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Evaluation of soybean based cropping systems: A review

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Abstract
Soybean (*Glycine max* L.) is an important oilseed and protein crop grown globally. However, average soybean productivity in India is low primarily due to predominant cultivation as *kharif* rainfed crop. Inclusion of soybean in different seasonal/intercropping systems may help diversify existing cropping systems and optimize productivity. A systematic review was conducted to evaluate research on soybean-based cropping systems. Studies published between 2000-2024 reporting evaluation of seasonal (*kharif*/*rabi*) cropping systems and intercropping systems involving soybean were selected. Key findings from relevant studies were extracted and summarized. Results indicated that soybean grown as a *rabi* or summer crop with applied irrigation performed better than *kharif* crop in terms of seed yield, Soybean-wheat/chickpea intercropping systems were found remunerative with higher land equivalent ratio and benefit: cost ratio compared to respective monocropping. Strip cropping of soybean with maize/sorghum helped realize 7-15% higher returns than normal planting. The review highlighted potential of including soybean as a seasonal/intercrop to diversify existing cropping systems and optimize resource use for enhanced productivity and income of farmers.

Keywords: Soybean, cropping systems, seasonal cropping, intercropping, productivity, profitability, yield gap

1. Introduction
Soybean (*Glycine max* L.) is one of the most important oilseed and protein crop worldwide. It has emerged as a key crop in global food and agricultural economy due to its versatile applications in the food and feed industries (Valle *et al.* 2020) [41]. Soybean production in India has witnessed significant growth over the last two decades and is now the fifth largest soybean producing country globally. However, the average soybean productivity in India (1.2 t/ha) is relatively low compared to global average (2.7 t/ha) indicating a substantial yield gap (Ahlawat *et al.* 2020) [2].

Narrowing the yield gap and optimizing productivity gains in soybean require evaluation and identification of suitable soybean-based cropping systems tailored for different agro-climatic regions of the country. However, soybean is traditionally grown as a rainfed *kharif* crop in rotation with cereal crops like maize, sorghum under rainfed conditions in major soybean producing states. Inclusion of soybean as a *rabi* crop or intercrop with other crops would not only help optimize resource utilization but also diversify and intensify the existing cropping systems (Mondal *et al.* 2020) [25].

A number of scientists have studied performance of soybean in different seasonal and intercropping systems over the years. However, a comprehensive review of research undertaken on evaluation of various soybean-based cropping systems is lacking. The present paper aims to review the research studies undertaken on evaluation of different seasonal soybean cropping systems including as *kharif* mono crop, *rabi* crop and intercropping systems with other crops. The review would provide insights on suitability and productivity of different soybean-based cropping systems and help identify the most remunerative systems for different agro-climatic regions of the country.

2. Methodology

A systematic literature review was conducted to evaluate research studies on different soybean-based cropping systems. Peer-reviewed journal articles published between 2000-2024 were searched using relevant keywords such as "soybean cropping systems", "soybean intercropping", "seasonal soybean" etc. in databases like CAB Abstracts, Scopus and Web of Science. Relevant information was also extracted from papers published in Indian scientific journals and reports available on various agricultural university/institute websites.

The studies selected for review met the following criteria:

1) Focused on evaluation of soybean grown either as a *kharif/rabi* seasonal crop or in intercropping systems.
2) Included various parameters to assess the productivity, profitability and resource use efficiency of different cropping systems.
3) Carried out on-station research trials or on-farm demonstrations/trials across different soybean growing regions in India.

Key information extracted from selected publications included location and duration of study, treatment details of different cropping systems, methodologies adopted for crop establishment and management, parameters studied and major findings.

The productivity, profitability and limitations of different seasonal cropping systems (*kharif, rabi*) and intercropping systems involving soybean were compared and summarized. Insights on suitability of these systems for various agro-climatic zones were identified. Research gaps to further optimize soybean-based cropping systems were also delineated.

3. Results

3.1 Soybean production scenario

World soyabean production in 2022-23 is estimated as 375.67 million tonnes from a total area of 120.50 million hectares. Brazil ranks first in soyabean production with 114.27 million tonnes followed by United States of America (96.79 million tonnes), Argentina (55.26 million tonnes), China (15.73million tonnes) and India (13.27 million tonnes) accounting for 34.25, 29.01, 16.56, 4.00 and 3.98 percent of world production (*Source: International Grains Council*, 2022-23). India ranks fourth in area with 11.34 million hectares (28.02 million acres) accounting for 9.41% of the world area and fifth in production with 11.22 million tonnes in 2019-20.

The major soyabean growing states are Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, and Telangana. According to the first advance estimates 2021-22 of Ministry of Agriculture, Soybean production is estimated at 127.20 lakh tonnes as compared to 128.97 lakh tonnes in 2020-21. (*Soyabean Outlook – January 2022: Agricultural Market Intelligence Centre, PJTSAU*).

In India, as on 17th September 2021 area under soyabean during 2021-22 was 121.76 lakh hectares as against 121.20 lakh hectares during 2020-21. Among the states, Madhya Pradesh stood first with 55.84 lakh ha followed by Maharashtra (46.01 lakh ha), Rajasthan (10.62 lakh ha), Karnataka (3.82 lakh ha), Gujarat (2.24 lakh ha) and Telangana (1.51 lakh ha). (*Source: www.agricoop.gov.in*).

3.2 Soybean based cropping systems

A cropping system refers to the type and sequence of crops grown on a piece of land over the course of a year. It is a vital strategy for increasing agricultural production. This approach includes methods such as sequential cropping, intercropping, and mixed cropping, all designed to utilize natural and manmade resources efficiently. The table below outlines the feasible and major productive soybean-based cropping systems in India.

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, P 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

3.3 Soybean based sequence/intercropping/cropping system

Kasbe *et al.* (2010) [20] found that the field trial results indicated that the 4:2 planting pattern and the intercropping system of soybean (JS-335) with pigeon pea were more profitable than other planting patterns and intercropping systems studied. Additionally, the highest values of grain equivalent, net monetary return, and land equivalent ratio were recorded in the intercropping system of soybean (JS-335) with pigeon pea (BSMR-736) using the 4:2 planting pattern. Raju (2014) [31] advocated from his experiment that strip cropping of cotton + soybean + pigeon pea (4:4:2) is most profitable under rainfed conditions by 47 and 58% over sole cotton in shallow and medium deep soils, respectively. Ansari *et al.* (2014) [5] found that pearl millet/pigeon pea intercropping consistently achieved higher productivity and profitability than traditional monoculture systems. Intercropping reduces the risks of low yields or crop failure under unpredictable drought conditions, especially when transpiration suppressants are used during moisture stress. Kebebew (2014) [21] stated from the results obtained that intercropping of maize with soybean found to be more valuable and productive compared to sole cropping system. The general productivity of the system become more effective and farmer in the area could be advantageous in additive mixture. Maize-soybean intercropping particularly with variety Awassa -95 at 50% planting density appeared to be more remunerative. Kumawat *et al.* (2012) [22] studied the response of pigeon pea+ black gram intercropping system to integrated nutrient levels. Intercropping failed to influence the dry matter production/plant, CEC of roots, root N content, yield and quality parameters of both crops. Both the intercropping systems gave significantly higher uptake of N, P and K when compared to sole pigeon pea. The soil available N, P, K after harvest of crop was maximum under sole pigeon pea followed by normal intercropping and lowest in paired intercropping. Vyas *et al.* (2013) [42] conducted experiment at Directorate of Soybean Research, Indore, Madhya Pradesh to study the productivity of soybean and wheat in Malwa region of Central India under a long-term field trial involving four soybean-based crop rotation (soybean-wheat, soybean-wheat-maize-wheat, soybean-wheat-soybean wheat-maize-wheat and soybean + maize-wheat) and three tillage systems (conventional-conventional, conventional-reduced and reduced-reduced). Result revealed that on mean basis, maximum soybean and yield was obtained in C-C tillage system (2.13 t ha^{-1}) which was 1.4 and 6.5% higher over C-R and R-R systems, respectively while, wheat grain (4.12 t ha^{-1}) yield under C-C tillage system was higher to the tune of 2.2 and 5.1% over C-R and R-R system. Alam *et al.* (2014) [4] reported that conservation tillage was found to be suitable for soil health and achieving optimum yield under wheat-mungbean- rice cropping system. Hati *et al.* (2015) [17] conducted a long-term field experiment at Bhopal and concluded that no tillage and reduced tillage systems with residue retention and recommended rate of N would be a suitable practice for sustainable production of soybean–wheat cropping system in *Vertisols* of central India and it also saved energy and time by reducing the frequency of tillage operations than conventional tillage. Long-term impact of conservation tillage practices on soil properties of *Vertisols* were studied under soybean–wheat system in Bhopal. Conservation tillage practices *viz.*no-tillage and reduced tillage were as effective as conventional tillage in terms of crop productivity under soybean and wheat (Hati *et al.* 2009) [18]. Wheat resid incorporation resulted in 20–22 percent higher yields in soybean and 15-25 percent in wheat as compared to residue burning (Subba Rao *et al.* 2009) [39]. Chouhan *et al.* (2018) [14] studied on characterization of physical properties of *Vertisols* under long-term fertilizer experiment in soybean-wheat cropping system Jabalpur (M.P) and reported that physical properties *viz.*, bulk density, infiltration rate, moisture content, fractions of different sized aggregates and mean weight diameter of soil were significantly affected by long-term application of integrated nutrients under soybean-wheat cropping system. It was found that integration of FYM increased the beneficial effect on physical properties over the treatments of inorganic nutrients application alone in both surface (0-15 cm) and sub-surface (15-30cm) soil under soybean-wheat cropping system. Singh *et al.* (2017) [36] recorded higher density and biomass of *Medicago denticulata*, *Chenopodium album* and *Phalaris minor* when conventional tillage was done in wheat under CT-CT tillage system followed by CTZT-ZT tillage system being minimum when zero tillage was done in presence of residue of preceding soybean crop in wheat under ZT+R-ZT+R-ZT+R tillage system. Higher density and biomass of M. denticulate and P. minor were observed under conventional tillage in wheat. Billore *et al.* (2013) [13] conducted field experiments were at Indore and reported that the values for gross and net return (Rs.38357 and 23129 ha^{-1}) and benefit: cost ratio (2.52) were higher in soybean-wheat as compared to soybean-chickpea system and in case of tillage the maximum gross and net return was obtained in minimum tillage (Rs. 36289 and 21935 ha^{-1}) than conventional tillage and no-tillage. Jaybhay *et al.* (2015) [19] conducted a field experiment during 2010-11 to 2013-14 at Agharkar Research Institute, Pune, Maharashtra and reported that soybean-wheat system gave higher gross and net monetary return for whole cropping system period. Increased wheat yield under soybean-wheat system resulted higher net return over soybean-chickpea system during all years under study. Inorganically managed wheat crop produced the highest net return over soybean-chickpea system and management practices i.e., organic and integrated. Established a field experiment on effect of resource conservation practices on productivity of maize intercropped with soybean under maize+soybean–wheat cropping system at Chatha, Jammu and reported that the higher gross return, net return and B:C ratio under conventional tillage practices. Even the cost of cultivation was higher in conventional tillage but higher gross return compensated the high cost of cultivation and resulted in higher net return and B:C ratio. Yadav *et al.* (2021) [43] carried out an experiment on sustaining the properties of black soil in central India through crop residue management in a conservation agriculture-based soybean–wheat system on black soil at the Indian Institute of Soil Science, Bhopal from 2014 to 2018. Results revealed that soil organic carbon (C) significantly increased from 0.67 to 1.0 percent in five years through 90 percent residue retention. Retaining 90 percent (7.0 t) of soybean residue added 2.9 t C, 197.3 kg nitrogen (N), 32.4 kg phosphorus (P), and 89.7 kg potassium (K) in 5 years, while 6.2 t C, 85.7 kg N, 15.3 kg P, and 232.2 kg K were added through 90 percent (13.8 t wheat residue during the same period. Billore *et al.* (2013) [13] conducted field experiments were at Indore and trend indicated that cropping system productivity in terms of soybean equivalent yield (SEY) established the numerical superiority of minimum tillage (3300 kg ha^{-1}) over conventional (3190 kg ha^{-1}) and no-till (3080 kg ha^{-1}). For soybean-wheat and soybean-chickpea systems, the SEY of minimum and conventional tillage was higher (between 3 and 7percent) than no-till, therefore, soybean–wheat system was more productive compared to soybean-chickpea. Aulakh *et al.* (2012) [7] reported the integrated effects of tillage, CR retainment, mineral fertilizers and FYM on soybean-wheat cropping system and found that higher system productivity under conservation agriculture in comparison to conventional tillage system.

Geeta and Shivashankar (1991) [15] 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 Baghel *et al.*

(1991) [8] found highest total productivity when kodo millet intercropped with soybean in alternate rows. Akunda (2001) [3] 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 (Seetharam, 2001) [35]. 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 (Adikant *et al.* 2014) [1]. 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* (Mishra, 2015) [24]. The maximum biological efficiency Billore *et al.* (2000) [12] 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, (Billore *et al.* 2002) [11]. Billore *et al. (*2004) [9] 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, (Rajkumar, 2007) [30]. 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 (64.91man 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 (Sarkar and Shit, 2008) [33]. 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 (Saudy and El-Metwally, 2009) [34]. 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 Olowe and Adebimpe (2009) [28]. 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 (Muhammad and Abdul, 2004) [26]. 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 (Giri *et al.* 2006) [16], and was as economical as that of cultural practice of 3 hand-weeding and hoeing at 3, 6 and 9 weeks after sowing. Sree Rekha *et al.* (2008) [38] 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 (Asewar *et al.* (2008) [6]. 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 (Sonawane *et al.* 2009) [37]. High productivity and greater stability through intercropping soybean with maize 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 (Billore and Joshi, 2004) [9] 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). Billore and Joshi (2005) [10] 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 postrainy season was higher when the preceding crops were sole soybean or soybean + maize intercropping (Ramesh *et al.* 2005) [32]. The maize with soybean (Padhi and Panigrahi 2006) [29] 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 (Meena *et al.* 2006) [23]. Muoneke *et al.* (2007) [27] reported 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 by Thomas and Erostus (2008) [40].

4. Conclusion

The review provides a systematic analysis of the research conducted on evaluating different seasonal and intercropping systems involving soybean in India. Results indicate that soybean performs better in terms of productivity if grown as a *rabi*/summer crop with assured irrigation compared to traditional *kharif* season. Intercropping soybean with cereals like wheat, maize or pulses like chickpea helps optimize resource use and enhances productivity, profitability and nutritional security of farmers. Strips cropping of soybean with cereals is another viable option. While monocropping of soybean remains dominant, inclusion of soybean in different cropping systems provides opportunities to diversify as well as intensify cropping systems for realizing higher returns. Overall, the review highlights substantial evidence on the suitability of seasonal cropping and intercropping approaches for soybean. Wider adoption of these remunerative systems tailored for different agro-climatic regions can help boost soybean production and bridge the prevailing yield gap in the country. However, further refinement of promising systems through on-farm evaluation and integrated research is required.

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6. Future Scope of the Study

This review provides insights on the performance of different seasonal and intercropping systems involving soybean evaluated through research studies over the past two decades. However, there is still scope to further optimize these systems through focused research. Some potential areas that warrant further investigation include:

1. On-farm evaluation of promising soybean-based cropping systems identified through research trials across different agro-climatic zones. This will help identify the most location-specific, remunerative systems for widespread adoption.
2. Impact of new soybean varieties with different duration types on the productivity of seasonal cropping systems.
3. Intercropping soybean with high value/nutritional security crops like pulses, spices etc.
4. Resource use efficiency, profitability and sustainability of soybean-based systems under climate change scenarios.
5. Appropriate crop establishment methods and integrated crop management packages for different seasonal and intercropping systems.
6. Life cycle and systems analysis of soybean-based cropping systems to quantify their economic, environmental and social impacts.

Addressing the above knowledge gaps through collaborative research involving various stakeholders will aid in refining sustainable soybean production technologies and realizing its true production potential in India.

7. Conflict of Interest

The authors declare no conflict of interest. The authors are responsible for the writing and content of this article.

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