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System productivity, energetics and economics of soybean (*Glycine max*)-wheat (*Triticum aestivum*) cropping system as influenced by weed management practices

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ABSTRACT

A field experiment was conducted during 2015–16 and 2016–17 to assess the system productivity, energetics and economics of weed management practices in soybean (*Glycine max* L.)-wheat (*Triticum aestivum* L.) cropping system at ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh. The experiment comprised 10 treatments having combinations of sole and sequential application of pre-emergence and post-emergence herbicides in both the crops, and their integration with hand weeding undertaken in randomized block design replicated thrice. The highest system productivity (8.04 t/ha) was obtained by employing two hand weedings, sequential application of pendimethalin followed by (fb) imazethapyr in soybean and pendimethalin fb mesosulfuron + iodosulfuron in wheat as well as by integrating either pre or post-emergence herbicides with one hand weeding. Among weed management practices, energy requirement was lowest in sole post-emergence herbicide treatment, however, integration of manual weeding required maximum energy. The energy input for hand weeding was a major share of integrated weed management practices, and it varied from 54–83% of the total treatment energy. Due to requirement of less energy for sole post-emergence herbicides, energy output, net energy return and energy ratio were the maximum. Total output energy was higher (258×10^3 MJ/ha) in post-emergence herbicide fb hand weeding treatment because of higher system productivity (7.29 t/ha), and this treatment was more energy efficient and gave the highest economic returns among the weed management practices. The highest benefit: cost ratio (3.10) was obtained by the application of post-emergence herbicides in both the crops.

Keywords: Economics, Energy efficiency, Soybean, System productivity, Weed management, Wheat

Soybean-wheat (S-W) (*Glycine max* L.–*Triticum aestivum* L.) is one of the major cropping systems on the Vertisols of central India occupying an area of 4.5 mha (Potkile *et al.* 2018). Weed menace is one of the major constraints in the cultivation of all the crops including soybean and wheat. Reduction in the yield of soybean and wheat to the tune of 26–71% and 37–50%, respectively, has been recorded depending upon the type and intensity of weeds (Kewat *et al*. 2000, Waheed *et al.* 2009, Chander *et al.* 2014). The system productivity of the S-W cropping system is also diminished by ~10%, if proper weed management is not followed (Kumar and Das 2008). Improper agronomic practices in S-W cropping system may reduce the productivity of the system in a significant manner (Behera *et al*. 2007).

Crop yields can be enhanced by increasing energy inputs or optimizing energy consumption in agricultural systems. Energy is one of the important elements in modern agriculture because the agricultural sector requires energy as an essential input to production (Kuemmel *et al*. 1998). The productivity and profitability of agriculture depends upon energy consumption also because there is a close relationship between agriculture and energy. Effective energy use in agriculture is one of the emerging threats for sustainable agricultural production, since it helps to save financial resources, conserve fossil fuels and reduce air pollution (Chaudhary *et al*. 2006). The amount of energy used depends on the mechanization level, quantity of active agricultural work and cultivable land (Ozkan *et al*. 2004, Alam *et al*. 2005).

Energy analysis can provide synthesized information useful to farmers and decisionmakers (Kalra and Arya 1980, Pervanchon *et al*. 2002). Energy calculation of weed management is very important because energy and economics are mutually dependent (Pimentel *et al*. 1994). Therefore, the present experiment was conducted to assess the system productivity, energy budgeting and economics of weed management practices in S-W cropping system.

MATERIALS AND METHODS

A field experiment was conducted during 2015–16 and

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2016–17 at the Research Farm, ICAR-Directorate of Weed Research, Jabalpur. The field selected for experimentation had uniform topography and was fairly infested with location specific weeds representing this area. The climate of Jabalpur region is typically sub humid, featured by hot dry summer and cool dry winter. The ten weed management treatments (Table 1) were laid out in randomized block design with three replications. Soybean 'JS 97-52' and wheat 'GW-273' were grown with row spacing of 45 cm and 22.5 cm and plant to plant spacing of nearly 5 cm and 3 cm, respectively, during both the years. Soybean was sown on 28 June and 29 June and harvested on 2 October and 5 October, respectively during 2015 and 2016. Wheat was sown on 4 November and 3 November and harvested on 21 March and 27 March during 2015–16 and 2016–17, respectively. The recommended dose of fertilizers for soybean and wheat was 20-60-40 and 120-60-40 kg N, P_2O_5 and K_2O/ha, respectively. The whole quantity of N, P_2O_5 and K_2O was applied through urea, di-ammonium phosphate and muriate of potash at the time of sowing of soybean while in case of wheat, half dose of N and full dose of P_2O_5 and K_2O was applied as a basal dose through urea, di-ammonium phosphate and muriate of potash while half dose of N was split into two parts and was applied as a top dressing at tillering and booting stage through urea. The field was irrigated immediately after sowing in case of wheat, while there was no need of irrigation in case of soybean. The pre-emergence (PRE) and post-emergence (POST) herbicides were applied with a knapsack sprayer with flat fan nozzles that delivered ~500 L/ha spray solution. In two hand weeded plots, weeds were removed manually at 20 and 40 days after sowing (DAS). In the weedy control, no weeding was done.

System productivity: Wheat equivalent yield (WEY) is an indicator of system productivity. The system productivity/WEY was calculated as per given formula.

$$\text{System productivity (WEY): } \frac{(Y_{soybean} \times P_{soybean})}{P_{wheat}} \times Y_{wheat}$$

where $Y_{soybean}$, the yield of soybean crop (kg/ha); $P_{soybean}$, the price of soybean crop (₹30.5/kg) Y_{wheat}; yield of wheat (t/ha) and P_{wheat}, the price of wheat (₹17.5/ kg).

Energy budgeting: The input energy was inclusive of both operational (direct) and non-operational (indirect) energy involved in S-W cropping system. Equivalents of different management practices and outputs were used for computation of energy balance (Mittal and Dhawan 1988, Kitani 1999, West and Marland 2002, Dagistan *et al*. 2009). The output energy from the produce (seed and grain for soybean and wheat, respectively) was calculated by multiplying the amount of production and its corresponding energy equivalent. The different energy-use indices were calculated as per the following formulae as suggested by Kalra and Arya (1980), Bockstaller *et al*. (1997).

Economics: Total input cost of cultivation of S-W cropping system was computed by adding the different input costs from crop cultivation.

Statistical analysis: The data were subjected to statistical analysis of variance (ANOVA) applicable to randomized block design. The means of the treatments were tested using the least significant differences at 5% probability.

RESULTS AND DISCUSSION

The S-W system yield was the maximum with two hand weedings (THW) treatment. Integration of weed management practices by including hand weeding (HW) following the PRE or POST herbicides or sequential application of PRE fb POST herbicides performed better in enhancing system productivity (Table 2). The integration

Table 1 Weed control treatments in soybean-wheat cropping system

Treatment	Rainy *(kharif)* season (Soybean)	Winter *(rabi)* season (Wheat)
Pendi-pendi	Pendimethalin 750 g/ha PRE	Pendimethalin 750 g/ha PRE
Pendi fb imaze-pendi fb meso+iodo	Pendimethalin 750 g/ha PRE fb imazethapyr 100 g/ha at 20 DAS	Pendimethalin 750 g/ha PRE fb mesosulfuron + iodosulfuron 12 + 2.4 g/ha at 30 DAS
Pendi fb HW-pendi fb HW	Pendimethalin 750 g/ha PRE fb 1 HW at 20 DAS	Pendimethalin 750 g/ha PRE fb 1 HW at 20 DAS
Metri-pendi	Metribuzin 500 g/ha PRE	Pendimethalin 750 g/ha PRE
Metri fb imaze-pendi fb meso+iodo	Metribuzin 500 g/ha PRE fb imazethapyr 100 g/ha at 20 DAS	Pendimethalin 750 g/ha PRE fb mesosulfuron + iodosulfuron 12 + 2.4 g/ha at 30 DAS
Metri fb HW-pendi fb HW	Metribuzin 500 g/ha PRE fb 1 HW at 20 DAS	Pendimethalin 750 g/ha PRE fb 1 HW at 20 DAS
Imaze-meso+iodo	Imazethapyr 100 g/ha at 20 DAS	Mesosulfuron+iodosulfuron (12 + 2.4 g/ha) at 30 DAS
Imaze fb HW- meso+iodo fb HW	Imazethapyr 100 g/ha at 20 DAS fb 1 HW at 40 DAS	Mesosulfuron+iodosulfuron 12 + 2.4 g/ha at 30 DAS fb 1 HW at 40 DAS
THW-THW	2 HW at 20 and 40 DAS	2 HW at 20 and 40 DAS
C-C	Unweeded control	Unweeded control

PRE, Pre-emergence; fb, Followed by; HW, Hand weeding; THW, Two hand weedings; DAS, Days after sowing.

Table 2 Input-output energy, NER, ER, system yield and economics in different weed management treatments in soybean-wheat

Treatment	Total input energy (MJ/ha)	Total output energy ($\times10^3$ MJ/ha)	NER ($\times10^3$ MJ/ha)	Energy ratio	System yield (t/ha)	Net returns (₹/ha)	Benefit : Cost
Pendi-pendi	32466	163f	131f	5.03f	4.08e	39713	1.98
Pendi fb imaze-pendi fb meso+iodo	32601	246bcd	213bcd	7.56bcd	6.71bc	87468	2.95
Pendi fb HW-pendi fb HW	33094	255abc	223abc	7.86abc	7.00bc	89176	2.83
Metri-pendi	32394	182e	150e	5.61e	4.77d	54089	2.35
Metri fb imaze-pendi fb meso+iodo	32529	241bcd	209bcd	7.43bcd	6.74bc	88464	2.99
Metri fb HW-pendi fb HW	33022	240cd	208cd	7.40cd	6.97bc	88963	2.84
Imaze-meso+iodo	32067	230d	198d	7.10d	6.44c	85546	3.10
Imaze fb HW- meso+iodo fb HW	32695	258ab	225ab	7.94ab	7.29b	94300	2.93
THW-THW	33313	268a	236a	8.26a	8.04a	103766	2.90
C-C	31932	131g	98g	4.03g	3.15f	25194	1.69

Values refer to the mean followed by the same letter in a column were not significantly different at $P<0.05$. Two years' pooled data.

of HW performed a major role in controlling those weeds which were not usually controlled with the application of sole herbicide application. The result is in close proximity with the findings of Singh (2007), Patel *et al*. (2016) who also found application of PRE herbicide fb hand weeding restricted the weed growth and enhanced the yield of soybean.

Total common input energy required for the S-W cropping system was 31932 MJ/ha (Table 2). Among the various herbicides, sole PRE herbicides required lower amount of energy than that of PRE fb POST herbicide. However, low dose high potency POST herbicides required a smaller amount of energy in comparison to high dose PRE herbicides in S-W cropping system. Among pendimethalin and metribuzin as PRE herbicide, metribuzin required 17% lesser amount of energy than that of pendimethalin. In S-W system, adoption of manual weeding or hand weeding as integrated weed management (IWM) approach required higher input energy than the sole PRE and PRE fb POST herbicides. Practice of manual weeding twice in each crop involved maximum energy input due to high use of manpower for uprooting of weeds. Among the various weed management approaches, energy requirement was lowest (135 MJ/ha) in sole POST (imazethapyr in soybean and mesosulfuron + iodosulfuron in wheat) herbicide applied treatment, because of its lower application rate.

The highest energy output, net energy return (NER) and energy ratio (ER) was noticed with THW treatment due to higher system productivity (Table 2). Among various herbicidal and integrated weed management approaches, higher energy output, net energy return and energy ratio was produced by low dose high potency POST herbicide (imazethapyr in soybean and mesosulfuron + iodosulfuron in wheat) fb integration of HW (imaze fb HW- meso+iodo fb HW) and pendimethalin as PRE in both the season fb integration of HW treatment. In unweeded control, the total energy output was lower because of meager crop growth and meager productivity. The energy ratio of soybean-wheat system was higher under integrated weed management system. The energy input for hand weeding constituted a major share for integrated weed management practices, and it varied from 54–83% of the total treatment energy. However, the total output energy was also higher in integrated weed management practices due to better management of weeds and provided ideal situation for crop growth and productivity. IWM practices were more energy efficient than that of other sole chemical and mechanical approach. The sole application of PRE herbicides in both the seasons had higher specific energy and energy intensiveness because of higher dose of herbicides. On the other hand, sole application of low dose POST herbicide in both the seasons had comparatively lower specific energy. Integration of manual weeding with low dose POST herbicide was significantly lesser energy intensive weed management practice in soybean-wheat system than the other IWM and sole weed management practices because it produced higher yield and consumed lesser energy. In context to human energy profitability, it was observed that application of PRE fb POST herbicide and sole POST herbicide in both the season had higher human energy profitability due to non-involvement of human labour for manual weeding. Whereas, THW and integration of manual labour with herbicide had lower human energy profitability because of involvement of higher input energy than that of sole chemical weed management method.

The production cost of S-W cropping system was the maximum with THW-THW treatment followed by IWM practices i.e. PRE herbicide fb HW and POST herbicide fb HW. Higher net returns (₹103766/- and ₹97300/-) was calculated in TWH-TWH and imaze fb HW- meso+iodo fb HW, respectively. Whereas, the maximum benefit-cost ratio was calculated in sole POST herbicide (imaze-meso+iodo) followed by PRE fb POST herbicide (metri fb imaze-pendi fb meso+iodo and pendi fb imaze-pendi fb meso+iodo) treated plots in soybean-wheat cropping system (Table 2).

It was concluded that, other than sole manual weeding, integration of one hand weeding with PRE and POST herbicides gave higher system productivity. Because of higher productivity, the total output energy was also higher in POST herbicide fb HW treatment. Whereas, the highest benefit-cost ratio was obtained by the application of POST herbicides in both the crops.

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