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Review Article

PERSPECTIVES OF SOYBEAN BASED CROPPING SYSTEMS IN INDIA: A REVIEW

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Abstract- World population is growing exponentially and it has to fulfill their food requirements and other side degradation of cultivable land, natural resources and competition for land from modern urbanization and industrialization limit that horizontal expansion of cultivable land. An alternate strategy for increasing productivity and labour utilization per unit area of available land through vertical expansion by intensive agriculture *viz.,* intercropping, sequential cropping on time and space dimension. The intensive systems are well known and have been increasing the production potential per unit area and insuring against total crop failure under aberrant weather conditions and also can improve and maintain soil fertility. Soybean (*Glycine max* L.) belongs to the legume family is known as the "Golden Bean or a Miracle crop" of the twentieth century. It is a very energy rich grain legume containing 38-40 per cent protein and 18-20 per cent oil in the seeds. Soybean has been cultivated as a monocrop that leads to establishment of harmful dominated weed flora and high infestation of insect-pests, which significantly reduces the yield of soybean. 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. The practices 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. This paper provides an overall view and evaluation of cropping systems with soybean, summarizing its main advantages supported by a number of key examples from the literature, which point out its great value in the context of sustainable agriculture.

Keywords- Soybean, intercropping, Sequence cropping, Soil fertility, Potential yield

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Introduction

World over the demand is growing and to meet the ever system, in simple terms, is the intensification or increasing targets intensive cropping needs to be adopted. Since, land resource is inelastic and yields are not stable under mono cropping, so we have to think of more productive, more efficient and remunerative cropping crops in space and time dimensions [1]. A chosen system has to be efficient in resource use and ensure sustained production preferably with no adverse effect on the bio ecosystem [2]. The synthesis and productivity of a system, therefore, is the function of production potential of natural resource base, capability and competitiveness of the producer, consumers' tastes, market/trade forces and policies and technological advances in production and who can normally only grow enough food to sustain themselves, recognize that intercropping is one way of ensuring their livelihood. Intercropping is broadly defined as the agronomic practice in which two or more crops are grown simultaneously in the same area of land [3]. This farming system may be a practical application of ecological principles based on biodiversity, biotic interactions and other natural regulation mechanisms [4], allowing efficient weed and insect pest management with low reliance on off-farm inputs. Soybean (*Glycine max* L.) is a dual purpose most important rainy season crop to meet pulse and oil requirements. It has a great nutritional significance, with over 38-40 % protein and 18-20% oil and has recognized as a potential supplementary source of edible oil. It is also highly adaptable to varying soil and climatic conditions, giving fairly high yields compared to other pulse crops [5]. Soybean offers good potentials to get involved in the cropping sequences or intercropping systems. It is a short duration (85 to 130 days depending on the latitude) leguminous energy rich crop. It is relatively tolerant to drought, excessive moisture, low pH and high aluminum content [6]. The other desirable features are that its cultivation does not cause any allelopathic effect on companion/succeeding crops, extends benefits of 45 to 60 kg residual nitrogen per hectare to the succeeding crop and creates salutary physio-chemical environment in the soil for crop growth [7]. Apart from these, the practice of intercropping also reduces the population density of insects-pests as the intercrop may not serve as their host [8]. 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 [9]. Soybean due to its trade and industrial significance and adaptability to varied agro-climatic conditions occupies greater part of potential cultivated area as an integral part of prevailing cropping systems in India and world over. Being a more exhaustive and pest ridden crop demanding high energy intensive external inputs, soybean cultivation assumes significance from environmental safety [10]. Diversifying cropping systems by increasing the spatial and temporal heterogeneity of agricultural mosaics has been proposed as a feasible alternative to overcome the negative effects of modern agriculture [11]. Within fields, temporal heterogeneity can be achieved by growing several crops in sequences, while spatial heterogeneity can be enhanced by intercropping species differing in the patterns of resource use and their associated flora and fauna [12]. In addition, intercropping may contribute not only to enhance planned biodiversity, which is associated with the crop types managed by the farmer in an agro-ecosystem, but also the associated biodiversity, which is the spontaneous biota occurring in agro ecosystems [13]. In view of this, soybean with sorghum, maize, pearl millet, minor millet, pigeon pea, chick pea, cotton, sugarcane, rice, oilseeds as intercrop were reviewed for productivity and economic benefits.

Soybean production scenario

Soybean is the largest oilseed produced in the world and the global cultivated area and production has been continuously increasing year after year. The world area, production and productivity of soybean for 2014-15 are 118.65 million ha, 318.8 million tones and 2.69 tonnes per ha, respectively [14]. The USA is the largest producer of soybean in the world and accounts for 32 per cent of world production followed by Brazil (30%), Argentina (19%), China (5%) and India (4%). In India, soybean is cultivated in 10.84 million ha with a production of 14.67 million tones and average productivity of 1162 kg/ha and it is lower than the world average of 2670 kg/ha [15] and it contributes 43 per cent to the total oilseeds and 25 per cent to the total oil production in the country. Currently, India ranks fourth in respect to production of soybean in the world. Soybean has largely been responsible in uplifting farmer's economic status in many pockets of the country. It usually fetches higher income to the farmers owing to the huge export market for soybean de-oiled cake. Therefore to keep pace with the increasing demand it is imperative to increase the productivity level of soybean in the country.

Soybean based cropping systems

Cropping system refers to the kind and sequence of crops grown on an area of land over a period of one year was considered as cropping system. It is one of the very important tools to augment the agricultural production. The approach involves sequential as well as intercropping and mixed cropping system aimed at efficient utilization of natural and manmade resources of production. The feasible and major productive soybean based cropping systems in India are given in following the table.

Soybean based cropping system and suitable varieties of soybean in India

Zone	Cropping Systems	Inter / mixed / companion cropping	Soybean varieties
Central	Soybean - Chickpea (R) Soybean - Wheat (I) Soybean - Potato (I) Early soybean - Garlic (I) Early soybean - Safflower (R) Early soybean - Rapeseed Early soybean - Mustard	Soybean + Pigeon pea Soybean + Corn Soybean + Sorghum Soybean + Cotton Soybean + Groundnut Soybean + Mango Soybean + Guava	JS 20-29, JS 20-34,RVS 201-4, NRC 86, JS 9560, JS 9305, JS 335, PK 472, Durga, Pb 1, Pusa 16, PK 262, MACS 57, MACS 58, MACS 124, MACS 13
Southern	Soybean-wheat - Groundnut (I) Soybean-finger millet - Beans (I) Wheat-soybean - Finger millet- (I)	Soybean + Pigeon pea Soybean + Finger millet Soybean + Sorghum, Soybean + Mango Soybean + Guava	JS 335, RKS 18, DSb 19, ASb 22, LSb 18, MACS 124, Monetta, PK 472, PK 426, PK 262, JS 235, Hardee, Pusa 16, MACS 58, Co 1, MACS 13
Northern Plains	Soybean - Wheat (I) Soybean - Potato (I) Soybean - Chickpea (R)	Soybean + Pigeon pea Soybean + Corn Soybean + Sorghum, Soybean + Mango Soybean + Guava	PS 11347, PS 1092, PS 1042, PS 1225, PS 19, SL 958, PK 472, PK 262, PK 327, PK 416, VLS 2, Bragg, JS 335, MACS 13
Northern Hill	Soybean - Wheat Soybean - Pea Soybean - Lentil Soybean - Toria	-	Himso 1585, Hara Soya, VLS 49, VLS 65, VLS 2, Bragg, JS 335, PK 262 PK 472, PK 416, PK 327, Shivalik
North Eastern	Paddy - Soybean Soybean - Paddy	-	JS 9752, JS 9305, JS 9752, RKS 18, JS 335, RKS 18, PK 262, Bragg, VLS 2, Birsa soya 1, Shivalik, Pusa 16, PK 327, PK 472

I = Irrigated; R = Rainfed [16, 17]

Soybean based sequence/intercropping system

The provision of species diversity by mixed cropping is considered as major advantage over sole cropping. This diversification tends to promote yield stability because all the crops in a mixed cropping culture are not likely to be affected by weather vagaries or pests and diseases. Yield stability and protection against crop failures are the primary reasons prompting a farmer to resort to mixed cropping. An interfering row strips in mixed cropping can act as physical barrier to insects and decrease in the spread of diseases further confirming the yield stability of the system.

As for as soybean is concerned, it offers excellent potentials to get involved in the intercropping systems, as it is a short duration leguminous crop which can fit in well with traditional cropping pattern. It also shows comparative tolerance to drought and excessive soil moisture conditions. The other advantages offered by the crop are better ability to fix atmospheric nitrogen, tolerance to low pH and high level of aluminum and economically viability. Besides, the crop imposes no allelopathic effects on companion crop and amicably adjusts with partial shade of companion crop in the system.

Soybean with rice

Soybean-rice intercropping in 1:2 rows 20 cm apart produced 15 to 27% more yield and Rs. 3,000 to Rs 3,300/ha monetary advantages over sole cropping [18]. In soybean indicating suitability of pendimethalin and integrated hand weeding with herbicide in intercropping system of rice + soybean. Weed dry weight was not influenced significantly due to intercropping treatments alone or their interaction effects with weed management practices [19]. Legumes in association with major staple food crops like rice could be successfully introduced to enhance the productivity of the system [10]. While attempting intercropping of rice with soybean green gram, groundnut and black gram in simultaneous and deferred plantings observed that fertile tillers per panicle were higher in rice grown alone while intercropping could increase grains per panicle and 100 grain weight. The soybean rice planting in 1:2 row ratio produced significantly higher grain yield than 1:4 ratio. Simultaneous planted crops produced higher yields than deferred planting due to marked differences in the maturity period. They further reported that among legumes, pure crops of soybean and peanut always gave rise to increased number of yield components than the other crops grown in association with rice. While at Kalyani and Jorhat, the 2:2 row combinations gave higher monetary returns and LER 1.16. The soybean is likely to form a sound combination with upland paddy [20].

Higher rice grain equivalent yield under rice + soybean (4:2) intercropping system in comparison to sole crop of rice under rainfed mid-hill dry terraces of Meghalaya. Similarly, weed management is big challenge in upland rice. The extent of yield reduction due to weed infestation was 15-20 per cent under transplanted system, 30-35 per cent under direct seeded low land system and more than 50 per cent under upland situation [21]. Significantly highest rice grain equivalent yield was obtained with rice + soybean intercropping with the ratio of 3:2 in pooled results. Amongst various interactions, highest rice grain equivalent yield was obtained with pendimethalin @ 0.75 kg/ha followed by one hand weeding at 25 days after sowing for rice +soybean intercropping at the ratio of 3:2 over rest of the interactions of weed management and intercropping of rice + soybean [22].

Soybean with wheat

The study conducted by [23] at Dharwad on black soils depicted that wheat *cv.* Kiran could be intercropped with soybean (cv. Monetta) without affecting the grain yield of wheat in 1:1 to 4:3 row combinations. They further reported that the highest LER of 1.33 was recorded in 1:2 row arrangements. Soybean-wheat cropping system with nutrient management practice recorded the highest total productivity followed by soybean-chickpea cropping system with integrated practice and also gave higher gross and net monetary returns for the whole cropping system period [24]. Soybean yields were more sustainable when grown before wheat rather than chickpea in rotation. The maximum buildup of soil organic matter (0.95%) was noticed in soybean-wheat cropping system under conservation tillage [25]. In conventional tillage the soybean receiving FYM + inorganic fertilizers followed by wheat fertilized showed maximum value of soil organic matter content. On an average, irrespective of cropping systems and nutrient management practices the soil organic matter content was 19.64 per cent higher in conservation tillage over conventional tillage [26].

Field experiments were conducted at Pune in Maharashtra [27] revealed that soybean equivalent yield (SEY) and System net returns (SNR) were significantly higher in soybean-wheat cropping system (2595 kg/ha and Rs. 86964/ha) than soybean-chickpea system (1304 kg/ha & Rs. 57872/ha).

Soybean with maize

High productivity and greater stability through intercropping soybean with maize [28] and suggested row orientation in north-south direction for achieving maximum productivity and also advocated soybean to be ideal intercrop in maize.

Planting of soybean [29] and maize either in 4:2/ 2:2 row ratio (30 cm) or 100 + 50% seed mixture or in 4:2 row ratio (30 cm) or two rows sorghum between paired rows of soybean (22.5/90 cm). [30] Proved to be better over other treatments of seed mixture by giving highest total productivity, monetary advantage and LER with better companion indicating low competition interference and high energy output and energy use efficiency and energy productivity. The sole cropping of sorghum and maize recorded higher biomass yield than sole soybean and their intercrops. In contrast, the biomass yield of wheat during post-rainy season was higher when the preceding crops were sole soybean or soybean + maize intercropping [31].

The maize with soybean [5] significantly recorded the highest maize-grain equivalent yield of 2570 kg per ha at 1:1 row ratio. The highest maize equivalent yield was observed with 2:2 maize + soybean intercropping sown at 30 cm distance with each other [32]. Application of 75% of RDF to maize (90 kg N/ha and 40 kg P/ha) and 50% to soybean (60 kg N/ha and 40 kg P/ha) significantly increased their respective yields, maize-equivalent yield, net returns and benefit in soybean. Increasing levels of fertility to maize and soybean up to 100% RDF increased the total nutrient uptake significantly over 75 and 50% in the intercropping system. [33] Higher production efficiency in soybean with maize intercropping system. Intercropped with maize in 2:2 alternate paired rows 30 cm apart yielded 2.9 to 4.1 tonnes/ha of maize and 1.4 to 1.5 tonnes/ha of soybean and thus produced advantages of 48 to 59% in yield and Rs. 4,300 to Rs. 5,800/ha in return over the sole cropping. Soybean maize intercropping in 1:1 rows 30 cm apart and in 2:1 rows 40 cm apart also gave advantages of 28 to 47% in yield and Rs. 2,500 to Rs. 4,600/ha in return over sole cropping [34].

Longer days to attain 50 % flowering for intercropped soybean in a soybean-maize [35] intercrop. The difference in results could be due to the growth habit of component crops, and possibly the arrangement of the component crops in the intercrop. [36] studied the performance of soybeab+maize intercropping in Sehore district of Madhya Pradesh and they found that monitory advantage based on land equivalent ratio indicted superior economic viability of soybean+maize intercropping in 4:2 ratio and registered the maximum net returns (Rs.37314/ha) and BC ratio (1:29) than the sole cropping of maize and soybean.

Grain yields in soybeans were increased by different proportions of maize + soybean population [37]. In Nagaland, [38] conducted an experiment to study the performance of maize + soybean intercropping system on yield and economics and they suggested that the paired rows of maize + soybean (2:2) is the best combination and registered the maximum LER, grain yield and net returns. Pre-emergence application of metolachlor @ 1.25 kg/ha and oxidiazon @ 1.0 kg/ha or alachlor @ 2.0 kg/ha [39] have been recommended for effective control of weeds and realizing more yields in maize + soybean system.

Soybean with sorghum

The sorghum + soybean[40] in 3:3 or 4:2 row ratio was profitable indicating 1.2 land equivalent ratio (LER). [41] reported LER value of 1.36 from sorghum (CHS 5) + soybean (JS 72-44) system planted in 1:1 row geometry. [42] reported that sorghum + legume intercropping enhanced the bulk density, water stable aggregates, infiltration rate, hydraulic conductivity and organic carbon contents of the soil. [43] on yield and yield components of soybean and sorghum in intercropping, it was observed that sorghum height had no significant influence on soybean grain weight but had effect on grain number per unit area; so that the grain number in soybeans intercropped with high sorghum pants was higher than that observed in soybean pants intercropped with dwarf sorghums.

With the increase in NPK dose from 0 to 100%, there was significant improvement in the dry matter production in sloe sorghum and soybean/sorghum intercropping system [44]. Planting of soybean and sorghum either in 4:2 row ratio (30 cm) or two rows sorghum between paired rows of soybean (22.5/90 cm) proved to be better over other planting patterns by giving highest total productivity, monetary advantage and LER (1.21/1.19) with better companion indicating low competition interference and high energy output and energy use efficiency and energy productivity [30]. [45] opined that yield and LER of both the intercrops increased over sole crops through based on Relative crowding coefficient, sorghum is more competitive than soybean.

Relative dry matter yield (RDY) and relative nitrogen yield (RNY) of sorghum were greater than the values of RDY and RNY of soybean [46] indicating inter-spices competition for N between component crops, peak competition being at 80 DAS. The competitive ratio of soybean increased (0.76 - 1.15) with increasing density of the soybean in the intercrop combinations, indicating higher competitiveness at higher densities than the sorghum component [47].

Soybean with pearl millet

The higher yield of pearl millet grown alone compared to growing with soybeans is attributed to the higher forage yield potential of pearl millet. Intercropping soybeans into or with pearl millet established a competition for nutrients, light and water by a lower productive plant at the sacrifice of the higher productive plant. Intercropping soybean in pearl millet could successfully be done without affecting the yields of later. The bonus crop of soybean yielded to the tune of 0.65 tones/ha in Tamil Nadu [48]. Application of phosphorus @ 40 kg/ha is essential and N @ 60 to 90 kg/ha is optimum for meeting [49] the requirement of the two crops and profitable production. atrazine @ 1.0 kg /ha or butachlor @ 2.0 kg/ha as pre-emergence are effective for control of weeds and reducing the yield losses from the system.

Soybean grain yields were highest following a pearl millet cover crop, followed by oat, wild bean, and sunflower cover crops, and the control [50]. The highest land equivalent ratio (LER) values, highest land equivalent coefficient (LEC) values and lowest competitive ratio (CR) values were recorded for pearl millet sown into soybean at the intra-row spacing of 15 cm, however, highest aggressivity was obtained sowing pearl millet into soybean at the intra-row spacing of 25 cm, the level at which both crops dominated each other [51].

Soybean with minor millets

[52] stated that the application of 4 t/ha organic amendments increased N uptake by ragi and soybean crops in intercropping. Residual availability of P was higher in intercropping than sole cropping. While [53] found highest total productivity when kodo millet intercropped with soybean in alternate rows. [54] demonstrated that higher soybean populations provided a way to optimizing growth and yields in soybean/millet intercropping systems.

Finger millet intercropping with soybean (4:1) ratio enhances the system productivity and net profit than sole crop cultivation [55]. Area- time equivalency ratio (ATER) was found superior in finger millet + soybean (4:1) having value of 2.03 and 2.01 respectively, and intercropping with pigeon pea was just after the soybean because the coverage of the crops over land area is more due to larger leaf surface [56]. Crop rotation with trap/catch crops like soybean and cotton, intercropping with groundnut, soybean and cowpea and green manuring crops like sunhemp help in reducing the problem of parasitic weed *Striga* [57].

The cost-benefit ratio analysis showed that the average net income from finger millet intercropped with soybean grown under improved organic methods (Rs.

13,735/ha) was substantially higher than that of similar intercrop grown under traditional (Rs. 7397/ha) organic farming practices [58].

Soybean with pigeonpea

The maximum biological efficiency [59] of system (LER 1.50 and ATER 1.18) were with soybean + pigeonpea in 2:1 row ratio, which resulted in highest monetary advantage due to non-competitive interference between the two crops (RCC 10.53). Planting of pigeonpea (MRG-66) at 90 cm with 1 row of soybean (Durga) and pigeonpea 150 cm with five rows of soybean recorded maximum net returns of Rs.17, 226/ha) and Rs.22, 035/ha, respectively. Pigeon pea, MRG-66 at 180 cm with six rows of soybean recorded maximum (1.39) LER [60]. [29] revealed that the soybean varieties like NRC 37 (Ahilya 4), PK 1029 and PK 1024 were found most compatible with pigeonpea variety ICPL 871 19 in 4:2 row ratio as adjudged by higher yield levels, soybean equivalent yield, LER, RCC, monetary returns and IER with low competition ratio.

Economics of major red gram based cropping systems in Bidar district [61]. Results of the study revealed that the CS-I (Redgram + jowar), CS-II (redgram + blackgram), CS-III (redgram + soybean), CS-IV (redgram + greengram) and CS-V (red gram sole) were the five important red gram based cropping systems followed in the study area. The study revealed that, in majority of the cases, net family income from different cropping systems were Rs.22,217.81, Rs.27,514.63, Rs.25,405.323, Rs.22,639.10 and Rs.8,971.74 in CS-I, CS-II, CS-III, CS-IV and CS-V, respectively. With respect to employment generation, CS-II generated higher employment (64.91 man days/ha) followed by CS-I (55.87 man days/ha) and CS-III (55.11 man days/ha). The intercropping cereals, pulses and oilseeds with normal planted base crop of pigeonpea increased land use efficiency and gave higher total yields compared to pure cropping of pigeonpea under rainfed conditions on upland Oxisols of Bihar plateau [62].

Weeds caused 79.93 per cent reduction in pigeonpea grain yield if weeds were allowed to grow till harvest; however, grain yield losses were only 38.19% in pigeonpea + soybean intercropping system [63]. Planting of pigeonpea (MRG-66) at 90 cm with one row of soybean (Durga) and pigeonpea, 150 cm with five rows of soybean recorded maximum net returns of Rs. 17,226/ha and Rs. 22,035/ha respectively. Pigeonpea, MRG-66 at 180 cm with six rows of soybean recorded maximum land equivalent ratio. The maximum soybean and pigeonpea yield was with FYM @ 5 t/ha + 75% of RDF and Zn @ 5 kg/ha + RDF. The application of Zn + RDF produced the maximum net returns and remained at par with Zn + 75% of RDF and RDF alone. While the highest B:C ratio was associated with Zn + 75% of RDF [64].

In maize with pigeon pea intercropping system, dry matter production per unit of photosynthetic active radiation (PAR) was higher than the sole crops [65]. Intercropping system is one such method which offers great scope for pulse crops sustainability in the overall productivity and profitability. Intercropping in general assumes great importance with regard to better stability, productivity and profitability. It is largely a system useful for small and marginal farmers [66]. Land equivalent ratio was significantly higher in soybean + pigeonpea (2:1) intercropping system (1.53) and was on par with the soybean + pigeonpea planted at 4:2 and 1:1 row ratios [67].

Field experiment conducted at Tamil Nadu Agricultural University, Coimbatore in Soybean + Pigeonpea (2:1) intercropping system revealed that application of 100 per cent RDF (20:80:40 kg N, P_2O_5 and K_2O/ha) to soybean registered the highest Land Equivalent Ratio (1.63), Area Time Equivalent Ratio (1.36) and Soybean Seed Equivalent Yield (3366 kg/ha) than application of 75 and 50 per cent RDF [68]. Provision of irrigation appears to further enhance the efficiency of system.

Soybean with chickpea

A field experiment conducted in soybean-chickpea cropping system at the College of Agriculture, Indore with different sulphur levels revealed that yield of soybean (8.96 to 38.52) and chickpea (11.08 to 28.91) as well as system productivity (10.50 to 25.25) increased linearly with the increase in levels of sulphur application up to 60 kg/ha and further increase in sulphur level decrease the yield of soybean [69]. Chickpea yield was significantly highest with integrated practice (1188 kg/ha) over inorganic (1050 kg/ha) and organic practice (958 kg/ha). Significantly higher chickpea yield with the application of 50% recommended dose of fertilizer and 50% FYM was reported by [70].

Soybean with sunflower

Soybean intercropped with sunflower produced higher yield when both the crops were enriched with carbon dioxide [71]. Soybean and sunflower are gaining importance due to being identified as potential substitutes [72] for the two traditional oil sources, peanut and oil palm. Sunflower/soybean intercrops produced more grain yield per unit area than both sole crops, which indicates that intercropping is more profitable than sowing a single crop (i.e. LER greater than one [73].

The land equivalent ratio (LER) for yield or gross margin reported for sunflower-soybean intercrops was generally high (1.2 to 1.6), indicating the agronomical and economic advantages of intercrops in comparison to sunflower and soybean sole crops. Moreover, the two rooting systems (deep for sunflower and shallower for soybean) can explore different soil layers, which could lead to niche resource complementarily for nutrients and water [74]. Intercropping soybean and sunflower is a worthwhile enterprise in the tropics. Intercropping of compatible crop species stabilizes returns over seasons since more than one commodity is derived from the system and the components can compensate for each other in case of price fluctuation in any of the components [75].

A multi-location trial conducted on diverse agro-climatic zones of the country indicated highest soybean yield recorded with 20 kg S/ha in north plains, 35 kg S/ha in north eastern and 30 kg S/ha in southern zone [76]. Sunflower–soybean intercrop grain yield tend to be higher than that for sole crops of the component species. This yield advantage for intercrop increased with water availability and was associated with an increase in intercropped soybean productivity. Intercrop sowing management had no effect on total intercrop grain yield. However, simultaneous sowing increased soybean contribution to intercrop yield [77].

Among them, a three year study on varied nutrient management in soybean (*Kharif*) - sunflower (*Rabi*) cropping system conducted under Vertisols in Hyderabad [78] results showed that application of recommended dose of NPK to proceeding crop of soybean followed by NPK to succeeding sunflower recorded significantly higher soybean equivalent seed yield (4,804 kg/ha), highest system gross return (Rs.1, 08,090), net return (Rs.78, 240) and BC ratio (3.62).

Intercropping sunflower and soybean is a feasible alternative for increasing land productivity in intensive farming systems, and hence farm income, in a more sustainable way than growing monoculture [79]. Sunflower-soybean intercrop grain yield tend to be higher than that for sole crops of the component species. This yield advantage for intercrop increased with water availability and was associated with an increase in intercropped soybean productivity. Intercrop sowing management had no effect on total intercrop grain yield [77].

Soybean with sesame

Among the intercropping patterns sesame intercropped with mungbean, mashbean, soybean and cowpea in the pattern of 100 cm spaced 4-row strips proved to be feasible, easily workable and more productive than sesame monocropping [80] reported that intercropping of soybean in sesame and sorghum in cotton significantly decreased the biomass and density of the weeds and increased net return.

Intercropping sesame with legumes appeared to be a dominant crop as indicated by its higher values of relative crowding coefficient, competitive ratio and positive significance of aggressivity [81]. LER show that the efficiency and benefits of soybean/sesame mixture over pure stands of each crop were enhanced by the application of 5t FYM/ha and sowing in double alternative row which recorded LER more than one [82].

Soybean with cotton

The prolific soybean varieties have smothering effect on the performance of cotton, the use of short, erect, less leafy and short duration varieties is recommended [83]. Cotton + soybean (1:1) in 45/30 cm configuration to be promising [84]. The system is reported to give LER 1.12, Area Time Equivalent Ratio (ATER) 0.85 and Area Harvests Equivalency Ratio (AHER) 0.90. The highest cotton equivalent yield of 1554 kg/ha was recorded in 1:2 row combination of cotton and soybean variety Monetta, followed by 1:1 row combination of cotton and PK 472 [85].

Growing of cotton in 1.20 m spaced double row strips proved superior to 0.80m spaced single rows. Soybean intercropped in the 1.20 m double row strips produced a significantly greater seed yield than that intercropped at 0.80 m spaced single rows [86].

In cotton + soybean intercropping, pre-emergence application of oxyfluorien @ 0.10 kg/ha supplemented with hand-weeding and hoeing at 6 weeks after sowing proved equally effective in controlling the population and dry weight of weeds [87], and was as economical as that of cultural practice of 3 hand-weeding and hoeing at 3, 6 and 9 weeks after sowing. [88] noted that the intercropping of cotton under rainfed conditions with soybean followed by greengram either in 1:1 or 1:2 ratio of each crop was more remunerative than sole crop of cotton.

The cotton-soybean intercropping systems recorded significantly higher seed cotton equivalent yield over sole cotton [89]. The intercropping system of cotton + soybean (2:4) was significantly superior to cotton + pigeonpea (2:1), cotton + black gram (2:4) and sole cotton, black gram and pigeonpea but it was at par with sole cropping of soybean. Cotton seed yield was not reduced when it was cultivated with soybean [90].

Soybean with sugarcane

Soybean is one of the important intercrop suitable and compatible with sugarcane. This is mainly due to the fact that soybean has adapted well to the climatic conditions of the sugarcane producing areas and has the greatest potential to fix nitrogen i.e up to 300kg N/ha. The growth rate of sugarcane during its early growth stages is slow, with the leaf canopy providing sufficient uncovered area for growing of other crops. Inter-cropping in sugarcane with short duration crops is agronomically advantageous and could provide additional revenue. To ensure optimum productivity in an intercropping system, one must ensure that the peak periods of growth of the two crops do not coincide, so that one quick-maturing crop completes its life cycle before the main period of growth of the other crop starts [91]. With this regard sugarcane offers a unique potential for intercropping. Blackgram, cowpea, greengram and soybean as intercrops in sugarcane, the incidence of shoot borer did not differ significantly amongst the different combinations and control [91].

When intercropping is practiced with sugarcane inter-row crop must therefore mature and be harvested within 85-90 days before the cane canopies. Therefore, crops selected in intercropping with sugarcane should be short duration, less shading and less bushy type, similar to sugarcane in input requirement, having no allelopathic effect, easily manageable by growers, none attractive to disease and pest and readily marketable [92]. Yielded the greatest profit per hectare, with a harvested soybean intercrop and non-harvested intercrop yielding lower returns [93].

However, the fact remains that, when planted as an intercrop, the soybeans will most likely need to be harvested by hand so that the sugarcane will not be damaged, and this is a labour-intensive operation [94]. The quantities of bacteria, fungi, and actinomyces increased by 42.62, 14.5 and 78.5 % in the intercropping sugarcane, while the intercropping soybean increased by 188, 183 and 73 %, respectively. Therefore, growing sugarcanes in combination with soybean can be considered a good agriculture management practice, helping to promote plant growth, yield and increase soil nutrients [95].

A soybean yield of 1.3 t/ha (12% moisture) was obtained in the SASRI research farm, while cane yields of 85.7 t/ha and 79.8 t/ha, as obtained for the cane-only control and the 66% N intercropped treatments respectively [96]. The soybean and sugarcane intercropping result indicated that one side of ridge planting of soybean as intercrop gave 5.25 per cent increased net return compared to the sole cropping of sugarcane [97]. Compared with sugarcane monoculture, the stalk diameter, millable stalks, cane yield and sugar production in the intercropping system were increased by 5.1%-8.7%, 7.9%-31.0%, 9.0%-40.5% and 5.6%-39.5%, respectively. Among the three sugarcane cultivars in the sugarcane-soybean intercropping pattern, the economic benefit was the highest in ROC22, while the ratoon cane yields of GT21 and B8 were higher than that of ROC22 [98].

Soybean with spices

Ginger at 60 cm row spacing intercropped with soybean produced handsome remuneration [99]. Leaf water potential of pepper plants intercropped with soybean was generally greater than that of mono cropped pepper plants [100]. The author speculated that this was the result of a windbreak effect from the soybean rows.

Soybean in plantation crops

Preliminary reports from [101] indicated that at least three to six successive intercropping of soybean, sunflower, cotton, greengram, sesame, sorghum, cowpea, turmeric, maize, Blackgram and groundnut can be taken in agroforestry with trees like *Eucalyptus tereticornis, Casuriana equisetifolia* and *Leucaena leucocethala* up to the age of 36 months. The work done by [102] on successful cultivation of cereal-pulse sequence in mango orchards indicates that a possibility to replace any of the rainy season legumes with soybean exists. The LER was 1.2 in the bamboo/ pigeonpea and bamboo/ soybean models, but 1.1 in the bamboo/ turmeric and bamboo/ ginger models. This means that the productivity of one hectare under intercropping is equivalent to that of 1.2 ha or 1.1 ha under monoculture [103].

Soil physical properties were improved after soybean intercropping with larch and ash in one growing season. The soil bulk density in larch/soybean and ash/soybean systems was 1.112 g/cm^3 and 1.058 g/cm^3, respectively, which was lower than that in the pure larch or ash plantation without intercropping [104]. Thus, the introduction of annual crops, such as soybean and groundnut in young oil palm plantation areas, has provided the opportunity to improve the efficiency and effective uses of environmental resources. The highest yield of tea (28555 kg/4 years) was obtained by soy double-planting pattern, and the lowest yield (23258 kg/4 years) was produced by single-row planting [105].

Presence of soybean and groundnut between the rows of one year-old oil palms was found not inhibiting the growth rate and development of oil palms as the main crop. On the contrary, there was a tendency that the oil palms planted with soybeans and groundnut to grow faster than those planted in monoculture. The shoot of soybeans and groundnuts could get enough growth space, solar radiation and CO_2. In terms of solar radiation, the empty spaces between the rows of the one year-old oil palms were still very much open that the radiation could reach up to the land surface [106]. The crop yield is certainly affected by the shade of the trees in tree-crop combinations but the resources use efficiency is better under trees than in open conditions. However, on system basis the productivity of the combination is more than pure cropping. Additionally, the multiple outputs can be realized by the small farmers with limited land holdings. The distribution of benefits and costs are important for the farmers to evaluate the intercropping options [107].

Soybean intercropping in mulberry field

Sericulture an agro-based industry is mainly practiced by small and marginal farmers in India for regular source of income. However, farmers come across silkworm cocoon crop loss due to diseases thereby aggravating the condition of the poor farmers [108]. This can be overcome by better sericulture technology adoption. It is in this context that the concept of intercropping comes to the rescue of the farmers by opening avenues of alternate source of income from the same piece of land. In sericulture mulberry is the base crop with distinct row arrangements and longer duration [109]. The other crops grown in mulberry can be termed as intercrops. In mulberry various types of intercrops can be taken up all the year round without adversely affecting the yield of mulberry. Intercropping may be practiced in the beginning of the establishment of mulberry or after the establishment of the mulberry. Intercropping in sericulture would increase the margin of profit further and also reduces the cost of production of leaf. Intercrops in mulberry should be of short duration, low canopy, shade loving, less competitive, low input requiring and highly remunerative [110]. However, the choice of intercrop in mulberry is governed by number of conditions such as type of mulberry garden, method of pruning, width of the ridge, stage of growth of mulberry and season.

Limitation of soybean based cropping system

Intercropping allows lower inputs through reduced fertilizer and pesticide requirements, thus minimizing environmental impacts of agriculture. However, intercropping has some disadvantages such as the selection of the appropriate crop species and the appropriate sowing densities, including extra work in preparing and planting the seed mixture and also extra work during crop management practices, including harvest. The selection of an appropriate intercropping system for each case is quite complex as the success of intercropping systems depend much on the interactions between the component species, the available management practices, and the environmental conditions. Plant breeding can contribute determinedly to increase of productivity of intercropping systems by investigating and exploiting the genetic variability to intercrop adaptation.

Additional cost for separation of mixed grains and lack of marketing of mixed grains, problems at harvest due to lodging, and grain loss at harvest also can be serious drawbacks of intercropping. Mechanization is a major problem in intercropping. Machinery used for sowing, weeding, fertilizing, and harvesting are made for big uniform fields. Harvesting remains a great problem, but it may be more easily overcome where the intercrops are harvested for forage or grazed. In the developing countries, the work needed in the field is mainly done by hand with simple tools because intercropping is very labour intensive [111]. In these countries, however, where manual labour is plentiful and cheap, it is not necessary to invest in expensive machinery especially for intercropping. From this point of view intercropping has no disadvantages, but for intercropping on a large scale basis, mechanization is generally believed to be impossible or inefficient.

Conclusion

Considering the multiple advantages that can occur from soybean based cropping system, particularly in the view of sustainable agricultural production and the environmental problems with current farming systems, it seems reasonable to continue research on the possibilities of growing more than one crop in a field at the same time. It also brings out that irrespective of row ratios, soybean offers better yield advantage than any other crop intercropped with traditionally cultivated crops. The work compiled above clearly brings out that soybean can be advantageously intercropped with most of the traditional crops grown in different agro-climatic regions of the country. In addition to higher combined yield, taking advantages of crop diversification, fertilizer economy, salutary soil environment for plant growth, smothering effect on weeds, natural check on pests and diseases and risk coverage, adoption of system is likely to provide sustainability.

Author Contributions

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Abbreviations

The following abbreviations are used

DAS: Days after sowing, @: at the rate, %: per cent, RDF: Recommended dose of fertilizer, N: Nitrogen, P2O5: Phosphorus, K2O: Potassium, S: Sulphur, Zn: Zinc sulphate, FYM: Farm yard manure, LER: Land equivalent ratio, LEC: Land equivalent coefficient, CR: Competitive ratio, ATER: Area time equivalent ratio, SEY: Soybean equivalent ratio, SNR: System net returns, RNY: relative nitrogen yield, AHER: Area harvests equivalency ratio, RDY: Relative dry matter yield, Rs/ha: Rupees per hectare, kg/ha: Kilogram per hectare, t/ha: tonnes per hectare, cm: centimeter, PAR: Photosynthetic active radiation, g/m^3: gram per meter cube.

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