indent and production, breeder seed is adequately available but its conversion into certified seed has to be monitored for efficient follow-up of seed chain. Integrated seed supply system spans even beyond governmental efforts. Fortunately, Indore (the epicentre of soy-revolution of India) has emerged as one of the neo-seed hubs of the country and many private companies and farmers take up seed production of even high volume-low value crops like wheat and soybean. JNKVV, Jabalpur is already significantly contributing towards soybean seed availability through its 'Jawahar Seed'. Besides these, there is a need to involve farmers themselves in a greater scale especially to improve the quality of farm-saved seed. A large number of farmers' seed cooperative have been established in Madhya Pradesh that also contribute to the cause, many a times in liaison with university and other agencies. Soybean farmers of Madhya Pradesh change/renew their seed less frequently than farmers of Maharashtra although soybean seed production is more in Madhya Pradesh than in Maharashtra. Farmers' participatory approach in seed production can help in fast spread of new varieties and also improve the quality of farm-saved seed. Further, innovative farmers should be selected in each Panchyat who may be supplied 5 -10 kg treated seed each of new/improved varieties. The seed produced from these plots/ informal demonstrations may again be distributed to the farmers for further demonstrations and informal spread. This will help in rapid spread of the newly developed varieties. The dissemination of seed could also be implemented through network of KVKs by utilizing existing distribution of seed minikits.

These initiatives could bring about overall enabling of soybean growers, link the research and developmental efforts at farm level and reduce the yield gap.

Summarizingly, the overview has covered the 'Indian soybean revolution' and main researchable issues such as yield gaps, raising the genetic ceiling of yield, employing new tools of science and related breeding strategies for yield, yield-associated characters, and stress resistance / tolerance, hybrid soybean, specialty soybeans, GMO issue, climate change, organic farming, sustainable agriculture, market drivers and trends and need for conducive and enabling policy. I trust and believe that the desiderata to surmount the challenges as presented in this overview could potentially help facilitate R&D endeavours towards raising the yield ceilings and enhancing the utilization of soybean.

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Regeneration of Three Indian Soybean Cultivar Using Cotyledonary Node Method

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ABSTRACT

We have developed a regeneration protocol through a single shoot using cotyledonary node a rapid and efficient protocol for three Indian soybean cultivars. Two explants were collected from single cotyledonary node and cultured in medium containing N^6-benzylaminopurine (BAP) for germination, BAP and indole-3-butyric acid (IBA) for shoot induction, Gibberellic acid (GA_3) for shoot elongation and IBA for rooting of explants. The best combination of hormones for all genotypes were obtained as germination of seeds on half B5 medium supplemented with 1 mg per l of BAP, shoot induction on full B5 medium having BAP 1 mg per l and IBA 0.2 mg per l and shoot elongation on GA_3 0.750 mg per l in the full MS medium. Under these conditions, the plantlets could be raised within 40-45 days. It was observed that selection of proper medium for regeneration of soybean can overcome genotype associated problems. This regeneration system can be used for soybean transformation.

Key words: *Glycine max*, mature cotyledonary node, shoot regeneration, ANOVA

Soybean [*Glycine max* (L.) Merrill] is widely used as oil and protein source for human and as livestock feed. It is also a source for plastic, adhesive as well as in a variety of items of processed food in industries. It contains 40 per cent of protein and 20 per cent of oil, which is the highest protein among the pulses. In soybean production, USA is in the first position with the annual production of about 80.7 million metric tons, followed by Brazil, Argentina and China. The annual production of soybean in India is 10.12 million metric tons (FAOSTAT, 2009).

The major constraints in soybean production are susceptible to pathogens and pests, environmental stresses, poor pollination and low harvest index. Traditional breeders have made an effort in the development of new cultivars of soybean for disease, pest and herbicide resistance, and increased nutritional value. But, traditional breeding programs are having limitation because soybean germplasm is extremely narrow and the majority of the soybean cultivars in use are derived from very few parental lines (Christou *et al*. 1990). Serkan *et al*. (2005) and Haliloglu (2006) reported that on the basis of efficient plant regeneration protocol, biotechnology can be applied successfully in crop improvement.

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Legumes are the most recalcitrant to *in vitro* manipulation but with great interest routine protocols are obtained for stable transformants for the major grain legumes such as the common bean (*Phaseolus vulgaris*), soybean (*Glycine max*), pea (*Pisum sativum*), peanut (*Arachis hypogea*), and alfalfa (*Medicago sativa*), as well as the model legume, barrel medic (*Medicago truncata*) (Christou, 1992; Puonti-Kaerlas *et al.*, 1990; Russell *et al.*, 1993).

To date many types of primary explants have been used for plant regeneration in soybean *via* direct organogenesis. These primary explants include cotyledonary node (Cheng *et al*., 1980; Barwale *et al*., 1986a, 1986b; Hinchee *et al*., 1988; Wright *et al*., 1986; Shetty *et al*., 1992; Kaneda *et al*., 1997), stem-node (Saka *et al*., 1980; Kim *et al*., 1990), primary leaf tissue (Wright *et al*., 1987a), epicotyl sections (Wright *et al*., 1987b), cotyledons (Mante *et al*., 1989; Franklin *et al*., 2004), plumules (Yang *et al*., 1990), hypocotyls (Kaneda *et al*., 1997; Dan and Reighceri, 1998; Yoshida, 2002) and embryonic axes (McCabe *et al*., 1988; Liu *et al*., 2004). Regeneration through mature cotyledonary node has set rapid regeneration of plants directly from explants which is more time-saving and presented as an effective strategy.

In general, soybean tissue culture is not only time consuming but also genotype dependent (Franklin *et al*., 2004). Each method has a limitation for the production of transgenic plants and the regeneration protocol does not seem high enough for soybean transformation. Therefore, an improvement in the regeneration would contribute to an increase in the production of transgenic soybean. An efficient protocol on regeneration of different Indian soybean cultivars is reported in this study.

MATERIAL AND METHODS

Plant material

Three Indian soybean *cv.* JS 335, JS 95-60 and NRC 37 were used to standardize the regeneration protocol with various parameters. The genotypes were obtained from the Directorate of Soybean Research, Indore, Madhya Pradesh, India.

Basal media and culture conditions

The medium used in this study was MS (Murashige and Skoog, 1962) and B5 (Gamborg *et al*., 1968) supplemented with various concentrations and combinations of plant growth regulators. The media were supplemented with 3 per cent sucrose and were solidified with 0.6 per cent agar, adjusted to pH 5.8 with 1N NaOH then autoclaved at 121-123°C for 20 min before using. The tissue culture room was maintained at 25°C under a light-dark cycle of 16:8 with a light intensity of 60 µmol per m^2 per s.

Explant preparation and regeneration

Dry, mature seeds of all three varieties were sterilized by treating seeds with chlorine gas made by mixing 3.5 ml of 12 N HCl and 100 ml bleach (4 % sodium hypochlorite) for 5-6 h (Di *et al*. 1996). Fifty sterilized seeds were placed in the germination medium (GM) (1/2 B5 supplemented with 3% sucrose, 0.6 % agar and pH 5.8) supplemented with various concentrations of N^6-benzylaminopurine (BAP) (0 mg/l, 1 mg/l, 2 mg/l, 3 mg/l, 4 mg/l and 5 mg/l). The planted seeds were kept in a tissue culture chamber at 26±2°C under cool white fluorescent lights (90-150 µmol photons/m^2/s) in a 18/6 h (light/dark) photoperiod for 5-6 days, or until the cotyledons become green and seed coat split open, but before the first leaves expanded to the length of the cotyledons (Olhoft *et al*., 2003).

Roots and the major portion of the hypocotyls approximately 3-5 mm below the cotyledonary node on the hypocotyls were removed, separating the cotyledons. A vertical cut through the remaining hypocotyls was made with a surgical blade. The epicotyl was subsequently removed and 100 such explants were placed on shoot induction medium (SIM) (full B5 medium supplemented with 3% sucrose, 0.6% agar and pH 5.8) having a constant concentration of BAP (1mg/l) and different concentration of indole-3-butyric acid (IBA) (0 mg/l, 0.2 mg/l, 0.5 mg/l and 1 mg/l). The explants were kept for 10-12 days.

After 12 days, the cotyledonary node were trimmed 1/3 from the explants and the explants with newly developed shoots were transferred to the shoot elongation medium (SEM) (full MS medium supplemented with 3% sucrose, 0.6% agar and pH 5.8) with different concentration of Gibberellic acid 3 (GA_3) (0 mg/l, 0.250 mg/l, 0.500 mg/l, 0.750 mg/l and 1 mg/l). The explants were sub-cultured in fresh SEM medium until the shoots elongated 4-5 cm in length.

When the shoot length reached 4-5 cm, the newly developed shoots were placed in rooting medium (1/2 B5 medium supplemented with 3 % sucrose, IBA 2 mg/l, 0.6 % agar, and pH 5.8). Explants remained in the same rooting medium throughout the rooting. The roots were formed in 15-20 days and rooted explants were shifted to the hardening medium. Explants remained in the hardening medium in 28ºC till the shoots became 60 cm in length. After this the well developed explants were placed in a National phytotron facility, IARI, New Delhi to maturity under a 16/8 h (light/dark) photoperiod and natural light supplemented with 1,000-W high-pressure sodium lamp.

Experimental design and statistical analysis

Four factors including BAP, IBA, GA_3 and soybean genotype were studied with reference to the above described regeneration protocol. The experiment was repeated three times to examine the influence of each factor on the efficiency of the regeneration protocol. Data were analyzed using one-way analysis of variance (ANOVA). The mean value of the treatments was analyzed using Duncan Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Researchers have proved that cotyledonary node is good candidate explant for shoot regeneration (Hinchee *et al*. 1988, Olhoft *et al*. 2007). The present study has some advantages over other methods. First, this system takes less time than other explants used. The whole process of regeneration is shortened to 40-45 days, because, fertile transgenic soybean production requires a short shoot-regeneration time period (Liu *et al.*2004). Secondly, using cotyledonary node as explant may lead fewer calluses on the medium supplemented with high concentration of BAP. Three Indian soybean cultivars were used in the present study to standardize the regeneration protocol, which showed that the protocol is genotype independent.

Effects of hormones on seed germination and shoot regeneration

Germination medium was supplemented with the cytokinin to stimulate shooting. Seeds of three cultivars were germinated on half B5 medium for 5-6 days. The medium was supplemented with BAP at different concentration (1 mg/l, 2 mg/l, 3 mg/l, 4 mg/l, 5 mg/l), in which the germination frequency was 97.2, 98.8, 98.9, 98.7, 98.7 and 98.6 per cent, respectively (data not shown). In a control medium in which no BAP was added and seedlings germinated had dark green cotyledon, thin and long hypocotyl and lateral roots, therefore were not selected for study (Fig. 1a). The seedlings which germinated on 1 mg per l of BAP had 8.1 cm longs on average with green cotyledon and without any lateral roots (Fig. 1b). Length of the seedlings decreased (5.50, 5.48, 4.18 and 2.97 cm) gradually with the increase in hormone concentration (Fig. 1c, 1d, 1e, 1f and Table 1).

The optimum concentration of BAP was observed to be 1 mg per l to produce a healthy shoot in all the variety. But, the shoot length started to decrease when the cytokinin concentration was further increased. This phenomenon is similar to a research on micropropagation of different banana cultivars, where the shoot length increased with higher BAP level until 22.2 μM after which the shoot length also began to fall (Shirani *et al.*, 2010). Tang *et al.* (2012) also reported that increased BAP concentration reduced shoot proliferation and increased the differentiation of abnormal shoots and suppressed the elongation of the shoots.

Table 1. Effect of BAP concentration on the shoot length of soybean explants in germination medium

Treat-ment No	BAP (mg/ l)	Genotype	Mean length of shoots [a]	Treat-ment No	BAP (mg/ l)	Genotype	Mean length of shoots [a]
1	0.0	JS 335	10.65 a	10	3.0	JS 335	6.00 c
2	0.0	JS 95-60	11.23 a	11	3.0	JS 95-60	5.40 c,d
3	0.0	NRC 37	11.14 a	12	3.0	NRC 37	5.04 c,d,e
4	1.0	JS 335	8.10 b	13	4.0	JS 335	4.45 d,e,f
5	1.0	JS 95-60	8.22 b	14	4.0	JS 95-60	4.10 e,f
6	1.0	NRC 37	8.10 b	15	4.0	NRC 37	4.00 e,f
7	2.0	JS 335	5.60 c	16	5.0	JS 335	3.70 f
8	2.0	JS 95-60	5.47 c,d	17	5.0	JS 95-60	2.55 g
9	2.0	NRC 37	5.60 c	18	5.0	NRC 37	2.67 g

[a] *The mean value were calculated from three replicates in each treatment and each replicate was represented by five plants; Values with the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level*

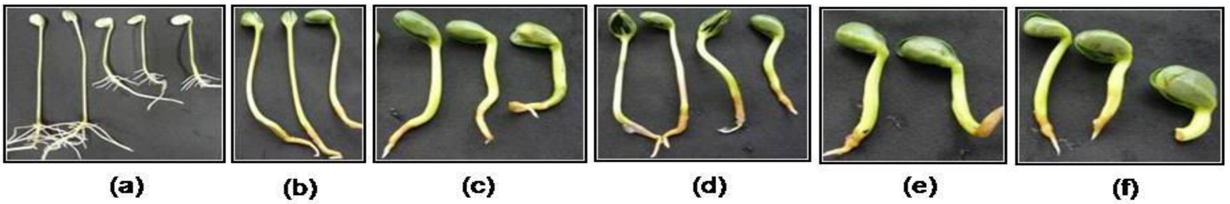

Fig. 1. Germination of Indian soybean cultivar (*cv*JS 335) at different concentrations of BAP: (a) 0 mg/l, (b) 1.0 mg/l, (c) 2.0 mg/l, (d) 3.0 mg/l, (e) 4.0 mg/l, (f) 5.0 mg/l

After the standardization of GM, the cotyledonary node was kept in shoot induction medium to induce the shoots. The medium was provided with cytokinin (BAP) for cell division and auxin (IBA) for shoot induction. The explants were transferred on the SIM to induce the shoots with a constant concentration of BAP (1 mg/l, as standardized in GM) and various concentrations of IBA (0 mg/l, 0.2 mg/l, 0.5 mg/l, 1 mg/l). The data were recorded 10 days after incubation on SIM. All of them produced adventitious single shoots. There were no obvious differences in regeneration frequency between the explants with different combination of hormones (96.6, 97.2, 97.6 and 97.5 %) (Data not shown). Longest shoots obtained on being an average 1.86 cm with the combination of BAP (1 mg/l) and IBA (0.2 mg/l). But, the length of the shoots decreased (1.55 and 1.15 cm) and browning of the contact surface of the cotyledonary node and hypocotyl increased gradually with the increase of IBA concentration (Fig. 2 and Table 2). The desirable concentration for shoot induction was found 0.2 mg per l for all three genotypes. The shoot length decreased and become abnormal below and above to 0.2 mg per l of IBA concentration (Table 2). This finding is supported by observation of Shirani *et al*. (2010) and Tang *et al*. (2012).

Table 2. Effect of BAP and IBA concentration on the shoot length of soybean explants in shoot induction medium

Treatment No	BAP (mg/l)	IBA (mg/ l)	Genotype	Mean length of shoots [a]
1	1.0	0.0	JS 335	1.02 h
2	1.0	0.0	JS 95-60	0.95 h
3	1.0	0.0	NRC 37	1.05 g,h
4	1.0	0.2	JS 335	1.95 a,b
5	1.0	0.2	JS 95-60	1.58 c,d
6	1.0	0.2	NRC 37	2.05 a
7	1.0	0.5	JS 335	1.55 c,d,e
8	1.0	0.5	JS 95-60	1.38 d,e,f
9	1.0	0.5	NRC 37	1.73 b,c
10	1.0	1.0	JS 335	1.30 e,f,g
11	1.0	1.0	JS 95-60	1.00 h
12	1.0	1.0	NRC 37	1.17 f,g,h

[a] *The mean value were calculated from three replicates in each treatment and each replicate was represented by five plants; Values with the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level*

After 10 days in SIM, the induced shoots were placed in SEM with different concentrations of gibbrellic acid (GA_3) (0 mg/l, 0.250 mg/l, 0.500 mg/l, 0.750 mg/l and 1 mg/l). In this study, only GA_3 was used for shoot elongation due to various reasons. First, it is a most powerful growth promoters because they, increase internode spacing. Second, GA_3 controls stem elongation by stimulating both cell division and elongation. Third, GA_3 promotes uniform growth of the shoot through cell enlargement. Fourth, it stimulates plants to grow tall and elongate with light green leaves.

(a) (b) (c) (d)

Fig. 2. Explants (soybean *cv.* JS 335) in shoot induction medium, having different concentration of BAP and IBA: (a) BAP: 1 mg/l, IBA: 0 mg/l, (b) BAP: 1 mg/l, IBA: 0.2 mg/l, (c) BAP: 1 mg/l. IBA: 0.5 mg/l, (d) BAP: 1 mg/l, IBA: 1.0 mg/l

Length of the shoots was measured after 20 days on SEM. Shoots elongated at all concentrations of GA_3. Length of shoots gradually increased up to 0.750 mg per l of GA_3 concentration on average 4.2 cm. But, length decreased (3.21 cm) at 1 mg per l of GA_3 (Fig. 3 and Table 3). This result showed that, increased concentration of GA_3 reduced the shoot length and increased the abnormal shoot formation. Janani and Kumari (2013) used various range of GA_3 for shoot elongation and observed the highest shoot length in the concentration of 10 µM GA_3. They observed less shoot length below and above 10 µM of GA_3.

The ANOVA table showed that the results are significant on single shoot regeneration of mature cotyledonary node ($P<0.01$) (Table 4). The length of shoots was maximized when the explants were kept in optimum concentration of hormones. In similar study by Janani and Kumari (2013), plant growth regulators increased shoot induction, improved shoot elongation and rooting for cotyledonary node.

Table 3. Effect of GA_3 concentration on the shoot length of soybean explants in shoot elongation medium

Treat-ment No	BAP (mg/ l)	Genotype	Mean length of shoots [a]	Treat-ment No	BAP (mg/l)	Genotype	Mean length of shoots [a]
1	0	JS 335	1.88 i,j	9	0.500	NRC 37	2.52 f
2	0	JS 95-60	1.72 j	10	0.750	JS 335	4.04 b
3	0	NRC 37	1.84 i,j	11	0.750	JS 95-60	4.26 a
4	0.250	JS 335	1.86 i,j	12	0.750	NRC 37	4.30 a
5	0.250	JS 95-60	1.94 h,i	13	1	JS 335	3.46 c
6	0.250	NRC 37	1.88 I,j	14	1	JS 95-60	2.98 e
7	0.500	JS 335	2.08 h	15	1	NRC 37	3.20 d
8	0.500	JS 95-60	2.30 g				

[a] *The mean value were calculated from three replicates in each treatment and each replicate was represented by five plants; Values with the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level*

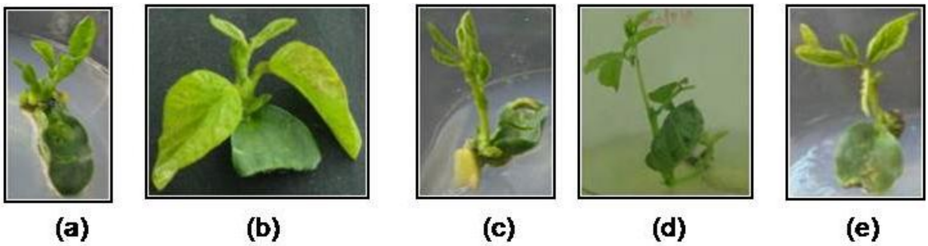

Fig. 3. Explants (soybean cv. JS 335) in shoot elongation medium, having different concentration of Gibbrellic acid: (a) 0 mg/l, (b) 0.250 mg/l, (c) 0.500 mg/l, (d) 0.750 mg/l, (e) 1 mg/l

Table 4. One way ANOVA of shoot regeneration from cotyledonary node of soybean [*Glycine max* (L.) Merrill]

Source	Degree of freedom	Mean square	F-value
Germination of seed	17	37.77	59.31*
e	72	0.64	
Induction of shoots	11	0.57	20.00*
e	36	0.03	
Elongation of shoots	14	4.50	221.24*
e	60	0.02	

*e Experimental error; * Level of difference at P<0.01*

Comparisons of different hormones and genotypes

Result showed that the regeneration frequency was genotype independent and was affected by only plant growth regulator regime in the medium (Verma *et al.* 2011). Single shoot was regenerated on SIM in all the combination of hormones. Whereas, on the 2nd treatment *i.e.*, SEM supplemented with various concentrations of GA_3, single shoot elongated. The results summarized in Tables (1, 2, 3) to illustrate the best combination of the hormones to regenerate single shoot. In Table 1, results show the best combination for germination produced by the medium supplemented with 1 mg per l of BAP for all genotypes. In Table 2, it is evident that the best combination of induction of single shoot is the medium supplemented with 1 mg per l BAP and 0.2 mg per l IBA for all genotypes. From the data in Table 3, it is clear that the medium supplemented with 0.750 mg per l of GA_3 was found best for elongation of shoots for all genotypes.

Comparisons among genotypes

The efficiency of genotypes (JS 335, JS 95-60 and NRC 37) were examined to determine the effect on shoot regeneration. These genotypes had no effect on regeneration efficiency. However, JS 95-60 showed the highest germination percentage followed by JS 335 and NRC 37.

Duration of regeneration using cotyledonary nodes

After sterilization, seeds were transferred on GM for 5-6 days. Two explants were excised from each seedling and placed to SIM. After 10-12 days, single shoot buds emerged which could regenerate directly from the cot node without a callus stage. Hereafter, induced single shoot was transferred on SEM to 3-4 cm long in 20-24 days. Most of the elongated shoots rooted on rooting medium in just 10-15 days. The whole *in vitro* regeneration period was completed in 40-50 days. The rooted plants were hardened in pot mix and transferred to the National phytotron facility to seed production (Fig. 4).

Fig. 4. Rooting and hardening of explants (soybean *cv*. JS 335): (a) Explants in rooting medium, (b) Explants in pot mix, (c) Explants in green house

This was the first study of regeneration of three Indian soybean cultivars using cotyledonary node as explants. Some differences were observed in genotypes with regards to the shoot length, but it was acceptable (Table 2). It was observed that selection of proper medium for regeneration of soybean can overcome genotype associated problems (Verma *et al.* 2011).

Overall, the regeneration period has been shortened to only 40-45 days, which is the shortest duration of soybean regeneration. This regeneration system standardized will be compatible with *Agrobacterium*-mediated soybean transformation and to develop transgenic.

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Evaluation of F_1 Hybrids for Grain Yield Components in Soybean [*Glycine max* (L.) Merrill]

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ABSTRACT

Thirty soybean hybrids derived from crossing ten lines and three testers in a line x tester mating design along with their thirteen parents were evaluated for thirteen yield and yield component characters to estimate heterosis. Eighteen hybrids Doko x JS 335, Doko x PS 1225, Doko x PS 1347, UPSM 534 x PS 1225, AGS 129 x JS 335, AGS 129 x PS 1225, AGS 129 x PS 1347, CM 60 x JS 335, CM 60 x PS 1225, CM 60 x PS 1347, DS 74 x PS 1225, Hardee x JS 335, Hardee x PS 1225, Hardee x PS 1347, PK 1029 x PS 1225, PK 1029 x PS 1347, PS 1042 x JS 335 and PS 1042 x PS 1347 recorded significant positive heterosis over better and standard parent for grain yield per plant. It is primarily due to complementary combination of component traits viz., plant dry weight and number of pods per plant. These heterotic cross combinations could be used for improved yield and enhanced biological production of soybean in future.

Key words: Heterosis, soybean, yield

Soybean is a dominant oilseed crop in the world trade accounting for about 25 per cent of the world's total oil and fats production. India stands at fourth place in area and fifth place in production of soybean at global level. Currently, soybean has occupiedfirst place among the nine oilseed crops in India with a mean national productivity of 1.2t per ha (Anonymous, 2012). Soybean has become the major source of edible vegetable oil and high quality protein for food and feed supplement all over the world. It contains about 40 proteins and 20 per cent oil.

The major thrust area in soybean breeding has been on the development of high yielding varieties for various agro-ecology. To achieve this objective, heterosis breeding has been commercially exploited in many crops. The scope for exploitation of hybrid vigour in soybean will depend on the direction and magnitude of heterosis, feasibility of seed production and the type of gene action involved. Discovery of a male sterile, female fertile mutant by Brim and Young (1971) suggested the possibility of exploiting heterosis in soybean breeding. The estimates of heterosis will help identify

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crosses which can lead to transgressive segregants in early generations. A careful choice of parents for use in any breeding programme is the first important step in the development of the high yielding cultivars. More diverse parents and greater chances of achieving heterotic F_1s exist with broad spectrum genotypes in the segregating generations. Beside *per se* performance, multivariate, heterosis and combining ability analysis have shown to be useful in selecting parents for hybridization. Therefore, the present investigation was undertaken to estimate heterosis for yield and yield components in soybean.

MATERIAL AND METHODS

Thirty F_1 hybrids produced by crossing ten lines (Bhatt, Doko, DS 74, Hardee, UPSM 534, AGS 129, PK 1029, CM 60, DT 21 and PS 1042) with three testers (JS 335, PS 1225 and PS 1347) along with thirteen parents including check PS 1042 were grown in a randomized completely block design with two replication at the N. E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar during *kharif* 2011. Each parental plot had three rows, whereas, one row of F_1s, with 1.5m length, spaced at 45 cm apart, and plant to plant distance was maintained at 5-7cm, and each F_1 plot was filled and guarded by border rows of PS 1347 (narrow leaflet variety) on either side. Five representative plants from each parental line and all F_1s were selected from each replication and tagged. The data for plant height(cm), number of nodes per plant, number of primary branches per plant, number of pods per plant, basal node height(cm), number of seeds per pod, basal pod height(cm), dry matter weight per plant(g), seed yield per plant(g) and harvest index(%) were recorded on these selected plants. Whereas, observations for days to 50 per cent flowering and days to maturity were recorded on whole plot basis, and hundred seed weight were calculated from composite seeds of selected plants. The average values for these characters were calculated and used for statistical analysis. Heterosis was calculated as percentage of deviation of the F_1 mean over better parent (BP) and standard parent (SP) for all cross combinations and all characters studied in the investigation and its significance was worked out with t-test.

RESULT AND DISCUSSION

The analysis of variance revealed significant difference among the genotypes for all the characters studied indicating the presence of variability in the materials studied. The better parent (heterobelteosis) and standard parent (economic) heterosis, either alone or in combination, are presented (Table1).

In the present study, significant negative heterosis over better and standard parents for days to 50 per cent flowering were recorded in two crosses, viz. CM 60 x PS 1347 and PS 1042 x PS 1347. The heterosis for days to 50 per cent flowering ranged from -12.037 to 12.500 and -5.00 to 15.00 per cent over better and standard parents, respectively. The heterosis for days to maturity ranged from -10.27 to 3.167 and -11.556 to 3.111 over better parents and standard parents, respectively. Significant negative heterosis in desired direction (early parent) over better and standard parents were recorded for eighteen crosses, of which Doko x JS 335 showed lowest mean value (99.5). Negative heterosis is desirable for development of early maturing genotype. From these cross combinations, it also appeared that the early parents contributed genes for early maturity and gene interactions. Arya *et al.* (2010) also observed significant negative better parent heterosis for days to 50 per cent flowering and days to maturity. Plants with greater height are likely to lodge quite.

In conclusion, majority of cross combinations manifesting heterosis for seed yield over better parent and standard parent also exhibited heterosis for multiple yield components (Table 2). Cross combinations viz. AGS 129 x PS 1347, CM 60 x PS 1347 and DS 74 x PS 1225 showed better parent and standard parent heterosis for maximum number of yield component traits. Therefore, chances of having good segregants from these crosses are higher and selection of these potential cross combinations in early generations for advancement could ultimately save the time and labour involved in soybean breeding. More over existence of considerable magnitude of heterosis for yield and yield components observed in this study further open up the scope of hybrid in soybean.

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Table 1. Estimates of heterosis in soybean over better parent (BP) and standard parent (SP) in per cents

	Days to 50 % flowering			Days to maturity			Plant height(cm)		
Crosses	F_1	BP	SP	F_1	BP	SP	F_1	BP	SP
Bhatt x JS 335	50.500	-9.009**	1.000	111.000	-3.057**	-1.333	106.00	64.354**	61.585**
Bhatt x PS 1225	54.500	-1.802	9.000**	110.500	-3.493**	-1.778*	114.50	62.112**	74.543**
Bhatt x PS 1347	56.000	.901	12.000**	109.000	-4.803**	-3.111**	100.00	87.617**	52.439**
Doko x JS 335	49.500	-9.174**	-1.000	99.500	-3.865**	-11.556**	74.000	14.738	12.805
Doko x PS1225	56.500	3.670*	13.000**	107.500	-4.018**	-4.444**	55.500	-21.421*	-15.396
Doko x PS 1347	56.000	2.752	12.000**	106.500	-6.987**	-5.333**	60.500	13.508	-7.774
UPSM 534x JS 335	54.000	12.500**	8.000**	114.000	3.167**	1.333	81.750	26.754*	24.619*
UPSM 534x PS 1225	52.500	9.375**	5.000*	100.500	-10.27**	-10.667**	57.500	-18.590	-12.348
UPSM 534 x PS 1347	53.500	11.458**	7.000**	116.000	1.310	3.111**	69.000	29.456*	5.183
DT 21 x JS 335	51.000	-.971	2.000	100.500	-6.512**	-10.667**	89.570	38.879**	36.540**
DT 21 x PS 1225	57.500	11.650**	15.000**	100.500	-10.27**	-10.667**	85.165	20.579*	29.825**
DT 21 x PS 1347	51.000	-.971	2.000	104.000	-9.170**	-7.556**	69.875	31.098*	6.517
AGS 129 x JS 335	55.500	12.121**	11.000**	104.500	1.951*	-7.111**	101.00	56.601**	53.963**
AGS 129 x PS 1225	53.500	8.081**	7.000**	105.500	-5.804**	-6.222**	102.19	44.684**	55.777**
AGS 129 x PS 1347	54.000	9.091**	8.000**	107.500	-6.114**	-4.444**	92.250	73.077**	40.625**
CM 60 x JS 335	48.500	-2.020	-3.000	107.500	2.871**	-4.444**	114.50	77.533**	74.543**
CM 60 x PS 1225	49.500	-1.980	-1.000	110.500	-1.339	-1.778*	127.50	80.518**	94.360**
CM 60 x PS 1347	47.500	-12.037**	-5.000*	107.500	-6.114**	-4.444**	108.20	103.011**	64.947**
DS 74 x JS 335	53.500	-6.957**	7.000**	112.500	.897	.000	124.25	92.651**	89.405**
DS 74 x PS 1225	57.500	0.000	15.000**	112.000	0.000	-.444	96.500	36.628**	47.104**
DS 74 x PS 1347	54.500	-5.217**	9.000**	111.500	-2.620**	-.889	60.00	12.570	-8.537
Hardee x JS 335	51.500	-8.036**	3.000	111.000	-3.057**	-1.333	78.00	20.940	18.902
Hardee x PS 1225	54.500	-2.679	9.000**	113.500	-.873	.889	81.330	15.149	23.979*
Hardee x PS 1347	54.000	-3.571*	8.000**	109.500	-4.367**	-2.667**	62.580	17.411	-4.604
PK 1029 x JS 335	49.500	0.000	-1.000	111.500	2.765**	-.889	65.165	1.039	-.663
PK 1029 x PS 1225	50.000	-.990	.000	108.500	-3.125**	-3.556**	56.750	-18.813	-13.491
PK 1029 x PS 1347	57.500	6.481**	15.000**	109.500	-4.367**	-2.667**	52.665	-1.191	-19.718
PS 1042 x JS 335	49.500	-1.000	-1.000	104.500	-7.111**	-7.111**	55.250	-14.334	-15.777
PS 1042 x PS 1225	49.500	-1.980	-1.000	108.500	-3.556**	-3.556**	57.750	-11.966	-11.966
PS 1042 x PS 1347	47.000	-12.037**	-5.000*	105.500	-7.860**	-6.222**	59.415	11.473	-9.428
	Nodes (No/plant)			Primary branches (No/plant)			Pods (No/plant)		

Table cont....

	F_1	$\overline{BP}$	$\overline{SP}$	F_1	$\overline{BP}$	$\overline{SP}$	F_1	$\overline{BP}$	$\overline{SP}$
Bhatt x JS 335	20.750	46.851**	35.091*	7.625	-1.667	-21.392	115.00	27.170	39.971
Bhatt x PS 1225	12.500	-14.763	-18.620	7.500	4.167	-22.680	95.500	2.876	16.237
Bhatt x PS 1347	19.500	34.205*	26.953	6.415	-1.308	-33.866*	91.375	40.577	11.216
Doko x JS 335	17.625	24.735	14.746	12.500	60.256**	28.866*	146.500	62.004***	78.311**
Doko x PS1225	14.000	-4.535	-8.854	9.000	25.000	-7.216	140.300	3.569	70.764**
Doko x PS 1347	15.700	8.052	2.214	11.000	69.231**	13.402	138.400	112.923**	68.452**
UPSM 534x JS 335	19.250	36.235*	25.326	8.375	9.263	-13.660	146.000	76.116**	77.702**
UPSM 534x PS 1225	16.000	9.103	4.167	7.000	-2.778	-27.835*	139.600	68.396**	69.912**
UPSM 534 x PS 1347	16.500	13.558	7.422	6.500	0.000	-32.990*	101.000	55.385*	22.931
DT 21 x JS 335	16.970	20.099	10.482	8.305	20.362	-14.381	89.970	12.463	9.506
DT 21 x PS 1225	16.165	10.228	5.241	10.00	69.492**	3.093	140.00	75.000**	70.399**
DT 21 x PS 1347	15.125	4.095	-1.530	6.750	14.407	-30.412*	85.000	30.769	3.457
AGS 129 x JS 335	27.500	94.621**	79.036**	8.750	45.833*	-9.794	159.00	95.332**	93.525**
AGS 129 x PS 1225	21.525	46.778**	40.137*	8.750	45.833*	-9.794	243.500	199.140**	196.373**
AGS 129 x PS 1347	25.000	72.058**	62.760**	11.750	95.833**	21.134	205.250	215.769**	149.817**
CM 60 x JS 335	20.675	46.320**	34.603*	9.775	35.201*	.773	130.025	43.785*	58.258*
CM 60 x PS 1225	20.580	40.334*	33.984*	11.580	60.833**	19.381	139.000	18.268	69.182**
CM 60 x PS 1347	19.955	37.337*	29.915	10.625	63.462**	9.536	197.625	204.038**	140.537**
DS 74 x JS 335	26.900	90.375**	75.130**	9.750	39.286*	.515	140.000	54.816**	70.399**
DS 74 x PS 1225	25.500	73.883**	66.016**	14.000	94.444**	44.330**	150.500	11.099	83.179**
DS 74 x PS 1347	17.000	16.999	10.677	8.500	30.769	-12.371	152.750	135.000**	85.918**
Hardee x JS 335	20.000	41.543*	30.208	9.500	43.939*	-2.062	196.500	117.295**	139.167**
Hardee x PS 1225	19.415	32.390*	26.400	8.665	31.288	-10.670	164.500	67.515**	100.219**
Hardee x PS 1347	19.500	34.205*	26.953	11.665	79.462**	20.258	235.830	262.815**	187.037**
PK 1029 x JS 335	15.580	10.262	1.432	7.415	-4.936	-23.557	112.000	39.860	36.319
PK 1029 x PS 1225	16.000	9.103	4.167	7.625	5.903	-21.392	191.000	138.511**	132.473**
PK 1029 x PS 1347	15.415	6.091	.358	8.830	35.846	-8.969	141.415	117.562**	72.121**
PS 1042 x JS 335	17.000	20.311	10.677	9.500	21.795	-2.062	151.000	83.777**	83.788**
PS 1042 x PS 1225	15.625	6.546	1.725	8.450	17.361	-12.887	109.800	33.634	33.642
PS 1042 x PS 1347	16.330	12.388	6.315	8.750	34.615	-9.794	125.250	92.692**	52.446*
	Basal node height(cm)			**Seeds (No/pod)**			**Basal pod height(cm)**		
	F_1	$\overline{BP}$	$\overline{SP}$	F_1	BP	$\overline{SP}$	F_1	$\overline{BP}$	$\overline{SP}$
Bhatt x JS 335	6.000	-29.412	-24.051	2.335	15.025	5.180	17.000	-12.054	-25.110*
Bhatt x PS 1225	4.000	-52.94**	-49.367**	2.200	8.374	-.901	7.500	-61.200**	-66.96**

Bhatt x PS 1347	4.125	-51.47**	-47.785**	2.365	16.502	6.532	12.790	-33.833*	-43.66**
Doko x JS 335	5.875	-28.917	-25.633	2.575	10.515	15.991*	16.000	-30.131*	-29.515*
Doko x PS1225	4.000	-51.60**	-49.367**	2.000	-11.504	-9.910	14.500	-36.681**	-36.123*
Doko x PS 1347	2.510	-69.63**	-68.228**	2.290	5.530	3.153	14.700	-35.808**	-35.242*
UPSM 534x JS 335	7.250	79.012*	-8.228	2.440	8.444	9.910	10.000	-5.794	-55.947**
UPSM 534x PS 1225	5.500	-8.789	-30.380	2.050	-8.889	-7.658	13.000	-8.451	-42.731**
UPSM 534 x PS 1347	6.500	45.089	-17.722	2.000	-7.834	-9.910	11.000	-20.000	-51.542**
DT 21 x JS 335	6.185	40.568	-21.709	2.150	-5.077	-3.153	15.000	-14.286	-33.921**
DT 21 x PS 1225	5.580	-7.463	-29.367	2.380	5.310	7.207	16.000	-8.571	-29.515*
DT 21 x PS 1347	3.250	-27.455	-58.861**	2.210	1.843	-.450	13.000	-25.714	-42.731**
AGS 129 x JS 335	7.500	-6.250	-5.063	2.800	13.360	26.126**	18.000	-40.594**	-20.705
AGS 129 x PS 1225	5.500	-31.250	-30.380	2.505	10.841	12.838	14.610	-51.782**	-35.639*
AGS 129 x PS 1347	3.250	-59.37**	-58.861**	2.450	12.903	10.360	17.000	-43.894**	-25.110
CM 60 x JS 335	5.000	-18.434	-36.709*	2.550	10.629	14.865	15.000	-9.091	-33.921*
CM 60 x PS 1225	3.580	-41.599	-54.684**	2.340	3.540	5.405	13.665	-17.182	-39.80**
CM 60 x PS 1347	3.290	-46.330*	-58.354**	2.300	5.991	3.604	11.955	-27.545	-47.34**
DS 74 x JS 335	6.000	3.448	-24.051	2.500	13.636	12.613	19.750	-33.051**	-12.996
DS 74 x PS 1225	3.000	-50.249*	-62.025**	2.400	9.091	8.108	13.500	-54.237**	-40.53**
DS 74 x PS 1347	3.750	-35.345	-52.532**	2.225	2.535	.225	18.000	-38.983**	-20.705
Hardee x JS 335	6.500	16.071	-17.722	2.450	7.930	10.360	16.000	-27.928*	-29.515*
Hardee x PS 1225	4.665	-22.637	-40.949*	2.290	1.327	3.153	15.000	-32.432**	-33.921**
Hardee x PS 1347	3.500	-37.500	-55.696**	2.530	16.590*	13.964	17.000	-23.423	-25.110*
PK 1029 x JS 335	5.165	15.548	-34.620*	2.430	8.000	9.459	10.290	.734	-54.67**
PK 1029 x PS 1225	4.500	-25.373	-43.038*	2.425	7.778	9.234	8.250	-41.901*	-63.66**
PK 1029 x PS 1347	4.750	6.027	-39.873*	2.280	5.069	2.703	11.915	-13.345	-47.51**
PS 1042 x JS 335	4.500	-43.038*	-43.038*	2.275	2.477	2.477	13.000	-42.731**	-42.73**
PS 1042 x PS 1225	4.210	-46.71**	-46.709**	2.160	-2.703	-2.703	11.625	-48.789**	-48.79**
PS 1042 x PS 1347	9.000	13.924	13.924	2.375	9.447	6.982	17.915	-21.079	-21.079
	Dry matter (g/plant)			**Seed yield (g/plant)**			**100-seed weight(g)**		
	F_1	**$\overline{BP}$**	**$\overline{SP}$**	**F_1**	**$\overline{BP}$**	**$\overline{SP}$**	**F_1**	**$\overline{BP}$**	**$\overline{SP}$**
Bhatt x JS 335	65.000	47.727	32.653	20.325	56.346*	-15.312	6.965	-12.665	-39.75**
Bhatt x PS 1225	50.000	13.636	2.041	23.000	76.923**	-4.167	8.050	.940	-30.36**
Bhatt x PS 1347	45.00	13.924	-8.163	22.600	73.846**	-5.833	7.890	-1.066	-31.75**
Doko x JS 335	81.415	76.989**	66.153**	32.365	70.342**	34.854*	11.230	20.364*	-2.855
Doko x PS1225	66.00	.763	34.694	35.000	112.121**	45.833**	8.955	4.007	-22.54**

Doko x PS 1347	76.000	92.405**	55.102*	34.420	67.902**	43.417**	9.745	-11.930	-15.70*
UPSM 534x JS 335	69.790	74.475*	42.429	30.695	104.633**	27.896	8.675	-7.020	-24.96**
UPSM 534x PS 1225	77.500	93.750**	58.163*	35.800	138.667**	49.167**	9.060	5.226	-21.63**
UPSM 534 x PS 1347	59.000	49.367	20.408	24.890	65.933**	3.708	11.790	23.910*	1.990
DT 21 x JS 335	67.500	46.739	37.755	21.000	31.250	-12.500	12.230	31.083**	5.796
DT 21 x PS 1225	105.330	72.672**	114.959**	30.030	87.688**	25.125	10.670	23.926*	-7.699
DT 21 x PS 1347	58.000	46.835	18.367	18.415	15.094	-23.271	19.230	75.616**	66.349**
AGS 129 x JS 335	105.000	128.261**	114.286**	39.120	152.387**	63.000**	8.945	12.516	-22.62**
AGS 129 x PS 1225	107.500	104.762**	119.388**	38.150	146.129**	58.958**	8.805	10.755	-23.83**
AGS 129 x PS 1347	110.000	178.481**	124.490**	46.00	196.77**	91.67**	8.730	9.811	-24.48**
CM 60 x JS 335	82.250	78.804**	67.857**	34.650	82.368**	44.375**	12.005	28.671**	3.849
CM 60 x PS 1225	88.915	35.748	81.459**	32.500	96.970**	35.417*	11.130	29.268**	-3.720
CM 60 x PS 1347	85.415	116.241**	74.316**	38.745	89.000**	61.437**	9.825	-11.207	-15.009*
DS 74 x JS 335	73.500	59.783*	50.000*	26.450	130.000**	10.208	7.180	8.706	-37.89**
DS 74 x PS 1225	90.000	61.435**	83.673 **	34.00	195.65**	41.67 **	11.385	72.369**	-1.514
DS 74 x PS 1347	67.500	70.886*	37.755	25.790	124.261**	7.458	10.545	59.652**	-8.780
Hardee x JS 335	97.500	111.957**	98.980**	40.200	123.333**	67.500**	11.685	40.276**	1.081
Hardee x PS 1225	98.540	79.164**	101.102**	40.875	147.727**	70.313**	8.265	-.780	-28.50**
Hardee x PS 1347	101.165	156.114**	106.459**	35.155	95.306**	46.479**	8.555	2.701	-25.99**
PK 1029 x JS 335	72.915	58.511*	48.806	29.370	54.579**	22.375	10.265	10.853	-11.202
PK 1029 x PS 1225	92.500	88.776**	88.776**	39.670	140.424**	65.292**	9.460	9.872	-18.166*
PK 1029 x PS 1347	83.330	110.962**	70.061**	35.190	75.950**	46.625**	10.450	12.851	-9.602
PS 1042 x JS 335	83.750	82.065**	70.918**	35.775	88.289**	49.063**	10.170	9.003	-12.024
PS 1042 x PS 1225	68.750	40.306	40.306	30.820	86.788**	28.417	9.175	6.562	-20.63**
PS 1042 x PS 1347	73.955	87.228**	50.929*	36.760	79.317**	53.167**	10.035	-9.309	-13.192
	Harvest Index (%)								
	F_1	**BP**	**SP**						
Bhatt x JS 335	31.270	5.856	-36.158**						
Bhatt x PS 1225	46.000	82.612**	-6.084						
Bhatt x PS 1347	48.88	65.471**	-.204						
Doko x JS 335	39.750	11.626	-18.844*						
Doko x PS1225	53.10	110.798**	8.412						
Doko x PS 1347	45.290	27.183*	-7.534						
UPSM 534x JS 335	43.980	17.280	-10.208						
UPSM 534x PS 1225	46.190	83.366**	-5.696						

UPSM 534 x PS 1347	42.190	12.507	-13.863						
DT 21 x JS 335	31.110	18.605	-36.484**						
DT 21 x PS 1225	28.540	13.299	-41.731**						
DT 21 x PS 1347	31.750	21.045	-35.178**						
AGS 129 x JS 335	37.250	26.186	-23.949**						
AGS 129 x PS 1225	35.490	40.889*	-27.542**						
AGS 129 x PS 1347	41.82	41.667**	-14.618						
CM 60 x JS 335	42.130	51.656**	-13.985						
CM 60 x PS 1225	36.550	45.097**	-25.378**						
CM 60 x PS 1347	45.360	63.283**	-7.391						
DS 74 x JS 335	35.990	74.455**	-26.521**						
DS 74 x PS 1225	37.78	83.131**	-22.866**						
DS 74 x PS 1347	38.210	85.216**	-21.989*						
Hardee x JS 335	41.230	25.970*	-15.823						
Hardee x PS 1225	41.480	64.669**	-15.312						
Hardee x PS 1347	34.750	6.172	-29.053**						
PK 1029 x JS 335	40.280	-1.323	-17.762*						
PK 1029 x PS 1225	42.890	70.266**	-12.434						
PK 1029 x PS 1347	42.240	3.479	-13.761						
PS 1042 x JS 335	42.720	3.438	-12.781						
PS 1042 x PS 1225	44.830	77.967**	-8.473						
PS 1042 x PS 1347	49.710	1.490	1.490						

*BP- Better parent; SP- Standard Parent; *significant at 5% level of probability; **significant at 1% level of probability*

Table 2. Crosses exhibiting significant heterobeltiosis (BP) and economic heterosis (SP) for seed yield and other yield components

Cross	Character
Doko x JS 335	days to maturity, number of primary branches per plant, number of pods per plant, number of seeds per pod, basal pod height, dry matter weight per plant
Doko x PS 1225	days to maturity, number of pods per plant, basal node height, basal pod height
Doko x PS 1347	days to maturity, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
UPSM 534 x PS 1225	days to maturity, number of pods per plant, basal pod height, dry matter weight per plant
AGS 129 x JS 335	days to maturity, plant height, number of nodes per plant, number of pods per plant, number of seeds per pod, dry matter weight per plant
AGS 129 x PS 1225	days to maturity, plant height, number of nodes per plant, number of pods per plant, basal pod height, dry matter weight per plant
AGS 129 x PS 1347	days to maturity, plant height, number of nodes per plant, number of pods per plant, basal node height, dry matter weight per plant
CM 60 x JS 335	days to maturity, plant height, number of nodes per plant, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
CM 60 x PS 1225	days to maturity, plant height, number of nodes per plant, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
CM 60 x PS 1347	days to 50% flowering, days to maturity, plant height, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
DS 74 x PS 1225	plant height, number of nodes per plant, number of primary branches per plant, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
Hardee x JS 335	number of pods per plant, basal pod height, dry matter weight per plant
Hardee x PS 1225	plant height, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
Hardee x PS 1347	days to maturity, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
PK 1029 x PS 1225	days to maturity, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
PK 1029 x PS 1347	days to maturity, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
PS 1042 x JS 335	days to maturity, number of pods per plant, basal node height, basal pod height, dry matter weight per plant
PS 1042 x PS 1347	days to 50% flowering, days to maturity, number of pods per plant, dry matter weight per plant

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Direct and Residual Effect of Zn alone and Incubated with Cow Dung on Growth Characters, Zn Content, Uptake and Quality of Soybean [*Glycine max* (L.) Merrill] –Wheat (*Triticum aestivum* L.) in a Vertisol

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ABSTRACT

An experiment was conducted in a Vertisol at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur during 2007-09 to study the direct and residual effect of Zn levels alone and incubated with cowdung on growth characters and Zn content at different growth stages, uptake, yield and quality of soybean (JS 93 05) and wheat (GW 273). Application of increasing levels of Zn alone and incubated with cow dung and its residual effects significantly increased the dry shoot weight and Zn content of soybean and plant height and leaf area of wheat over control, respectively at different growth stages except leaf area with Zn @ 1.25 kg per ha alone at 60 and 90 days. The application of Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung and its residual effect also increased the Zn content in seed and stover and its uptake by soybean and wheat and available Znafter harvest of soybean and wheat over control, respectively. While the application of Zn @ 5 kg per ha alone and increasing levels of Zn incubated with cow dung significantly increased the yield, protein and oil content of soybean over control. The application of Zn @ 5 kg per ha incubated with cow dung significantly increased the plant height and leaf area at different growth stages of soybean and wheat grain yield over control, respectively. The residual effect of Zn @ 5 kg per ha alone and incubated with cow dung were found significantly superior to Zn @ 1.25 kg per ha alone and incubated with cow dung for Zn content in wheat grain.

Key words: Cow dung, direct and residual effect of Zn, incubation, nutrient content and uptake, soybean, Vertisol, wheat

Soybean-wheat is one of the most important cropping sequences of central India. In India, soybean is cultivated in an area of 9.6 million ha with the production of 12.74 million tonnes having the productivity of 1,327 kg per ha, while, wheat is cultivated in the area of 29.07 million ha producing 86.87 million tonnes with the productivity of 2,988 kg per ha. In Madhya Pradesh soybean and wheat is cultivated in an area of 5.56 million ha and 4.34 million ha with the production of 6.67 million tonnes and 14.93 million tonnes and having the productivity of 1,200 kg per ha and 1,758 kg per ha respectively, during 2010-

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11 (Anonymous, 2012). The lower productivity of soybean and wheat in Madhya Pradesh might be due to wide-spread deficiency of Zn as 71 per cent soil samples analyzed were deficient in Zn (Khamparia *et al.,* 2010). Soybean and wheat respectively, have been reported to be highly and mildly sensitive to Zn deficiency (Havlin *et al.,* 2007). The Zn application in soybean increased the DTPA–Zn content and had a significant residual effect on wheat crop (Barman *et al.,* 1998). To ameliorate Zn deficiency and improvement in produce quality, the Zn fertilizers are used, which hardly have use efficiency of 1-5 per cent due to very high Zn fixation. To improve the use efficiency of applied Zn, the addition of organic manure is recommended to enhance the Zn availability and thereby improving yield and quality of crop produce. Use of cow dung enriched with Zn @ 5 kg per ha is reported to produce the highest pearl millet grain and straw yield (Patel *et al.,* 2004). The information on such aspect for different cropping sequence is not available; hence the present investigation was planned.

MATERIAL AND METHODS

To study the direct and residual effect of Zn levels alone and incubated with cow dung, an experiment was conducted during 2007-08 and 2008-9 at research farm of JNKVV, Jabalpur. The soil of the experimental area had 25.3, 17.9 and 56.8 per cent sand, silt and clay, respectively, pH 7.2, electrical conductivity 0.08 dS per m, $CaCO_3$ 7.3 g per kg, organic carbon 6 g per kg, available N, P, K, and Zn is 182, 16, 228 kg per ha and 0.56 mg per kg, respectively. The treatments comp-rised of 4 level of Zn (0, 1.25, 2.5 and 5 kg/ha) alone and these zinc levels mixed and incubated with 200 kg fresh cow dung for 30 days. There were seven treatments replicated 4 times in a randomized block design. The Zn treatments were applied at the time of sowing of soybean crop only and their residual effect was observed in wheat crop. The recommended doses of N, P_2O_5 and K_2O fertilizers for soybean and wheat applied were @ 30-60-40 and 60-80-40 kg per ha, respectively as a basal dose at the time of sowing. The soybean (JS 93 05) and wheat seed (GW 273) were sown @ 100 and 120 kg per ha with 40 and 22.5 cm row to row spacing on 9.7.2007, 18.12.2007 and 19.7.2008, 25.12.2008 during first and second year, respectively. The 60 kg N per ha was top dressed at the crown root initiation (CRI) stage of wheat. The rainfall received during rainy season of 2007 and 2008 was 956 and 1054.5 mm, respectively. The 5 randomly selected plants per plot of soybean and wheat at 30, 60 and 90 DAS were utilized for the physiological observations of soybean and wheat and Zn content in soybean plant during 2007-8. The seed/grain and stover/straw samples of soybean and wheat were collected at the time of harvest during both the years for analysis of Zn. The soybean and wheat crops were harvested on 24.10.2007 and 23.3.2008 during first year and 23.10.2008 and 23.3.2009 during second year. The Zn content in grain and stover/straw of soybean and wheat were determined in digested diacid (sulfuric and perchloric acid in 2.5:1 ratio) using atomic absorption spectrophotometer (Jackson, 1965). The protein and oil content in soybean grain was determined by AOAC. (1965). The Zn use efficiency was estimated using the following formula.

Zn use efficiency = Zn uptake in treated plot – Zn uptake in control plot/Dose of Zn x 100

RESULTS AND DISCUSSION

Direct effect of zinc on soybean

Growth characters

The application of Zn @ 5 kg per ha incubated with 200 kg of cow dung significantly increased plant height of soybean over control at all the growth stages (Table 1). However, the Zn levels were found to be at par amongst themselves at 30 and 60 days after sowing (DAS). Though the application of Zn @ 2.5 and 5 kg alone and it's all the levels incubated with 200 kg cow dung per ha were found to give significantly higher plant height at 60 DAS over control. While Zn application @ 5 kg per ha alone and incubated with cow dung significantly increased the leaf area over control at all the growth stages of soybean except @ 5 kg Zn per ha alone at 30 DAS, but the Zn levels alone were found to be at par amongst themselves. The leaf area with 5 kg Zn incubated with 200 kg cow dung per ha was found significant over all the Zn treatments at 30 DAS. The incubated Zn levels were found significant over control for leaf area at 60 and 90 DAS but the incubated Zn levels were found at par amongst themselves. The application of increasing levels of Zn alone and incubated with cow dung significantly increased the dry shoot weight per plant over control at all growth stages. However, the dry shoot weight per plant successively and significantly increased with increasing levels of Zn alone and incubated with cow dung at 60 and 90 DAS except Zn @ 2.5 kg alone at 60 DAS. All the Zn alone levels were found at par amongst themselves at 30 DAS. The Zn levels incubated with cow dung were also found significantly superior to the same level of Zn alone, except Zn @ 1.25 kg per ha for dry shoot weight at all growth stages.

The increase of growth characters of soybean namely, plant height, leaf area and dry shoot weight due to the application of Zn as Zn plays important roles in synthesis of tryptophane and production of growth harmones (auxin) likes indole acetic acid which regulates various metabolic reaction (nitrogen metabo-lism) in the formation of chlorophyll and promote photosynthesis and production. Reduced plant growth such as height, leaf area and dry shoot weight in control treatment might be due to reduction in growth hormones production and inhibition of net photosynthesis due to disturbed chloroplast structure, which causes the shortening of internodes and leaves smaller than normal. The increase of plant height, leaf area and dry shoot weight due to Zn application have been reported by Agrawal *et al.* (1996), Khamparia (1996) and Achakzai *et al.* (2002).

The increased plant height, leaf area and significant increase in dry shoot weight of soybean with Zn levels incubated with cow dung over their respective Zn levels alone might be due to higher Zn availability in soil by soluble Zn chelation of applied Zn with fatty acids released on fermentation of cow dung and resulted higher Zn content in soybean plant at different growth stages of soybean with incubated Zn levels than the same levels of Zn alone.

Zn content and uptake

The application of increasing levels of Zn alone and incubated with cow dung significantly increased the Zn content of soybean over control at 30, 60, 90 DAS (Table 1). The Zn content with application of Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung at 90 and 60 DAS were found significantly superior to their respective lower levels of Zn.

Increasing levels of Zn alone and incubated with cow dung significantly

Table 1. Effect of Zn levels alone and incubated with cow dung on growthcharacters and Zn content at different stages of soybean during 2007

Treatment	Plant height (cm)			Leaf area (cm²)			Dry shoot wt (g /plant)			Zn Content (mg/kg)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Control	25.8	41.2	43.9	33.2	39.5	40.1	5.20	15.56	17.57	1.1	14.4	15.1
Zn @ 1.25 kg/ ha	26.1	43.7	45.0	33.7	43.5	43.9	5.75	15.73	17.72	1.3	16.0	21.0
Zn @ 2.5 kg/ ha	26.1	44.3	45.3	33.9	44.0	44.3	5.82	15.78	17.87	1.8	17.0	25.7
Zn @ 5.0 kg/ ha	27.2	44.7	45.5	35.5	45.1	46.0	5.87	16.02	17.97	2.0	18.5	28.4
Zn @ 1.25 kg /ha + cow dung @ 200 kg/ha	26.6	44.4	45.7	35.2	45.6	46.0	5.87	16.08	18.00	1.4	16.6	21.2
Zn @ 2.5 kg/ha + cow dung @ 200 kg/ha	27.5	44.9	45.6	35.6	47.8	48.2	6.00	16.27	18.17	1.9	17.2	26.0
Zn @ 5.0 kg/ha + cow dung @ 200 kg/ha	28.6	45.1	46.6	38.3	48.9	48.9	6.12	16.52	18.47	2.1	18.6	29.6
SEm (±)	0.86	0.89	0.8	0.8	1.7	1.76	0.04	0.05	0.03	0.04	0.4	0.96
C D (P = 5 %)	**2.6**	**2.7**	**2.2**	**2.4**	**5.2**	**5.23**	**0.13**	**0.16**	**0.09**	**0.1**	**1.0**	**2.84**

increased the Zn content in seed and stover of soybean over control (Table 2). However, the Zn content in seed and stover with 2.5 kg Zn per ha alone and incubated with cow dung was found significantly superior to 1.25 kg Zn per ha alone and incubated with cow dung, respectively. The application of Zn @ 5 kg per ha alone and incubated with cow dung was also found significantly superior to Zn @ 2.5 kg per ha alone and incubated with cow dung for Zn content in seed and stover except in case of stover with Zn @ 5 kg per ha incubated with cow dung. The increase of Zn content at 30, 60 and 90 DAS and in seed and stover at harvest with increasing levels of Zn might be due to increase in the availability of Zn with increasing levels of Zn. The higher Zn content with incubated Zn levels than Zn alone might be due to chelation of Zn with fatty acids released on fermentation of cow dung due to incubation which increased the Zn availability more than Zn alone levels hence increased the Zn content in plant parts. The increase of Zn content in seed and stover with Zn application was reported by Khamparia *et al.* (1984) and Sharma *et al.* (1987).

The uptake of Zn by seed and stover of soybean significantly increased with increasing levels of Zn alone and incubated with cowdung over control except in case of stover with application of Zn @ 1.25 kg per ha alone but the Zn uptake by stover between Zn @ 2.5 and 5.0 kg per ha alone and incubated Zn levels was found non-significant (Table 2). However, the Zn uptake by seed and total Zn uptake by soybean progre-ssively and significantly increased with increasing levels of Zn alone and incubated with cow dung. While the Zn uptake by stover with Zn @ 5 kg per ha alone and 2.5 and 5 kg per ha incubated with cow dung was found significant over Zn @ 1.25 kg per ha alone and incubated with cow dung, respectively but the difference between Zn @ 2.5 and 5 kg per ha levels was found non-significant. However, the total Zn uptake by soybean with Zn @ 5 kg incubated with cow was found significantly superior to Zn @ 5 kg alone. The increase of Zn uptake with increasing levels of Zn alone and incubated with cow dung might be due to increase of Zn content in seed and stover and soybean yield as a result of increased Zn availability in the soil. The higher Zn uptake due to Zn application was also reported by Deverajan and Ramanathan (1995) and Dubey *et al.* (1999).

Protein content

The application of Zn @ 5 kg per ha alone and increasing levels of Zn incubated with cow dung significantly increased the protein content in soybean seed over control (Table 3). However, the protein content with increasing Zn levels incubated with cow dung were found significantly superior to Zn @ 1.25 kg per ha alone but the Zn levels were found at par amongst themselves. The lowest protein content at control might be due to inhibition of protein synthesis under Zn deficiency and lower activity of Zn containing RNA polymerase. The increase of protein content in soybean seed with increasing Zn levels might be due to synergistic effect of Zn application on N availability in soil and also as Zn helps to increase nodulation and more leg haemoglobin formation (Saxena and Rewari, 1990). The higher protein content in Zn incubated with cow dung was possibly due to higher Zn availability as a result of Zn chelation by the addition of cow dung as organic matter. The increase of protein content with Zn application was also reported by Sharma and Dixit (1987).

Oil content

The application of Zn @ 5 kg per ha alone and increasing levels of Zn incubated with cow dung were found significantly

Table 2. Effect of Zn levels alone and incubated with cow dung on Zn content and uptake by soybean (pooled data of 2007 and 2008)

Treatment	Zn content (mg/kg)		Zn uptake (g/ha)		Total Zn uptake (g/ha)
	Seed	Stover	Seed	Stover	
Control	40.1	17.6	49.5	29.3	78.7
Zn @ 1.25 kg/ ha	48.3	21.3	64.4	38.4	102.8
Zn @ 2.5 kg/ ha	54.2	24.7	76.9	47.5	124.4
Zn @ 5.0 kg/ ha	60.4	27.4	93.3	56.1	149.4
Zn @ 1.25 kg /ha + cow dung @ 200 kg/ha	50.4	21.8	70.4	40.0	110.3
Zn @ 2.5 kg/ha + cow dung @ 200 kg/ha	55.2	27.5	82.4	54.4	136.8
Zn @ 5.0 kg/ha + cow dung @ 200 kg/ha	63.8	29.5	102.1	62.9	165.0
SEm (±)	1.60	0.70	3.70	3.40	4.60
C D (P = 5 %)	**4.50**	**2.10**	**10.50**	**9.70**	**13.10**

superior to control (Table 3). Though the application of Zn @ 2.5 and 5 kg per ha incubated with cow dung were also found significant over Zn @ 1.25 kg per ha. However, the application of Zn @ 5 kg per ha incubated with cow dung was found significantly superior to Zn @ 1.25 kg per ha incubated with cow dung and all levels of Zn alone. The increased oil content with Zn application might be due to activation of NADPH dependent dehydro-genase involved in fat synthesis (Iweive and Weiner, 1972). Similar findings have been reported by Muralidhardu and Singh (1990) in the past.

Soybean yield

The seed yield of soybean significantly increased with the application of Zn @ 2.5 and5 kg per ha alone and increasing levels of Zn incubated with cowdung over control but the difference between Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung was found non-significant (Table 3). The application of Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung was also found significantly superior to control for stover yield of soybean. However, Zn @ 5 kg per ha alone and incubated with cow dung was also found significantly superior to Zn @ 1.25 kg per ha alone and incubated with cow dung for seed and stover yield but the adjacent Zn levels were found at par for seed and stover yield. The increase of soybean yield with the Zn application might be due to response of Zn in Zn deficient soil. The cow dung incubated Zn levels gave higher seed and stover yield than Zn levels alone might be due the higher values of plant height, leaf area and dry shoot weight per plant with incubated Zn levels than Zn alone. Krishna and Singh (1992) and Sharma and Bapat (2000) reported response of crop to applied Zn in the Zn deficient soil. The

Table 3. Effect of Zn levels alone and incubated with cow dung on yield and quality of soybean and post harvest available Zn (pooled data of 2007 and 2008)

Treatment	Protein content (%)	Oil content (%)	Seed yield (t/ha)	Stover yield (t/ha)	Available Zn (mg/kg)
Control	34.42	16.25	1.23	1.70	0.48
Zn @ 1.25 kg/ ha	35.94	16.85	1.33	1.78	0.57
Zn @ 2.5 kg/ ha	36.63	17.16	1.41	1.92	0.78
Zn @ 5.0 kg/ ha	37.62	17.75	1.54	2.04	1.01
Zn @ 1.25 kg /ha + cow dung @ 200 kg/ha	38.25	17.74	1.39	1.84	0.60
Zn @ 2.5 kg/ha + cow dung @ 200 kg/ha	38.69	18.31	1.48	1.97	0.93
Zn @ 5.0 kg/ha + cow dung @ 200 kg/ha	38.89	19.50	1.60	2.13	1.24
SEm (±)	0.77	0.44	0.05	0.07	0.03
CD (P = 5 %)	**2.22**	**1.28**	**0.14**	**0.20**	**0.08**

increased soybean yield due to cow dung application and pearl millet grain and straw yield with cow dung enriched with Zn @ 5 kg per ha was reported by Ndaeyo *et al.* (2000) and Patel *et al.* (2004).

Residual effect of Zn on wheat

Growth characters

The residual effect of Zn levels alone and incubated with cow dung significantly increased the plant height of wheat over control at 30, 60 and 90 DAS during 2007-08 (Table 4). However, the plant height significantly increased with residual levels of Zn @ 1.25 and 2.5 kg per ha incubated with cow dung over the same dose of Zn alone, but the residual effect of Zn levels alone were found at par amongst themselves at 30 DAS. The residual effect of Zn @ 2.5 kg per ha alone and incubated with cow dung was found significantly superior to Zn @ 1.25 kg per ha alone and incubated with cow dung at 60 and 90 DAS. While the residual effect of Zn levels alone and incubated with cow dung significantly increased the leaf area of wheat plant over control at 30, 60 and 90 DAS, except with Zn @ 1.25 kg per ha alone at 60 and 90 DAS. However, the Zn levels incubated with cow dung significantly increased the leaf area over their respective Zn level alone at all the growth stages except with Zn @ 1.25 kg per ha incubated with cow dung at 60 DAS. The leaf area with residual effect of Zn @ 5 kg per ha incubated with cow dung also found significant over residual effect of Zn @ 1.25 kg per ha incubated with cow dung at 30, 60 and 90 DAS, but the difference between residual effect of Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung was found non-significant at 60 and 90 DAS. The increase of plant height and leaf area of wheat plant with the residual effect of Zn levels alone and incubated with cow dung might be due to higher Zn availability as a result of Zn application in soybean.

Zn content and uptake

The residual effect of Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung significantly increased the Zn content in grain and straw and their uptake over control. Though the Zn content in grain and their Zn uptake with residual effect of 1.25 kg Zn alone and incubated with cowdung was also found significantly superior to control. However, the residual effect of Zn @ 5 kg per ha alone and incubated with cow dung was found significantly superior for Zn content in grain and straw and their Zn uptake as well as total Zn uptake to Zn @ 2.5 kg per ha alone and incubated with cow dung respectively. The Zn content in grain and straw, Zn uptake by grain and total Zn uptake were found significantly superior with residual effect of Zn @ 5 kg per ha incubated with cow dung to residual effect of Zn @ 5 kg per ha alone. The higher Zn content in wheat grain and straw and its uptake by grain, straw and total Zn uptake might be due to higher residual Zn availability (Table 3). The residual effect of Zn levels in Zn content in and uptake by grain and straw of wheat was also reported by Math and Trivedi (2000), Varshney *et al.* (2008) and Dubey *et al.* (1999).

Wheat yield

The residual effect of Zn @ 2.5 and 5 kg per ha alone and incubated with cow dung was found significantly superior to control (Table 5). However, the residual effect of Zn @ 5 kg per ha incubated with cow dung was found significantly superior to Zn @ 1.25 and 2.5 kg per ha alone and Zn @ 1.25 kg per ha incubated with cow dung for wheat grain yield. The residual effect of Zn levels alone and incubated with cow dung also increased the straw yield over control, but the Zn treatments were found non-significant. The higher wheat yield with increasing levels of Zn and incubated with cowdung might be due to higher plant height and leaf area of wheat with incubated Zn levels than Zn alone levels (Table 3). The increased wheat yield might be due to the beneficial residual Zn availability in the soil (0.60 to 1.24 mg/kg) after harvest of soybean. The residual effect of Zn levels on succeeding wheat after harvest of soybean yield also have been reported by Barman *et al.* (1998) and Mehla (2004).

Available Zn content after harvest of soybean and wheat

The data presented in table 3 and 5 revealed that the application of increasing levels of Zn alone and incubated with cow dung and its residual effect successively and significantly increased the available Zn content in soil after harvest of soybean and wheat. However, incubation of Zn @ 2.5 and 5 kg per ha with cow dung and its residual effects were found significantly superior to the same levels of Zn alone after soybean and wheat. The increasing levels of Zn alone and incubated with cow dung and its residual effect might have increased the availability of Zn in soil after harvest of soybean and wheat, respectively. Barman *et al.* (1998) reported that the application of Zn in soybean increased the DTPA-Zn content in soil and had a significant residual effect on wheat. The higher Zn availability with Zn fertility was also supported by Chitdeshwari and Krishnaswami (1998) and Ravanker *et al.* (2002). The increased Zn availability with Zn levels incubated with cow dung might be due to soluble Zn chelation by alifattic acid

Table 4. Residual effect of Zn levels alone and incubated with cow dung on growth characters during 2007-08 and Zn content and uptake by wheat (pooled data of 2007-08 and 2008-09)

Treatment	Plant height (cm)			Leaf area (cm²)			Zn content (mg/kg)		Zn uptake (g/ha)		Total Zn uptake (g/ha)
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	Grain	Straw	Grain	Straw	
Control	78.6	101.8	102.3	31.25	57.27	80.7	25.4	6.8	115.9	34.9	150.8
Zn @ 1.25 kg/ ha	80.6	102.5	103.1	33.24	61.02	86.26	28.8	7.3	138.0	39.0	177.1
Zn @ 2.5 kg/ ha	81.0	103.9	104.4	33.57	63.61	91.49	30.8	8.5	156.6	48.1	204.7
Zn @ 5.0 kg/ ha	81.9	104.8	105.3	34.99	64.56	95.81	34.6	10.0	182.2	56.5	238.7
Zn @ 1.25 kg /ha + cow dung @ 200 kg/ha	82.8	106.2	106.6	35.37	64.47	99.34	29.7	7.4	144.1	40.1	184.2
Zn @ 2.5 kg/ha + cow dung @ 200 kg/ha	83.1	107. 5	108.1	36.47	69.29	103.8	31.4	9.3	164.8	53.9	218.7
Zn @ 5.0 kg/ha + cow dung @ 200 kg/ha	83.9	109.1	109.6	40.87	73.21	109.2	36.6	10.7	202.7	62.4	265.1
SEm (±)	0.5	0.14	0.2	0.58	1.69	1.99	0.80	0.20	**6.97**	2.31	8.04
CD (P = 5 %)	1.4	0.4	0.6	1.72	5.03	5.92	2.20	0.60	20.13	6.67	23.21

released on fermentation of cow dung. Meena *et al.* (2006) also confirms the findings of increased DTPA- Zn content in soil with the application of Zn enriched FYM.

Zn use efficiency

The Zn use efficiency decreased with increasing levels of Zn alone and incubated with cow dung (Table 5). The decreased Zn use efficiency with increasing Zn levels might be due to higher Zn fixation with higher Zn levels than lower levels and disproportionate increase of Zn content in seed/grain and straw and their uptake by soybean and wheat. The higher Zn use efficiency with incubated Zn levels than Zn alone might be due to higher Zn availability in soil due to Zn chelation by aliphatic acid present in cow dung helped to increase the Zn content, uptake and yield of soybean and wheat crop. The decrease of Zn use efficiency with increasing levels of Zn and increase of Zn use efficiency with FYM also reported by Chaube *et al.* (2007).

Table 5. Residual effect of Zn levels alone and incubated with cow dung on wheat yield, post harvest available Zn and Zn use efficiency in soybean- wheat sequence (pooled data of 2007-08 and 2008-09)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Available Zn (mg/kg)	Zn use efficiency (%)
Control	4.51	5.13	0.50	-
Zn @ 1.25 kg/ ha	4.82	5.40	0.57	4.24
Zn @ 2.5 kg/ ha	5.01	5.57	0.79	3.96
Zn @ 5.0 kg/ ha	5.28	5.69	0.97	3.27
Zn @ 1.25 kg /ha + cow dung @ 200 kg/ha	4.91	5.48	0.61	5.49
Zn @ 2.5 kg/ha + cow dung @ 200 kg/ha	5.19	5.78	0.89	5.03
Zn @ 5.0 kg/ha + cow dung @ 200 kg/ha	5.54	5.81	1.15	4.04
SEm (±)	0.17	0.20	0.01	0.53
CD (P = 5 %)	**0.49**	**NS**	**0.03**	**NS**

Application of increasing levels of Zn alone and incubated with cow dung and its residual effect significantly increased the Zn content in seed / grain and stover / straw and their uptake by soybean and wheat respectively and available Zn over control except Zn uptake by soybean stover with Zn @ 1.25 kg per ha alone and Zn content in wheat straw and its uptake with Zn @ 1.25 kg per ha alone and incubated with cowdung. The application of Zn @ 2.5 and 5 kg per ha alone and its residual effect significantly increased the soybean and wheat seed/grain yield, respectively over control. The protein and oil content of soybean were found significantly higher with Zn @ 5 kg per ha alone than control. However, these qualities of soybean were found significantly superior with Zn @ 1.25 kg per ha incubated with cow dung over control. Thus, the application of Zn incubated with cow dung gave higher protein and oil content of soybean, yield, Zn content and uptake of soybean and wheat as well as available Zn after harvest as compare to Zn alone.

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Soybean Productivity and Sustainability as Affected by Irrigation Scheduling Under Different Agro-Ecological Regions of India

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ABSTRACT

The field experiments were conducted at 6 locations of three agro-ecological zones namely, North plain, Central and Southern zone of soybean under All India Coordinated Research Project on Soybean during 2009 to 2011 to study the effect of irrigation levels on productivity and sustainability of soybean. The results accrued over three years across the centres revealed that the soybean yield significantly increased as the levels of irrigations were increased when long dry spells prevailed during the critical stages of the crop. The yield enhancement was to the tune of 6 to 119 per cent as compared to control (no irrigation). Among the critical stages, the seed filling stage was found to be the most sensitive one followed by flower initiation and seedling stage. The maximum sustainability yield index and stable performance of the soybean was associated with three irrigations at seedling, flower initiation and seed filling stage. The maximum water use efficiency was recorded with two irrigations at seedling + flower initiation stage in North plain and Southern zone while it was maximum with flower initiation + seed filling stage. However, the highest net returns were associated with three irrigations at seedling + flower initiation + seed filling stage.

Key words: Irrigation, soybean, stability, sustainability yield index

Soybean is the most important oil crop of the world as well as of India. Soybean is predominantly grown as rainfedcrop in semi-arid regions of India mainly occupied by Vertisols and associated soils. These soils need more attention for soil moisture and nutrient management aspects for maximization of soybean yield. In India, seed yield of soybean is very low as compared with its yield potential of cultivars grown and the yield harnessed by other soybean growing countries. Soybean being a rainfed crop, the production is often limited by a large variation in amount and distribution of rainfall. There are many factors limiting soybean production. Among several factors limiting the productivity of soybean, maintenances of soil moisture is of prime importance. All the physiological processes of plant are directly and indirectly influenced by water availability to plant. Plant water requirements vary as a function of the species, soil, and weather conditions during the growing season (Scott *et al.,* 1987). For example, water requirements for soybeans are higher during anthesis and the pod filling period (Doss *et al.,* 1974). Studies on irrigation scheduling for soybean have demonstrated

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that avoiding irrigation during the vegetative stages could result in yields as high as those obtained if the crop was irrigated during the entire growing season (Ashley and Ethridge, 1978; Elmore *et al.*, 1988; Spetch *et al.*, 1989). This practice allows for more stress during the less critical growth periods such as vegetative growth, but reduces plant water stress during the critical growth periods such as reproductive growth and grain filling. It is well known that the overall root length of soybean increases under water stress (Hoogenboom *et al.*, 1987b) whereas its shoot growth rate is reduced but then compensated during periods of rainfall with a result of a small shoot/root ratio during early season, which is considered an excellent strategy for maintaining turgor during critical seed-filling stages (Hoogenboom *et al.*, 1987a). As a practical consequence, this could result in an improvement of irrigation water use efficiency, mainly due to elimination of irrigation during the vegetative stages, when soil evaporation is the main cause for water loss (Neyshabouri and Hatfield, 1986). More recently, Dogan *et. al.* (2007) revealed that any drought stress imposed during R3 (beginning of pod), R5 (beginning of seed), and R6 (full seed) stages resulted in a substantial yield reduction when compared with the full irrigation treatment under semi-arid climatic conditions. Several studies conducted for a wide range of environments have demonstrated that soybean yield increases with irrigation (Karam *et al.*, 2005; Dogan *et al.*, 2007; Sincik *et al.*, 2008; Bajaj *et al.*, 2008; Gercek *et al.*, 2009). Rainfall is highly variable during the growing season, under such conditions; supplemental irrigation during dry periods during the growing season is often needed to ensure a high yield (Nijbroek *et al.*, 2003; Karam *et al.*, 2005).

Keeping in view, the present investigation was initiated to study the effect of irrigation levels on soybean productivity and sustainability in India.

MATERIAL AND METHODS

The field experiments were conducted at **7** locations of three agro-ecological zones namely-North plain (Ludhiana) with variety SL 525, Central (Kota, Amravati and Parbhani) with variety JS 97 52and Southern (Pune, Coimbatore and Bengaluru) zone with variety RKS 18 of soybean under All India Coordinated Research Project on Soybean during 2009 to 2011. At Ludhiana centre, the experiment was vitiated during 2010 due abnormal weather conditions.In all eight treatments of irrigation schedule viz., Irrigation at seedling stage (15-20 DAS), Irrigation at flower initiation, Irrigation at seed filling (20 days after flower initiation), Irrigation at seedling stage (15-20 DAS) + flower initiation, Irrigation at seedling stage (15-20 DAS) + seed filling (20 days after flower initiation), Irrigation at flower initiation + seed filling (20 days after flower initiation), Irrigation at seedling stage (15-20 DAS) + flower initiation + seed filling (20 days after flower initiation) and Control (no irrigation) were laid out in Randomized Block Design with three replications at each centre. In case of sufficient rainfall (40 mm) coinciding the time of irrigation schedule, application of irrigation was omitted. The recommended dose of fertilizers was 20 N:60 P_2O_5:20 K_2O:30 S kg/ha for North plain zone, 20 N:80 P_2O_5:40 K_2O:40 S kg/ha for North Eastern zone, 20 N:60 P_2O_5:40 K_2O:20 S kg/ha for Central zone and 20 N:80 P_2O_5:20 K_2O:30 S kg/ha for Southern zone. Soybean yield data were collected from all the locations and grouped under different zones and then statistically analyzed. Based on the three years data, the various parameters like sustainability yield index (SYI) (Singh *et al.*, 1990; Wanjari *et al*., 2004) and stability coefficient (Finlay and Wilkinson, 1963) were determined.

RESULTS AND DISCUSSION

North plain zone

Soybean yield significantly influenced by the levels of irrigation during both the years of study as well as in the pooled data. The magnitude of response was almost similar in both the years. The magnitude of irrigation response was to the tune of 43 to 218 per cent during 2009, 30 to 57 per cent during 2011 and 36 to 119 per cent in pooled data (Table 1). Comparison of provision of single irrigation to soybean at any of the critical stages (seedling, flowering or seed filling stage) revealed that the seedling and seed filling stages were more sensitive to available soil moisture levels as compared to flower initiation stage which resulted in higher yield by 7.63 and 6.85 per cent. Provision of two irrigations at two critical stages, the most vulnerable stage was seedling + seed filling stage followed by flower initiation + seed filling stage as compared to seedling + flower initiation which enhanced the yield to the tune of 77.44 and 52.47 per cent, respectively. However, the application of irrigations at all the three critical stages resulted in maximum yield (119 %) as compared to control and 5.17 per cent higher than two irrigation applied at seedling stage (15-20 DAS) + seed filling (20 days after flower initiation). The maximum sustainable yield index was recorded when soybean was irrigated at all the three critical stages followed by two irrigations either at seedling + seed filling and flower initiation + seed filling stage and these treatments showing the negative regression coefficient. The lowest variation in yield was associated with two irrigations at flower initiation + seedling stage. The maximum water use efficiency was recorded with two irrigations at seedling + seed filling stage and closely followed by three irrigations (seedling + flower initiation + seed filling stage). The highest net returns were associated with three irrigations.

Central zone

Application of irrigation at various critical growth stages brought out an appreciable improvement in soybean yield during all the three years of investigations (Table 2).The yield improvement was to the tune of 8.5 to 49.5 per cent in 2009, 6.6 to 21.97 per cent in 2010, 2.3 to 24 per cent in 2011 and 6.18 to 30.27 per cent in pooled data. Among the single irrigation, the irrigation at seed filling stage showed its superiority over irrigation at flower initiation or at seedling stage. While in case of two irrigations, irrigation at flower initiation + seed filling followed by seedling stage + seed filling stage had an edge over irrigation at seedling + flower initiation stage. Irrigation at flower initiation stage showed lower yield variations over years as compared to remaining treatments. The highest sustainability yield index was associated with three irrigations followed by two irrigations. The irrigation at flower initiation, seedling + flower initiation, flower initiation + seed filling and seedling + flower initiation + seed filling stage showed regression coefficient value lesser than unity which indicated that these treatments performed very well under unfavorable conditions , while remaining treatments did well under favourable conditions ($b > 1$). The highest water use efficiency was noted with two irrigations at flower initiation + seed filling stage which was closely followed by one irrigation at seed filling stage. The maximum net returns was observed with three irrigations (seedling + flower initiation + seed filling stage) and closely followed by two irrigations at flower initiation + seed filling stage.

Table 1. Effect of irrigation scheduling on soybean productivity of soybean over years in North plain zone

Treatment	Soybean yield (kg/ha)			SD	SYI	b	WUE (kg/ha cm)	Net returns (Rs/ha)
	2009	2011	Mean					
Irrigation at seedling stage (15-20 DAS)	934	1263	1099	232.64	0.62	3.995	10.19	6869
Irrigation at flower initiation	833	1208	1021	265.17	0.54	4.636	9.41	5488
Irrigation at seed filling (20 days after flower initiation)	960	1222	1091	185.26	0.65	3.105	10.17	6847
Irrigation at seedling stage (15-20 DAS) + flower initiation	1010	1388	1199	267.29	0.67	4.613	10.37	8167
Irrigation at seedling stage (15-20 DAS) + seed filling (20 days after flower initiation)	1792	1340	1566	319.61	0.90	-6.582	14.21	15725
Irrigation at flower initiation + seed filling (20 days after flower initiation)	1540	1291	1416	176.07	0.89	-3.823	12.73	12853
Irrigation at seedling stage (15-20 DAS) + flower initiation + seed filling (20 days after flower initiation)	1843	1451	1647	277.19	0.99	-5.811	13.92	16703
Control (no irrigation)	580	923	752	242.54	0.37	4.305	7.40	4672
SEm (±)	73.69	61.46	47.98				0.79	1541
CD (P=0.05)	**223**	**186**	**139**				**2.32**	**4535**

Table 2. Effect of irrigation scheduling on soybean productivity of soybean over years in Central zone

Treatment	Soybean yield (kg/ha)				SD	SYI	b	WUE (kg/ha cm)	Net returns (Rs/ha)
	2009	**2010**	**2011**	**Mean**					
Irrigation at seedling stage (15-20 DAS)	1414	1994	1590	1666	297.38	0.60	1.230	29.41	22466
Irrigation at flower initiation	1628	1882	1570	1693	165.94	0.67	0.659	29.29	23049
Irrigation at seed filling (20 days after flower initiation)	1691	2255	1847	1931	291.23	0.72	1.209	36.27	27977
Irrigation at seedling stage (15-20 DAS) + flower initiation	1652	1999	1604	1752	215.54	0.67	0.873	30.26	24223
Irrigation at seedling stage (15-20 DAS) + seed filling (20 days after flower initiation)	1729	2245	1855	1943	269.02	0.73	1.121	33.94	27760
Irrigation at flower initiation + seed filling (20 days after flower initiation)	1882	2271	1897	2017	220.39	0.79	0.917	36.70	29353
Irrigation at seedling stage (15-20 DAS) + flower initiation + seed filling (20 days after flower initiation)	1948	2281	1903	2044	206.48	0.81	0.836	35.15	29744
Control (no irrigation)	1303	1870	1535	1569	285.05	0.56	1.148	28.61	20620
SEm (±)	56.19	47.57	71.50	34.21				1.13	1159
CD (P=0.05)	**170**	**144**	**216**	**988**				**3.33**	**3409**

Table 3. Effect of irrigation scheduling on soybean productivity of soybean over years in Southern zone

Treatment	Soybean yield (kg/ha)				SD	SYI	b	WUE (kg/ha cm)	Net returns (Rs/ha)
	2009	2010	2011	Mean					
Irrigation at seedling stage (15-20 DAS)	1906	1714	1732	1784	106.04	0.72	0.916	42.54	23297
Irrigation at flower initiation	1969	1696	1950	1872	152.43	0.73	1.118	37.85	24192
Irrigation at seed filling (20 days after flower initiation)	2056	1727	1761	1848	180.93	0.71	1.515	38.94	24853
Irrigation at seedling stage (15-20 DAS) + flower initiation	2105	1877	2007	1996	114.37	0.80	1.008	41.78	26491
Irrigation at seedling stage (15-20 DAS) + seed filling (20 days after flower initiation)	2185	1910	1973	2023	144.07	0.80	1.263	43.90	27134
Irrigation at flower initiation + seed filling (20 days after flower initiation)	2279	2033	2156	2156	123.00	0.87	1.099	41.97	29897
Irrigation at seedling stage (15-20 DAS) + flower initiation + seed filling (20 days after flower initiation)	2343	2051	2130	2175	151.04	0.86	1.334	41.76	30444
Control (no irrigation)	1693	1614	1631	1646	41.58	0.68	0.409	43.56	22070
SEm (±)	39.98	35.22	58.29	26.32				0.70	1006
CD (P=0.05)	**121**	**107**	**176**	**75**				**2.06**	**2960**

Southern zone

A substantial improvement was recorded when irrigation applied to the soybean crop at different critical stages of soybean (Table 3). The yield enhancement with the irrigation was to the extent of 12.5 to 38.4 per cent in 2009, 5.8 to 27.0 per cent in 2010, 6.2 to 30.6 per cent in 2011 and 8.38 to 32.13 per cent in pooled data. Among the one irrigation treatments, irrigation at flower initiation proved its superiority over irrigation at seedling stage and marginally higher than irrigation at seed filling stage. When two irrigations were compared, the soybean benefited maximum when irrigated at flower initiation + seed filling stage, while remaining two treatments were more or less equally responsive. However, the maximum yield was recorded with three irrigations. The lowest variability in yield was recorded in control followed by irrigation at seedling stage. Among the treatments, irrigation at seedling stage and control did well under unfavourable conditions, while remaining treatments performed very well under favourable conditions. The average stable performance was associated with irrigations at seedling + flower initiation followed by flower initiation + seed filling stage. The highest sustainability yield index was noted with irrigation at flower initiation + seed filling stage which remained at par with three irrigations. The maximum water use efficiency was recorded with two irrigations at seedling + seed filling stage. The highest net returns were associated with three irrigations which were closely followed by two irrigations at flower initiation + seed filling stage.

The maximum soybean yield was recorded under three irrigations at seedling, flower initiation and seed filling stages followed by two irrigations at flower initiation and seed filling stages might be due to that the reproductive stage of soybean is much more sensitive to available soil moisture level and irrigation at these sensitive stages might have resulted in higher translocation of nutrients and photosynthates from source to sink, formation of more yield attributes and retention of active source for longer period and increased seed weight which ultimately contributed to the higher yield. These results are in conformity with the findings of Ali *et al*. (2009) and Gracia *et al.* (2010), who stipulated that growth rates of all plant components were enhanced by more frequent irrigation, that senescence was delayed, and that the leaf area was retained later in the growing season for soybean in a semi-arid tropical environment. In general, seed yield increased at a rate of 7.20 kg for each mm of total water received (rainfall + irrigation) by the crop. While, Kobraee *et al*. (2011) reported that withholding irrigation at R1 (omit irrigation at the onset of flowering stage) had the most effect on number of sub-branch, number of pod and seed per main stem, sub-stem and plant. Water deficit at seed - filling stage (R6) had the major effect on reducing 100 – seed weight. Withholding irrigation at R3 had more effect on reducing pod and seed dry weight.

Soybean is more sensitive to deficit soil moisture during its reproductive development especially at flowering and seed filling stage. It is thus concluded that for optimizing the productivity of soybean 3-irrigations are necessary. However, in case of limited availability of irrigation water, two irrigations at flower initiation and at seed filling stage or one irrigation at seed filling stage need be provided.

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Effect of Seed Rate and Row Spacing on Productivity of Soybean Varieties under Different Agro-climatic Zones of India

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ABSTRACT

A multi-locational trial was conducted in diverse four agro-ecological zones of India during 2009-2011 to optimize the seed rate and row spacing for newly released soybean varieties. Results accrued over three years revealed that the soybean planting with 65 kg per ha seed rate was found to be more productive, sustainable and stable in North plain, North Eastern and Central zones, while in Southern zone, 75 kg per ha seed rate was more productive, sustainable and stable than rest of rates. The planting of soybean at 45 and 30 cm row spacing produced maximum sustainable and stable yield in North plain, North Eastern, Central and Southern zones, respectively. Soybean varieties namely SL 525, RKS 18, JS 95- 60 and RKS 18 were found to be more productive, sustainable and stable as compared to other varieties.

Key words: Row spacing, seed rate, sustainability yield index, soybean, stability, variety

Plant population is an important non-monetary input and a factor for optimum higher realization through light penetration in crop canopy. If plant density is above or below the optimum, the plant growth may be poor due to competition for nutrients, light and space thus resulting in poor yield. As seeding rate increases plant competition increases, generating stress on the canopy, minimizing the benefit to narrow row spacing, especially when environmental conditions limit plant growth (Elmore, 1998). The optimum plant population according to row spacing has been optimized for soybean crop (Whigham, 1998 and Whigham and Lundvall, 1996). The optimum plant density with proper geometry of planting is dependent on a variety, its growth habit and prevailing agro-climatic conditions. The row-to-row spacing with plant population should be maintained for getting better results from this crop. The equi-distant plant spacing increase crop growth rate, dry matter accumulation, and seed yield (Andrade *et al*., 2002). Abiotic and biotic stresses can mitigate the yield response of soybean to narrow-row spacing production. Moisture stress has been documented to reduce the yield benefit from narrow row spacing (Heitholt *et al*., 2005). Therefore, it is imperative to find out the optimum seeding rates and row spacing for newly released soybean cultivars under different agro-climatic regions of India to improve yield potential of soybean.

MATERIAL AND METHODS

Field experiments during 2009-11were conducted at 10 locations of four agro-ecological zones (as defined under All India

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Coordinated Research Project on Soybean) namely, North plain (Pantnagar and Hisar), North Eastern (Ranchi and Imphal), Central (Sehore, Amravati, Kota, Ujjain) and Southern (Pune and Bengaluru) zones of soybean. Three row spacing (30,45 and 60 cm) in North plain, North Eastern and Central zones, while two row spacing (30 and 45 cm) in southern zone along with two varieties each in north plain zone(PS 1347 and SL 525), North Eastern zone(RKS 18 and JS 97- 52), in Central zone (JS 95- 60 and JS 97- 52) and Southern zone(RKS 18 and MAUS 61) as main plot and three seeding rates (55, 65 and 75 kg/ha) as sub-plot were arranged in split plot design with three replications. The recommended dose of nutrients (20 N:60 P_2O_5:20 K_2O:30 S kg/ha for North plain zone, 20 N:80 P_2O_5:40 K_2O:40 S kg/ha for North Eastern zone, 20 N:60 P_2O_5:40 K_2O:20 S kg/ha for Central zone and 20 N:80 P_2O_5:20 K_2O:30 S kg/ha for Southern zone) was applied. Soybean yield data were collected from all the locations and grouped under different zones and then statistically analyzed using years as replications. Based on the three years data, the stability coefficient (Finlay and Wilkinson, 1963) were determined. The sustainability yield index (SYI) was determined by using the formula- Average yield – standard deviation/ maximum yield in the experiment.

RESULTS AND DISCUSSION

North plain zone

Soybean yield was found to differ non-significantly by soybean varieties (Table 1). Soybean cultivar SL 525 produced higher

Table 1. Effect of seed rate and row spacing on productivity (kg/ha) of soybean varieties in North plain zone

Treatment	2009	2010	2011	Mean	% change	SD*	SYI	b
Variety								
PS 1347	2033	1946	2190	2056	-	124	0.68	0.222
SL 525	2576	1930	2039	2182	6.13	346	0.65	1.775
SEm (±)				119.46				
CD (P=0.05)				**376.73**				
Row spacing (cm)								
30	2387	1820	2327	2178	0.41	311.49	0.77	1.286
45	2328	2083	2431	2281	5.16	178.76	0.86	0.767
60	2199	1913	2395	2169	-	242.40	0.79	1.009
SEm (±)				32.16				
CD (P=0.05)				**93.69**				
Seed rate (kg/ha)								
55	2334	1873	2277	2161	-	251.33	0.77	1.008
65	2334	1944	2469	2249	4.07	272.63	0.80	1.137
75	2246	1996	2414	2219	2.68	210.34	0.81	0.855
SEm (±)				146.30				
CD (P=0.05)				**461.38**				

**SD- Standard deviation*

yield (6.13 %) as compared to PS 1347(2,056 kg/ha). However, cultivar PS 1347 showed lower level of variation in yield over the years along with higher SYI and performed very well under unfavorable environments as evidenced from the regression coefficient (b), which was lower than unity.

Significantly maximum soybean was associated with row spacing 45 cm which yielded 4.73 and 5.16 per cent more than 30 and 60 cm row spacing. Though, the difference between 30 and 60 cm row spacing was non-significant. Planting of soybean 45 cm apart possessed maximum SYI and had lower yield variation over years and did better under unfavorable environments while narrow and wider row spacing performed better under favorable environments.

All the three seeding rates behaved identically. However, seeding rate of 65 kg per ha produced marginally higher yield (4.07 and 1.35 %, respectively) than 75 and 55 kg per ha seed rate. However, the 75 kg per ha seed rate showed minimum yield variability over the years. Application of 75 and 65 kg per ha seed rate was found to be more sustainable than 55 kg per ha seed rate. Among the seed rates, 55kg per ha seed rate was found to be more stable than remaining two treatments. The higher seed rate (75 kg/ha) performed better under unfavourable environments, while 65 kg per ha did well under favourable environments as evidenced from the regression coefficient values.

North Eastern zone

Soybean variety RKS 18 showed its superiority over variety JS 97-52 during two out of three years and produced higher yield

Table 2. Effect of seed rate and row spacing on productivity (kg/ha) of soybean varieties in North eastern zone

Treatment	2009	2010	2011	Mean	% change	SD*	SYI	b
Variety								
RKS 18	1222	2297	2613	2044	13.97	729.20	0.46	1.280
JS 97-52	1691	1739	2478	1969	-	441.17	0.54	0.712
SEm (±)				139.05				
CD (P=0.05)				**438.51**				
Row spacing (cm)								
30	1448	1933	2063	1815	10.87	324.13	0.66	0.737
45	1573	1984	2274	1944	18.75	352.24	0.70	1.036
60	1349	1591	1972	1637	-	314.07	0.58	1.205
SEm (±)				28.79				
CD (P=0.05)				**83.87**				
Seed rate (kg/ha)								
55	1449	1774	1925	1716	-	243.24	0.65	0.737
65	1447	1896	2115	1819	6.00	340.54	0.65	1.036
75	1474	1838	2270	1861	8.45	398.48	0.64	1.205
SEm (±)				170.30				
CD (P=0.05)				**537.07**				

**SD- Standard deviation*

by 3.81 per cent over JS 97-52 (Table 2).Yield data revealed that the high yielding variety showed higher variability over years as compared to lower yielding variety. Variety JS 97-52 showed higher SYI and performed better under unfavourable environments, while reverse was true with variety RKS 18.

Significantly maximum yield was associated with 45 cm row spacing as compared to higher and lower row spacing which enhanced the yield to the tune of 7.10 and 18.75 per cent over 30 and 60 cm row spacing. However, 30 cm row spacing gave higher yield by 10.87 per cent than 60 cm row spacing. Planting of soybean at 45 cm row spacing appeared to be more sustainable and stable as compared to 30 and 60 cm row spacing though the 45 cm row spacing showed maximum yield variability over years. Wider row spaced soybean tend to perform better under favourable environments.

Soybean yield remained unaffected due to variation in seeding rates. However, marginally higher yield was recorded with 75 kg per ha seeding rate, which gave 2.30 and 8.45 per cent higher yield over 65 and 55 kg per ha, respectively. The minimum yield variability was observed with 55 kg per ha seeding rate. All the three seeding rates were found to be equally sustainable. Seeding rate of 65 kg per ha showed stable performance as compared to others. The higher seeding rates tend to perform better under favourable conditions.

Table 3. Effect of seed rate and row spacing on productivity (kg/ha) of soybean varieties in Central zone

Treatment	2009	2010	2011	Mean	% change	SD*	SYI	b
Variety								
JS 95-60	1641	1816	1630	1696	7.21	104.36	0.816	0.126
JS 97-52	1507	1488	1751	1582	-	146.67	0.736	1.641
SEm (±)				37.37				
CD (P=0,05)				**117.85**				
Seed rate (kg/ha)								
55	1561	1587	1807	1652	-	135.15	0.816	0.865
65	1566	1679	1804	1683	1.88	119.05	0.841	0.794
75	1496	1697	1859	1684	1.94	181.85	0.808	1.220
SEm (±)				45.77				
CD (P=0,05)				**144.34**				
Row spacing (cm)								
30	1578	1668	1826	1691	4.45	125.54	0.81	0.984
45	1568	1720	1935	1741	7.54	184.40	0.80	1.439
60	1578	1570	1710	1619	-	78.62	0.80	0.577
SEm (±)				17.78				
CD (P=0,05)				**51.80**				

**SD- Standard deviation*

Central zone

The yielding ability of both the varieties was statistically at par, however, variety JS 95-60 produced 7.21 per cent higher yield over JS 97-52 and also found to be sustainable and stable performance along with minimum yield variations over the years (Table 3). Variety JS 97-52 did well under favourable environments.

Planting of soybean at 45 cm apart produced maximum yield and remained at par with 30 cm row spacing which gave 2.96 and 7.53 per cent higher yield over 30 and 60 cm row spacing, respectively. Narrow row planting was found to be more sustainable and stable. The minimum yield variation over years was associated with 60 cm apart planting. Planting of soybean either at narrow or wider row spacing performed very well under unfavourable environments.

All the three seeding rates behaved identically. Though, the numerically higher (1.94 %) yield was recorded with 75 kg per ha seeding rate. However, planting at 65 kg per ha seeding rate appeared to be more sustainable while 55 kg per ha was found to be more stable. The lower seeding rates tend performed better under unfavourable conditions.

Southern zone

Soybean variety RKS 18 showed its superiority (17.02%) over variety MAUS 61(2,350 kg/ha) in all the parameters, which indicated that the minimum yield variations over years and more sustainable and stable (Table 4).

Planting of soybean at narrow row spacing (30 cm) produced 4.41 per cent higher yield as compared to 45 cm row spacing and

Table 4. Effect of seed rate and row spacing on productivity (kg/ha) of soybean varieties in Southern zone

Treatment	2009	2010	2011	Mean	% change	SD*	SYI	b
Variety								
RKS 18	2680	2858	2712	2750		94.89	0.93	1.004
MAUS 61	2300	2474	2277	2350	17.02	107.71	0.78	1.123
SEm (±)				36.55				
CD (P=0,05)				**126.64**				
Row spacing (cm)								
30	2535	2697	2503	2578	4.41	104.01	0.92	1.227
45	2445	2474	2487	2469	-	21.50	0.91	-0.537
SEm (±)				29.33				
CD (P=0,05)				**87.93**				
Seed rate (kg/ha)								
55	2434	2362	2360	2385	-	42.16	0.88	-0.381
65	2543	2652	2533	2576	8.01	66.01	0.95	1.218
75	2493	2741	2581	2605	9.22	125.73	0.93	2.189
SEm (±)				36.55				
CD (P=0,05)				**126.63**				

**SD- Standard deviation*

also showed marginally higher sustainability yield index with higher yield variations over years. Narrow planting tend to be performed better under favourable environments.

Significantly higher yield was associated with75 kg per ha as compared to 55 kg per ha seeding rate and produced 1.13 and 9.22 per cent higher yield over 65 and 55 kg per ha seeding rates, respectively. Higher seeding rate showed higher variability in yield over years along with higher sustainability yield index and tend to performed better under favourable environments.

The results show that growth and seed yield varied significantly among the varieties. The variation in yielding ability of soybean varieties may be attributed to their differences in genetic makeup. This is in line with reports from earlier workers who showed significant genotypic differences in growth and seed yield of soybean (Chandrappa *et al*., 1999 and Haq *et al*., 2002).

The higher yield was observed in 30 to 45 cm across the zones. An advantage of narrow row spacing is more equi-distant plant spacing, which leads to increased leaf area development and greater light interception earlier in the season. These changes in canopy formation increase crop growth rate, dry matter accumulation, and seed yield. These results are in line with the earlier findings of Grau *et al*., (1994) and De Bruin and Pederson, (2008). However, instances occur when there was no yield response to narrow row spacing (Pedersen and Lauer, 2003). The magnitude of the response was location, year and cultivar specific (Grau *et al*., 1994).

The maximum yield was recorded with 65 kg per ha seeding rate. The optimum plant population is the function of appropriate seeding rate which resulted in optimum plant canopy and increased light intensity and leads to higher dry matter accumulation and finally yield. These results are in agreement with the findings of Bruin and Pederson (2008). Cox *et al*. (2010) reported that drilled soybean in 0.19 m rows compensated for increased space at lower seeding rates by increasing branch, biomass, pods and seeds per plant, which resulted in similar yield across seeding rates. Yield showed a quadratic response to seeding rates irrespective of row spacing (Cox and Cherney, 2011). Furthermore, optimum economic seeding rates are often less than seeding rates that result in maximum yield because of the high costs of soybean seed (De Bruin and Pedersen, 2008).

On the basis of fore going results it could be concluded that the planting of soybean 30 to 45 cm apart with 65-75 kg seed rate was found to be more productive, sustainable and stable.

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Optimization of Sulphur Levels for Soybean – Chickpea Cropping System under Different Application Frequencies

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ABSTRACT

Field experiments were conducted during 2008-09 and 2009-10 to study the effect of sulphur levels and their application frequency on productivity of soybean–chickpea cropping system. Results revealed that the application of sulphur up to 60 kg per ha linearly increased the yield of the crops as well as system productivity and further increase in sulphur levels to 80 kg S per ha led to decline in yield levels. Relationship between yield and sulphur levels was found to be curvilinear. The economic optimum level of sulphur was 45.48, 44.48 and 90.13 kg S per ha for soybean, chickpea and the system which gave the yield levels of 1,640, 1,721 and 4,377 kg per ha, respectively. The regular dressing of sulphur to both crops was found to be more beneficial as compared to its application either in kharif *or* rabi *only.*

Key words: Economic optimum level, maximum yield level, sulphur, soybean equivalent yield

Soybean and chickpea, both are the premier crops of Madhya Pradesh and constitute the promising cropping system under rainfed conditions. The application of sub-optimal dose of fertilizers by the farmers is one of the important factors restricting the realization of actual potential yield of both the crops. Among the essential nutrients, sulphur is one of the limiting plant nutrients threatening the sustainability of crop production in semi-arid tropical regions of India covering 73 million ha of Vertisols and associated soils (Subbarao and Ganeshamurthy, 1994). Sulphur as a fertilizer or as a constituent of other fertilizers is generally not applied by farmers. As a result, large areas of S deficiency are reported from this agro-ecological region (Ganeshmurthy and Saha, 1999). The role of sulphur in pulses is important because the deficiency of the sulphur containing amino acids cysteine, cystine and methionine may limit the nutritional value of food and feed (Sexton *et al.*, 1998). The results of on-farm demonstrations revealed an average increase in productivity by 24 per cent in cereals, 32 per cent in oilseeds and 20 per cent in pulses due to sulphur application as compared to NPK alone (Singh, 1991).

Since the farmers of Malwa region are largely with limited cash, which restricts their capacity to buy fertilizers, it is important to develop production systems that are more nutrient-use efficient. Synchrony of nutrient supply with crop requirement and optimal utilization of residual fertilizer and soil S by succeeding crops grown in rotation are among the practical ways to achieve such an

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objective. The main objective of our study was to assess strategies for S management in a soybean-chickpea cropping system by combining economic profitability with agronomic suitability and improved understanding on the differences in S transformation and supply under soybean and chickpea system.

MATERIAL AND METHODS

Field experiments were conducted at fixed site during *kharif* and *rabi*seasons of 2008-09 and 2009-2010 at Research Farm of College of Agriculture, Indore (Madhya Pradesh). The experimental soil was clay loam in texture and classified as fine, isohypothermic, montmorollitic family of Typic Haplausters with pH 7.76, EC 0.18 dS per m, organic carbon 4.2 g per kg (low) and available S 10.12 mg per kg. The experiment consisted of thirteen treatments which were laid out in randomized block design under factorial arrangement in four replications. The thirteen treatment combinations involved four levels of sulphur (20, 40 60 and 80 kg/ha), three frequencies (applied to soybean only; direct for soybean and residual for succeeding chickpea, applied to chickpea only; direct for chickpea and residual for succeeding soybean and applied to both the crops in the system; cumulative and one control. Soybean 'JS 95 60' and chickpea 'JG 218' were timely sown and harvested, and normal crops were raised following the recommended package of practices during the experimentation. Chickpea crop was irrigated at once, before flowering. A uniform basal dose of fertilizer (20 N: 60 P_2O_5:20 K_2O kg/ha) applied through di-ammonium phosphate and muriate of potash to both the crops. The appropriate quantity of sulphur as per the treatments was applied through gypsum (14 % S). The rainfall during 2008-09 and 2009-10 was 622.8 and 1074.1 mm, respectively.

The relationship between yield of both the crops and sulphur levels was worked out using the quadratic equation, *i.e.* $Y= a + bx + cx^2$. The economic optimum level of sulphur was computed for both the crops individually as well as for cropping system as a whole. The prevailing market prices of input (S @ Rs.25/kg) and output (soybean @ Rs. 36/kg and chickpea @ Rs. 40/kg) were considered for computation of economic optimum level of sulphur. The pooled analysis, maximum yield level and economic optimum level were determined as suggested by (Gomez and Gomez, 1984).

RESULT AND DISCUSSION

Effect of sulphur levels

The soybean yield significantly increased as the levels of sulphur increased up to 60 kg S per ha and further increase in sulphur level to 80 kg per ha decreased the yield significantly during both the years of study and also when the pooled data was analysed. Increase in sulphur level with concomitant yield decrease might be due to imbalance caused by increasing level of sulphur without concomitant increase in other fertilizers (Nasreen and Farid, 2006). However, the yield difference between control and 20 kg S per ha remained at par. The increase in soybean yield was to the tune of 8.9, 22.1, 38.5 and 25.5 per cent by the application of 20, 40, 60 and 80 kg S per ha, respectively as compared to control. When the recommended level of sulphur was compared with higher levels, yield enhancement was to the extent of 12.1, 27.1 and 18.0 per cent due to 40, 60 and 80 kg S per ha, respectively.

Chickpea seed yield also increased significantly as the levels of sulphur increased up to 60 kg per ha and thereafter a decline was observed during both the years of study. The application of 20 and 40 kg S per ha and control were found to be statistically at par during 2008. However, these differences were significant in 2009 and in the pooled data. Enhancement of chickpea yield was 11.1, 19.5, 28.9 and 24.6 per cent by the applied sulphur @ 20, 40, 60 and 80 kg S per ha over control. The yield increment was 7.6, 16.1 and 12.2 per cent due to 40, 60 and 80 kg S per ha, respectively as compared to 20 kg S per ha (Table 1).

Table 1. Soybean and chickpea yield as influenced by sulphur levels and their application frequencies

Treatment	**Seed yield (kg/ha)**						**Soybean Equivalent Yield (SEY) (kg/ha)**
	Soybean			**Chickpea**			
	2008	**2009**	**Pooled**	**2008 -09**	**2009 -10**	**Pooled**	
Sulphur level (kg/ha)							
20	1737	1860	1799	1797	2137	1967	4949
40	1944	2087	2016	1930	2303	2117	5381
60	2188	2391	2289	2124	2443	2283	5924
80	2014	2229	2122	2111	2303	2207	5638
SEm (±)	49	62	39	31	31	22	**45**
CD (P = 0.05)	**142**	**177**	111	**88**	**89**	62	**128**
Sulphur application frequency							
Kharif only	2038	2120	2079	1884	2127	2005	5295
Rabi only	1709	1983	1846	1905	2344	2124	5229
Kharif + *rabi*	2162	2323	2242	2182	2419	2301	5894
SEm (±)	43	53	34	27	27	19	**39**
CD (P = 0.05)	**123**	**153**	96	**76**	**77**	53	**111**
Control	**1575**	**1727**	1651	**1717**	**1826**	1771	4431
SEm (±)	89	111	71	55	56	39	**82**
CD (P = 0.05) Treatment *v/s* control	**255**	**319**	201	**159**	**161**	**111**	**231**

Significantly highest soybean equivalent yield was recorded with the application of 60 kg S per ha during both the years. The soybean equivalent yield increased to the tune of 11.7, 21.4, 33.7 and 27.2 per cent by the application of 20, 40, 60 and 80 kg S per ha, respectively over control and 8.7, 19.7 and 13.9 per cent over 20 kg S per ha by the application of 20, 40, 60 and 80 kg S per ha, respectively as evidenced from the pooled data (Table 1).

The increase in grain yield due to S addition could be attributed to the increased yield attributes, like dry matter accumulation which ultimately translocated to sink, activities of roots and nodules in nutrient extraction from large soil volume and greater biological nitrogen fixation, growth efficiency and net assimilation rate of crops, pods per plant, seed yield per plant and seed index (Farhad *et al.*, 2010). S fertilization also resulted in an increased uptake of nutrients, *viz*. N, P, K and S, thus resulting in higher yield (Krishnamurthi and Gnanamurthy, 2002). The higher magnitude of seed yield response indicates greater contribution of S in grain production. The beneficial effect on soybean of sulphur application @ 20 to 40 kg per ha on seed yield were also reported by Farhad *et al.* (2010).

Effect of application frequency

Significantly higher seed yield of soybean was recorded when sulphur was applied in both the seasons (*kharif* and *rabi*) during both the years. The soybean yield hike was found to be 21.4 and, 12.6 per cent when sulphur was applied in both the seasons and *kharif* only, respectively over sulphur applied only in *rabi* season. Application of sulphur in both the seasons produced 7.8 per cent more yield as compared to sulphur applied to *kharif* crop only. The yield difference between control and sulphur applied to *rabi* season only was found to be non-significant.

The maximum chickpea seed yield was also recorded when sulphur was applied to both the crops during both the years of study. The yield difference between sulphur applied to *kharif* only, *rabi* only and control was found to be non-significant during 2008-09. While in 2009-10 and when the data were pooled, these variations were significant. The chickpea seed yield increased to the extent of 13.2, 19.9 and 29.9 per cent due to sulphur applied to *kharif*, *rabi* and both the crops over control and 5.9 and 14.8 per cent, respectively as compared to sulphur applied to *kharif* only. The sulphur application in both the seasons produced 8.8 per cent higher yield as compared to sulphur applied in only *rabi* season.

Significantly highest and lowest soybean equivalent yield was recorded when 60 kg S per ha applied in both the seasons and 20 kg S per ha applied in *kharif* only, respectively.

Interaction effect of sulphur level and application frequency

The interaction effect of sulphur levels and application frequency on soybean seed yield was non-significant during both the years as well as when the data pooled over years. The interaction effect of sulphur levels and their application frequency on chickpea seed yield was found to be significant during both the years as well as when the data pooled. Significantly highest and lowest chickpea yields were recorded with 60 kg S per ha when applied in both the seasons and 20 kg S per ha applied in *kharif* only, respectively.

Physical maximum and economic optimum level of sulphur

The relationship between sulphur levels and crop yield was curvilinear. In case of soybean, the maximum yield level of sulphur varied from 55.3 to 57.7 kg S per ha, which resulted in soybean yield from 1,409 to 1,831 kg per ha, respectively (Table 2). However, the economic optimum level of sulphur ranged from 44.3 to 46.1 kg S per ha which produced the soybean yield of 1,404 and 1,824 kg per ha. On the basis of pooled data, it was observed that the maximum yield level and economic optimum level of sulphur was 56.85 and 45.48 kg S per ha for soybean and resulted in 1,646 and 1,640 kg per ha yield, irrespective of the sulphur application frequency. The differences among the application frequencies were very meagre with reference to maximum yield level and economic optimum level of sulphur.

Table 2. Relationship between yield and sulphur levels under different sulphur application frequencies during 2008-09, 2009-10 and pooled data

Sulphur application frequencies	2008-09	2009-10	Pooled
Soybean			
Kharif	$Y= 1480.96 + 49.294x - 4.317x^2$	$Y= 1552.44 + 51.236x - 4.468x^2$	$Y= 1516.96 + 50.212x - 4.385x^2$
Rabi	$Y= 1290.78 + 42.761x - 3.865x^2$	$Y= 1480.66 + 47.693x - 4.191x^2$	$Y= 1385.65 + 45.231x - 4.029x^2$
Kharif + rabi	$Y= 1548.74 + 52.751x - 4.663x^2$	$Y= 1670.40 + 55.538x - 4.813x^2$	$Y= 1609.66 + 54.151x - 4.739x^2$
Mean	$Y= 1440.12 + 48.260x - 4.281x^2$	$Y= 1567.86 + 51.493x - 4.491x^2$	$Y= 1504.20 + 49.882x - 4.387x^2$
Chickpea			
Kharif	$Y= 1418.44 + 45.796x - 4.033x^2$	$Y= 1575.34 + 51.881x - 4.553x^2$	$Y= 1498.68 + 48.738x - 4.292x^2$
Rabi	$Y= 1417.98 + 42.714x - 3.523x^2$	$Y= 1707.52 + 58.460x - 5.301x^2$	$Y= 1571.44 + 50.574x - 4.411x^2$
Kharif + rabi	$Y= 1590.98 + 53.797x - 4.816x^2$	$Y= 1749.92 + 62.976x - 5.907x^2$	$Y= 1670.38 + 58.375x - 5.359x^2$
Mean	$Y= 1481.90 + 47.445x - 4.125x^2$	$Y= 1678.74 + 57.701x - 5.253x^2$	$Y= 1580.26 + 52.577x - 4.690x^2$
Equivalent Yield			
Kharif	$Y= 3737.30 + 61.087x - 2.685x^2$	$Y= 4081.35 + 67.339x - 2.963x^2$	$Y= 3909.05 + 64.208x - 2.823x^2$
Rabi	$Y= 3584.24 + 55.808x - 2.397x^2$	$Y= 4179.36 + 69.783x - 3.119x^2$	$Y= 3881.33 + 62.789x - 2.757x^2$
Kharif + rabi	$Y= 4073.33 + 69.118x - 3.083x^2$	$Y= 4440.39 + 77.615x - 3.543x^2$	$Y= 4256.84 + 73.367x - 3.312x^2$
Mean	$Y= 3798.25 + 61.999x - 2.721x^2$	$Y= 4233.79 + 71.577x - 3.208x^2$	$Y= 4015.89 + 66.787x - 2.964x^2$

Table 3. Economic optimum and maximum yield levels of sulphur as influenced by the sulphur levels and their application frequency

Sulphur application frequency	Economic optimum sulphur level (kg/ha)	Economic optimum yield (kg/ha)	Physical Maximum sulphur level (kg/ha)	Physical maximum yield (kg/ha)
Soybean-2008	45.09	1571	56.36	1576
Kharif	45.67	1616	57.09	1622
Rabi	44.26	1404	55.32	1409
Kharif + rabi	45.25	1692	56.56	1698
Soybean-2009	45.86	1703	57.33	1715
Kharif	45.87	1693	57.34	1699
Rabi	45.52	1611	56.90	1616
Kharif + rabi	46.15	1824	57.70	1831
Soybean pooled	45.48	1640	56.85	1646
Kharif	45.80	1655	57.25	1661
Rabi	44.91	1508	56.13	1513
Kharif + rabi	45.71	1758	57.13	1764
Chickpea-2008-09	46.01	1613	57.51	1618
Kharif	45.42	1542	56.78	1548
Rabi	48.50	1542	60.62	1547
Kharif + rabi	44.68	1735	55.85	1741
Chickpea- 2009-10	43.94	1839	54.92	1837
Kharif	45.57	1717	56.97	1723
Rabi	44.11	1863	55.14	1869
Kharif + rabi	42.65	1911	53.31	1918
Chickpea pooled	44.84	1722	56.05	1728
Kharif	45.42	1632	56.78	1637
Rabi	45.86	1711	57.33	1716
Kharif + rabi	43.57	1823	54.46	1829
SEY- 2008-09	91.14	4137	113.93	4152
Kharif	91.11	4070	113.78	4085
Rabi	93.13	3896	116.41	3909
Kharif + rabi	89.69	4445	112.11	4460
SEY-2009-10	89.26	4617	111.58	4633
Kharif	90.91	4449	113.63	4464
Rabi	88.30	4552	110.37	4570
Kharif + rabi	87.64	4848	109.55	4865
SEY pooled	90.13	4377	112.66	4392
Kharif	91.02	4260	113.70	4274
Rabi	91.08	4225	113.85	4239
Kharif + rabi	88.59	4647	110.74	4663

In chickpea, the maximum yield level of sulphur ranged from 53.31 to 60.62 kg S per ha, which produced the chickpea yield of 1,918 and 1,548 kg per ha, respectively during both the years of study. The corresponding economic optimum level of sulphur varied from 42.65 to 48.50 kg S per ha which produced the yield level of 1,911 and 1,542 kg per ha, respectively.

The maximum yield level and

economic optimum level of sulphur for chickpea was found to be 56.05 and 44.84 kg S per ha, which resulted in the production of 1,728 and 1,722 kg per ha, respectively irrespective of sulphur application frequency. The application of sulphur in both the season showed lower levels of maximum yield level and economic optimum level of sulphur for chickpea crop as compared to sulphur applied in individual crops (Table 3).

With reference to soybean equivalent yield, the physical maximum sulphur level irrespective of sulphur application frequency was found to be 113.9, 111.6 and 112.7 kg S per ha, which resulted in 4,152, 4,633 and 4,392 kg per ha soybean equivalent yield during 2008-09, 2009-10 and pooled data, respectively. The corresponding economic optimum level for the soybean–chickpea system was 91.1, 89.3 and 90.1 kg S per ha which reflected the total system productivity of 4,137, 4,617 and 4,377 kg per ha during 2008-09, 2009-10 and in pooled data, respectively. These results are in agreement with the findings of Sharma *et al* (2007) they reported that the economic optimum dose of sulphur for wheat and rapeseed respectively was 45 and 38 kg S per ha supplied through gypsum. The regular dressing of sulphur in both the crops showed lower values of physical maximum and economic optimum level of sulphur for the soybean – chickpea system (Table 3). The regular dressing of sulphur in both the seasons maintained the sulphur availability in soil as per the crop requirement which resulted in higher growth, development and yield. These results are in agreement with the findings of Krishnamurthi and Gnanamurthy (2002), and Sarangthem e*t al*. (2008).

On the basis of two years results, it could be concluded that the optimum level of sulphur was found to be 45.5, 44.5 and 90.1 kg S per ha for soybean, chickpea and for the system which yielded 1,640, 1,721 and 4,377 kg per ha, respectively and its regular dressing to soybean–chickpea cropping system is essential to achieve optimise yield.

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Influence of Improved Technology *vs* Farmers' Practice on Yield and Economies of Soybean Cultivation in Vidisha District of Madhya Pradesh

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ABSTRACT

The results of twenty replicated demonstrations on soybean cultivation practices conducted in four tank area under command of Betwa river basin of district Vidisha, Madhya Pradesh, were analysed to differences in crop grown under improved package of practice and farmers' practice, which explore the potential of farmers for enhancement crop and water productivity of soybean crop. Sowing on ridge and furrow system with recommended row spacing improved the seed yield of soybean by 62 per cent as compared to narrow sowing on flat land of farmers' practices. As compared to application fertilizers by farmers' practices, recommended dose fertilizers could enhance the seed yield by 40 per cent through RDF. Improvement in pest management practices led to 53 per cent increase over farmers' practices. Similarly, use of certified seed over farm saved seed and appropriate weed management over farmers' practices, enhanced the yield by 53 and 40 per cent, respectively. The results of these demonstrations brought out that correction in farmers' practice by intervention of technology is capable of improving the soybean productivity in Betwa river basin of Vidisha district.

Key words: Improved production technology, soybean, insect-pest management, weed management

Soybean is a major crop grown during *kharif* or monsoon season (July-October) in the rainfed areas of central and peninsular India. Madhya Pradesh is known as the "soybean state" of India with coverage of5.76 millionhectares recording production of 6.49 million tonnes with an average productivity of 1,124 kg per ha (Anonymous, 2011). The crop covers 55 per cent of the total national area under soybean cultivation. Soybean yield in Madhya Pradesh, and India as a whole, is low as compared to not only other major soybean growing countries, but also the potentials of soybean varieties in cultivation in India. The reasons of low productivity are use of farm saved seed by most of the farmers and non-adoption of research emanated production technologies. To convince the farmers on the role of individual improved productions technology on enhancement of productivity, demonstrations taking most prominent factors were conducted and results thereof have been reported in this paper.

MATERIAL AND METHODS

For the present study, 20 farmers' fields in four villages namely, Ghatera, Dimrolli, DaudBasoda and Karondakhurd were

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selected under command areas of Jajon and Ghjatra tank in Betwa river basin, district Vidisha, Madhya Pradesh during 2010 and 2011 for field demonstrations on productivity enhancement of soybean through improved technology where soybean was grown as major *kharif* crop in rotation with wheat or chickpea.

At these selected sites, the demonstrations included five factors, each with two treatment levels of soybean cultivation to be studied locally; the training curriculum aimed at developing the skills of farmers to conduct all stages of the study independently (Berg and Lestari, 2001). Consequently, the factor and treatment levels varied between sites, unlike in centrally planned studies. Crop was sown during 12th June, 2010 and 15th June, 2011, and harvested on 24th September, 2010 and 27th September, 2011. The average rainfall during 2010 and 2011 was 703 mm and 1,272 mm, respectively.

Table 1. Experimental details

Factor	Treatments	Description
Sowing method	Improved practice	Ridge furrow system (45 cm row to row spacing) with 75 kg seed per ha
	Farmers' practice	Narrow spacing (22.5 cm row to row spacing) with 100 kg seed per ha
Varietal performance	Improved practice	Early maturing variety JS 95 60 (90 days); certified seed procured from State Seed Corporation
	Farmers' practices	Farm saved seed of varieties JS 335/JS 93 05
NPKS	Improved practice	Application of recommended $N:P_2O_5:K_2O:S$ (20:60:20:45 kg/ha) through urea (44 kg), single super phosphate (380 kg) and muriate of potash (34 kg) as a basal
	Farmers' practice	Application of $N:P_2O_5$ (27:57 kg/ha) through di-ammonium phosphate (50 kg) mixed with seed
Weed management	Improved practice	One spray of Turga super at 20 DAS + one hand weeding at 45 days after sowing (DAS)
	Farmers' practice	One spray of Turga super/Pursuit at 25-35 DAS
Insct-pest management	Improved practice	IPM practices namely, seed treatment with Thiamethoxam @ 3 ml per kg seed, 1st spray of Chlorpyriphos @ 3 ml per litre water at 20 DAS, removal of hairy caterpillar infested plants and 2nd spray of Trizophos @ 1.6 ml per litre water at 45 DAS
	Farmers' practice	One spray of Trizophos @ 1.6 ml per litre water at 30-40 DAS

Note: Crop management practices other than the treatments were constant within sites but variable between sites in accordance with local practices

The soil of the experimental sites was clayey in texture with available moisture contents varying between 12.20 and 15.75 per cent. The surface soil of these lected locations analysed: pH 7.8-8.3, EC 0.81dS per m and available nitrogen 250-280 kg per ha, available phosphorus 4.26-21.1 kg P_2O_5 per ha, and available K 185-363 kg K_2O per ha.

All the demonstrations were laid out in randomised block design with two treatments under two replications (Table 1). The seed yield was recorded by harvesting 2.5 m x 2.5 m area from the centre of each plot.

RESULTS AND DISCUSSION

The result of the field demonstrations based on the mean values for two consecutive years indicated that the improved technology led to higher seed yield as compared to farmers' practice (840 to 1,240 kg per ha). The maximum seed yield in these demonstrations ranged from 1,395 to 2,025 kg per ha. Mean yield of 20 demonstration worked out to 1,357 kg per ha from demonstration whereas the average yield obtained in case of farmers' practices was 1,080 kg par ha. This revealed that the improved production technologies collectively are capable of enhancing the productivity by 33.33 per cent over farmers practice. Factor wise enhancement of yield over farmer's practices was; sowing method 62 per cent, improved variety 24 per cent, optimum nutrition 40 per cent, weed management 40 per cent and insect-pest management 53 per cent (Table 2).

Table 2. Performance of soybean under improved technologies as compared to farmers' practice (mean of 2010 and 2011)

Factor	Seed yield (kg/ha)			Additional over farmers' practices (kg/ha)	Increase over farmers' practices (%)
	Improved technology		Farmers' practice		
	Maximum	Mean			
Sowing method	1920	1575	975	600	61.53
Varietal performance	1395	1041	840	200	23.80
NPKS	2025	1565	1240	325	26.20
Weed management	1540	1236	880	356	40.45
Insect-pest management	1690	1310	1055	255	24.17
Mean	1714	1357	1018	339.40	33.33
SEm (±)	11.36	24.76	18.39	28.11	2.46
C D (P=0.05)	**32.24**	**73.81**	**55.09**	**96.28**	**7.13**

Economic evaluation (Table 3) brought out that per hectare gross returns of Rs 40,722 were obtained in demonstrations while Rs 30,540 in farmers' practice resulting in additional returns of Rs 10,182. The average net returns worked out to Rs 34,212 for improved technology, which was 38.51 per cent higher than farmers' practice (Rs 24, 700). The B: C ratio under improved practices (5.25) was 24.53 per cent higher over farmer's

Table 3. Economic evaluation of improved technologies of soybean cultivation (mean of 2010 and 2011)

Particulars	Farmers' practice	Improved technologies	Actual increase over farmers' practices	% increase over farmers' practices
Average yield (kg/ha)	1018	1357	339	33.33
Gross return (Rs/ha)	30540	40722	10182	33.33
Cost of cultivation (Rs/ha)	5840	6510	926	13.13
Net returns (Rs/ha)	24700	34212	9512	38.51
B:C ratio	4.22	5.25	1.03	24.53

Price of soybean- Rs 30 per kg

practice (4.22). These findings are in agreement with the findings of Raghuwanshi *et al.* (2010) and Bhatnagar (2001).

Studies showed that adoption of each component of improved production technology imparted to farmers resulted in substantial yield enhancement of soybean. During the course of this participatory programme (2010 and 2011), it was conceived that the farmers need training to improve their cultivation practices and live demonstrations are most effective in this pursuit. Farmers from command area of Jajon and Ghatera tank in Betwa riverin Vidisha district can optimise their yield levels profitably by adopting important components improved production technology.

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Dynamics of Soybean Production in Different Districts of Madhya Pradesh

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ABSTRACT

Looking to the importance of soybean in the Madhya Pradesh, the present study on dynamics of soybean production in 16 major soybean growing districts of Madhya Pradesh was carried out based on the time series secondary data for the years starting from 1980 to 2010 to analyze the growth and variability in area, production and productivity of soybean. The whole study period was divided into 4 sub- groups, viz. 1981-1990 (1980s), 1991-2000 (1990s), 2001-2010 (2000s) and overall period (1981-2010) for the purpose of detail analysis. The growth of area was found to be positive and significant during all the periods in all the major soybean growing districts except in Raisen and Betul (1990s) and Indore and Sehore (2000s), The increase in production was also positive and significant in all the districts and in all the periods except in Dhar, Hoshangabad, Raisen and Ujjain (1990s) and Sehore and Hoshangabad (2000s). The districts with high productivity (greater than all India average) were identified as Chhindwara, Vidisha, Indore, Ujjain, Sehore and Dhar (1980s); Dewas, Chhindwara, Indore, Ratlam, Mandsaur, Raisen and Ujjain (1990s) and Dhar, Indore, Chhindwara, Sehore and Dewas (2000s). In overall period (1981-82 to 2009-10), high productivity was recorded in Sehore, Dewas, Indore, Dhar, Ujjain and Betul districts. The variability in production was found to be more during 1980s (77.02 %) and thereafter declined during 1990s (37.56 %) and 2000s (32.41 %) in all the major soybean producing districts. The soybean cultivation was found to be preferred by the farmers as it is more profitable over the other crops which resulted in change of cropping pattern and there is still scope of harvesting yield up to 1800 kg per ha at farmers' field. Hence, there is need to identify the focal point of intervention and thrust areas for breaking yield barriers at farmers' level. The enhancement of yield not only helps in increasing production at national level but also reduces the cost of production and makes it more competitive and cost effective at international market.

Key words: Dynamics, Madhya Pradesh, production, soybean

India is the fifth largest producer of soybeans in the world, which is grown in area of 9,673 thousand hectares with the production of 9,720 thousand tonnes (SOPA, 2010). The average productivity of the crop is 1,021 kg per ha (Table 1), which is lower as compared to other soybean growing countries of the world. However, while comparing the productivity on per day basis, India's soybean productivity is not that much lower as the maturity period of soybean in India is only 90 days in comparison to other

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countries (120 days and above). Madhya Pradesh being "Soya-State" accounts for 54.96 per cent of area and 57.62 per cent of production of soybean in the country with an average productivity of 1, 052 kg per ha. Maharashtra state stands second in terms of soybean production in the country sharing 31.28 per cent of acreage and 29.39 per cent production, Rajasthan the third important state in terms of soybean production (7.48 %) in the country. These three states together accounted for more than 92 per cent of area and production of the soybean in the country (Table 1).

Table 1. Present status of soybean crop in India (Average TE- 2010)

Soybean growing states	Area sown (000, ha)	Perce-ntage to total	Yield (kg/ha)	Perce-ntage to total	Total production (000,t)	Perce-ntage to total
Madhya Pradesh	5317	54.96	1052	103.04	5601	57.62
Maharashtra	3026	31.28	988	96.83	2857	29.39
Rajasthan	724	7.48	941	92.16	702	7.22
Andhra Pradesh	174	1.80	1055	103.36	166	1.71
Karnataka	222	2.30	1022	100.10	208	2.14
Chhattisgarh	123	1.27	950	93.08	127	1.31
Rest of India	88	0.91	937	91.77	60	0.62
India	9673	100.00	1021	100.00	9720	100.00

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation (2008, 2009), Department of Farmer Welfare and Agriculture Development, MP (2009-10)

Commercial cultivation of soybean was introduced in Madhya Pradesh during late seventies. A remarkable increase in area, production and yield of soybean was observed in Madhya Pradesh during the period from 1991-92 to 2000-01 over the period 1981-82 to1990-91, even after 1991-92 to 2000-01, the trend of increase in area, production and yield remained continued but at slower rate (Fig. 1). The area of soybean increased tremendously due to the shift of area from cotton, groundnut, cereals, *etc.* (Nahatkar *et al.*, 2005).

Amongst different major oilseeds cultivated in Madhya Pradesh, coverage of soybean in terms of the total area was found to be maximum (79.10 %) followed by rapeseed and mustard (10.7 %), sesame (3.8 %), groundnut (3.1 %), linseed (1.7 %) and niger (1.6 %).

Similarly share of soybean (79.07 %) in production of oilseeds also recorded maximum followed by rapeseed & mustard (10.66 %), sesame (3.77 %), groundnut (3.08 %), linseed (1.68 %) and niger (1.58 %). It is also clear from the data that the acreage as well as production of major oilseeds was found maximum in *kharif* (87 %) and *rabi* (13 %) (Table 2).

To analyse the trend in growth and variability in area, production and productivity of soybean in different districts

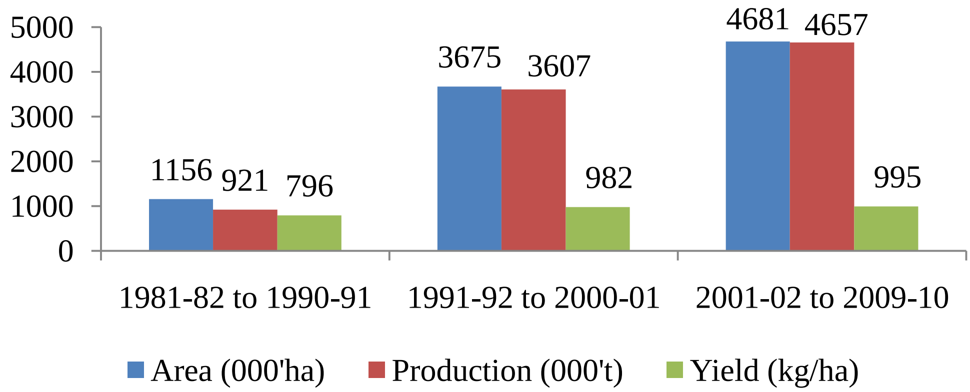

Fig. 1. Average area, Production, and yield of soybean in Madhya Pradesh from 1951-52 to 2009-10

Source: www.mpkrishi.org and Commissioner Land record, Gwalior (M.P)

Table 2. Share of selected oilseeds: TE 2009-10

Oilseeds	Share of different oilseeds (%)	
	Area	Production
Groundnut	3.1	3.08
Soybean	79.1	79.07
Rapeseed-mustard	10.7	10.66
Sesame	3.8	3.77
Sunflower	0.0	0.00
Safflower	0.0	0.00
Niger	1.6	1.58
Castor seed	0.0	0.02
Linseed	1.7	1.68
Total oilseeds	100.0	100.00
Kharif	87.4	87.42
Rabi	12.6	12.58

Source: Department of Farmer Welfare and Agriculture Development, Compendium 2010 and www.mpkrishi.org

of Madhya Pradesh, this study was formulated considering different periods, *i.e.* 1990s, 2000s and 2010s.

MATERIAL AND METHODS

The study is based on the decade-wise time series secondary data on area, production and productivity of soybean in different districts of the state for the years 1980 to 2010. The study period was divided in to 4 sub-group, *viz*. 1981-90 (1980s), 1991-2000 (1990s), 2001-2010 (2000s) as well as whole period 1981-2010 (1980s-2000s). The growth and variation of area, production and productivity has been analyzed to draw conclusions. However, the study confined to 16 major soybean growing districts of Madhya Pradesh (Table 3), which covered 83.56 per cent of total soybean area of the state.

Table 3. Major soybean growing districts of Madhya Pradesh

Districts	Area (000'ha)	Percentage to total
Betul	183.8	3.47
Chhindwara	166.6	3.15
Dewas	298.9	5.65
Dhar	252.2	4.77
Guna + Ashoknagar	282.7	5.34
Hosangabad + Harda	360	6.81
Indore	221.5	4.19
Mandsaur + Nimach	385.2	7.28
Raisen	147.4	2.79
Rajgarh	290.2	5.49
Ratlam	210	3.97
Sagar	328.6	6.21
Sehore	308.8	5.84
Shajapur	337.4	6.38
Ujjain	444	8.39
Vidisha	203	3.84
Total Selected Districts	4420.3	83.56
Madhya Pradesh	5289.8	100.00

Source: Department of Farmer welfare and Agriculture Development, Compendium 2010 & www.mpkrishi.org

RESULTS AND DISCUSSION

Growth in area, production and yield

The growth in area of soybean was found to be positive and significant in all the periods as well as in all the major soybean growing districts of Madhya Pradesh except in Raisen and Betul (1990s) and Indore and Sehore (2000s) where it was found to be positive and stagnating. However, in Chhindwara, the growth in area of soybean was found to be negative and stagnate during 1990s (Table 4). The classification of districts according to growth in production of soybean (Table 5) showed that it was positive and significant in all the districts and in all periods except in Dhar (1990s), Hoshangabad (1990s and 2000s), Raisen (1990s), Ujjain (1990s) and Sehore (2000s), where it was found positive but non-significant. In Madhya Pradesh, the growth of production of soybean was found to be negative only in Betul, but non-significant in 1990s.

Table 4. Growth in area of soybean in major soybean growing districts of Madhya Pradesh

Particulars	1980s	1990s	2000s	1981-82 to 2009-10
Significant positive growth in area	Betul, Chhindwara, Dewas, Dhar, Guna + Ashoknagar, Hosangabad + Harda, Indore, Mandsaur + Nimach, Raisen, Rajgarh, Ratlam, Sagar, Sehore, Shajapur, Ujjain, Vidisha	Dewas, Dhar, Guna + Ashoknagar, Hosangabad + Harda, Indore, Mandsaur + Nimach, Rajgarh, Ratlam, Sagar, Sehore, Shajapur, Ujjain, Vidisha	Betul, Chhindwara, Dewas, Dhar, Guna + Ashoknagar, Mandsaur + Nimach, Raisen, Rajgarh, Ratlam, Sagar, Shajapur, Ujjain, Vidisha	Betul, Chhindwara, Dewas, Dhar, Guna + Ashoknagar, Hosangabad + Harda, Indore, Mandsaur + Nimach, Raisen, Rajgarh, Ratlam, Sagar, Sehore, Shajapur, Ujjain, Vidisha
Significant negative growth in area	_	_	_	_
Positive stagnant area	_	Raisen, Betul	Indore, Sehore	_
Negative stagnant area	_	Chhindwara	_	_

As far as the productivity of soybean during different periods and in different major soybean growing districts (Table 6) of Madhya Pradesh is concerned , the districts like Chhindwara, Vidisha, Indore, Ujjain, Sehore, and Dhar were found to have high productivity as these districts had recorded productivity above national average, while districts like Betul, Dewas, Guna, Hosangabad, Mandsour, Raisen, Ratlam, Sagar, Shajapur and Rajgarh were under low productivity districts in the period 1980s. Among all these districts, the growth in productivity was found to be positive and significant in Chhindwara, Vidisha, Indore and Ujjain districts; positive and stagnate in

Sehore, Dhar Betul, Dewas, Guna, Hosangabad, Mandsour, Raisen, Ratlam, Sagar and Shajapur, and negative and stagnate in only Rajgarh district in period 1980s. (Table 6).

Table 5. Growth in production of soybean in major soybean growing districts of Madhya Pradesh

Particulars	1980s	1990s	2000s	1981-82 to 2009-10
Significant increase in production	Betul, Chhindwara, Dewas, Dhar, Guna + Ashoknagar, Hosangabad + Harda, Indore, Mandsaur + Nimach, Raisen, Rajgarh, Ratlam, Sagar, Sehore, Shajapur, Ujjain, Vidisha	Dewas, Guna + Ashoknagar, Indore, Mandsaur + Nimach, Rajgarh, Ratlam, Sagar, Sehore, Shajapur, Vidisha	Betul, Chhindwara, Dewas, Dhar, Guna + Ashoknagar, Indore, Mandsaur + Nimach, Raisen, Rajgarh, Ratlam, Sagar, Shajapur, Ujjain, Vidisha	Betul, Chhindwara, Dewas, Dhar, Guna + Ashoknagar, Hosangabad + Harda, Indore, Mandsaur + Nimach, Raisen, Rajgarh, Ratlam, Sagar, Sehore, Shajapur, Ujjain, Vidisha
Significant decline in production	_	Chhindwara	_	_
Positive trend but statistically non-significant	_	Dhar, Hosangabad + Harda, Raisen, Ujjain,	Hosangabad + Harda, Sehore,	_
Negative trend but statistically non-significant	_	Betul	_	_

Table 6. Growth of productivity of soybean in major soybean growing districts of Madhya Pradesh

Particulars	**Significant increase in yield**	**Significant decline in yield**	**Stagnant yield with positive sign**	**Stagnant yield with negative sign**
		1981-82 to 1990-91		
High productivity (> All India)	Chhindwara, Vidisha, Indore, Ujjain	_	Sehore, Dhar	
Low productivity	_	_	Betul, Dewas, Guna + Ashok-nagar, Hosangabad + Harda, Mandsaur + Nimach, Raisen, Ratlam, Sagar, Shajapur	Rajgarh,
		1991-92 to 2000-01		
High productivity	Dewas,	Chhindwara	Indore, Ratlam, Mandsaur + Nimach, Raisen, Ujjain	Betul
Low productivity	Vidisha	_	Sehore, Shajapur, Hoshangabad+Harda	Dhar, Sagar
		2001-02 to 2009-10		
High productivity	Dhar, Indore, Chhindwara		Sehore, Dewas	
Low productivity	Ujjain, Raisen, Betul, Vidisha, Guna + Asholnagar		Hoshangabad + Harda, Rajgarh, Ratlam, Sagar, Mandsaur+Nimach	
		1981-82 to 2009-10		
High productivity	Sehore, Dewas, Indore, Dhar, Ujjain		Betul	Chhind-wara
Low productivity	Raisen, Vidisha, Guna + Asholnagar, Hoshangabad + Harda, Rajgarh, Shajapur, Ratlam		Mandsaur + Nimach, Sagar	

During 1990s, districts *viz*. Dewas, Chhindwara, Indore, Ratlam, Mandsour, Raisen, Ujjain and Betul were found belonging to high productivity, whereas Vidisha, Sehore, Shajapur, Hosangabad, Dhar and Sagar were low productivity districts. Amongst all these districts, the growth in productivity of soybean was found to be positive and significant only in Dewas and Vidisha; negative and significant in Chhindwara; negative and stagnate in Betul and positive and stagnate in Indore, Ratlam, Mandsour, Raisen, Ujjain, Sehore, Shajapur and Hosangabad districts (Table 6).

As per the data presented in Table 6, during 2000s the districts like Dhar, Indore, Chhindwara, Sehore, Dewas falls under high productivity districts, where as Ujjain, Raisen, Betul, Vidisha, Guna, Hosangabad, Raigarh, Ratlam, Sagar, and Mandsour found their place in low productivity districts. In this period, none of the district showed negative growth in productivity of soybean. Further, the districts like Dhar, Indore, Chhindwara, Ujjain, Raisen, Betul, Vidisha and Guna recorded positive and significant growth, while Sehore, Dewas, Hosangabad, Raigarh, Ratlam, Sagar, and Mandsour districts showedpositive and stagnate growth of soybean in Madhya Pradesh.

While comparing the productivity in 2010s, the districts, *viz*. Sehore, Dewas, Indore, Dhar, Ujjain, Betul, and Chhindwara were under high productivity districts, while Raisen, Vidisha, Guna, Hosangabad, Rajgarh, Shajapur, Ratlam, Mandsour, and Sagar were under low productivity districts. Above all, none of the districts recorded significant decline yield of soybean in Madhya Pradesh. The districts like Sehore, Dewas, Indore, Dhar, Ujjain, Raisen, Vidisha, Guna, Hoshangabad, Rajgarh, Shajapur and Ratlam showed significant increase in yield of soybean in Madhya Pradesh, while districts like Betul, Mandsaur and Sagar showed positive and stagnate productivity levels, beside Chhindwara showed negative and stagnate yield of soybean in 2010s in Madhya Pradesh (Table 6).

Variability in area, production and yield

The observed variability in area, production and productivity of soybean (Table 7) showed that during 1980s, amongst all major soybean growing districts, the variability was found maximum in Mandsaur (100.90 %) followed by Ratlam (85.71 %), Guna (82.99 %), Vidisha (70.66 %), Sagar (67.19 %), Ujjain (59.40 %) and Shajapur (54.16 %). During 1990s, the variability in area of soybean was found between 6.38 per cent (Indore) to 35.07 per cent (Betul), while in 2000 it ranged between 2.04 per cent (Indore) to 35.83 per cent (Sehore). In overall period, it ranged between 36.08 per cent (Indore) to 76.41 per cent (Mandsaur).

The variability of production of soybean was also found more in case of soybean as compared to its competitive crop, *i.e.* maize in all the periods and in all the major soybean producing districts of Madhya Pradesh. The variability in production of soybean was found to be more in 1980s (77.02 %) as compared to 1990s (37.56 %) and 2000s (32.41 %). In overall period (1980s-2000s), it was found to be 67.90 per cent and ranged between 55.20 per cent (Indore) to 89.92 per cent (Guna). During 1980s it ranged between 17.47 per cent (Hoshangabad) to 59.12 per cent (Chhindwara), while in the period of 1990s and 2000s it ranged between 13.63 per cent (Indore) to 50.77 per cent (Rajgarh) and 17.30 per cent (Indore) to 100.21 per cent (Ratlam).

The variability in productivity of soybean was found to be more during 1980s (27.28 %) as compared to 1990s (26.06 %) and 2000 (23.64 %). In overall period, it was found to be 30.54 per cent and ranged between 18.71 per cent (Sagar) to 49.24 per cent (Chhindwara). With regards to different districts, in 80s the maximum variability in yield of soybean was found in Chhindwara (48.36 %) in 1980s, 55.81 per cent 1990s and 34.24 per cent in 2000s.

Factors underlying changes in cropping pattern

Cropping pattern is governed by various factors such as price of input and output, agro-climatic conditions, market

Table 7. Variability in area, production and yield of soybean in major soybean producing districts of Madhya Pradesh

Districts	Area (000'ha)				Production (000't)				Yield (kg/ha)			
	80s	90s	2000s	80s-2000s	80s	90s	2000s	80s-2000s	80s	90s	2000s	80s-2000s
Betul	5291	3507	956	4127	6424	2754	2824	5432	1797	2329	2082	2863
Chhindwara	4136	1743	1911	4187	7493	5839	4565	5929	4836	5581	3183	4924
Dewas	3594	1821	473	4591	6763	3132	1334	6215	4002	1862	1125	3120
Dhar	5041	1340	458	4671	6843	4119	2496	6528	2305	3831	2145	3296
Guna + Ashoknagar	8299	2414	2104	7048	9401	4397	3819	8992	2653	3303	2626	3299
Hosangabad + Harda	3419	2677	285	4857	4550	4130	3044	6851	2572	2692	3065	3395
Indore	3794	638	204	3608	5938	2017	2830	5220	2366	1626	2759	2732
Mandsaur + Nimach	10090	3397	982	7641	12200	5175	2191	8269	2924	3067	2184	3495
Raisen	4826	3479	3139	4617	6974	4452	4407	6340	2660	2672	1728	2972
Rajgarh	6382	1916	479	5159	6260	4783	3118	7145	2230	3595	3051	3301
Ratlam	8571	1403	934	6096	11485	4017	3475	7569	3187	3123	3217	3637
Sagar	6719	3046	3302	7107	7156	3616	4112	7652	1760	1823	2169	1871
Sehore	5284	1203	3583	5039	7442	2222	4379	6599	2285	1322	1743	2562
Shajapur	5416	1437	327	4742	6430	2529	2255	5590	1812	1522	2136	2062
Ujjain	5940	1585	594	4928	8623	3149	3763	6474	2842	2363	3424	3157
Vidisha	7066	3276	2308	6945	9251	3766	3247	7833	3419	981	1179	2177
Average	5867	2180	1377	5335	7702	3756	3241	6790	2728	2606	2364	3054
MP	5151	1875	945	5164	6841	2405	2493	6054	1927	1200	1830	1973

Source: Commissioner land Record Gwalior, Department of Farmer Welfare and Agriculture Development and Various Publications of Districts Statistical Hand book.

forces and technological development along with irrigated potential in the area, which determine their makeup. Soybean mainly grown in rain-fed areas is best suited to soils of Madhya Pradesh. The soybean cultivation is preferred by the farmers, being observed more profitable over other crops and also due to low input cost technologies adopted by most of the marginal and small farmers. These farmers with marginal lands and rain-fed cultivation prefer oilseeds instead of cereals and pulses in their cropping pattern (Sharma *et al*., 2000). The de-oiled cake (by-product of oilseeds) is also found remunerative and generate extra income which leads to enhance the profitability of the farmers, in general, and contribute significant role in the state economy in particular, as Soybean having tremendous export potential. There are various other soybean by-products available in the market, which fetches very good price in the international market leading to enhance export earnings and fulfilling the demand (Pandey *et al*., 2002).

It is clear that the higher growth in production of soybean in the different districts during different periods of the study was observed due to significant higher growth in area followed by moderately visible growth in productivity. Further growth in soybean production in the state is possible only through breaking yield barriers at farmers' field through introduction of recommended packages of practices, seed replacement and popularization of associated input including farm mechanization. The results of various field level demonstration revealed that there is scope of harvesting yield of soybean at least up to 1,800 kg per ha under farmer's field condition through adoption and management strategy (Tiwari *et al.,* 2001). Similarly soybean shows positive relationship between rate of adoption and levels of yield (Sharma *et al.,* 2001). Hence, there is need to identify the focal point of intervention and thrust areas for breaking yield barriers at farmers' level. The enhancement of yield not only helps in increasing production at national level but in also reduce the cost of production so that it can be made more competitive and cost effective at international market.

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Performance of Soybean plus Maize Intercropping in Sehore District of Madhya Pradesh

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Soybean [*Glycine max* (L.) Merrill) is an important economic leguminous oilseed crop and isconsidered as a good source of protein and edible oil for human being. Soybean has been a predominant crop in Madhya Pradesh especially in Sehore district which accounts for 84 per cent area (3, 25, 421 ha) under soybean cultivation during *kharif* season (Districts Statistics Book, 2010). The district Sehore falls under Vindhyan plateau zone of Madhya Pradesh and lies between 22^0, 31 to 23^0, 40 north and 76^0, 22 to 78^0, 08 east. It is established that soybean has been a predominant crop in Sehore district during *kharif* season and being cultivated as a mono-crop that leads to establishment of harmful dominated weeds flora and high infestation of insect-pests, which significantly reduces the yield of soybean crop. Though control of weeds and insect-pest infestation is possible by use of various chemical pesticides, however, it may gradually develop resistance against them. In such a situation, diversification of cropping system is necessary to get higher yield, net returns, maintain soil health, preserve environment and meet daily food and fodder requirement of human and animals (Padhi and Panigrahi, 2006). Thus, it is advised to change either the crop rotation or inclusion of short duration crop as an inter crop. The practice of intercropping explore efficient utilization of all given and available resources, which maintain stability in production and obtain higher net returns accordingly which is not possible through sole cropping system (Dutta and Bandyopadhyay, 2006; Singh *et al*., 2008). Apart from these, the practice of intercropping also reduces the population density of insect-pests as the intercrop may not serve as their host (Songa *et al.,* 2007). Intercropping also demonstrate weed control advantages over sole crops as intercrops are more effective than sole crops in usurping resources from weeds or suppressing weed growth through allelopathy (Liebman and Dyck, 1993). In view of this, soybean with maize as an intercrop was evaluated for productivity and economic benefits in Sehore district of Madhya Pradesh.

In order to study the relevance of intercropping of soybean plus maize, the

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trials were carried out at instructional farm of Krishi Vigyan Kendra, Sehore during 2009 and 2010. The size of each plot was 100 m^2 and soil of all the fields was medium to black and well drained. The experiment comprised of five treatments, namely sole improved maize variety 'HQPM-1' (high quality protein maize-1), sole soybean variety 'JS 93 05', intercropping of soybean variety (JS 93 05)+ maize variety (HQPM 1) in row ratio of4:2, sole variety of maize 'Satha' and sole variety of soybean 'JS-335'. The crops were sown during last week of June. Planting spacing for sole and intercropping system in maize and soybean crops was respectively kept as 70 cm × 30 cm and 60cm × 30 cm, and 45 cm × 7cm and 40 cm × 7 cm. The maize and soybean crops under sole cropping system were fertilized respectively with 120:60:50 and 20:60:20 kg $N:P_2O_5:K_2O$ per ha. The crop under intercropping system was fertilized with 25 kg N, 75 kg P_2O_5 and 25 kg K_2O per hectare for both crops. For sole maize crop and intercrop of soybean +maize, full dose of phosphorus and potash and 1/3 dose of nitrogen was applied at the time of sowing and remaining dose of nitrogen was applied at knee height and tasseling while entire quantities of recommended fertilizers were applied as basal at the time of sowing in soybean crop. The soybean seed was treated with carbendazim + thiram (@ 1+2 g/kg seed) followed by *Rhizobium japonicum* and PSB culture @ 10 g per kg seed prior to sowing. Foliar spray of Profenofos @ 1 lit per ha (dissolved in 500 litre water) for the management of insect-pests in soybean crop. Maize seed was treated with carbendazim + thiram (@ 1+2 g/kg seed), *Azotobacter* and PSB culture (@ 10 g/kg seed) before sowing. Observations on yield parameters (plant population/m^2, number of pods or cobs/plant, number of grains/pod or cob, and seed index) of both the crops on randomly selected five plants from each quadrate (1 m^2) and seed yield per plot were recorded at the time of harvest.

Crop equivalent yield was calculated by converting the seed yield of all intercrop to base crop (soybean) on the basis of existing selling price in the market. Competition functions like land equivalent ratio (LER) (yield of base crop / yield of sole crop + yield of inter crop/yield of sole crop) and production efficiency (net monetary returns of system/duration of system) were estimated as described by Willey (1979). Total system productivity was drawn from equivalent yield of system = (equivalent yield of inter crop + equivalent yield of sole crop) + equivalent yield of any one sole crop based on price of produce.

Land equivalent ratio: LER of soybean + maize intercropping system was recorded as 1.4 which clearly showed 40 per cent increment in yield or to get same level of yield from sole crop, 1.4 ha area would be required (Table 2). Other workers have also reported LER greater than 1 in soybean plus maize intercropping system (Addo-Quaye *et al.*, 2011). Rekha and Dhurua (2009) also observed LER of 1.3 from pigeon pea + soybean intercropping. The higher productivity of the intercropping system may be attributed to complementary and efficient use of available resources by the component crops (Ghosh *et al.*, 2006; Li *et al.*, 2006). Solanki *et al.*, (2011) also observed that in maize + pigeon pea intercropping system, dry matter production per unit of photosynthetic active radiation (PAR) absorbed was higher than the sole crops. The higher PAR conversion efficiencies under intercropping systems may be attributed to greater spread and distribution of light over leaf area of intercrop canopies during early stage of growth. Similar observations were also recorded by Muoneke *et al*. (2007).

Production efficiency: Higher production efficiency was obtained under soybean + maize intercropping (373.1 %) than sole cropping system (Table 2). The superior production efficiency from soybean + maize intercropping could be due to spatial and temporal advantages as compared to sole cropping system. Similar findings were also reported by Ghosh *et al.* (2006). They reported that 60 per cent greater yield was obtained from intercropping system (soybean + pigeon pea) than that from sole soybean.Muoneke *et al.* (2007) also reported higher production efficiency in soybean + maize intercropping system.

Total system productivity: Maize and soybean cultivars 'HQPM-1' and 'JS 93 05' recorded highest grain yield under both cropping system as compared to existing cultivars 'Satha' and 'JS 335' and contributed to higher total system productivity (6,718 kg/ha) under intercropping system (Table 2). This might be accredited to lesser competition, temporal comple-mentarities and better utilization of resources by the component crops having differential rooting pattern, canopy distribution and nutrient requirements. Padhi and Panigrahi (2006) and Rana (2006) also reported beneficial effects of intercropping in terms of higher total productivity and profitability.

Performance of maize cultivar: The maize cultivar ('HQPM-1') recorded higher yield (4,090 and 2,600 kg/ha) than existing cultivar 'Satha' under both cropping systems. It might be attributed to higher number of cobs per plant and number of grains per cob (Table 1). 'HPQM-1' is a medium duration variety; yellow dent, responsive to higher dose of fertilizers, tolerant to frost/cold and resistant to Maydis leaf blight and common rust.

Table 1. Effect intercropping on yield parameters of soybean and maize

Crops	**Plant Population (No/m²)**	**Cobs or pods (No/plant)**	**Grains (No/cob or pod)**	**Seed index (g/100 seeds)**	**Yield (kg/ha)**
Sole maize *cv*. 'Satha'	5.5	1.02	230	15.0	1640
Sole maize *cv*. 'HQPM-1'	5.5	1.2	400	15.5	4090
Sole soybean *cv*. 'JS 335'	33	17	2.3	10.5	1340
Sole soybean *cv*. 'JS 93-05'	33	20	2.7	10.1	1760
Soybean *cv*. 'JS 93-05'+ maize *cv*. 'HQPM-1' (4:2)	22.8/2.64	21.5/1.4	2.9/440	10/15.5	1420/ 2600

Table 2. Effect of different cropping system on yield equivalence, LER, production efficiency and B: C ratio

Practices	Duration (Days)	Total system productivity (kg/ha)	Equivalent yield of the crop or system	Land equivalent ratio	Production efficiency (%)	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio (Rs/ha)
Sole maize *cv.* 'Satha'	90	-	-	-	71.1	13,000	19,400	6,400	1:1.5
Sole maize *cv.* 'HQPM-1'	100	-	-	-	247	16,200	40,900	24,700	1:2.5
Soybean *cv.* ' JS 335'	100	-	-	-	140.8	15,000	29,078	14,078	1:1.9
Sole soybean *cv.* 'JS 93-05'	90	-	-	-	241	16,500	31,192	21,692	1:2.3
Soybean *cv.* 'JS 93-05'+ maize *cv.* 'HQPM-1' (4:2)	100	6708	2618 + 409 0	1:1.4	373.1	19,500	56,814	37,314	1:2.9

Market price of produce: Maize- Rs 10/kg, soybean- Rs 21.70/kg

Performance of soybean cultivar: The soybean cultivar ('JS 93 05') recorded higher yield (1,760 and 1,420 kg/ha) than existing cultivar ('JS 335') under both cropping systems. It might be due to higher number of pods per plant and number of grains per pod as compared to existing cultivar 'JS 335' (Table1). Due to regular cultivation of 'JS 335' since long time and use of higher seed rate (100-125 kg /ha against 80-88 kg /ha) use of higher seed rate (100-125 kg /ha against 80-88 kg /ha) made it highly susceptible against semi looper, girdle beetle and pod borer infestation. Apart from these, premature shedding of flowers, pods and leaves also causes reduction in yield under stress conditions. While cultivar 'JS 93 05' is resistant against diseases, insect-pests and shows tolerance to moisture stress. Therefore, the genotypic combination of 'JS 93 05' (soybean) and HQPM-1 (maize) recorded significantly higher total system productivity than other systems. Besides these, JS 93 05 and HQPM 1 are short duration cultivars as compared to JS 335 and pigeon pea (if selected as an intercrop) that facilitate the timely sowing of wheat, gram and mustard during *rabi* season which is likely to give higher productivity.

Economic evaluation: The monetary advantage based on land equivalent ratio indicated superior economic viability of soybean plus maize intercropping in 4: 2 ratio over other cropping system (Table 2). Soybean + maize intercropping system recorded maximum net returns (Rs 37,314/ha) and benefit cost ratio (1:2.9) followed by sole maize cultivar 'HQPM-1' (Rs 24,700 / ha and 1:2.5), soybean cultivar 'JS 93 05' (Rs 21, 692/ha and 1:2.3), JS 335 (Rs 14,078/ha and 1:1.9) and maize cultivar 'Satha' (Rs 6,400/ha and 1:1.5), which clearly indicated the superiority of this system over sole cropping systems.

The results clearly revealed that intercropping of soybean plus maize during *kharif* season enhanced the productivity and profitability under rainfed conditions. Application of recommended dose of fertilizers along with improved varietal combination is necessary for both sole and intercropping system. Since duration of life cycle of crops used in this intercropping system was within 100 days, farmers can efficiently utilize residual moisture through early sowing of few short duration *rabi* crops. Thus, the farmers of Sehore district could use maize crop as an intercrop with soybean for higher profits and economic benefits.

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Evaluation of Sulphur Levels on Performance of Soybean in Nimar Region of Madhya Pradesh

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Key words: Soybean, sulphur, Nimar

Soybean has become a prominent *kharif* crop of central India. Area under soybean cultivation in the upcoming Nimar region of the state is consistently increasing. It is gaining momentum among the farmers of this region as it is acash crop and fits well in traditional cropping systems.

Sulphur, now recognized as forth major nutrient with nitrogen, phosphorus and potassium, is a constituent of three sulphur containing amino acids (cysteine, cystine and methionine), which are the building blocks of protein and about 90 per cent of plant S is present in these amino acids. Sulphur improves protein and oil content in seeds and is also associated with special metabolism in plant and the structural characteristics of protoplasm. Average removal of sulphur by one tonne of oilseeds ranges between 8-12 kg, by pulses 4-8 kg as compared to 3-5 kg by cereal crops. Similarly, oilseeds from one ha remove sulphur between 10-25 kg and that of pulses 5-10 kg annually which depends upon nature of crop, soil and environmental factors (Singh, 1999).

Sulphur deficiency is becoming more critical with each passing year which is severely restricting crop yield, produce quality, nutrient use efficiency and economic returns from the soybean crop. Keeping in view the central role of sulphur in improving crop yield and produce quality of soybean, the present investigation has been conducted.

A field experiment was conducted at farmer field during *kharif* 2011 in Burhanpur (Madhya Pradesh) of '*Nimar*' region. The treatments under randomized block design included five levels of sulphur (0, 10, 20, 30 and 40 kg/ha) replicated five times. The soil of the experimental site belonged to Vertisols and pre-experimental samples (15 cm) analyzed: pH 7.8, EC 0.24 dS per m, organic carbon 0.46 per cent, and available N, P, K and S 280, 12, 444, and 4.8 kg per ha respectively. Soybean variety JS 93 05 @ of 75 kg per ha was sown on 25th June, 2011 and harvested on 30th September, 2011. Sowing was done using bullock drawn seed drill at 45 cm row to row distance. The crop was raised under rainfed conditions and recommended dose of fertilizers (20:80:20: N: P_2O_5: K_2O) and graded levels of sulphur were applied as basal as per treatments. Fertilizer carriers utilized were NPK mixture (12:32:16) and gypsum. Before sowing the seed treated with thirum + carbendazim (2 g + 1 g) per kg seed followed by *Bradyrhizobium japonicum* culture @ 5 g per kg seed. Soil was treated with *Trichoderma viridie* culture @ 10 kg per ha.

Observations on number of pods per plant and number of seeds per pod were recorded utilizing randomly selected five

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plants from each treatment. Seed yield per plot were recorded and expressed as kg per ha. Economic evaluation was done by working out benefit cost ratio by dividing gross returns by gross cost reflecting returns per rupee invested.

Number of pods per plant ranged from 21.4 (control) to 30.2 (30 kg S/ha). All the sulphur levels were significantly better than control except its application at 10 kg per ha. Application of sulphur at 30 and 40 kg per ha were at par but significantly different from 10 kg S per ha. Seeds per pod exhibited a trend similar to pods per plant, which ranged from 1.96–2.12. The value of seed index ranged between 9.13 g (control) and 9.57 g (30 kg S/ha), and results were not significant. Sulphur application @ 30 kg S per ha gave boldest seed (Table 1).

Seed yield showed a progressive increase with sulphur levels up to 30 kg per ha (2,380 kg/ha), which was statistically at par with 40 kg S per ha (2,378 kg/ha), but significantly superior over lower levels (2,170 and 2,060 kg/ha) and control (1,960 kg/ha). The highest yielding treatment revealed 21.4 per cent yield increase over control (Table 1). The results obtained in the experiments corroborate findings (Farhad *et al.*, 2010; Mohanti *et al.*, 2004; Gokhale *et al.*, 2005; Nasreen and Farid, 2006; Mahmoodi *et al.*, 2013) in other regions.

Table 1. Effect of treatments on yield attributes, seed yield and B: C ratio

Level of sulphur (kg/ha)	Pods (No/plant)	Seeds (No/pod)	Seed index (g/100 seeds)	Seed yield (kg/ha)	Returns/ rupee invested
Control	21.4	1.96	9.13	1960	1.88
10	24.7	1.99	9.26	2060	2.07
20	26.3	2.05	9.34	2170	2.56
30	30.2	2.12	9.57	2380	2.80
40	29.97	2.12	9.52	2378	2.75
SEm (±)	1.28	0.026	0.65	31.81	
CD (P = 5 %)	**3.85**	**0.08**	**NS**	**95.36**	

Better yield attributing traits like pods per plant, seeds per pod and seed index led to maximum seed yield and returns per rupee invested by application of 30 kg S per ha. The results indicated that to optimize soybean yields in '*Nimar*' region of Madhya Pradesh, inclusion of sulphur in fertilizer recommendation schedule is necessary and best dose of sulphur is 30 kg S per ha.

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Performance of Quizalafop-p-ethyl 5 % EC against Weeds and Yield of Soybean

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Key words: Soybean, herbicides, seed yield

Soybean (*Glycine max*) is important oil yielding rainy season (*kharif*) crop having multiple uses. Weeds are the major biotic factor responsible for poor yield in soybean. Simultaneous emergence and rapid growth of large number of weed species causes severe crop-weed competition and reduction in crop yield (30-80 %) depending upon the type of weed flora and weed density (Kuruchania *et al.,* 2000). The incessant rains do not permit timely inter-cultivations and manual control of weeds on account of high cost and labour shortage during weeding peaks. Therefore, there is a need for alternative method for reducing the weed load. Under such situation, herbicidal weed control particularly post-emergence remains the only viable option. Recently a molecule of post-emergence herbicide (quizalafop-p-ethyl) is being marketed with the assurance of selective control of grassy weeds in soybean. The objective of this study was to evaluate the efficacy of quizalafop-p-ethyl, market as well as sponsor sample on weed management of soybean.

A field experiment was conducted during *kharif* of 2011 at G B Pant University of Agriculture and Technology, Pantnagar, to see the influence of quizalafop-p-ethyl 5 per cent EC against weeds and yield of soybean. The experiment was conducted in RBD with three replications. Experiment was comprised of three different doses of quizalafop-p-ethyl sponsor sample (SS)at 37.5, 50 and 100 g per ha and market sample (MS) at 37.5 and 50 g per ha, imazethapyr 100 g per ha, twice hand weeding at 20 and 40 DAS and weedy check. The post emergence herbicides (quizalafop – p - ethyl and imazethapyr) were sprayed on 20 days after sowing using 500 litres of water per hectare. Sowing of soybean (var. PS 1347) was done manually on well prepared beds with seed rate of 80 kg per ha. The row to row spacing was kept with 60 cm and plant to plant 10 cm. The crop was raised by following recommended package of practices. The rainfall received during crop growth period was 1663.2 mm.

The performance of different treatments was studied in terms of all the types of weed flora, weed density, weed

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biomass and their subsequent effect on growth and yield of soybean. For density of weed species (No/m^2), an area of 0.25 m^2 was selected randomly at three spots using a quadrate of 0.5 x 0.5 m. The collected weeds were first sundried and kept in electric oven at 70^0C till the weight become constant and weed biomass expressed as g per m^2. Weed control efficiency and relative weed density was worked out using the formula as given below.

Relative weed density	=	(Density of individual weed species in the community/Total density of all weed species in the community) x 100
Weed control efficiency (%)	=	[Weed dry weight in control (g/m^2)- Weed dry weight in treated plot (g/m^2)/ Weed dry weight in control (g/m^2)] x100

Data on yield and its attributes were recorded from the net plot. As wide range of variation existed in data, number of weeds was log transformed by adding 1.0 to original value before analysis of variance. Comparison of treatment means for significance at 5 per cent level was done using differences suggested by Gomez and Gomez (1984).

Weed infestation

The major weed flora infested in the experimental plot was *E. indica* and *C. rotundus,* the least was *P. niruri* having relative density of 45.5 and 36.1 and 1.5 per cent at 45 DAS, respectively. *F. miliaceae* was not present at 30 DAS but appeared at latter growth stages (45 and 75 DAS) (Table 1).

Influence of herbicides on weed density

The data on the weed density of soybean at 30, 45 and 75 DAS as influenced by different herbicides indicated that number of weeds was significantly affected by different herbicidal application (Table 2). The number of dominant grassy weeds was gradually decreased with the increase of doses of quizalafop-p-ethyl (SS) in all the three dates of observation. The reduction in the density of grassy weeds by the application of quizalafo-p-ethyl has also been reported by Kushwa and Vyas (2006). Better control of grassy weeds *viz., E. colona, E. indica, P. maxicum* were observed with application of quizalafop-p-ethyl (MS as well as SS) as compared to imazethapry 100 g per ha. Earlier research work (Vijayalaxmi *et al.*, 2012) also reported better control of weeds by the application of quizalafop-p-ethyl at 75 g per ha as compared to imazethapyr 75 g per ha. Twice hand weeding recorded the lowest weed density. Similar observation is also recorded by Benke *et al.* (2011). Application of quizalafop-p-ethly (SS) at 50 and 100 g per ha provided complete control of *E. colona* at all the crop growth stages. Imazethapyr 100 g per ha controlled *P. hysterophrous, P. niruri* and *F. miliacea* excellently than quizalafop – p - ethyl. Imazethapyr 100 g per ha showed better control of *C. rotundus* at all the growth stages as compared to quizalafop-p-ethyl, which is mainly active against grassy weeds. Among herbicidal treatments, application of imazethapyr 100 g per ha was found more effective in controlling broad leaved weed which remained at par with twice hand weeding and superior to MS and SS of quizalafop-p-ethyl. The broad spectrum control of weed by imazethapyr is the reason for better control of broad leaved weeds and sedges (Meena *et al.*, 2011).

Influence of herbicides on weed dry weight and weed control efficiency

Application of graded dose of quizalafop-p-ethyl significantly curtailed the dry weight of weeds at all the growth stages as compared to weedy check. Lowest weed biomass at 30 and 40 DAS was recorded with quizalafop-p-ethyl (SS) 100 g per ha and at 75 DAS it was with its lower dose applied at 50 g per ha. Quizalafop-p-ethly (SS) 100 g per ha gave higher weed control efficiency when applied at 2-3 leaf stage of weeds at 30 and 45 DAS (Table 3). It was closely followed by its lower dose applied at 50 g per ha Overall result showed that the tested herbicide quizalafop-p-ethyl was comparatively more effective against grassy weeds than broad leaved weeds and sedges.

Influence of herbicides on yield and yield attributes

Significantly higher seed yield (2,969 kg/ha) was obtained with twice hand weeding followed by imazethapyr 100 g per ha and quizalafop-p-ethly (SS) 100 g per ha when compared with weedy check (Table 4). However, quizalafop-p-ethyl (SS) at 50 g per ha was at par with twice hand weeding. The yield attributing characters (seeds/pod, plants/m^2) followed the similar trend. The superior performance of these treatments was mainly due to relatively weed free environment on account of post emergence application of herbicides. Imazethapyr 100 g per ha recorded higher seed yield of soybean than all the doses of quizalafop-p-ethyl SS as well as MS. This might be due to broad spectrum control of grassy and non grassy weeds.

From the results, it can be stated that the application of quizalafop–p-ethyl as post-emergence can effectively control only grassy weeds. Higher level of quizalafop –p-ethyl (SS) at 50 and 100 g per ha showed better suppression of all the species of grassy weeds throughout the crop growing season and also recorded higher seed yield than its lower dose and market sample of quizalafop–p-ethyl. So it may be safely staterd that higher yield may be achieved in soybean crop without any phytotoxicity under the treatment quizalafop ethyl at 100 g per ha, which is at par with imazethapyr at 100g per ha

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Table 1. Relative weed density of different weed species in soybean

Weed species	Weed type	Family	Days after sowing		
			30	45	75
Echinochloa colona	Grassy	Poaceae	2.8	3.9	15.2
Eleusine indica	Grassy	Poaceae	19.1	45.5	9.1
Panicum maxicum	Grassy	Poaceae	25.3	11.5	30.8
Parthenium hysterophorous	Broad leaf weed	Asteraceae	5.9	6.1	11.7
Phyllanthus niruri	BLW	Euphorbiaceae	0.6	1.5	3.5
Cyperus rotundus	Sedges	Cyperaceae	6.9	36.1	14.7
Fimbristylis miliacea	Sedges	Cyperaceae	-	0.7	1.7

DAS: Days after sowing

Table 2. Density (no/m²) of dominant weeds as affected by different weed control treatments at different days after sowing (DAS)

Treatment	Dose (g a.i./ ha)	Grassy weeds								
		Echinochloa colona			*Eleusine indica*			*Panicum maximum*		
		30 DAS	45 DAS	75 DAS	30 DAS	45 DAS	75 DAS	30 DAS	45 DAS	75 DAS
Quizalafop-p-ethyl (SS)	37.5	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.8 (45.3)	0.0 (0.0)	0.0 (0.0)	2.9 (20.0)	1.8 (5.3)	1.3 (4.0)
Quizalafop-p-ethyl (SS)	50	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.4 (30.7)	0.0 (0.0)	0.0 (0.0)	2.7 (14.7)	0.0 (0.0)	0.0 (0.0)
Quizalafop-p-ethyl (SS)	100	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.3 (25.3)	0.0 (0.0)	0.0 (0.0)	2.0 (8.0)	0.0 (0.0)	0.0 (0.0)
Quizalafop-p-ethyl (MS)	37.5	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.6 (36.0)	0.0 (0.0)	0.5 (1.3)	3.0 (20.0)	1.6 (4.0)	0.0 (0.0)
Quizalafop-p-ethyl (MS)	50	0.0 (0.0)	1.1 (2.7)	0.0 (0.0)	3.0 (24.0)	0.0 (0.0)	0.0 (0.0)	2.6 (13.3)	0.0 (0.0)	0.0 (0.0)
Imazethapyr 10%SL	100	0.5 (1.3)	1.6 (4.0)	1.9 (6.7)	3.3 (26.7)	3.8 (128.0)	3.2 (25.3)	3.5 (32.0)	0.5 (1.3)	3.2 (24.0)
Hand weeding twice (20 and 40 DAS)		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Weedy check	-	2.5 (12.0)	3.1 (21.3)	3.8 (46.7)	4.4 (81.3)	4.4 (248.0)	3.3 (28.0)	4.6 (108.0)	4.1 (62.7)	4.6 (94.7)
SEm (±)		0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.2
LSD (P = 0.05)	**-**	**0.6**	**0.6**	**0.4**	**0.6**	**0.3**	**0.7**	**0.7**	**0.7**	**0.7**

Table 2.- Conti.

Treatment	Dose (g a.i. / ha)	Broad leaf weeds						Sedges				
		Parthenium hysterophrous			*Phyllanthus niruri*			*Cyperus rotundus*			*Fimbristylis miliaceae*	
		30 DAS	45 DAS	75 DAS	30 DAS	45 DAS	75 DAS	30 DAS	45 DAS	75 DAS	45 DAS	75 DAS
Quizalafop-p-ethyl (SS)	37.5	2.9 (17.3)	3.6 (36.0)	3.6 (34.7)	0.7 (2.7)	1.8 (5.3)	2.1 (8.0)	3.6 (37.3)	4.7 (112.0)	4.2 (65.3)	1.3 (4.0)	2.0 (6.7)
Quizalafop-p-ethyl (SS)	50	3.0 (20.0)	3.8 (49.3)	3.9 (48.0)	1.1 (2.7)	1.3 (4.0)	2.3 (9.3)	3.4 (30.7)	4.5 (90.7)	3.7 (52.0)	1.1 (2.7)	2.3 (9.3)
Quizalafop-p-ethyl (SS)	100	3.4 (28.0)	3.6 (48.0)	3.8 (45.3)	1.1 (2.7)	0.5 (1.3)	1.8 (5.3)	3.4 (30.7)	4.4 (81.3)	4.3 (78.7)	1.1 (2.7)	1.5 (5.3)
Quizalafop-p-ethyl (MS)	37.5	3.0 (20.0)	3.9 (52.0)	3.8 (46.7)	1.6 (4.0)	1.6 (4.0)	1.6 (6.7)	3.8 (44.0)	4.5 (94.7)	3.6 (34.7)	1.3 (4.0)	2.0 (6.7)
Quizalafop-p-ethyl (MS)	50	3.6 (37.3)	3.7 (84.0)	3.9 (52.0)	0.7 (2.7)	0.5 (1.3)	1.6 (6.7)	3.3 (29.3)	4.7 (117.3)	4.2 (68.0)	1.1 (2.7)	2.1 (8.0)
Imazethapyr 10%SL	100	1.3 (4.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.1 (2.7)	0.5 (1.3)	2.6 (13.3)	0.5 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Hand weeding twice (20 and 40 DAS)		0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Weedy check	-	3.2 (25.3)	3.4 (33.3)	3.6 (36.0)	1.1 (2.7)	2.2 (8.0)	2.4 (10.7)	1.5 (29.3)	4.5 (88.0)	3.8 (45.3)	1.3 (4.0)	1.8 (5.3)
SEm (±)		0.2	0.4	0.1	0.5	0.4	0.4	0.5	0.2	0.3	0.5	0.3
LSD (P = 0.05)	**-**	**0.7**	**1.3**	**0.3**	**NS**	**1.2**	**1.3**	**1.6**	**0.7**	**0.8**	**NS**	**0.9**

Table 3. Weed biomass and weed control efficiency at different days of sowing in soybean field as affected by different weed control treatments

Treatment	Dose (g a.i./ ha)	Total weed dry weight (g/m²)			Weed control efficiency (%)		
		30 DAS	45 DAS	75 DAS	30 DAS	45 DAS	75 DAS
(Quizalofop ethyl 5% EC) (SS)	37.5	103.1	117.2	101.2	50.29	63.19	76.82
(Quizalofop ethyl 5% EC) (SS)	50	96.3	104.5	53.3	53.57	67.15	87.79
(Quizalofop ethyl 5% EC) (SS)	100	84.3	94.0	24.0	59.35	70.48	94.50
Quizalofop ethyl 5% EC (MS)	37.5	105.1	138.0	154.7	49.32	56.66	64.56
Quizalofop ethyl 5% EC (MS)	50	95.7	106.4	140.4	53.86	66.58	67.84
Imazethapyr 10% SL	100	107.5	102.5	52.4	48.17	67.78	87.99
Hand weeding (20 and 40 DAS)	-	0.0	0.0	0.0	100.00	100.00	100.00
Weedy (control)	-	207.4	318.4	436.5	-	-	-
SEm (±)		6.1	29.9	26.8	-	-	-
LSD (P=0.05)		**18.4**	**89.7**	**80.6**	**-**	**-**	**-**

Table 4. Seed yield and yield attributes as affected by different weed control treatments

Treatment	Dose (g a.i./ ha)	Plant height (cm)	Plants (No/ two m row)	Pod (No/ plant	Seeds (No/pod)	100 seed weight (g)	Seed yield (kg/ha)
Quizalofop ethyl 5% EC (SS)	37.5	55.7	21.7	77.4	2.17	12.38	2375
Quizalofop ethyl 5% EC (SS)	50	58.5	21.3	79.8	2.19	12.43	2667
Quizalofop ethyl 5% EC (SS)	100	59.1	21.0	80.1	2.21	12.60	2698
Quizalofop ethyl 5% EC (MS)	37.5	57.9	21.3	75.1	2.18	12.30	2521
Quizalofop ethyl 5% EC (MS)	50	58.1	21.0	78.1	2.20	12.33	2542
Imazethapyr 10% SL	100	59.7	20.0	78.5	2.19	12.22	2781
Hand weeding (20 and 40 DAS)	-	60.1	24.3	79.9	2.21	12.63	2969
Weedy (control)	-	55.5	15.7	55.6	1.70	11.88	1875
SEm (±)		2.8	1.2	3.9	0.1	0.2	102
CD(P=0.05)		**NS**	**3.7**	**11.6**	**0.3**	**NS**	**305**

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

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