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Research Article

Effect of Irrigation Levels and Nitrogen Sources on Growth, Yield and Input Use Efficiency of Soybean in a Sandy Loam Soil of Semi-Arid Environment

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ABSTRACT

A field experiment was conducted on a sandy loam soil at the research farm of the Indian Agricultural Research Institute, New Delhi during *kharif* 2011 to study the effect of irrigation and nutrient management practices on growth and yield of soybean and to find out the optimum irrigation schedule for soybean under inorganic, organic and integrated nutrient management strategies for achieving higher yield and input use efficiency. Soybean (cv. Pusa-9814) was grown in a split-plot design with four levels of irrigation and three sources of nitrogen. The main plot factor had irrigation treatments *viz*., I_1: rainfed, I_2: one irrigation at pod formation stage, I_3: two irrigations at flowering and pod formation stage, and I_4: three irrigations at flowering, pod formation and grain filling stages; the sub-plot factor consisted of nutrient management *viz*., N_1: 20 kg N ha^{-1} as urea, N_2: 10 kg N ha^{-1} as urea + 10 kg N ha^{-1} as farmyard manure (FYM), and N_3: 20 kg N ha^{-1} as FYM. Grain yield in I_1 was at par with I_2, but significantly higher than I_3 and I_4. Integrated use of urea and FYM (N_2) registered significantly higher yield, water use efficiency and partial factor productivity (PFP) of N over sole use of urea or FYM. Higher grain yield of soybean in urea+FYM was attributed to better root growth, greater biomass partitioning towards pods and greater utilization of water and nutrients. Hence under well distributed rainfall situation, soybean may be grown under rainfed condition or with one irrigation at pod formation stage with integrated use of urea and FYM to obtain higher yield and water and nitrogen use efficiency in Delhi region.

Key words: Root growth, Biomass, Water use efficiency, Partial factor productivity of nitrogen, Soybean

Introduction

Soybean (*Glycine max* (L) Merril.) is world's most important seed legume, which contributes 25% to the global edible oil. India ranks 4th in terms of area (9.3 mha) and 5th (10.13 Mt) in terms of production of soybean. However, its productivity in India (1.1 t ha^{-1}) is half of world's average productivity (2.2 t ha^{-1}). Factors responsible for low productivity of soybean in India include erratic monsoon rains, imbalanced and inefficient use of nutrients, low or non use of organic manures, low soil organic carbon (SOC) and poor soil health, growing continuously in the same piece of land etc. Results from different studies revealed that continuous application of farmyard manure (FYM) and green manure improved the SOC under different soils and cropping systems (Biswas *et al.*, 1971; Khilani and More, 1984; Nambiar, 1994; Swarup, 1998;

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Kundu *et al.*, 2002). Therefore, nutrient management practice that can improve SOC helps in sustaining crop productivity at higher level. However, neither inorganic fertilizers nor organic manures alone can sustain productivity (Prasad, 1996) and judicious use of these is essential (Lian, 1994). Furthermore, modification of the root architecture by soil management practices holds promise for sustainable soybean production. Integrated use of nutrients can improve root growth through improvement in soil physical properties. This facilitates efficient utilization of soil moisture and nutrients from the profile, which helps in mitigating the adverse effect of water stress and improves soybean productivity. The positive effect of integrated use of FYM and inorganic fertilizers on soybean has been reported by many workers (*e.g.,* Bobde *et al.*, 1998; Singh *et al.*, 1999; Hati *et al.*, 2000; Mandal *et al.*, 2000; Bandyopadhyay *et al.*, 2003; Hati *et al.*, 2006; Ghosh *et al.*, 2006; Bhattacharyya *et al.*, 2008). During later part of growth, soybean suffers from water stress due to withdrawal of monsoon. With this backdrop, a field experiment was conducted with the objectives: (i) to study the effect of irrigation and nutrient management practices on growth and yield of soybean and (ii) to find out the optimum irrigation schedule for soybean under inorganic, organic and integrated nutrient management strategies for achieving higher yield and input use efficiency in a sandy loam soil of Delhi region.

Materials and Methods

Soil and climate

The field experiment was carried out during *kharif* 2011 at the research farm of the Indian Agricultural Research Institute, New Delhi (between 28°37' and 28°39' N latitude and 77°90' and 77°11' E longitude and at an altitude of 228.7 m above mean sea level). Summers are long (early April-August) with the monsoon setting in between (July-September). Weather condition during soybean growth is given in Fig. 1. The soil is sandy loam (Typic Haplustept) with medium to angular blocky in structure, non-calcareous and slightly alkaline in reaction; low in organic carbon and available N and medium in available P and K content. The bulk density varied from 1.51 (0-15 cm) to 1.62 (60-90 cm) Mg m^{-3}. Soil water retention ranged from 24-26 (0.033MPa) and 8-10 (1.5MPa) % at different layers of for 0-90 cm soil profile.

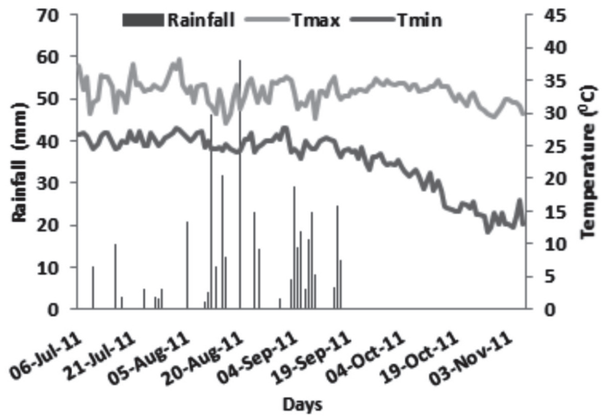

Fig. 1. Maximum and minimum temperature and rainfall during soybean growth in 2011

Crop culture

The experiment was laid out in a split-plot design with 3 replications with each plot of 5m × 3.5 m in size. Soybean (cv. Pusa-9814) was sown with a seed rate of 100 kg ha^{-1} at a row spacing of 30 cm in the 1st week of July and harvested in the 1st week of November. The main plot had irrigation treatments as I_1: rainfed, I_2: one irrigation at pod formation, I_3: two irrigations at flowering and pod formation and I_4: three irrigations at flowering, pod formation and grain filling stages, while the sub-plot consisted of nutrient management as N_1: 20 kg N ha^{-1} as urea, N_2: 10 kg N ha^{-1} as urea and 10 kg N ha^{-1} as FYM, and N_3: 20 kg N ha^{-1} as FYM. The entire dose of NPK and FYM was applied as basal. The FYM was prepared mainly from cow dung and wheat straw, and had 0.48% N, 0.17% P and 0.38% K. Thus, the FYM application rate under N_2 and N_3 treatments were 2.1 and 4.2 t ha^{-1}, respectively. Two preparatory tillage operations by disc plough and duck foot tine cultivator were applied for seed bed preparation and mixing of manures and fertilizers in all the treatments.

Biomass partitioning and leaf area index estimation

Representative plant samples were collected from 1 m row length, separated into leaf, stem and pod, oven-dried at 65^{0}C till constant weight was achieved and the dry weight was recorded.

Root studies

Root samples were collected at flowering using root sampling core (15 cm height, 7 cm diameter) at 15 cm depth increments up to 60 cm. The root samples were soaked overnight in water containing sodium hexametaphosphate in small amount in a pail (Aggarwal and Sharma, 2002). The water on the top with floating roots was decanted, and the roots were separated by carefully passing the decanted water over a fine sieve. The procedure was repeated 3-4 times for complete separation of roots from soils. Then, the roots were air-dried for scanning. The root length was determined using RHIZO system (Regent Instruments Inc.). Root samples were then oven-dried at 65^{0}C and the dry weights were recorded. The root length and mass were divided by core volume to estimate root length density (RLD) and root mass density (RMD), respectively.

Soil water dynamics and water use efficiency

Soil moisture content (0-90 cm) was determined thermo-gravimetrically at 15 days interval during the crop growth period to study the distribution and redistribution of soil water in the profile. Evapotranspiration (ET) was computed by water balance method using the following equation.

$$ET = P_{eff} + I - (S_f - S_i)$$

Where P_{eff} is effective precipitation (Brouwer and Heibloem, 1986), I is depth of irrigation, S_f and S_i are initial (at sowing) and final (at harvest) moisture storage.

Water use efficiency (WUE) was computed as Y/ET, where Y is the seed yield of soybean.

Statistical analysis

The data were analyzed by analysis of variance as outlined by Gomez and Gomez (1984). The significance of the treatment effect was determined using F-test, and significance between two treatments were tested through least significant differences (LSD) at 5% probability level and Duncan's multiple range test. Correlations and regressions were determined using the data analysis tool pack of MS-Excel.

Results and Discussion

Soil water dynamics

The temporal variation in the soil moisture followed the trend similar to the daily rainfall pattern during the crop growth and it increased with increase in irrigation levels (Fig. 2). Throughout the growth period, the soil moisture remained between the wilting point and field capacity moisture content. Soil moisture storage was higher when N was supplied through FYM than when it was supplied through urea. This may be attributed to lower biomass production and hence, lower ET under FYM treatment. The

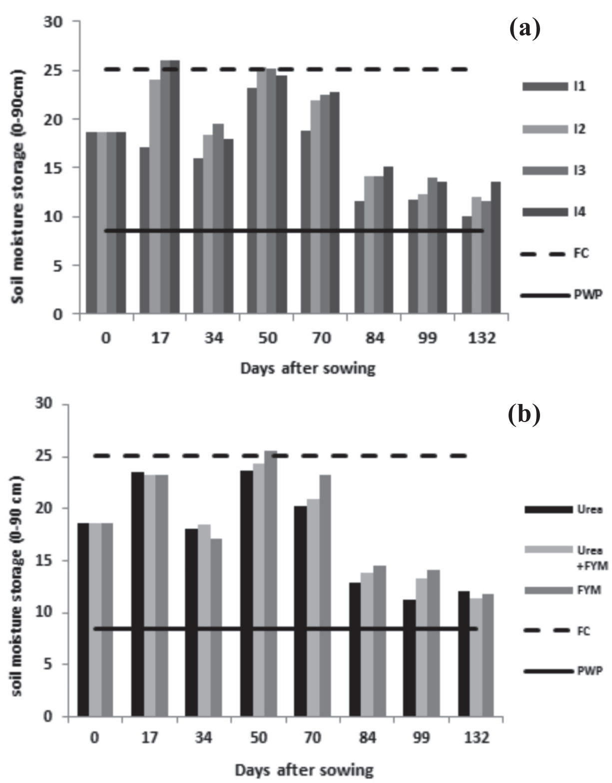

Fig. 2. Temporal variation in soil moisture storage in the profile as influenced by (a) irrigation levels and (b) nitrogen sources

differences in soil moisture storage due to nutrient management were more conspicuous during the period of dry spell (Bandyopadhyay *et al.*, 2003).

Root growth

Maximum root length and mass was recorded in 0-15 cm depth (Figs. 3 and 4). There was decline in root length density (RLD) and root mass density (RMD) with depth. However, the rate of decline in RMD was faster than that of RLD, which indicated that the finer roots were mostly present in the deeper layers. Percentage of total RLD at 0-15 cm soil layer was 75.6, 74.5 and 62.3% in urea, urea+FYM and FYM treatments, respectively. However, RMD at 0-15 cm layer was 97.1, 96.1 and 94.7% in these treatments, respectively. The length to mass ratio of roots increased with depth. Pooled over all the treatments, the ratio was 144, 1255, 1930 and 1960 cm g^{-1} in 0-15, 15-30, 30-45 and 45-60 cm soil layers, respectively. Allmaras *et al*. (1975) also reported higher root length/weight ratio of soybean at greater depths. It was noteworthy that with the highest irrigation level (I_4), there was less root length density and more root mass density compared to the rainfed (I_1) in 0-15 cm layer. Use of urea+FYM registered higher RLD

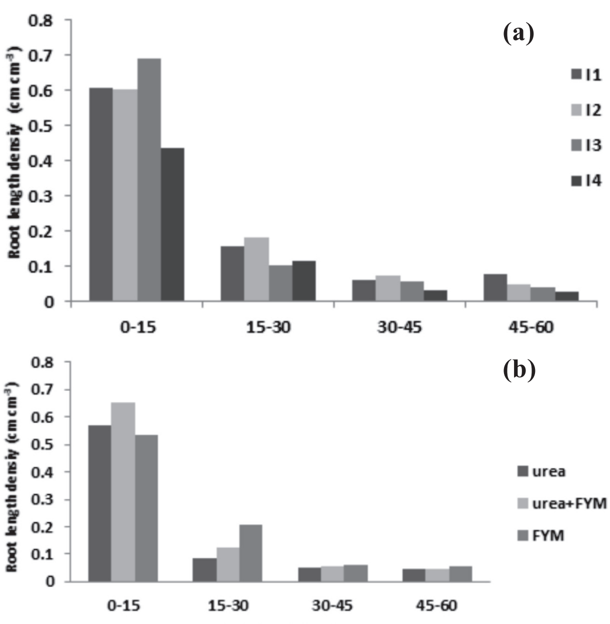

Fig. 3. Root length density of soybean as influenced by (a) irrigation levels and (b) nitrogen sources

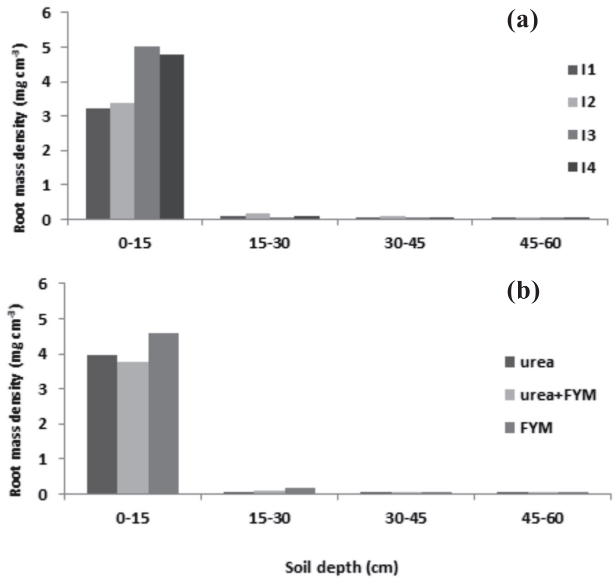

Fig. 4. Root mass density of soybean as influenced by (a) irrigation levels and (b) nitrogen sources

in the 0-15 cm layer than the sole use of urea. This may be attributed to better nutrient supply and creation of better physical environment through lowering of bulk density and penetration resistance in the presence of manures (Bandyopadhyay *et al.*, 2010). The RLD and RMD at 0-30 cm soil layer could account for 32 and 47% variations in grain yield of soybean, respectively.

Biomass partitioning of soybean

With increase in irrigation levels, total biomass production increased and was significantly higher than rainfed. However at physiological maturity stage, distribution of biomass towards pods was more in case of rainfed (I_1) than the highest irrigation level (I_4) (Fig. 5). Distribution of biomass towards pods was 46, 43, 45 and 27% for I_1, I_2, I_3 and I_4 treatments, respectively. Among the N sources, total biomass and its partitioning towards pod formation was significantly higher with integrated use of urea and FYM than sole use of urea or FYM. This finding is in agreement with Bandyopadhyay *et al.* (2010). Partitioning of biomass towards pods was 39, 42 and 38% for urea, urea+FYM and FYM treatments, respectively. Thus, the harvest index (HI) of soybean decreased with increase in

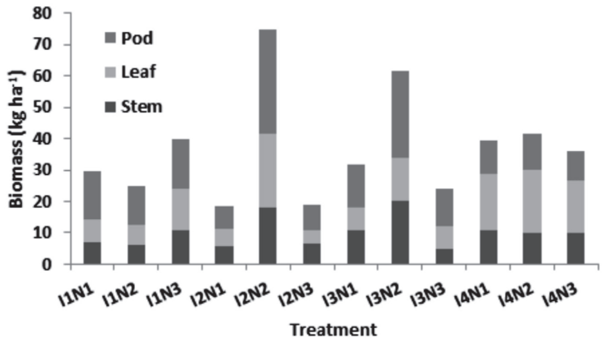

Fig. 5. Partitioning of biomass in soybean at physiological maturity stage as influenced by irrigation and nitrogen management

irrigation levels and among the N sources, the highest HI was recorded with urea+FYM. Among the treatment combinations, application of irrigation only at pod formation stage with use of urea+FYM (I_2N_2) registered the maximum biomass and the greatest partitioning of biomass towards pod formation.

Grain yield and input use efficiency

With increase in irrigation levels, there was decline in grain yield but increase in straw yield (Table 1). The grain yield under I_1 was at par with I_2, but significantly higher than that under I_3 and I_4. This could be attributed to a well-received rainfall during the study year (Fig. 1) resulting in above-wilting-point soil moisture during the entire period (Fig. 2). There was saving of irrigation water and increase in yield by growing soybean under rainfed. Use of urea+FYM (N_2) registered higher grain yield over sole use of urea (N_1) or FYM (N_3). Thus, integrated use of urea and FYM could save 50% of urea application. The water use efficiency and PFP of N decreased with an increase in the irrigation level (Table 1). Urea+FYM resulted in higher water use efficiency and PFP of N over sole use of urea or FYM. Higher grain yield in urea+FYM was attributed to better root growth, greater biomass portioning towards pods and efficient utilization of water and N than sole use of urea or FYM (Table 1). This finding is in agreement with Bandyopadhyay *et al*. (2003), Hati *et al*. (2006), Bhattacharyya *et al*. (2008) and Bandyopadhyay *et al*. (2010). Grain yield *vs* seasonal ET followed quadratic relationships (Eq. 1 to 3). The seasonal ET could account for 97, 78 and 89% variations in grain yields with urea, urea+FYM and FYM treatments, respectively.

$$y = -0.255ET^2 + 187ET - 32728, \quad R^2 = 0.97 \text{ (only urea)} \qquad \ldots(1)$$

Table 1. Grain and straw yields, water and nitrogen use efficiencies and grain quality of soybean as influenced by irrigation and N supply

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Water use efficiency (kg grain ha^{-1} mm^{-1})	Partial factor productivity of N (kg grain kg^{-1} N applied)	Grain protein (%)	Grain oil (%)
			Irrigation levels			
I_1	1824a	11168b	5.03a	15.3a	41.8a	20.5a
I_2	1733a	10371b	4.97a	14.5ab	41.4a	20.5a
I_3	1424b	11020b	3.95ab	11.9bc	41.8a	19.9a
I_4	1337b	13441a	3.86b	11.1c	42.3a	19.7a
			Nitrogen sources			
Urea	1488b	11262b	4.23b	12.4b	41.8a	20.2a
Urea + FYM	1721a	12274a	4.81a	14.4a	41.7a	20.2a
FYM	1530b	10964b	4.32b	12.8ab	41.9a	20.2a

*Values in a column followed by same letter are not significantly different at P<0.05 as per DMRT

$y = 1.967ET^2 - 1411ET + 25454,$
$R^2 = 0.78$ (urea+FYM) …(2)

$y = -3.137ET^2 + 2223ET - 39195,$
$R^2 = 0.89$ (only FYM) (3)

There was no significant difference in soybean grain quality with respect to grain protein and oil content due to irrigation levels or N sources (Table 1).

Conclusions

It may be concluded that there was improvement in root growth, total biomass production and its partitioning towards pod, grain yield, water use efficiency and partial factor productivity of N when soybean was grown with integrated use of urea and FYM under rainfed condition or with irrigation at pod formation stage. Hence under well distributed rainfall situation, soybean without irrigation or irrigation only at pod formation stage, and with integrated use of urea and FYM can give higher yield and water and nitrogen use efficiencies in sandy loam soils of Delhi region.

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