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Productivity and profitability of soybean (*Glycine max*) and wheat (*Triticum aestivum*) genotypes grown in sequence under system of crop intensification

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ABSTRACT

The field experiment was conducted at the ICAR–Indian Agricultural Research Institute, New Delhi during *kharif* and *rabi* seasons of 2014-15 and 2015-16 to study the productivity and profitability of soybean (*Glycine max* L.) and wheat (*Triticum aestivum* L.) genotypes grown under system of Crop Intensification (SCI). Three cultivation methods, conventional, SCI (45 × 45 cm) and SCI (30 × 30 cm) for soybean and conventional, viz. and system of Wheat Intensification (SWI) (20 × 20 cm) and SWI (20 × 10 cm) for wheat were assigned to horizontal-plots and four varieties for each of soybean (Pusa 9712, PS 1347, DS 12-13 and DS 12-5) and wheat (HD 2967, HD 3086, HD 2851 and HD 2894) were assigned to vertical-plots in a strip-plot design and replicated thrice. Soybean and wheat sown under SCI produced larger yield attributes, yields and economic returns compared to conventional method. Significantly higher pods/plant, seeds/pod and 100–seed weight of soybean were obtained from SCI (45 × 45 cm) and SCI (30 × 30 cm) than the conventional. Highest soybean seed yield and net returns were obtained with SCI (30×30 cm) than the other cultivation methods. The soybean DS 12-13 and DS 12-5 performed better than the other varieties with respect to yield attributes, yield and net return. Higher effective tillers/m^2, grains/spike, 1000-grain weight; grain, straw and biological yields; net returns and benefit-cost ratio of wheat were found under SWI (20 × 20 cm) compared to conventional method of sowing. Amongst wheat varieties, yield attributes, yield and economic returns were obtained with HD 2967 over remaining varieties. The highest system productivity in terms of wheat-equivalent yield (WEY) (11.62 t/ha and 12.02 t/ha) was recorded at both geometries of SCI and SWI than the conventional method.

Key words: Productivity, Profitability, System of Crop Intensification (SCI), System of Wheat Intensification (SWI), System productivity, Wheat-equivalent yield

Green revolution era witnessed un-precedent growth in the food grain production, especially in South-Asia (Dass *et al.* 2014). However, continuous adoption of rice–wheat cropping system (RCWS) in Indo-Gangetic Plains (IGP) of South-Asia has not only threatened environmental safety but also promoted degradation, inefficient use of natural resources, emergence of insects–pests as well as environmental pollution through emission of greenhouse gases (Gupta and Seth 2007, Humphreys *et al.* 2010). In RWCS, diversification of rice with less water requiring crops (soybean, maize and pigeonpea) may enhance productivity of system without adversely affecting the soil health and environment quality. In this regard, soybean (*Glycine max* L.)–wheat (*Triticum aestivum* L.) system is very promising as it meets dual objectives of crop diversification and soil health maintenance (Verma and Sharma 2007).

Soybean is the vital oilseed crop of world and offers many nutritional, and health benefits (Dass and Bhattacharyya 2017, Dass *et al.* 2018). In India, it is grown on 11.66 million ha and produce 8.59 million tonnes with average yield of 737 kg/ha during the year 2015-16 (DAC and FW 2017). It is mainly cultivated in rotations with crops like wheat, chickpea, mustard, potato, safflower, pigeonpea, sorghum, cotton, etc. Among all, soybean–wheat rotation is the most predominant in India (Sharma *et al.* 2012) and practised on 4.5 million ha area mainly in the central India (Monsefi *et al.* 2014).Wheat is an important staple food and meets about 61% of the protein requirement and serves as the main source of protein in developing nations (Braun *et al.* 2010). India is the second largest producer (93.2 million tonnes) after China and has the largest area under wheat (30.2 million ha) with a productivity of 3093 kg/ha (DAC and FW 2017).

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Using System of Crop Intensification (SCI) methods, small and marginal farmers in many countries are obtaining higher crop yields and more productivity from their land, labour, seeds, water and capital. Crops cultivated using SCI methods have shown greater resilience to the hazards of climate change (Thakur *et al.* 2009, Zhao *et al.* 2009, Dass *et al.* 2015). The soybean under SCI produced 4.2 times more branches/plant, 2.75 times greater dry matter/ plant, 3.7 times more pods/plant, 4.3 times more seeds/plant and 4% higher 100-seed weight compared to traditional practice (AKRSP-I 2013). Another version of SCI of wheat cultivation is System of Wheat Intensification (SWI), which can enhance yield by two- to three-times through some improvements in crop management components (Uphoff *et al.* 2011). Plant height and yield attributes were found higher in SWI method (Adhikari 2013). A dibbling version of SWI gave 13% yield advantage, with 30-40% less labour than transplanting version. According to Styger and Ibrahim (2009), growing wheat using SRI principle was not very successful due to mortality of transplanted seedlings (9-22%) in the cold winter climate. SWI does require more labour and more organic matter inputs, so costs of SWI production/hectare is about 60% higher than with conventional practices (PRADAN 2012). However, once a new practice gets established and famers become adequately acquainted with it, the costs also come down, and tremendously higher yields make the SWI more profitable.

During the past decades, crop productivity is declining due to use of highly input habituate technologies. To meet the food demand of our burgeoning population, we have to intensify crop production through modification in cultivation practices like seed rate, sowing methods, precise water and weed management along with improvement in input-use efficiency and crop yield. SCI is an agricultural production strategy that seeks to increase and optimize the benefits that can be derived from making better use of available resources like soil, water, seeds, nutrients, solar radiation, and air (Adhikari *et al.* 2017). Although, SCI is a labour-intensive technology, yet resource-poor households seeking to get maximum yield from the small landholdings find that the additional effort and care in crop management enhance net returns as well as livelihood security (Shiva Dhar *et al.* 2015). Keeping in view the above facts, the current field investigation was made to standardise the SCI and to compare the conventional and innovative SCI methods in terms of productivity and profitability of soybean and wheat varieties.

MATERIALS AND METHODS

The field experiment was conducted during *kharif* and *rabi* seasons of 2014-15 and 2015-16 at the research farm of ICAR-IARI, New Delhi located at 28.40°N latitude and 77.12°E longitude and 229 m above mean sea level (MSL). During experimental period, the mean maximum temperature was 34.3, 33.5°C, mean minimum temperature 22.8, 22.1°C, total rainfall 665.8, 707.4 mm, and mean evaporation 6.01, 4.95 mm in 2014-15 and 2015-16, respectively. The soil of experimental site was sandy clay loam in texture, low in organic carbon (0.39%) and $KMnO_4$ oxidizable N (155.2 kg/ha), medium in 0.5 N $NaHCO_3$ extractable P (14.2 kg/ ha), high in 1.0 N NH_4OAC extractable K (311.4 kg/ha), alkaline in pH (7.8) with electrical conductivity of 0.4 dS/m and bulk density of 1.6 g/cm^3. The experiment was laid-out in strip-plot design with three cultivation methods: conventional, SCI (45 × 45 cm) and SCI (30 × 30 cm) for soybean; conventional, SWI (20 × 20 cm) and SWI (20 × 10 cm) for wheat assigned to horizontal-plots and four varieties each of soybean (Pusa 9712, PS 1347, DS 12-13 and DS 12-5) and wheat (HD 2967, HD 3086, HD 2851 and HD 2894) assigned to vertical-plots and replicated thrice. Under conventional method, soybean and wheat were sown at 45 cm and 22.5 cm apart lines by seed drill using a seed rate of 80 and 100 kg/ha, respectively. The recommended dose of fertilizers (25:60:40 kg N, P_2O_5 and K_2O/ha for soybean; 150:60:60 kg N, P_2O_5 and K_2O /ha for wheat) and irrigations (flowering and pod formation stage in soybean and at crown-root initiation, tillering, late-jointing, boot, flowering, milking and at grain filling stages in wheat) were applied to each of the crops. Imazethapyr 10% SL at 0.1 kg a.i. /ha at 30 days after sowing (DAS) and sulfosulfuron at 25 g/ha at 25 DAS under conventional method of sowing were applied for weed management in soybean and wheat, respectively.

Under SCI and SWI method, seeds were treated with specific seed treatment solution, which was formulated by mixing jaggery (2.5 kg) in 20-25 l of hot water (60°C), cow urine (5.0 litre) and vermicompost (2.5 kg). Whenever required, suitable quantity of water was added to keep the slurry in a liquid state. An earthen-pot was used as metal containers are not recommended. For preparing seed treatment solution, water was heated to 60°C, then cow urine poured into it and the solution was stirred. After that, mixture of jaggery and vermicompost with water (60°C) was prepared separately. The above mixtures (jaggery and vermicompost in water and cow urine mixture) were intermixed properly. After 30 min, the seeds of soybean or wheat were soaked in mixture for 4–5 and 6–8 hr respectively. The mixture was filtered to separate the seeds. The soybean seeds were treated with *Rhizobium* and PSB culture and kept for drying in shade for 6-7 hr.

SCI protocol for soybean: At the time of field preparation the recommended dose of nutrients were applied through FYM at 5.0 t/ha treated with *Trichoderma* (2.5 kg/t) and remaining phosphorus dose through single super phosphate at 250 kg/ha. For SCI (45 × 45 cm) and SCI (30 × 30 cm), seeds were sown at 15 and 25 kg/ha, respectively. For both spacing two sprouted seeds were sown at each spot without damaging the seed coat. Gap filling was done 7 DAS with treated seed to maintain optimum plant population. Thinning was done after 15 days of sowing to remove any plants found between the marked geometric points. Two hand hoeing were carried out at 20 and 40 DAS to remove weeds and enhance soil aeration, microbial activity and root growth. The crop was irrigated at flowering and pod formation stages.

SWI protocol for wheat: The standard SWI protocols were adapted from Shiva Dhar *et al.* (2015) for wheat. Seed rate at 25 and 50 kg/ha was used for SWI (20 × 20 cm) and SWI (20 × 10 cm), respectively. For both the spacing, two sprouted seeds were dibbled per hill at crossing point of line and plant spacing. The *Trichoderma*-treated (2.5 kg/t) compost at 2.0 t/ha plus 68 kg dia-ammonium phosphate (DAP) and 33 kg/ha muriate of potash (MOP) were applied before sowing and 68 kg urea/ha was applied on 16^{th} day; vermicompost at 500 kg/ha plus PSB culture at 6.25 kg/ha on 20^{th}day; 34 kg urea/ha and 34 kg MOP/ha on 36^{th}day; vermicompost at 500 kg/ha was applied on 40^{th} day. Three manual hoeings were performed for weed management using cono-weeder at 20, 30 and 40 DAS. Five shallow irrigations were given as per SWI protocol at 15, 35, 60, 95 and 105 DAS.

All yield attributing characters were recorded as per standard procedure for both soybean and wheat crop. Total biomass of each net plot area was harvested and threshed after sun-drying. The grains were cleaned and sun-dried for 4 to 5 days and weighed. The economic returns for both crops were computed on basis of prevailing market price of inputs and output during 2014–15 and 2015–16. Wheat-equivalent soybean yield and system productivity were calculated as per formula given by Sharma (2014). The data were analyzed as per the standard procedure for strip-plot design as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Soybean

Yield attributes and yield: The yield attributes and yield of soybean varied significantly under different cultivation methods and varieties (Table 1). Among cultivation methods, SCI (45 × 45 cm) and SCI (30 × 30 cm) were found significantly superior to the conventional method; however, both SCI versions were at par with each other for pods/plant, seeds/pod and 100-seed weight. These attributes increased by 1.5 to 2.1, 1.1 to 1.2 and 1.15 to 1.19 folds, respectively at SCI (45 × 45 cm) and SCI (30 × 30 cm) over conventional methods. Among varieties, DS 12-13 and DS 12-5 were significantly superior to Pusa 9712 and PS 1347 for pods/plant and seeds/pod; while, PS 1347 produced bolder seeds than other varieties. The lowest values of yield attributes were recorded with conventional method and in varieties PS 1347. Wider spacing and square planting along with microbe loaded organic sources of nutrients provided better chance for development of roots and other plant parts. Low plant density encourages the plant to give superior yield attributes (Prasad *et al.* 1993, Abbas *et al*. 1994). The wider spacing resulted in better growth of individual plants due to more availability of space, moisture and light was presumably responsible for enhancement of yield attributes and yields (Dass *et al.* 2015).

Soybean sown as SCI (30 × 30 cm) produced significantly higher seed yield (9% and 12%) over conventional and SCI (45 × 45 cm) methods, respectively. Seed yields obtained with wider spaced SCI (45 × 45 cm) and convention method were at par. Stover and biological yields under conventional and SCI (30 × 30 cm) methods were also similar. The lowest seed, stover and biological yields were recorded with SCI (45 × 45 cm). Apart from this, the highest harvest index (HI) was observed with both SCI over conventional sowing. Seed, stover and biological yields were found statistically at par for DS 12-13 and DS 12-5 varieties; both varieties produced significantly higher yields over PS 1347. The lowest seed and stover yields were obtained from conventional method and among varieties with PS 1347. Harvest index of all varieties did not showed any significant variation. The increase in yield attributing characters due to better plant vigour resulted in higher yield.

Table 1 Effect of cultivation methods and varieties on yield attributes and yield of wheat (mean of 2 years)

Treatment	Effective tillers/m^2	Grains/ spike	1,000-grain wt. (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
Cultivation methods							
Conventional	413	47.4	35.5	5.19	8.10	13.29	39.1
SWI (20×20 cm)	470	63.0	37.6	7.23	11.40	18.62	38.8
SWI (20×10 cm)	463	61.5	37.5	7.05	11.13	18.18	38.8
SEm±	3	0.4	0.27	0.05	0.07	0.10	0.17
CD (P=0.05)	11	1.6	1.08	0.19	0.28	0.40	0.67
Wheat varieties							
HD 2967	466	62.0	37.7	6.77	10.83	17.59	38.5
HD 3086	448	59.5	37.2	6.64	10.60	17.24	38.6
HD 2851	437	47.2	36.6	6.47	9.96	16.43	39.5
HD 2894	444	60.4	36.0	6.08	9.44	15.53	39.2
SEm±	5	0.3	0.20	0.02	0.08	0.08	0.21
CD (P=0.05)	16	1.0	0.70	0.08	0.29	0.27	0.71

SWI: System of Wheat Intensification

Ramboo *et al.* (2003) recorded highest seed yield from 20 plants/m^2 compared to 40 plants/m^2. Wide space sowing produced higher seed and stover yield, while stover yield was on par with narrow row spacing (Pandya *et al.* 2005).

The interaction effect of cultivation methods and varieties significantly influenced the 2-year mean seed yield of soybean (Fig 1). The seed yield of all varieties was higher in SCI (30×30 cm) than under other cultivation methods. Seed yield obtained from DS 12-13 grown as SCI (30×30 cm) was higher than remaining combinations of cultivation methods and varieties. However, DS 12-5 also produced at par yield at SCI (30×30 cm). Combination of conventional and SCI (30×30 cm) with DS 12-13 and DS 12-5 were found on par to each other, however, produced significantly higher seed yield over other combinations. Similar seed yield was obtained from combination of Pusa 9712, PS 1347 and DS 12-5 with conventional and SCI (45 × 45 cm). However, Ferehewoit and Firew (2017) observed that the interaction effect of varieties and row spacing did not influence the soybean seed yield.

Economic returns: Among the cultivation methods, SCI (30×30 cm) gave significantly higher gross returns (82.5 ×10^3 ₹/ha) and net returns (₹ 46.5 × 10^3 ₹/ha) as compared to SCI (45 × 45 cm) and conventional method (Table 3). However, the highest benefit: cost ratio (B: C ratio, 1.42) was found under conventional method of sowing because of lower cost of cultivation. The higher net returns was mainly due to high seed yield at SCI (30 × 30 cm) than SCI (45 × 45 cm). Similarly, De Bruin and Pedersen (2008) observed less benefits from high plant density due to increase in seeding rate and lower yield.

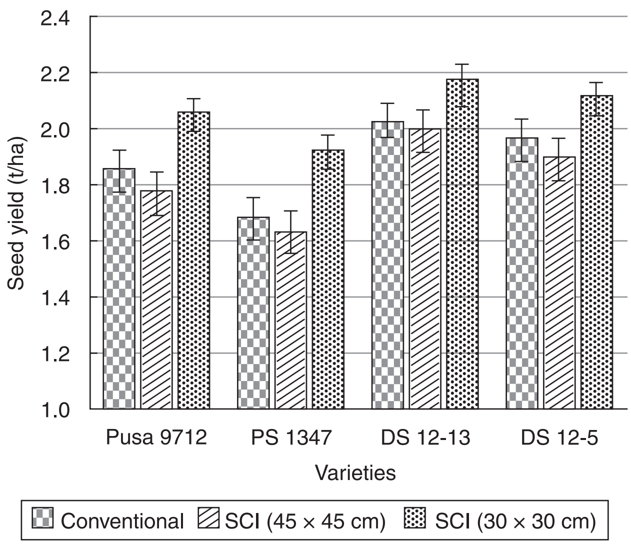

Fig 1 Interaction effect of cultivation methods and varieties on seed yield of soybean. SCI: System of Crop Intensification.

Wheat

Yield attributes and yield: Wheat yield attributes and yields varied significantly due to cultivation methods and varieties (Table 2). Both SWI crop geometries (20 × 20 cm or 20 × 10 cm) were found at par to each other, but significantly superior to the conventional method for effective tillers/m^2, grains/spike and 1,000-grain weight. These values were 13.8, 32.9 and 5.83%, respectively, higher in SWI (20 × 20 cm) over conventional method. Among the wheat varieties, maximum number of grains/spike was obtained from HD 2967 compared to remaining varieties.

Table 2 Effect of cultivation methods and varieties on economics and system productivity in soybean-wheat sequence (mean of 2 years)

Treatment		Soybean				Wheat				WEY of soybean (t/ha)	System productivity (t/ha)
Soybean	Wheat	Cost of cultivation (×10^3 ₹/ ha)	Gross returns (×10^3 ₹/ ha)	Net returns (×103 ₹/ ha)	B:C ratio	Cost of cultivation (×10^3 ₹/ ha)	Gross returns (×10^3 ₹/ ha)	Net returns (×10^3 ₹/ ha)	B:C ratio		
Cultivation methods											
Conventional	Conventional	31.3	75.7	44.4	1.42	38.2	115.6	77.4	2.02	4.53	9.72
SCI (45×45 cm)	SWI (20×20 cm)	35.6	73.0	37.4	1.05	51.8	161.6	109.7	2.12	4.39	11.61
SCI (30×30 cm)	SWI (20×10 cm)	36.0	82.5	46.5	1.29	52.7	157.7	105.1	1.99	4.97	12.02
SEm±			1.18	1.18	0.03		0.92	0.92	0.02	0.07	0.11
CD (P=0.05)			4.64	4.64	0.14		3.60	3.60	0.08	0.27	0.44
Varieties											
Pusa 9712	HD 2967	34.3	75.8	41.6	1.22	47.6	152.0	104.4	2.19	4.55	11.32
PS 1347	HD 3086	34.3	70.1	35.8	1.05	47.6	149.1	101.5	2.13	4.20	10.84
DS 12-13	HD 2851	34.3	82.6	48.3	1.42	47.6	143.5	95.9	2.01	4.96	11.43
DS 12-5	HD 2894	34.3	79.7	45.4	1.33	47.6	135.3	87.7	1.85	4.79	10.87
SEm±			1.05	1.05	0.03		0.42	0.42	0.01	0.07	0.07
CD(P=0.05)			3.64	3.64	0.11		1.45	1.45	0.03	0.23	0.25

SCI: System of Crop Intensification, SWI: System of Wheat Intensification, WEY: Wheat grain equivalent

HD 2967 and HD 3086 were found at par but statistically superior over HD 2851 and HD 2894 for effective tillers/m^2 and 1,000-grain weight.

The highest grain (7.23 t/ha), straw (11.4 t/ha) and biological (18.6 t/ha) yields were realized with SWI (20 × 20 cm) compared to the conventional method, however, it was on par with modified SWI (20 × 10 cm). The SWI (20 × 20 cm) produced higher grain, straw and biological yields over the conventional method by 39.30, 40.70 and 40.11%, respectively. Harvest index of wheat varieties remained unaffected by cultivation methods. Among varieties, HD 2967 produced the highest yield with highest HI.

Use of organic sources of nutrients, frequent hoeing could have resulted in better soil aeration, continuous and supply of balanced nutrients and improvement of soil environment facilitating better root proliferation leading to higher absorption of water and nutrients. This might have led to better crop growth, increased number of effective tillers/unit area and grains per spike, and ultimately increased grain yield. These findings were in conformity with recent findings of Shiva Dhar *et al.* (2015) and Kumar *et al.* (2015).

Interaction effect of cultivation methods and varieties on grain yield was significant (Fig 2). Both versions of SWI produced significantly higher grain yield than conventional for all the varieties; however, HD 2967 sown under both SWIs was found superior for grain yield over the HD 2851 and HD 2894; and over all varieties grown conventionally. HD 2967 and HD 3086 varieties under either version of SWIs were found on par and produced significantly higher grain yield over rest of the cultivation × variety combinations. Plant geometry and row spacing are the important factors that affect yield directly, however, different wheat cultivars respond differently in this regard (Alignan *et al.* 2009).

Economic returns: Economic returns of wheat were significantly affected due to different cultivation methods and varieties (Table 3). The cultivation cost of SWI (20 × 20 cm) and SWI (20 × 10 cm) was 35.6 and 37.8%, respectively

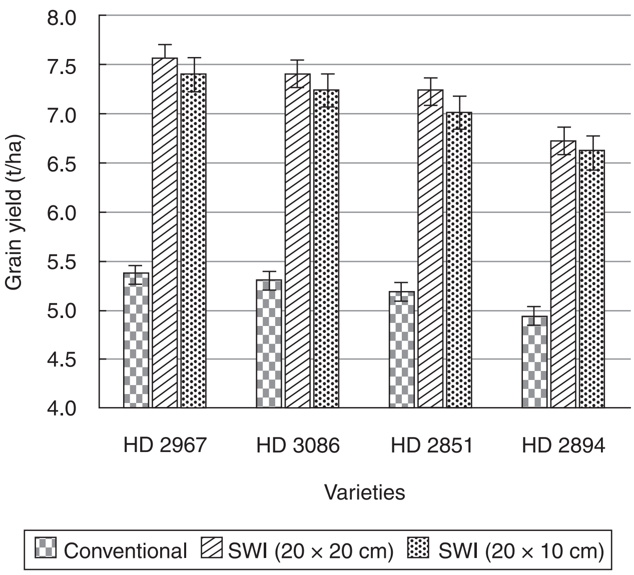

Fig 2 Interaction effect of cultivation methods and varieties on grain yield of wheat. SWI: System of Wheat Intensification.

higher over conventional method. The net returns (109.7 × 10^3 ₹/ha) and B: C ratio (2.12) were found significantly higher with SWI (20×20 cm). SWI (20×10 cm) also gave significantly higher net returns (₹ 105.7 × 10^3/ha) over conventional method (77.33 × 10^3 ₹/ha). The SWI (20 × 20 cm) gave 1.42 and 1.04 times higher net returns than the SWI (20×10 cm) and conventional method, respectively. The variety HD 2967 accounted for maximum net returns (104.7 ×10^3 ₹/ha) and B: C ratio (2.20) as compared to the other varieties. The high net returns and B: C ratio due to high production under of HD 2967 under SWI (20×20 cm). Though the cost of cultivation was higher in SWI method, the higher net returns compensated the higher cost and gives more profits (Shiva Dhar *et al.* 2015).

System productivity: System yield varied significantly due to cultivation methods and varieties in soybean-wheat sequence (Table 3). Wheat-equivalent yield (WEY) of soybean and system productivity in terms of WEY were recorded higher at SCI (30 × 30 cm) followed by (fb) SWI (20 × 10 cm) and SCI (45 × 45 cm) fb (20 × 20 cm) over the conventional method of sowing. The variety DS 12-13 fb HD 2851 and Pusa 9712 fb HD 2967 were observed at par with each other but superior over the PS 1347 fb HD 3086 and DS 12-5 fb HD 2894 with respect to WEY of soybean and system productivity. The higher WEY of soybean and system productivity might be due to integrated nutrient application which results improved microbial and nutrient dynamics in rhizosphere of both crops for promotion of crop growth. These results are in agreement with those of Billore *et al.* (2005).

Based on the findings of investigation, SCI (30 × 30 cm) for soybean and SWI (20 × 20 cm) may be adopted for higher yield, economic returns and system productivity. Soybean variety DS 12-13 under SCI (30 × 30 cm) and wheat variety HD 2967 under SWI (20 × 20 cm) may be more profitable and remunerative over other varieties under conventional method.

REFERENCES

Abbas M, Singh M P, Nigam K B and Kandalkar V S. 1994. Effect of phosphorus, plant densities and plant type on yield attributing characters of soybean. *Indian Journal of Agronomy* **3**: 249–51.

Adhikari D. 2013. Short communication: System of wheat intensification in farmers' field of Sindhuli. *Nepal Agronomy Journal* **3**: 169–72.

Adhikari P, Araya H, Aruna G, Balamatti A, Banerjee S, Baskaran P, Barah B C, Behera D, Berhe T, Boruah P, Shiva Dhar, Edwards S, Fulford M, Gujja B, Ibrahim H, Kabir H, Kassam A, Khadka R B, Koma Y S, Natarajan N S, Perez R, Sen D, Sharif A, Singh G, Styger E, Thakur A K, Tiwari A, Uphoff N T and Verma A. 2017 System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: experience with diverse crops in varying agroecologies. I*nternational Journal of Agricultural Sustainability* DOI: 10.1080/14735903.2017.1402504

AKRSP-I 2013. *Impact Assessment of Soybean Intensification Pilot Project in Madhya Pradesh*. Report for Aga Khan Rural Support Project-India, Khandwa, Madhya Pradesh, India, pp 1−18.

Alignan M, Roche J, Bouniols A, Cerny M, Mouloungui Z and Merah O. 2009. Effects of genotype and sowing date on phytostanol–phytosterol content and agronomic traits in wheat under organic agriculture. *Journal of Food Chemistry* **117**: 219–25.

Billore S D, Vyas A K and Joshi A K. 2005. Effect of integrated nutrient management on productivity, energy-use efficiency and economies of soybean (*Glycine max*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricultural Sciences* **75**(10): 644–6.

Braun H J, Atlin G and Payne T. 2010. Multi-location testing as a tool to identify plant response to global climate change. *Climate Change and Crop Production*, pp 115–38. Reynolds M P (Eds). CABI Publication, London, UK.

DAC and FW. 2017. *Annual Report*. Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

Dass A, Suri V K and Choudhary A K. 2014. Site-specific nutrient management approaches for enhanced nutrient-use efficiency in agricultural crops. *Journal of Crop Science and Technology* **3**(3): 1–6.

Dass A, Chandra S, Choudhary A K, Singh G and Sudhishri S. 2015. Influence of field re-ponding pattern and plant spacing on rice root-shoot characteristics, yield and water productivity of two modern cultivars under SRI management in Indian Mollisols. *Paddy and Water Environment* **14**(1): 45–59.

Dass A, Dey D, Lal S K and Rajanna G A. 2018. Tank-mix insecticide and herbicide application effects on weeds, insect–pest menance and soybean productivity in semiarid northern plains of India. *Legume Research*. Published online. Article ID: LR –3855.

Dass A and Bhattacharyya R. 2017. Wheat residue mulch and anti-transpirants improve productivity and quality of rainfed soybean in semi-arid north-Indian plains. *Field Crop Research* **210**: 9–19.

De Bruin J L and Pedersen P. 2008. Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal* **100**(3): 704–10

Ferehewoit D and Firew M. 2017. Effect of seed age, varieties and intra row spacing on yield of soybean [*Glycine max* (L.) Merrill] in Dangur District, Metekle Zone, West Southern Ethiopia. *World Journal of Pharmaceutical and Life Sciences* **3**(1): 28–43.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, p 704. John Wiley & Sons, Singapore.

Gupta R and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice–wheat cropping systems of the Indo-Gangetic Plains (IGP). *Crop Protection* **26**: 436–47.

Humphreys E, Kukal S S, Christen E W, Hira G S, Singh B, Yadav S and Sharma R K. 2010. Halting the groundwater decline in North-West India – which crop technologies will be winners? *Advances in Agronomy* **109**: 155–7.

Kumar A, Raj R, Shiva Dhar and Pandey U C. 2015. Performance of System of Wheat Intensification (SWI) and conventional wheat sowing under North Eastern Plain Zone of India. *Annals of Agricultural Research New Series* **36**(3): 258–62.

Monsefi A, Sharma A R, Zan N R, Behera U K and Das T K. 2014. Effect of tillage and residue management on productivity of soybean and physico-chemical properties of soil in soybean–wheat cropping system. *International Journal of Plant Production* **8**(3): 429-40.

Pandya N, Chouhan G S and Nepalia V. 2005. Effect of varieties, crop geometries and weed management on nutrient uptake by soybean [*Glycine max* (L.) Merrill] and associated weeds. *Indian Journal of Agronomy* **50**(3): 218–20.

PRADAN 2012. *Cultivating Finger Millet with SRI Principles: A Training Manual*. PRADAN, Ranchi, Jharkhand, and Sir Dorabji Tata Trust, Mumbai. Publisher SRI−Rice, CIIFAD, Ithaca, New York. http://sri.ciifad.cornell.edu/aboutsri/othercrops/fingermillet/In_SFMI_Pradan.pdf

Prasad J V N S, Ramaiah N V and Satyanarayanan V. 1993. Response of soybean [*Glycine max* (L.) Merrill] to varying levels of plant density and phosphorus. *Indian Journal of Agronomy* **38**(3): 494–5.

Rambo L, Costa J A, Pires J LE, Parcianellao G and Ferreira F G. 2003. Soybean yield response to plant arrangement. *Ciência Rural* **33**(3): 405–11.

Sharma A. 2014. *Numerical Agronomy*, p 194. Kalyani Publishers, New Delhi, India.

Sharma M P, Gupta S, Sharma S K and Vyas A K. 2012. Effect of tillage and crop sequences on arbuscular mycorrhizal symbiosis and soil enzyme activities in soybean (Glycine max) rhizosphere. *Indian Journal of Agricultural Sciences* **82**(1): 25–30.

Shiva Dhar, Barah B C, Vyas A K and Uphoff N T. 2015. Comparing System of Wheat Intensification (SWI) with standard recommended practices in the north-western plain zone of India. *Archives of Agronomy and Soil Science* **62**(7): 994–1006.

Styger E and Ibrahim H. 2009. The System of Wheat Intensification (SWI) First Time Testing by Farmers in Goundam and Dire, Timbuktu, Mali 2009, July 7, 2009. http://ciifad.cornell.edu/sri/countries/mali/MaliSWIrpt071309.pdf

Thakur A K, Choudhari S K, Singh R and Kumar A. 2009. Performance of rice varieties at different spacing grown by the system of rice intensification in eastern India. *Indian Journal of Agricultural Sciences* **79**: 443–7.

Uphoff N T, Marguerite, Devi J, Behera D, Verma A K and Pandian B J. 2011. *National Colloquium on System of Crop Intensification (SCI). Field Immersion of System of Crop Intensification (SCI)* on 28/02/2011. http://sri.ciifad.cornell.edu/ aboutsri/othercrops/index.html.

Verma S and Sharma P K. 2007. Effect of long-term manuring and fertilizers on carbon pools, soil structure and sustainability under different cropping systems in wet-temperate zone of north-west Himalayas. *Biology and Fertility of Soils* **44**: 235–40.

Zhao L, Wu L, Li Y S, Lu X H, Zhu D F and Uphoff N T. 2009. Influence of the system of rice intensification on rice yield and nitrogen and water-use efficiency with different application rates. *Experimental Agriculture* **45**: 275–86.