



Yield gap analysis of recommended soybean (*Glycine max*) production technologies and their impact on energy and carbon budgeting

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) season of 2017–18 at Research farm of ICAR-IISR, Indore, Madhya Pradesh, to study the effect of different agronomic practices on productivity, energy indices and carbon balance of soybean [*Glycine max* (L.) Merr.]. The additional use of micronutrients (Zn, B and Mo) and secondary nutrients along with full package of practices showed positive yield effect by 6.08% and 3.20% as compared to whole package. The narrow row planting (30 cm) and 50% RDF + 2% urea spray along with full package of practices had very little negative effect on the yield. On pooled average basis, the deletion of any recommended practice from the full package of practices reduced the yield by 1.14–71.69%. The highest yield reduction was associated with the 50% reduction of seed rate in full package of practices. Energy output followed the similar trend as observed in seed yield. Highest energy use efficiency was recorded with 50% RDF + 2% urea spray. The maximum specific energy and energy profitability was registered under full package of practices + 50% (30 kg/ha) seed rate treatment. Highest carbon use efficiency was registered with full package of practices without RDF. Thus, when comparing the carbon intensity (biomass and seed), the maximum carbon intensity was associated with full package of practices + 50% seed rate.

Keywords: Carbon use efficiency, Energy use efficiency, Soybean, Yield

Soybean [*Glycine max* (L.) Merr.] is a rainfed leguminous crop. The productivity is between 1 to 1.2 t/ha in the country which is just 50% as compared to countries like USA, Brazil and Argentina (Billore 2017). Crop production is both producer and consumer of energy. In addition to the choice of crop, decisions about management practices can have a large impact on energy use and GHG emissions. Two of the most pressing sustainability issues are the depletion of fossil energy resources and the emission of atmospheric greenhouse gases (GHGs) like carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) into the atmosphere. The agricultural sector is already a large contributor to global energy use and greenhouse gas (GHG) emissions, and the environmental impact of agriculture is likely to increase as our population grows, and demands more protein and calories. Agriculture emits CO₂ by using fossil energy and through oxidation of soil organic matter (Bose *et al.* 2014). Cultivation of soybean consumes water, uses synthetic fertilizers and pesticides, and also results in emissions of greenhouse gases (Rana *et al.* 2014). Decreasing the amount of energy needed for

crop production would be one of the most effective ways to decrease the carbon footprint. Unfortunately, information on energy and GHG emissions from agricultural crops is scattered throughout the literature, and estimates for the same crop species can be quite variable. One major factor causing variability in the results is the different energy and GHG emission parameters used in the studies (Gelfand *et al.* 2010). The objective of the present study was to evaluate the carbon footprint and energy use pattern of soybean production.

MATERIALS AND METHODS

Site description and soil characteristics: A field experiment was conducted during rainy (*kharif*) season of two consecutive years (2017–18) at Research farm of ICAR-Indian Institute of Soybean Research, Indore, Madhya Pradesh, which lies at Malwa Plateau (22° 43' 37" N latitude, 75° 52' 7" E longitude and 540 m amsl). The climate of the Malwa Plateau of Madhya Pradesh is semi-arid with an average annual rainfall of 800 mm of which 80% is received through south-west monsoons during July–September. Soil is deep black cotton (0–30 cm layer) with a pH 7.5 (1:2.5 soil: water ratio), Walkley–Black C (oxidizable-SOC) 0.53%, alkaline KMnO₄-oxidizable–N 298 kg/ha, 0.5 M NaHCO₃-extractable P 14.9 kg/ha and 1 N NH₄OAc-extractable K 340 kg/ha. The plot size was 6 m × 3.6 m.

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Experimental set up: The experiment comprised 13 treatments, viz. full package of practices + Zn, B, Mo (full package of practices included land preparation with one ploughing, two cultivators followed by planking was carried out for seedbed preparation; nutrient management was supplied through inorganic fertilizers as per recommended doses (RDF) amounting 24 kg N + 64 kg P₂O₅ + 32 kg K₂O were applied as basal through IFFCO NPK complex fertilizer 12:32:16. Soybean seed was treated with thiram + carbendazim (2:1) @3 g/kg of seed. Weeds controlled with diclosulam 84 WDG @22 g a.i./ha. Insects were controlled with chlorantraniliprole @100 ml/ha for soybean) + Zn (25 kg/ha through zinc sulphate), B (1 kg/ha through borax), Mo (1 kg/ha through ammonium molybdate) [T₁], full package of practices + 25 kg Sulphur/ha through bentonite sulphur [T₂], full package of practices [T₃], 50% RDF as basal + 2% urea spray at pod initiation stage [T₄], full package of practices + narrow row spacing (30 cm) [T₅], full package of practices + 50% seed rate (30 kg/ha) [T₆], omission of RDF [T₇], omission of seed treatment [T₈], omission of biofertilizer [T₉], omission of herbicide [T₁₀], omission of insecticide [T₁₁], intercultural operation (dora)/no herbicide use [T₁₂], control (land preparation and seed and sowing) [T₁₃] and were laid out in RBD with three replications. The soybean cv. JS 20-34, was sown with a seed rate of 65 kg/ha during second fortnight of June in 2017 and 2018 with a row spacing of 45 cm. The sowing of soybean was done by

seed drill. At maturity, the soybean was harvested manually. The harvested produce was left in the field for 3 days for sun-drying. The threshing of the soybean, harvested from 21.6 m² area was done manually using ALMACO Pullman Thresher and the grains were cleaned and weighed. The yield per plot was adjusted at 9–10% moisture for soybean and expressed as t/ha.

Measurements and calculations: The inputs and outputs of soybean was converted in terms of energy input and output using energy equivalents and used for calculation of different energy parameters as suggested by Singh and Mittal (1992). The energy input/consumption under different inputs and nutrient supply options of crop was computed mean over years. The inputs used and field operations adopted in raising the crops were converted into carbon input equivalent per hectare (C/ha) using the carbon emission equivalents (West and Marland 2002). The carbon input and output so obtained were used to calculate carbon efficiency and carbon footprint.

Statistical analyses: All data recorded were analyzed using analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for split-plot design using SAS 9.3 software (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Yield: Results indicated that individual component of the recommended package of practices significantly

Table 1 Effect of recommended soybean production technologies on yield and energy indices in soybean production

Treatment	Seed yield (t/ha)	Straw yield (t/ha)	Energy input (×10 ³ MJ/ha)	Energy output (×10 ³ MJ/ha)	Net energy output (×10 ³ MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)	Specific energy (MJ/kg)	Energy intensiveness	Seed to straw energy ratio	Energy profitability (MJ/₹)
FPP + Zn, B, Mo	2.91	3.51	11.4	116.5	105.1	10.25	0.256	3.91	0.403	1.66	9.25
FPP + 25 kg sulphur/ha	2.83	3.44	11.4	113.7	102.3	10.01	0.249	4.02	0.422	1.64	9.01
FPP	2.74	3.53	11.3	112.6	101.3	9.94	0.242	4.14	0.444	1.55	8.94
50% RDF as basal + 2% urea spray at pod initiation stage	2.71	3.37	10.3	109.8	99.5	10.68	0.263	3.80	0.432	1.61	9.68
FPP + narrow row spacing (30 cm)	2.67	3.67	11.3	112.8	101.4	9.95	0.236	4.24	0.444	1.45	8.95
FPP + 50% seed rate (30 kg/ha)	1.60	2.84	9.7	75.3	65.6	7.76	0.164	6.08	0.409	1.13	6.76
Omission of RDF	2.36	3.31	10.2	100.4	90.2	9.84	0.231	4.32	0.514	1.43	8.84
Omission of seed treatment	2.45	3.30	11.3	102.5	91.2	9.05	0.217	4.62	0.445	1.49	8.05
Omission of biofertilizer	2.46	3.33	11.3	103.1	91.7	9.10	0.217	4.61	0.444	1.48	8.10
Omission of herbicide	2.22	3.20	11.3	95.4	84.2	8.48	0.197	5.08	0.474	1.38	7.48
Omission of insecticide	2.27	3.07	11.2	95.3	84.0	8.47	0.202	4.94	0.486	1.48	7.47
Intercultural operation (dora)/no herbicide use	2.22	3.06	11.5	93.7	82.3	8.16	0.193	5.17	0.466	1.46	7.16
Control (land preparation and seed and sowing)	1.80	2.97	8.7	82.1	73.3	9.38	0.206	4.87	0.563	1.21	8.38
SEm±	0.159	0.098	0.35	5.14	4.91	0.36	0.01	0.26	0.02	0.06	0.36
CD (P=0.05)	0.464	0.259	1.010	14.97	14.33	1.06	0.04	0.75	0.05	0.18	1.06

*FPP, Full package of practices. Pooled data of two years.

influenced crop productivity (Table 1). The maximum yield was recorded with full package of practices + micronutrients (Zn, B, Mo) and it was statistically non-significant with full package of practices + secondary nutrient (S), full package of practices, full package of practices with 50 % RDF + 2% urea spray and full package of practices + narrow planting. The reason could be that addition of micronutrients to soil might have enhanced the availability of the nutrients and enzymatic activities. Adequate doses and sources of micronutrient increase soybean yield (Lacerda *et al.* 2017). Highest straw yield was recorded with full package of practices + narrow planting and was non-significant with T₃, T₁ and T₂. The lowest seed and straw yield were observed with full package of practices + 50% seed rate. The addition of micro and secondary nutrients to full package of practices increased by 3.20–6.08% as compared to full package of practices. The omission of any recommended practice from full package of practices reduced the seed yield to the extent of 1.14–71.69% when compared to full package of practices. The deletion of 50% recommended dose of fertilizers + 2% urea spray at pod initiation stage and narrow planting showed very little adverse effect on yield (1.14–2.48%). The omission of seed treatment (T₈) and bio-fertilizers (T₉) from full package of practices reduced the seed yield by 11.74% and 11.50%, respectively, while deletion of RDF (T₇) declined the yield by 15.98%. Nutrition imbalance is one of the important constraints for low soybean productivity in India. Proper nutrient management is one of the ways to enhance the soybean productivity, nutrient availability and environmental stewardship (Raghuvver and Keeerti 2017). Furthermore, balanced nutrition with mineral fertilizers assisted in integrated pest management to reduce damage from infestations of pests and diseases and saved inputs required to control them (Hellal and Abdelhamid 2013). The deletion of insecticide from whole package had a negative effect on yield by 20.48%. The omission of herbicide or weed management carried out manually reduced the yield by 23%. The substantial yield reduction was associated with full package of practices + 50% seed rate followed by control (52.35%). Inappropriately used soybean production technologies were prominent threats to soybean production and could have been factors in the lower yields. These finding are also in consonance with Balboa *et al.* (2019).

Energy: The addition of hand weeding instead of herbicide, secondary and micronutrients with full package of practices increased the energy consumption by 1.39%, 0.22% and 0.30% as compared to full package of practices, respectively (Table 1). However, the removal or absence of any practice from the full package of practices reduced the energy consumption by 22.81% (control-land preparation and sowing), 14.33% (50% seed rate), 9.94% (without RDF), 9.28% (50% RDF +2% urea spray), 0.82 % (without insecticide), 0.68% (without herbicide application), 0.11% (without biofertilizer), and 0.08% (without seed treatment). The energy required to grow a crop can be calculated by accounting for the energy associated with the inputs

required for production. Some of these differences are also a result of different management practices. The details of the management and inputs to these scenarios were reported by Ryan (2010). Gross energy output follows the same pattern as was observed in the soybean yields indicating that the maximum yield resulted in highest gross energy output. The additional inputs like secondary micronutrients and narrow row spacing resulted in higher net energy gain as compared to the full package of practices. However, the deletion of any management practice from the full package of practices brought out a setback to net energy gain and minimum being with full package of practices with 50% seed rate which was lower than the control. Treatment differences between full package of practices and full package of practices + S 25 kg/ha, full package of practices without seed treatment and without seed inoculation behaved identically at statistical significance level. Full package of practices without herbicide, insecticide, with hand weeding and control showed non-significant differences among themselves with reference to net energy gain. The substantially higher energy use efficiency was recorded with 50% RDF + urea spray @2% followed by addition of secondary and micronutrients to full package of practices indicating higher energy use efficiency (>10). The lowest energy use efficiency was associated with full package of practices + 50% seed rate. The lower value of energy ratio may be explained by comparatively lower yield of soybean and lower energy use management. Energy ratio (energy use efficiency) can be increased either by decreasing total energy input or by increasing the total energy output or through application of both specified actions at the same time (Prajapati *et al.* 2018). Energy productivity behaved in similar fashion as was observed in energy use efficiency. Energy productivity varied from 0.193–0.263 kg/MJ. The maximum specific energy and energy profitability was recorded with full package of practices + 50% seed rate closely followed by full package of practices + hand weeding and whole package without herbicide.

Carbon budgeting: GHG emission in terms of kg CO₂ was determined in all the treatments (Table 2). The addition or deletion of any practice/input increases or decreases the carbon input which depends on the nature of the input. However, the addition of micro and secondary nutrients to full package of practices marginally increased carbon input, while the deletion of any practice from full package of practices significantly reduced the carbon input. The maximum carbon input was associated with full package of practices + micronutrients closely followed by full package of practices + secondary nutrient and full package of practices. The highest carbon output was with full package of practices + micronutrients and remained at par with full package of practices + secondary nutrient and full package of practices, narrow spacing and 50% RDF +2% urea spray and remaining treatments showed lower carbon output. The highest net gain of carbon was with full package of practices + micronutrients and closely followed by 50% RDF +2% urea spray, narrow spacing,

Table 2 Effect of recommended soybean production technologies on carbon budgeting in soybean production

Treatment	CO ₂ e input (kg/ha)	CO ₂ e output (kg/ha)	Net CO ₂ e output (kg/ha)	CO ₂ e use efficiency	CO ₂ e intensity (kgCO ₂ e/g biomass)	CO ₂ e intensity seed (kgCO ₂ e/g seed)	GHG Intensity kgCO ₂ e/ MJ
*FPP + Zn, B, Mo	575	3207	2633	5.58	90	198	0.0049
FPP + 25 kg sulphur/ha	558	3134	2575	5.61	89	197	0.0049
FPP	557	3134	2577	5.63	89	203	0.0049
50% RDF as basal + 2% urea spray at pod initiation stage	421	3037	2617	7.22	69	155	0.0038
FPP + narrow row spacing (30 cm)	557	3174	2617	5.70	88	208	0.0049
FPP + 50% seed rate (30 kg/ha)	542	2216	1674	4.09	122	339	0.0072
Omission of RDF	277	2834	2557	10.23	49	117	0.0028
Omission of seed treatment	553	2875	2323	5.20	96	225	0.0054
Omission of biofertilizer	549	2893	2344	5.27	95	223	0.0053
Omission of herbicide	555	2709	2154	4.88	102	250	0.0058
Omission of insecticide	552	2672	2119	4.84	103	243	0.0058
Intercultural operation (dora)/no herbicide use	598	2639	2040	4.41	113	269	0.0064
Control (land preparation and seed and sowing)	258	2383	2124	9.22	54	144	0.0032
SEm±	45.92	126.20	121.36	0.75	0.01	0.02	-
CD (P=0.05)	134.04	368.38	354.26	2.18	0.02	0.07	-

*FPP, Full package of practices. Pooled data of two years.

full package of practices + S, full package of practices and no RDF. The least carbon net gain was recorded with full package of practices + 50% seed rate. Significantly highest carbon use efficiency was noted with full package of practices without RDF followed by control and 50% RDF + 2% urea spray. This might be due to the lower carbon input used in these treatments. The carbon intensity varied from 49–122 and 117–339 kg CO₂ e/g biomass and seed, respectively. When comparing the carbon intensity (biomass and seed), the maximum carbon intensity was associated with full package of practices + 50% seed rate followed by full package of practices + hand weeding (with no use of herbicide), full package of practices without insecticide and herbicide. The lowest carbon intensity was recorded with full package of practices without fertilizers. Emissions related to the fertilizer subsystem are the most important contributors to greenhouse gas emissions (Tongwane *et al.* 2016). Pesticides, have relatively lesser contribution to the carbon footprint. Application of appropriate agricultural operations is a strategy to reduce energy consumption and greenhouse gas emissions (Alimagham *et al.* 2014). The effect of energy optimization in reduction of GHG emission was found to be 363.74 kg CO₂ eq/ha (Pelesaraei *et al.* 2014).

To sum up, addition of secondary nutrients and micronutrients to the full package of practices showed positive yield advantage over full package of practices alone while the deletion of any recommended practice from the full package of practices had negative impact on yield.

The substantially higher energy use efficiency (>10) was recorded with 50% RDF + urea spray @2% at pod initiations followed by addition of secondary and micronutrients to full package of practices.

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