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Precision nutrient and irrigation management influences the growth, rhizosphere characters and yield of soybean (*Glycine max*) under system of crop intensification

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2020 and 2021 at research farm of ICAR-IARI, New Delhi to study the effect of precision nutrient and irrigation management on growth and productivity of soybean [*Glycine max* (L.) Merr.] under system of crop intensification (SCI). The study was carried out in a split-plot design and replicated thrice. The main-plot included 3 irrigation practices, I_1, [standard flood irrigation at 50% DASM (FI)] and sprinkler (Spr); I_2 (Spr 80% ETc); I_3 (Spr 60% ETc) and sub-plots having 5 precision nutrient management (PNM) practices, viz. PNM_1 [SCI protocol]; PNM_2 [RDF, Basal dose incorporated (50% N, full dose of P and K)]; PNM_3 [RDF, Basal dose point placement (BDP) (50% N, full dose of P and K)]; PNM_4 [75% RDF, BDP (50% N, full dose of P & K)] and PNM_5 [50% RDF, BDP (50% N, full P and K)] and 1 absolute control with conventional practice. Further, for PNM_2-PNM_5 remaining 50% N was supplied through SPAD assisted top-dressing. PNM and irrigation practices improved the plant height and number of branches of soybean. Spr 80% ETc recorded significantly higher crop growth indices, viz. CGR (9.13 g/m^2/day), RGR (31.48 mg/g/day), NAR (16.47 mg/cm^2/day) and LAI (2.02 cm^2/plant) over FI at 60–90 DAS. Root attributes also improved under SCI over control. The mean grain yield was significantly higher in Spr 80% ETc (2.50 tonnes/ha) over FI. Similarly, PNM_3 recorded significantly higher mean grain yield (2.44 tonnes/ha) over PNM_5. Overall, precision nutrition and irrigation enhanced the soybean growth and yield under SCI, hence could be propounded in the soybean growing regions.

Keywords: Irrigation, Precision nutrient management, Root-traits, Soybean yield, System of crop intensification (SCI)

Introduction of legume-based cropping system into traditional rice-wheat cropping system in Indo-Gangetic Plains (IGP) would help bring crop diversification and solves the several related problems (Banjara *et al.* 2022). Soybean [*Glycine max* (L.) Merr.] being a legume crop improves soil fertility and also enriches organic matter (SOM) content of the soil through leaf litter thereby helps in restoring SOM in cropping systems (Dass and Bhattacharrya 2017, Dass *et al.* 2019). Poor crop management coupled with imbalanced nutrient and irrigation management results in low crop productivity of soybean. System of crop intensification (SCI) is a crop management technique, wherein its basic principles lies in best use of on-farm resources with minimum dependence on external input (Dass *et al.* 2018). Providing optimum space for crop growth and development to exploit the native available resources and enhance the rhizosphere activity of the plant through repeated inter cultivation leads to better aeration and keeps the soil loose and friable. Precise application of nutrients and irrigation water around the root zone of crop helps in maximum root development thereby enhances the forage activity of roots which, in turn, is reflected on enhanced assimilation of nutrients through higher biomass accumulation and yield (Dass *et al.* 2014a). Use of sensor tools like SPAD meter and GreenSeeker helps in top dressing of N fertilizer, and avoids the excessive application of nutrients thereby enhances the resource-use efficiency (Dass *et al.* 2014b). Scheduling the crop irrigation as per the need of the crop based on evapo-transpiration (ETc) requirements would help in saving the water (Hussein *et al.* 2014, Solgi *et al.* 2022). Micro irrigation like sprinkler irrigation have the potential to offset various stresses experienced by the crop. Hence, the current study was designed to know the effect

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of precision nutrient and irrigation management under SCI on growth, rhizosphere characters and yield of soybean.

MATERIALS AND METHODS

Experimental details: A field experiment was conducted during rainy (*kharif*) seasons of 2020 and 2021 at research farm of ICAR-Indian Agriculture Research Institute, New Delhi (latitude 28°.38′N and longitude of 77°.09′E) under SCI with soybean-wheat rotation. The experimental farm typically falls under the semiarid sub-tropics climate of Indo-Gangetic Plains region. Soil of the experimental site was sandy loam in texture belonging to the order Typic Ustochrepts. The average annual rainfall (2020 and 2021) during the crop period was 1168 mm, of which 73% occurred during June-September. The experimental site had a *p*H 7.8, EC 0.32 dS/m, oxidizable organic carbon 0.53%, available N (195.3 kg/ha), P (12 kg/ha), K (262.8 kg/ha). The experiment was conducted in a split-plot design and replicated thrice. The main-plot treatments included 3 irrigation practices, I_1, [standard flood irrigation at 50% DASM (FI)] and sprinkler (Spr); I_2 (Spr 80% ETc); I_3 (Spr 60% ETc)], whereas sub-plots had 5 precision nutrient management practices (PNM): PNM_1 [SCI protocol for nutrient management]; PNM_2 [RDF, Basal dose incorporated (50% N, full dose of P and K) + 50% N SPAD based top-dressing]; PNM_3 [RDF, Basal dose point placement (50% N, full dose of P and K) + (50% N SPAD based top-dressing)]; PNM_4 [75% RDF, Basal dose point placement (50% N, full dose of P and K) + (50% N SPAD based top-dressing)] and PNM_5 [50% RDF, basal-point placement (50% N, full P and K) + (50% N SPAD based top-dressing)], and 1 absolute control (conventional management).

Crop management: The major crop management principles of SCI include seed priming, early and healthy plant establishment with the sowing of sprouted seeds at greater spacing (30 cm × 30 cm), careful water application to maintain moist aerobic soil conditions, application of organic manure, mechanical weeding and hoeing to improve soil aeration, promotion of root growth, and beneficial soil organisms. For preparing seed treatment mixture, 10 L warm water (60°C), 2 kg of compost (properly decomposed), 10 L of cow urine, and 2 kg of separately produced jaggery solution were used to treat seeds. The above-mentioned combinations were thoroughly mixed, then 5 kg of seeds were dipped in the mixture in successive lots initially for 30 min followed by a subsequent soaking of 2 h. In order to separate the seeds, the mixture was filtered, immediately after separation of seeds from filtrate, seeds are treated with bio-fertilizers. The treated seeds were dried under shade for 10–12 h and the pre-germinated seeds were used for sowing in the field. Two pre-germinated seeds of soybean were dibbled at 30 cm × 30 cm per hill by hand sowing. The experimental plots were irrigated with portable sprinklers as per treatment. The crop was watered to a depth as determined by estimating crop ET_C on daily basis, 80% ET_C and 60% ET_C of soybean and 50% depletion of available soil moisture. The crop ET_C was worked out as the product of reference pan evaporation (ET_0) and crop co-efficient values (Kc) given in equation (1) (Allen *et al.* 1998).

$$ETc = Kc \times ET_0 \tag{1}$$

The amount water added through irrigation as determined by Spr 80% ETc and Spr 60% ETc was 547.6, 508.3 mm and 402.7, 381.2 mm, respectively during 2020 and 2021 while in flood irrigation, it was 580.8 and 549.0 mm, respectively. In absolute control plots, total water use was 608.3 in 2020 and 589.0 mm in 2021.

For SCI nutrient management (PNM_1) at the time of field preparation, the recommended dose of nutrients was applied through vermicompost @2.5 tonnes/ha treated with Trichoderma (2.5 kg/t), and the remaining phosphorus dose through single super phosphate at 250 kg/ha. The recommended fertilizer dose (RDF) for soybean for the New Delhi region is 52:72:40 (N: P_2O_5: K_2O kg/ha) based on soil test-based recommendation (STCR) (Anonymus 2014). RDF based on STCR was used for PNM_{2-5}. N was applied in 2 splits depending on the treatment combination-first dose was given as basal application and the other as top-dressing, while full doses of P and K were applied as basal regardless of the treatment combination. Based on the SPAD value at 30 DAS, the remaining 50% of the N top dressing was applied. When the SPAD value approached 30, the remaining N was applied to the crop. SPAD value 30 was used as the standard reference reading for top-dressing of N in soybean (Dass *et al.* 2022, Rajanna *et al.* 2022). The fertilizers were applied to the soil in 2 different ways: (1) broadcasting, and (2) point placement (manually application of fertilizers in a circular pattern around the plant's root zone).

Data collection and statistical analyses: The crop growth parameters, like plant height, branches/plant, dry matter accumulation (DMA), leaf area, leaf area index, rhizospheric parameters and yields were measured using standard procedures (Rana *et al.* 2014). Crop growth indices like CGR, RGR, and NAR were calculated using standard equations (Watson 1952).

The difference between the treatments were statistically analyzed through ANOVA by using JMP® software from SAS. The significant difference between the two treatment means values was determined by performing post hoc mean separation test Tukey's HSD test ($P<0.05$). Comparison was made between SCI versus control ($P<0.05$) and control versus rest of the treatment combinations for yield parameters to compare the crop performance between conventional and SCI cultivation.

RESULTS AND DISCUSSION

Growth parameters: Sprinkler irrigation at 80% ET_C (Spr 80% ET_C) recorded significantly higher plant height compared to standard flood irrigation at 50% DASM (FI) at 60 and 90 DAS (Table 1). Among precision nutrient management, the per cent increase in plant height for PNM_3 ranged from 3.4–3.9 and 4.7–4.9% over PNM_5 at 60 and 90 DAS, respectively, during both the years. SCI showed

Table 1 Effect of precision nutrient and irrigation management on plant height and branches per plant of soybean under system of crop intensification (SCI)

Treatment	Plant height (cm)						Branches/plant					
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Irrigation												
I_1	29.2	29.6	57.8	58.2	65.5	63.6	1.5	1.8	3.6	4.5	5.2	6.6
I_2	29.4	29.7	62.2	61.9	71.8	71.8	1.6	2.1	4.7	5.9	6.3	8.0
I_3	29.3	29.7	59.9	59.6	68.2	70.5	1.5	1.9	4.0	5.0	5.9	6.7
SEm±	0.60	0.54	0.80	0.70	1.20	1.40	0.30	0.29	0.11	0.20	0.14	0.20
CD (P=0.05)	NS	NS	3.20	2.60	4.50	5.51	NS	NS	0.44	0.77	0.56	0.77
Precision nutrient management												
PNM_1	29.2	29.7	60.7	60.2	69.1	69.3	1.4	1.8	4.2	5.4	6.0	7.2
PNM_2	29.5	29.8	59.7	59.8	67.5	68.2	1.6	2.0	4.0	4.9	5.6	7.2
PNM_3	29.7	29.6	60.9	60.8	70.3	70.3	1.7	2.0	4.3	5.5	6.1	7.6
PNM_4	28.8	29.7	60.0	60.0	68.4	68.4	1.6	2.0	4.1	5.1	5.9	7.1
PNM_5	29.2	29.6	58.6	58.8	67.1	67.0	1.4	2.0	4.0	4.9	5.4	6.5
SEm±	0.58	0.52	0.49	0.43	0.47	0.45	0.11	0.32	0.08	0.19	0.15	0.19
CD (P=0.05)	NS	NS	1.43	1.27	1.37	1.33	NS	NS	0.22	0.57	0.43	0.57
SCI versus control												
SCI	29.3	30.1	65.0	64.7	71.3	68.6	1.30	2.00	4.10	5.16	5.79	7.10
C	29.3	29.7	60.0	59.9	68.5	67.4	1.53	1.93	2.01	4.66	5.00	6.20
SEm±	0.26	0.23	0.22	0.19	0.21	0.19	0.12	0.14	0.03	0.05	0.07	0.09
CD (P=0.05)	NS	NS	0.64	0.77	0.61	0.55	NS	NS	0.10	0.14	0.19	0.25

significant improvement in plant height both at 60 and 90 DAS over control. The branches/plant were significantly higher in Spr 80% ETc followed by Spr 60% ETc over FI. The PNM_3 showed increment in branches/plant to the extent of 7.5–12.2% and 12.9–6.9% over PNM_5 at 60 DAS and 90 DAS respectively in 2020 and 2021. The SCI methods exhibited significantly higher branches/plant over control (Table 1).

Sprinkler irrigation helps in maintaining turgidity of cells and optimum relative water content which is congenial for growth of crops. Point placement of N, P and K coupled with SPAD assisted N top-dressing caused enhancement in plant height and number of branches/plant through better cell expansion and cell division, as N and P are the building blocks of amino acids and used for formation of protoplasm which is essential for growth and development (Begum *et al.* 2015). Wider plant spacing under SCI, reduced interplant competition, and allowed penetration of sunlight to lower leaves and thus improving its interception, and improved nutrient acquisition by plants as compared to conventional cultivation (Kuttimani and Velayudhum 2016, Dass *et al.* 2017).

Crop growth indices and dry matter accumulation (DMA): Spr irrigation 80% ET_C recorded CGR of 9.10 and 9.16 g/m^2/day that was superior to FI (7.69 and 8.06 g/m^2/day); Spr irrigation 80% ET_C and Spr irrigation 60% ET_C were statistically at par. The PNM_3 showed an increment of 14.1 and 16.8% in CGR over PNM_1 and PNM_5 at 60–90 DAS. SCI methods recorded a 22.5% increment in CGR over control. Spr 80% ETc recorded significantly higher RGR over FI at 60–90 DAS during 2020 and 2021 (Table 2). The PNM_3 showed an increment of 3.4 to 4.3% over PNM_5. NAR which is indirect indication of photosynthetic ability of plant also showed significant improvement due to sprinkler irrigation and precision nutrient management. Spr 80% ETc recorded an increase in 20–55.3% increase in NAR over FI. PNM_3 showed an increment of 19.8–32.5% over PNM_5. SCI recorded significantly higher NAR (13.85 mg/cm^2/day) over control. The LAI of soybean followed the decreasing order of Spr 80% ET_C> Spr 60% ET_C> FI. LAI was found to be significantly higher in PNM_3. The DMA with Spr 80% ETc was significantly higher compared to FI during 2020 and 2021. PNM_3 showed an increment of 7.8 to 13.9% in DMA over PNM_1. LAI and DMA did not differ significantly between SCI and control.

Sprinkler irrigation altered the micro-climate of the crop and maintains favourable moisture condition around the root profile of the crop thereby increases the solubility, absorption and translocation of nutrients (Dass and Chandra 2013). Point placement of fertilizer resulted in maximum nutrient concentration around the root zone of the crop, thus, roots could easily take up the available nutrients, hence resulted in improved crop growth indices through better DMA during crop growth period (Nayaka *et al.* 2021). In-season

Table 2 Effect of precision nutrient and irrigation management on crop growth indices, dry-matter accumulation (DMA), grain yield, stover yield and harvest index of soybean under SCI

Treatment	CGR ($g/m^2/day$)		RGR (mg/g/day)		NAR ($mg/cm^2/day$)		LAI		DMA (g/m^2)		Grain yield (t/ha)		Stover yield (t/ha)		Harvest index (%)	
	60–90 DAS		60–90 DAS		60–90 DAS		60–90 DAS		60–90 DAS							
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Irrigation																
I_1	7.69	8.06	25.37	28.86	11.38	12.41	1.10	1.88	349.9	472.9	1.99	1.97	4.54	3.36	32.5	30.8
I_2	9.10	9.16	32.53	30.44	13.66	19.28	1.60	2.44	531.1	501.4	2.45	2.56	5.16	4.47	32.0	33.3
I_3	8.43	8.74	28.84	29.55	11.19	15.04	1.45	2.10	525.6	486.1	2.15	2.30	4.35	3.98	31.8	34.5
SEm±	0.31	0.18	0.88	0.17	0.32	0.42	0.13	0.06	8.17	5.37	0.03	0.10	0.09	0.11	0.62	0.73
CD (P=0.05)	1.22	0.72	3.46	0.66	1.26	1.64	0.11	0.23	32.10	21.07	0.14	0.39	0.34	0.45	NS	NS
Precision nutrient management																
PNM_1	8.16	8.85	29.89	29.89	13.18	15.66	1.41	2.19	483.6	496.8	2.27	2.34	4.79	3.97	32.1	32.8
PNM_2	8.13	8.48	28.15	29.31	11.82	14.91	1.34	2.10	467.1	480.9	2.17	2.29	4.62	3.91	31.6	31.2
PNM_3	9.92	8.98	30.59	30.24	13.77	17.53	1.48	2.23	491.7	525.0	2.45	2.43	5.22	4.25	32.0	32.4
PNM_4	7.92	8.68	29.19	29.40	11.22	15.15	1.36	2.17	446.0	470.5	2.20	2.12	4.62	3.82	32.9	33.3
PNM_5	7.91	8.29	26.74	29.23	10.39	14.63	1.32	2.02	456.1	460.8	1.89	2.20	4.16	3.74	31.8	34.6
SEm ±	0.30	0.16	0.80	0.18	0.31	0.40	0.04	0.05	7.93	2.56	0.03	0.06	0.08	0.03	0.62	0.93
CD (P=0.05)	0.87	0.48	2.35	0.53	0.91	1.17	0.11	0.14	23.19	7.48	0.08	0.19	0.24	0.07	NS	NS
SCI versus Control																
SCI	8.65	8.65	28.9	29.6	12.1	15.6	1.38	2.14	468.9	486.8	2.20	2.28	4.68	3.94	32.1	32.9
C	7.72	6.50	21.5	22.6	11.2	13.1	1.85	2.44	507.6	509.8	1.95	1.83	4.80	2.95	28.7	26.7
SEm±	0.07	0.07	0.36	0.08	0.14	0.19	0.02	0.08	2.8	1.14	0.05	0.03	0.04	0.01	1.08	1.61
CD (P=0.05)	0.22	0.22	1.05	0.24	0.40	0.57	NS	NS	NS	NS	0.13	0.08	0.11	0.03	3.15	4.70

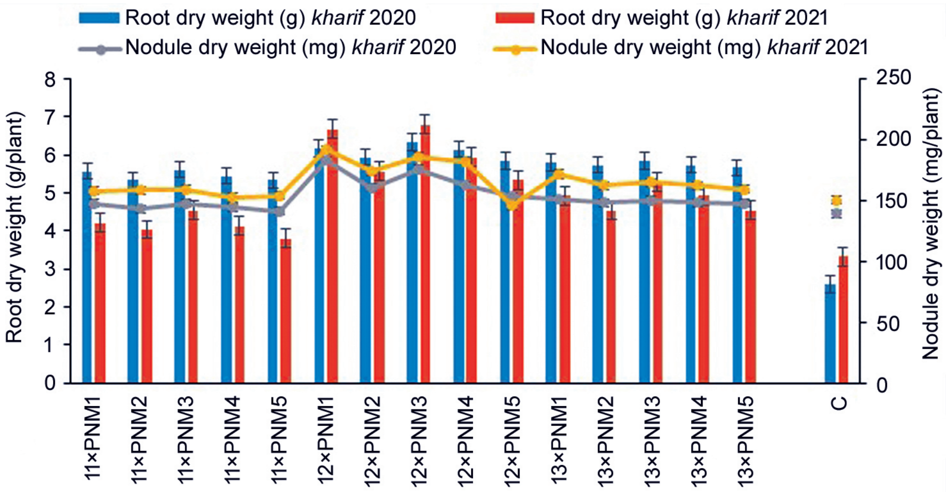

Fig 1 Effect of precision nutrient and irrigation management on root dry weight, nodule dry weight of soybean under system of crop intensification. The vertical bars represent $LSD_{0.05}$ values.

nutrient-management through SPAD assisted N management resulted in optimum chlorophyll content in leaves bettering photosynthesis and ultimately increasing crop growth and development (Rajanna *et al.* 2022). SCI facilitated optimum sunlight availability and space for growth of crop with minimum competition from the neighbouring plants for varied resources (Dass *et al.* 2018).

Rhizosphere characters: The root dry weight of soybean followed the order of Spr 80% ETc>Spr 60% ET_C > FI. PNM_3, recorded significantly higher root dry weight compared to PNM_5. The interaction effect of root dry weight was found significant (Fig 1); $I_2 \times PNM_3$ combination recorded significantly higher root dry weight compared to all other treatment combinations. However, $I_2 \times PNM_1$ stood at par with $I_2 \times PNM_3$. Highest nodule dry weight was recorded in Spr 80% ETc followed by Spr 60% ETc. Precision nutrient management options followed the order PNM_1>$PNM_3$$PNM_2$> PNM_4>PNM_5 for nodule dry weight. Both nodule dry weight and root dry weight were significantly higher in SCI over control. SCI principles ensures sufficient space to crop for optimum root development and repeated inter-cultivation keeps the soil in friable condition and provides better aeration both leading to enhanced root proliferation (Dass and Chandra 2013, Singh *et al.* 2018). Seed treatment with bio-fertilizer coupled with adequate application of organic manures under SCI resulted in enhanced beneficial microbial activity around the root surface which causes the root to produce more number of nodules leading to higher nodule dry weight (Choudhary *et al.* 2011). Sprinkler irrigation helps keep soil profile moisture at optimum condition throughout the crop growth. In addition, fertilizer placed around the root zone of crop resulted in positive interaction between water and nutrients thereby promoted the root development which was responsible for the significant interaction effects (Fig 1).

Yield of soybean: Significantly higher grain yield of 2.45 and 2.56 tonnes/ha was noticed in Spr 80% ETc which was followed by Spr 60% ETc (2.15 and 2.30 tonnes/ha); the per cent increase in grain yield ranged from 23.1–29.1% over FI. Grain yield was significantly higher in PNM_3 (2.45 tonnes/ha and 2.43 tonnes/ha) followed by PNM_1 (2.43 tonnes/ha and 2.12 tonnes/ha) (Table 2). PNM_3 recorded significantly higher stover yield over PNM_5. Harvest index was not affected significantly by treatments. The positive impact of sprinkler irrigation on canopy temperature and soil moisture resulted in improvement in growth parameters, viz. plant height, number of branches and dry-matter accumulation during vegetative stage which helps in better partitioning of photosynthates towards sinks during reproductive stage (Rahman *et al.* 2011). Again, point placement of fertilizer coupled with SPAD assisted N-management resulted in higher resource-use efficiency with minimum wastage of resource, which corroborated the improvement in yield of soybean (Dass *et al.* 2014a, Rajanna *et al.* 2022). The increment in yield of soybean under SCI could be attributed to better establishment of plants, reduction in plant density, enrichment of soil with organic matter, keeping the soil well aerated, and strong root system (Dass *et al.* 2016).

The 2-year field study demonstrated that precision nutrient and irrigation management under SCI enhanced the crop growth and rhizosphere characters which, in turn, enhanced the yield of soybean. Comparison of SCI with control showed significant improvement in soybean yield over control. In general, for growth and yield the decreasing order of crop performance for irrigation followed the trend Spr 80% ETc> Spr 60% ETc> FI. Among the PNM treatments, PNM_3 performed better for almost all studied parameters. Thus cultivation of soybean under SCI coupled with precision nutrient management PNM_3-RDF: basal dose point placement (50% N, full dose of P and K) + (50% N SPAD based top-dressing) and irrigation (Spr ETc 80%) would result in enhancing the yield under semi-arid environments of Indo-Gangetic plains and other similar regions.

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