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# Energy utilization in maize-wheat cropping system in north west plain zone of India with the impact of paddy residue and weed management

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## ABSTRACT

*A field experiment was conducted at CCS Haryana Agricultural University, Regional Research Station, Karnal, India during the year 2020-21 and 2021-22 to optimize the use of energy in maize-wheat cropping systems. Incressing energy demand in conventional agriculture has been contributing to the depletion of non-renewable energy sources while also encouraging the use of chemical fertilizers and pesticides that pollute the environment. Thus the following experiment has been planed to explore the energy outcome in different planting methods and weed management in maize wheat-cropping system. The experiment was laid out in a strip plot design with three replications. Factor A comprised of ten planting methods (zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) fb ZTW, zero-tillage sowing with press wheel (without residues) fb ZTW, ridge sowing with dibbling method (with paddy residues @ 6 t/ha) fb CTW), ridge sowing with dibbling method (without residues) fb CTW, multi crop ridge planter (with paddy residues @ 6 t/ha) fb CTW, multi crop ridge planter (without residues) fb CTW, raised bed wide bed planter (with paddy residues @ 6 t/ha) fb ZTW (reshaping of beds), raised bed wide bed planter (without residues) fb ZTW (reshaping of beds), pneumatic maize planter (with paddy residues @ 6 t/ha) fb ZTW and pneumatic maize planter (without residues) fb ZTW) and factor B has four weed control treatments (unweeded check, weedy check, tembotrione 120 g/ha at 15 DAS and topramezone 25.2 g/ha at 15 DAS) in maize-wheat cropping system (MWCS). Raised bed wide bed planter (with paddy residues @ 6 t/ha) fb ZTW (reshaping of beds) gave maximum maize and wheat yield which was significantly higher than all the planting methods except zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) during both the year. The lower weed density and dry weight of grassy, broad leaf and sedges was recorded with tembotrione 120 g/ha at 15 DAS 120 which was at par with topramezone 25.2 g/ha at 15 DAS while maximum weed density was recorded in weedy check during both the years in maize crop and lowest weed density of weeds were observed in raised bed wide bed planter (with paddy residues @ 6 t/ha) fb ZTW (reshaping of beds). The maximum MEY (157.81, 159.17 kg/ha), net return (157128, 184941 ₹/ha), and cost-benefit ratio (1.73, 1.83) was obtained in raised bed wide bed planter (with paddy residues @ 6 t/ha) fb ZTW (reshaping of beds) but at par with zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) fb ZTW. The input energy productivity was significantly higher in zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) fb ZTW which was statistically at par with raised bed wide bed planter (with paddy residues @ 6 t/ha) fb ZTW (reshaping of beds).*

***Keywords:*** *Planting methods, weed control, maize, wheat, paddy residue, weed, RWCS, crop growth, grain yield, and energy*

## Introduction

The maize crop is widely adaptable and compatible with a variety of soil and climatic conditions. As a result, it is regarded as one of the potential drivers of crop diversity in various contexts. With an area of over 1.8 million ha, the maize-wheat cropping system is one of the most important cropping systems in India. It is mostly grown in the Indo-Gangetic Plains. Maize has the largest genetic yield potential among cereals; it is referred to as the "queen of cereals". It is grown on 205.9 million hectares of land worldwide, producing 1210.2 million tonnes of grain with an average yield of 58.8 q/ha. With a 9.9-million-hectare area, 31.7 million tonnes of production, and an average grain yield of 31.2 q/ha, it is the third most significant cereal crop in India after rice and wheat [7]. In Haryana, the *Kharif* season's maize acreage is approximately 9300 ha, with production of roughly 28000 tonnes and an average productivity of 30.1 q/ha. [3]

In the rice-wheat cropping system (RWCS), farmers of north-western India in states like Haryana and Punjab typically produce rice as a lowland crop from June to October followed by wheat as an upland crop from November to April. These exhausting cereal crops cause a significant loss of soil nutrients. Burning of rice crop residue exacerbates this issue, with an estimated 23 metric tonnes burned annually by about 2 million farmers in northwest and eastern India. It contributes significantly to premature (human) mortality through air pollution. The Central Pollution Control Board of India reported that in several cities in northwest India, particulate air pollution in 2017 surpassed acceptable daily threshold limits by more than five times, resulting in serious health issues in both rural and urban areas [2]. Farmers need innovative alternatives to manage agricultural wastes, especially rice straw which is a challenging and costly task.

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Crop rotation or diversification is must to way out of these serious problems. Maize needs less water than paddy crop. The study carried out by [19] reported that maize being a C4 plant, has a competitive edge over C3 plants. The C4 plants use three-fold less water, allowing them to grow in conditions of drought, high temperature, and carbon dioxide limitation. C4 plant such as maize can tolerate higher optimal temperatures for undertaking photosynthesis than C3 plants due to the operation of a $CO_2$ concentrating system that inhibits *Rubisco oxygenase* activity. Maize gives a higher yield per hectare even in a shorter period than any other food grain crop. Increased energy use in agriculture has been contributing to the depletion of non-renewable energy sources while also encouraging the use of chemical fertilizers and pesticides that pollute the environment [12]. Energy consumption, however, is a factor in any agricultural production's productivity and profitability. Soil tillage is one of the biggest energy and labor users in the growing of arable crops. Primary tillage procedures account for 75% of the total energy used before sowing [15]. Therefore, evaluations of the system's energy saving and environmental pollution control are included in the choice of an appropriate tillage method.

## Materials and Methods

### Experimental site and climatic conditions

An agronomy field experiment was conducted at Regional Research Station, Karnal, CCS Haryana Agricultural University, Hisar, India, at a latitude of 297 32' 05.80″ N longitude of 769 85' 35.20″ E and an altitude of 253 meters above mean sea level. The experiment was conducted during two successive years (2020-21 and 2021-22) with a maize-wheat cropping system. The soil texture was clay loam with low in available N, high in available $P_2O_5$ and medium in available K. The total rainfall was 824.6 mm during *Kharif* 2020, while it was 697.6 mm during *kharif* 2021. The rainfall was 81.8 mm in *rabi* 2020-21 and 157.6 mm in *rabi* 2021-22. In *kharif*, mean weekly minimum ($T_{min}$) and maximum temperatures ($T_{max}$) ranged from 31.5 to 35.4$^0$C and 22.6 to 26.8$^0$C, respectively during *kharif* 2020, while the respective figures for *kharif* 2021 were 24.4-27.4 $^0$C and 30.7-38.5 $^0$C. Weekly mean relative humidity (morning) varied from 90.0 to 98.0 % and 76 to 97.4 % in 2020 -21 and 2021-22, respectively, whereas respective figures for RH (E) were 50-87% and 48-88%. During the *rabi* seasons, $T_{max}$ and $T_{min}$ were 16.7-35.9$^0$C and 4.0-17.8$^0$C in 2020-21, respectively, and during 2021-22 these were 12.6-40.6$^0$C and 4.9-21.3$^0$C, respectively. Mean weekly meteorological data during the experiment recorded at the observatory located in Central Soil Salinity Research Institute (CSSRI), Karnal have been depicted in Fig.3.1 and 3.2.

### Experimental design and study material

The experiment was laid out in strip plot design with three replications, maize hybrid cultivar HQPM 1 was tested with ten planting methods ($M_1$: zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) *fb* ZTW, $M_2$: zero-tillage sowing with press wheel (without residues) *fb* ZTW, $M_3$: ridge sowing with dibbling method (with paddy residues @ 6 t/ha) *fb* CTW), $M_4$: ridge sowing with dibbling method (without residues) *fb* CTW, $M_5$: Multi crop ridge planter (with paddy residues @ 6 t/ha) *fb* CTW, $M_6$: Multi crop ridge planter (without residues) *fb* CTW, $M_7$: raised bed wide bed planter (with paddy residues @ 6 t/ha) *fb* ZTW (reshaping of beds), $M_8$: raised bed wide bed planter (without residues) *fb* ZTW (reshaping of beds), $M_9$: pneumatic maize planter (with paddy residues @ 6 t/ha) *fb* ZTW and $M_{10}$: pneumatic maize planter (without residues) *fb* ZTW) and weed control treatments ($W_1$: unweeded check, $W_2$: weedy check, $W_3$: tembotrione 120 g/ha at 15 DAS and $W_4$: topramezone 25.2 g/ha at 15 DAS) in maize-wheat cropping system (MWCS). The maize cultivar HQPM-1 and wheat HD - 2967 are used for sowing during both years. The maize sowing with spacing 60x20 cm and wheat with 20 cm line sowing with different planting methods *viz*. zero tillage, permanent bed, multi-crop planter, bed planter, and conventional sowing. The treatment with paddy residues @ 6 t/ha was applied at the emergence of maize seedlings.

### Data recording and statistical analysis

**Data recording and statistical analysis:** Data were recorded for maize grain yield (kg/ha), stover yield (kg/ha), number of plants/ha, number of cobs/ha, plant height (cm), test weight (g), cob length (cm), cob girth (cm), number of grain rows/cob, shelling (%), number of effective tillers, height of wheat plant, panicle length, wheat grain yield and maize equivalent yield, system productivity and net returns (Rs. /ha) B:C ratio. Phenological developments of the maize and wheat crop were recorded in terms of several days taken by the crop to reach a particular phenological stage. The data recorded were analyzed for mean, coefficient of variation and critical difference by using online software OPSTAT. Energy balance on soil tillage and crop rotations was determined by the methods explained by Hülsbergen *et al*. (2001). Energy equivalents of the inputs and outputs used in mung bean-wheat productions to evaluate the energy efficiency of agricultural production are given in Table 1. Input energy (MJ /ha) is divided into two main groups; direct and indirect energy.

### Direct energy (Ed)

It consists of fuel consumption and human labor and indirect energy (Ei) comprises the energy used for machinery, fertilizer, herbicide and seed. In agricultural production systems, human labor energy is usually not taken into consideration in energy balance calculations [4] [8]. But labor energy has been included in the calculations of the present study. It was calculated using the formula given below [1] [8] [18]

$$E_d=(HL\times E_{HL})+(FC\times E_{FC})$$

Where,

HL- Human labour and FC – Fuel

$E_{HL}$- Energy equivalent of Human Labour and $E_{FC}$ - Energy equivalent of fuel

### Indirect energy

In calculation of indirect energy ($E_i$), the following formula was used [8]

$$E_i= ((ME \times E_{ME})/(T \times E_{FC})) + (FE \times E_{FE}) + (HE \times E_{HE}) + (SE \times E_{SE})$$

In the formula, each addition component means the energies for machinery, fertilizer, herbicide and seed, respectively. The pertinent component values recommended for agricultural production [12] are as shown in Table 1.

### Total energy input

Energy input is obtained by the sum of direct energy and indirect energy. In calculating the input energy, the energy required for storage and transportation was not taken into consideration [8]. This input energy was calculated for each soil tillage for both the crops.

$$E_{Ti}= E_d+Ei$$

 

**Output energy (MJ /ha)**

Energy output for each crop (mung bean and wheat) was obtained by the following formula [1] [18]

$Eo = Eg + Es$

While calculating the energy output, both grain (Eg) and straw (Es) energy values were used.

**Input-output energy ratio**

The energy parameter input-output energy ratio in crop production was calculated [17]

$$\text{Energy input} - \text{output ratio (Energy use efficiency)} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy Input (MJ/ha)}}$$

**Specific energy (MJ /kg)**

Energy parameter specific energy used in crop production was calculated as under [17]

$$\text{Specific energy (MJ/kg/ha)} = \frac{\text{Energy input (MJ/ha)}}{\text{Wheat/maize grain yield (kg/ha)}}$$

*Table 1: Energy equivalents of the inputs and outputs in maize-wheat cropping system*

| Particulars | Unit | Energy equivalent | Reference |
|---|---|---|---|
| **A. Input** | | | |
| Human labour | H | 1.96 | Tabatabaeefar *et al.* (2009) |
| Diesel fuel | L | 56.31 | Singh (2002) |
| Farm- machinery | H | 62.70 | Singh (2002) |
| Tractor | kg | 68.4 | |
| Threshers | kg | 17.40 | |
| Nitrogen | kg | 78.23 | Ali *et al.* (2013) |
| Phosphate | kg | 13.07 | Tabatabaeefar *et al.* (2009) |
| Potash | kg | 6.70 | |
| ZnSO4 | kg | 20.9 | |
| Herbicide | L | 120.0 | Ali *et al.* (2013) |
| Electricity | Kw | 11.93 | Pathak and Binning (1985) |
| Seed (Wheat) | kg | 14.70 | Ali *et al.* (2013) |
| Seed (Mung bean) | kg | 14.70 | Ali *et al.* (2013) |
| **B. Output** | | | |
| Grain (Wheat) | kg | 14.70 | Ozkan *et al.* (2004) |
| Straw (Wheat) | kg | 12.50 | |
| Grain (Maize) | kg | 14.70 | Ali *et al.* (2013) |
| Stover (Maize) | kg | 12.50 | |

*Note: Distribute the weight of the machinery equally over the total life span of the machinery (hours) for the particular operation of the crop*

## Results

In the present study, the results obtained from the analysis of variance revealed significant differences among the different treatments for different characters.

**Yield performance (maize)**

**Grain yield**

Among planting methods maximum grain yield (9435, 9662 kg/ha) was obtained in $M_7$ which was significantly higher than all the planting methods but at par with $M_1$ (9026, 9257 kg/ha), respectively during both the years. Grain yield was significantly higher in $W_1$ (8126, 8364 kg/ha) as compared to $W_2$ (5787, 5914 kg/ha), but at par with $W_3$ (8064, 8307 kg/ha) and $W_4$ (8055, 8276 kg/ha) respectively during both the years (Table 2).

The interaction between planting methods and weed management was significant. The maximum grain yield was found with planting method M7 with combination $W_3$ (9463, 9613 kg/ha), $W_4$ (9282, 9403 kg/ha) and $W_2$(9208, 9389 kg/ha) followed by $M_1$ with combination W3 (9075, 9269 kg/ha), $W_4$ (9086, 9200 kg/ha) and $W_2$ (9007, 9095 kg/ha); and $M_8$ with combination $W_3$ (9007, 9145 kg/ha) and $W_4$ (8833, 9034 kg/ha) (Table 3).

**4.3.2 Stover yield**

Among planting methods maximum stover yield (13211, 13529 kg/ha) was obtained in $M_7$ which was significantly higher than all the planting methods but at par with $M_1$ (12706, 13031 kg/ha), respectively during both the years. Stover yield was significantly higher in $W_1$(11953, 12303 kg/ha) as compared to $W_2$ (8486, 8674 kg/ha), but at par with $W_3$ (11862, 12219 kg/ha) and $W_4$ (11850, 12175 kg/ha) respectively during both the years (Table 2).

**4.3.3 Biological yield**

Among planting methods maximum biological yield (22647, 23192 kg/ha) was obtained in $M_7$which was significantly higher than all the planting methods but at par with $M_1$ (21732, 22288 kg/ha), respectively during both the years. The biological yield was significantly higher in $W_1$ (20079, 20667 kg/ha) as compared to $W_2$ (14272, 14588 kg/ha), but at par with $W_3$ (19926, 20526 kg/ha) and $W_4$ (19906, 20451 kg/ha) respectively during both the years (Table 2).

**4.3.4 Harvest index**

Among planting methods maximum harvest index (41.67, 41.75) was obtained in $M_7$ which was significantly higher than all the planting methods but at par with $M_1$ (41.54, 41.50), respectively during both years. The Harvest index was significantly higher in $W_1$ (40.42, 40.40) as compared to $W_2$ (40.24, 40.30), but at par with $W_3$ (40.42, 40.40) and $W_4$ (40.40) respectively during both the years (Table 2).

*Table 2. Effect of various planting methods and weed management on grain yield, stover yield, biological yield and harvest index on maize*

| Treatment | | Grain yield (kg/ha) | | Stover yield (kg/ha) | | Biological yield (kg/ha) | | Harvest index | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| Planting methods | | | | | | | | | |
| $M_1$ | Zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) *fb* ZTW | 9026 | 9257 | 12706 | 13031 | 21732 | 22288 | 41.54 | 41.50 |
| $M_2$ | Zero-tillage sowing with press wheel (without residues) *fb* ZTW | 7277 | 7444 | 10584 | 10827 | 17861 | 18271 | 40.72 | 40.67 |
| $M_3$ | Ridge sowing with dibbling method (with paddy residues @ 6 t/ha) *fb* CTW) | 8040 | 8250 | 11940 | 12251 | 19981 | 20501 | 40.24 | 40.00 |
| $M_4$ | Ridge sowing with dibbling method (without residues) *fb* CTW | 6455 | 6675 | 9827 | 10162 | 16282 | 16837 | 39.61 | 39.83 |
| $M_5$ | Multi crop ridge planter (with paddy residues @ 6 t/ha) *fb* CTW | 7623 | 7896 | 11395 | 11803 | 19018 | 19699 | 40.08 | 40.00 |
| $M_6$ | Multi crop ridge planter (without residues) *fb* CTW | 5638 | 5869 | 8636 | 8990 | 14274 | 14859 | 39.45 | 39.50 |
| $M_7$ | Raised bed wide bed planter (with paddy residues @ 6 t/ha) *fb* ZTW (reshaping of beds) | 9435 | 9662 | 13211 | 13529 | 22647 | 23192 | 41.67 | 41.75 |
| $M_8$ | Raised bed wide bed planter (without residues) *fb* ZTW (reshaping of beds) | 7642 | 7891 | 11058 | 11417 | 18700 | 19308 | 40.84 | 40.92 |
| $M_9$ | Pneumatic maize planter (with paddy residues @ 6 t/ha) *fb* ZTW | 7835 | 7959 | 11658 | 11842 | 19493 | 19801 | 40.20 | 40.00 |
| $M_{10}$ | Pneumatic maize planter (without residues) *fb* ZTW | 6109 | 6248 | 9363 | 9576 | 15471 | 15824 | 39.41 | 39.58 |
| SEm ± | | 127 | 135 | 230 | 224 | 375 | 352 | 0.13 | 0.18 |
| CD (p=0.05) | | 433 | 420 | 735 | 716 | 1161 | 1127 | 0.39 | 0.57 |
| Weed Management | | | | | | | | | |
| $W_1$ | Unweeded check | 8126 | 8364 | 11953 | 12303 | 20079 | 20667 | 40.42 | 40.40 |
| $W_2$ | Weedy check | 5787 | 5914 | 8486 | 8674 | 14272 | 14588 | 40.24 | 40.30 |
| $W_3$ | Tembotrione 120 g/ha at 15 DAS | 8064 | 8307 | 11862 | 12219 | 19926 | 20526 | 40.42 | 40.40 |
| $W_4$ | Topramezone 25.2 g/ha at 15 DAS | 8055 | 8276 | 11850 | 12175 | 19906 | 20451 | 40.42 | 40.40 |
| SEm ± | | 165 | 174 | 244 | 249 | 408 | 420 | 0.32 | 0.51 |
| CD (p=0.05) | | 511 | 524 | 760 | 784 | 1270 | 1307 | N.S. | N.S. |

*Table 3: Interaction effect of planting methods and weed management on grain yield of maize*

| Treatment | | Grain yield (kg/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | | | | 2021 | | | |
| | | Weed management | | | | | | | |
| | | Unweeded check | Weedy check | Tembotrione 120 g/ha at 15 DAS | Topramezone 25.2 g/ha at 15 DAS | Unweeded check | Weedy check | Tembotrione 120 g/ha at 15 DAS | Topramezone 25.2 g/ha at 15 DAS |
| Planting methods | | | | | | | | | |
| $M_1$ | Zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) *fb* ZTW | 9137 | 9007 | 9075 | 9086 | 9324 | 9095 | 9269 | 9200 |
| $M_2$ | Zero-tillage sowing with press wheel (without residues) *fb* ZTW | 8147 | 6737 | 8108 | 8077 | 8497 | 6951 | 8415 | 8338 |
| $M_3$ | Ridge sowing with dibbling method (with paddy residues @ 6 t/ha) *fb* CTW) | 8295 | 8159 | 8248 | 8243 | 8346 | 8170 | 8313 | 8286 |
| $M_4$ | Ridge sowing with dibbling method (without residues) *fb* CTW | 7865 | 2818 | 7733 | 7677 | 7961 | 2435 | 7834 | 7761 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $M_5$ | Multi crop ridge planter (with paddy residues @ 6 t/ha) *fb* CTW | 7868 | 7635 | 7762 | 7724 | 7996 | 7718 | 7921 | 7832 |
| $M_6$ | Multi crop ridge planter (without residues) *fb* CTW | 7054 | 2455 | 6996 | 6939 | 7475 | 2125 | 7222 | 7168 |
| $M_7$ | Raised bed wide bed planter (with paddy residues @ 6 t/ha) *fb* ZTW (reshaping of beds) | 9501 | 9208 | 9463 | 9282 | 9769 | 9389 | 9613 | 9403 |
| $M_8$ | Raised bed wide bed planter (without residues) *fb* ZTW (reshaping of beds) | 9053 | 6203 | 9007 | 8933 | 9200 | 6672 | 9145 | 9034 |
| $M_9$ | Pneumatic maize planter (with paddy residues @ 6 t/ha) *fb* ZTW | 8181 | 7957 | 8158 | 8084 | 8541 | 8301 | 8538 | 8456 |
| $M_{10}$ | Pneumatic maize planter (without residues) *fb* ZTW | 7542 | 2316 | 7477 | 7302 | 7681 | 2219 | 7564 | 7516 |
| Factor (B) at same level of A | | | | | | | | | |
| SEm ± | | 332 | | | | 289 | | | |
| CD (p=0.05) | | 1032 | | | | 974 | | | |
| Factor (A) at same level of B | | | | | | | | | |
| SEm ± | | 355 | | | | 271 | | | |
| CD (p=0.05) | | 1108 | | | | 981 | | | |

## Yield performance (Wheat)

### Grain yield

The grain yield is the principle criterion for evaluating the efficiency of various treatments because the ultimate effects of experimental variables are reflected in the form of final grain yield. It is a function of effective tillers, number of grains/spike, and 1000-grain weight. The grain yield of wheat increased irrespective of different planting methods. The data on the grain yield of wheat revealed that among planting methods $M_7$ produced the maximum grain yield (6164, 6213 kg/ha) as compared to all planting methods but statistically at par with $M_8$ (5960, 6101 kg/ha) and $M_1$ (5742, 5967 kg/ha), respectively during both the years (Table 4).

Among weed management grain yield does not significantly differ with treatments. Maximum grain yield was observed in $W_1$ (5635, 5867 kg/ha) and lower grain yield was observed in $W_2$ (5448, 5702 kg/ha), respectively during both the of years study.

### Straw yield

The straw yield is an important criterion for evaluating the efficiency of various treatments as it reflects the plant growth. A perusal of data in Table 4 revealed that among planting methods $M_7$ produced maximum straw yield (6993, 7349 kg/ha) as compared to all planting methods but statistically at par with $M_8$ (6752,7246 kg/ha) and $M_1$ (6823, 7168 kg/ha), respectively during both the years.

Among weed management straw yield do not significantly differ with treatments. Maximum grain yield was observed in $W_1$ (6628, 6888 kg/ha) and lower grain yield was observed in $W_2$ (6457, 6685 kg/ha), respectively during both the of study.

*Table 4. Effect of various planting methods and weed management on grain yield, straw yield, biological yield, and harvest index of wheat*

| Treatment | | Grain yield (kg/ha) | | Straw yield (kg/ha) | | Biological yield (kg/ha) | | Harvest index | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 | 2020 | 2021 |
| Planting methods | | | | | | | | | |
| $M_1$ | Zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) *fb* ZTW | 5742 | 5967 | 6823 | 7168 | 12565 | 13135 | 45.7 | 45.7 |
| $M_2$ | Zero-tillage sowing with press wheel (without residues) *fb* ZTW | 5592 | 5817 | 6608 | 6854 | 12199 | 12671 | 45.8 | 45.9 |
| $M_3$ | Ridge sowing with dibbling method (with paddy residues @ 6 t/ha) *fb* CTW) | 5426 | 5616 | 6438 | 6601 | 11864 | 12217 | 45.7 | 45.9 |
| $M_4$ | Ridge sowing with dibbling method (without residues) *fb* CTW | 5302 | 5582 | 6339 | 6470 | 11641 | 11953 | 45.5 | 46.7 |
| $M_5$ | Multi-crop ridge planter (with paddy residues @ 6 t/ha) *fb* CTW | 5294 | 5464 | 6390 | 6506 | 11683 | 11970 | 45.3 | 45.6 |
| $M_6$ | Multi-crop ridge planter (without residues) *fb* CTW | 5235 | 5574 | 6294 | 6369 | 11529 | 11943 | 45.4 | 46.6 |
| $M_7$ | Raised bed wide bed planter (with paddy residues @ 6 t/ha) *fb* ZTW (reshaping of beds) | 6164 | 6213 | 6993 | 7349 | 13157 | 13562 | 46.8 | 46.9 |
| $M_8$ | Raised bed wide bed planter (without residues) *fb* ZTW (reshaping of beds) | 5960 | 6101 | 6752 | 7246 | 12712 | 13246 | 46.7 | 46.1 |
| $M_9$ | Pneumatic maize planter (with paddy residues @ 6 t/ha) *fb* ZTW | 5632 | 5901 | 6514 | 7012 | 12147 | 12913 | 46.3 | 46.0 |
| $M_{10}$ | Pneumatic maize planter (without residues) *fb* ZTW | 5449 | 5775 | 6382 | 6842 | 11831 | 12616 | 46.0 | 45.8 |
| SEm ± | | 79 | 84 | 90 | 107 | 132 | 144 | 0.3 | 0.4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CD (p=0.05) | | 234 | 247 | 265 | 312 | 385 | 438 | N.S | N.S |
| **Weed control** | | | | | | | | | |
| **$W_1$** | Unweeded check | 5635 | 5867 | 6628 | 6888 | 12263 | 12755 | 45.9 | 45.9 |
| **$W_2$** | Weedy check | 5448 | 5702 | 6457 | 6685 | 11906 | 12388 | 45.7 | 46.0 |
| **$W_3$** | Tembotrione 120 g/ha at 15 DAS | 5609 | 5829 | 6586 | 6855 | 12195 | 12684 | 45.9 | 45.9 |
| **$W_4$** | Topramezone 25.2 g/ha at 15 DAS | 5545 | 5799 | 6541 | 6813 | 12087 | 12612 | 45.8 | 45.9 |
| SEm ± | | 227 | 239 | 87 | 102 | 129 | 141 | 0.2 | 0.3 |
| CD (p=0.05) | | N.S | N.S | N.S | N.S | N.S | N.S | N.S | N.S |

### 4.3.3 Biological yield

A perusal of data in Table 4 revealed that under different planting methods, $M_7$ produced maximum biological yield (13157, 13562 kg/ha) as compared to all planting methods but statistically at par with $M_8$ (12712, 13246 kg/ha) and $M_1$ (12565, 13135 kg/ha), respectively during both the years. Among weed management straw yield not significantly differ with treatments. Maximum grain yield was observed in $W_1$ (12263, 12755 kg/ha) and lower grain yield was observed in $W_2$ (11906, 12388 kg/ha), respectively during both the of study.

### Harvest index

The data about harvest index is presented in Table 4. Harvest index of wheat was not influenced significantly among planting methods as well as in weed management.

### Energy

Energy plays an important role in sustainable development from the perspective of natural resource use and greenhouse gas emissions. Due to rapid population growth and economic development, energy consumption has been increasing continuously. Agriculture contributes about 14% to global greenhouse gas emissions. The development of agricultural production demands more energy to operate equipment and machinery, support the production process and produce chemicals and fertilizers. Perusal of data on energy *viz.* input energy, output energy, input-output energy ratio and energy productivity for cultivation of maize-wheat cropping system given in Table 5.

### Input energy

Among planting methods, it was shown that lowest input energy requirement (33.02 MJ /ha) was estimated with $M_2$ while the highest with $M_5$ and $M_3$ (38.60, 33.02 MJ/ha) in both the years, respectively. Among weed management lowest input energy required in $W_2$ (36.78 MJ/ha) which was significantly lower as compared to all the treatments, respectively during both years (Table 5).

### Output energy

The maximum output energy (503.06 and 522.68 MJ /ha) was obtained with $M_7$ in both the years, respectively, which was significantly higher than all the planting methods. Among weed management maximum input energy required in $W_1$ (444.78 and 460.44 MJ/ha) which was significantly higher than W2 but at par with $W_3$ (441.83 and 456.49 MJ/ha) and $W_4$ (438.11 and 456.49 MJ/ha), respectively during both the years (Table 5).

### Input-output energy ratio

The Input-output energy ratio was recorded as maximum (13.93 and 14.43 MJ/ha) with $M_1$ that was significantly higher all the planting methods and but at par with $M_7$ (13.44, 14.41 MJ/ha), respectively during both years. Among weed management maximum input-output energy ratio was recorded in W3 (12.03 and 12.52 MJ/ha) which was significantly higher than $W_2$ but at par with $W_4$ (11.99 and 1251 MJ/ha) and $W_1$ (11.97 and 12.50 MJ/ha), respectively during both the years (Table 5).

### Specific energy

The lowest specific energy (2261.88 and 2187.97 MJ/kg) was required under $M_1$ as compared to all the planting methods except $M_7$ (2406.73 and 2288.62 MJ/kg) and $M_2$ (2614.17 and 2536.99 MJ/kg) during both the years of study, respectively. Among weed management maximum specific energy was recorded in $W_3$ (2725.89 and 2619.53 MJ/kg) which was significantly higher than $W_2$ but at par with $W_4$ (2740.41 and 2626.47 MJ/kg) and $W_1$ (2734.37 and 2625.73 MJ/kg), respectively during both the years (Table 5).

### Energy productivity

Among planting methods, the energy productivity was significantly higher with $M_1$ (1.03 and 1.06 kg/MJ/ha) as compared to all the planting methods during the years 2020-21 and 2021-22, respectively. Among weed management energy productivity was significantly higher with $W_3$ (0.88 and 0.91 kg/MJ/ha) as compared to W2 but at par with $W_4$ (0.87 and 0.91kg/MJ/ha) and $W_1$ (0.87 and 0.91kg/MJ/ha), respectively during both the years (Table 5).

*Table 5. Effect of various planting methods and weed management on output energy, input-output ratio, and specific energy of maize- wheat cropping system*

| Treatment | | 2020-21 Input energy (MJ /ha) | 2020-21 Output energy (MJ /ha) | 2020-21 Input-output energy ratio | 2020-21 Specific energy (MJ /kg) | 2020-21 Energy productivity (kg/MJ/ha) | 2021-22 Input energy (MJ /ha) | 2021-22 Output energy (MJ /ha) | 2021-22 Input-output energy ratio | 2021-22 Specific energy (MJ /kg) | 2021-22 Energy productivity (kg/MJ/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Planting methods** | | | | | | | | | | | |
| $M_1$ | Zero-tillage sowing with press wheel (with paddy residues @ 6 t/ha) *fb* ZTW | 33.22 | 462.82 | 13.93 | 2261.88 | 1.03 | 33.22 | 479.47 | 14.43 | 2187.97 | 1.06 |
| $M_2$ | Zero-tillage sowing with press wheel (without residues) fb ZTW | 33.02 | 436.71 | 13.22 | 2614.17 | 0.91 | 33.02 | 454.01 | 13.75 | 2536.99 | 0.94 |
| $M_3$ | Ridge sowing with dibbling method (with paddy residues @ 6 t/ha) *fb* CTW) | 38.60 | 434.20 | 11.25 | 2878.36 | 0.82 | 38.60 | 441.77 | 11.44 | 2792.11 | 0.85 |
| $M_4$ | Ridge sowing with dibbling method (without residues) *fb* CTW | 38.41 | 377.17 | 9.82 | 3415.78 | 0.73 | 38.41 | 383.72 | 9.98 | 3272.85 | 0.75 |
| $M_5$ | Multi-crop ridge planter (with paddy residues @ 6 t/ha) fb CTW | 38.60 | 416.34 | 10.79 | 2996.33 | 0.80 | 38.60 | 426.96 | 11.06 | 2895.84 | 0.82 |
| $M_6$ | Multi-crop ridge planter (without residues) *fb* CTW | 38.41 | 354.02 | 9.21 | 3758.15 | 0.67 | 38.41 | 365.96 | 9.52 | 3554.77 | 0.70 |
| $M_7$ | Raised bed wide bed planter (with paddy residues @ 6 t/ha) *fb* ZTW (reshaping of beds) | 37.44 | 503.06 | 13.44 | 2406.73 | 0.96 | 36.27 | 522.68 | 14.41 | 2288.62 | 1.01 |
| $M_8$ | Raised bed wide bed planter (without residues) fb ZTW (reshaping of beds) | 37.24 | 457.62 | 12.29 | 2823.12 | 0.84 | 36.08 | 487.70 | 13.52 | 2620.51 | 0.90 |
| $M_9$ | Pneumatic maize planter (with paddy residues @ 6 t/ha) *fb* ZTW | 37.44 | 433.80 | 11.59 | 2798.13 | 0.84 | 37.44 | 453.79 | 12.12 | 2710.78 | 0.87 |
| $M_{10}$ | Pneumatic maize planter (without residues) *fb* ZTW | 37.24 | 368.40 | 9.89 | 3396.39 | 0.73 | 37.24 | 385.05 | 10.33 | 3254.18 | 0.76 |
| SEm ± | | - | 6.57 | 0.18 | 51.76 | 0.013 | - | 5.52 | 0.159 | 37.88 | 0.010 |
| CD (p=0.05) | | - | 19.33 | 0.52 | 152.54 | 0.04 | - | 16.36 | 0.47 | 112.12 | 0.03 |
| **Weed control** | | | | | | | | | | | |
| $W_1$ | Unweeded check | 37.25 | 444.78 | 11.97 | 2734.37 | 0.87 | 37.25 | 460.44 | 12.50 | 2625.73 | 0.91 |
| $W_2$ | Weedy check | 36.78 | 372.94 | 10.22 | 3538.95 | 0.72 | 36.78 | 386.72 | 10.69 | 3374.11 | 0.74 |
| $W_3$ | Tembotrione 120 g/ha at 15 DAS | 36.91 | 441.83 | 12.03 | 2725.89 | 0.88 | 36.91 | 456.49 | 12.52 | 2619.53 | 0.91 |
| $W_4$ | Topramezone 25.2 g/ha at 15 DAS | 36.91 | 438.11 | 11.99 | 2740.41 | 0.87 | 36.91 | 456.80 | 12.51 | 2626.47 | 0.91 |
| SEm ± | | - | 7.18 | 0.20 | 52.15 | 0.017 | - | 3.50 | 0.11 | 37.41 | 0.013 |
| CD (p=0.05) | | - | 21.31 | 0.59 | 154.35 | 0.05 | - | 11.81 | 0.32 | 111.49 | 0.04 |

## Discussion

Among planting methods, it was showed that lowest input energy requirement was estimated with $M_2$ while the highest with $M_5$ and $M_3$ in both years. Among weed management lowest input energy required in $W_2$ was significantly lower as compared to all the treatments, respectively during both the years. The maximum output energy was obtained with $M_7$ in both the years, which was significantly higher than all the planting method. Among weed management maximum input energy was required in $W_1$ which was significantly higher than $W_2$ but at par with $W_3$ and $W_4$ during both the years. The input-output energy ratio was recorded as maximum with $M_1$ which was significantly higher than all the planting method and but at par with $M_7$ during both the years. Among weed management maximum input-output energy ratio was recorded in $W_3$ which was significantly higher than $W_2$ but at par with $W_4$ and $W_1$ during both years. The lowest specific energy was required under $M_1$ as compared to all the planting methods except $M_7$ and $M_2$ during both the years of study. Among weed management maximum specific energy was recorded in $W_3$ which was significantly higher than $W_2$ but at par with $W_4$ and $W_1$ during both the years. Among planting methods, the energy productivity was significantly higher with $M_1$ as compared to all the planting methods during both the years 2020-21 and 2021-22. Among weed management energy productivity was significantly higher with $W_3$ as compared to $W_2$ but at par with $W_4$ and $W_1$, both the years.

Zero tillage sowing is the most efficient method in respect of energy calculations (NE, EUE, energy profitability, specific energy, energy productivity, energy intensiveness, energy intensity in physical terms, energy intensity in economic terms) followed by bed planting [6]. Energy indices, input, and output energy showed that the grain yield of wheat did not compensate for the higher input energy used in intensive input scenarios as compared to conservation tillage. Lower energy in land preparation, irrigation, higher system output, net energy and energy use-efficiency in ZT and permanent bed (PB) than the CT under maize-wheat cropping system [14]. Average fuel consumption for raised bed planters was lower as compared inclined plate planters [11]. Zero-tillage improved the specific energy by 17% and the energy usage efficiency by 13% as compared to conventional tillage [10]. Soil tillage is one of the highest energy and labour consumer in arable farming and no-till had the lowest energy consumption [18]. Conventional soil tillage had the highest and no-till has the lowest fuel consumption. The energy consumption in conventional soil tillage was more than conservation tillage [20]. Conservation (RT) system with chisel plough and multi-tiller spent 37.5% less, while no-till (NT) system required even 85.1% less energy when compared with conventional tillage (CT) [9]. The use of no-tillage method for wheat sowing provided significant energy savings in fuel and machinery [21].

## Conclusion

- The maximum maize equivalent yield (157.81, 159.17 kg/ha) was obtained in $M_7$ as compared to other planting methods in maize-wheat cropping system during both the years, respectively.
- In maize- wheat cropping system, maximum returns (₹ 1,57,128, 1,84,941) were obtained in M7 followed by $M_1$ (₹ 1,49,813, 1,38,831). In first year (2020) the B:C was similar (1.73) with $M_1$ and M7 but in second year the cost-benefit ratio was higher (1.88) with $M_7$ as compared to $M_1$ (1.84).
- The input energy was lowest in zero-tillage sowing with press wheel (without residues) *fb* ZT wheat and output energy was maximum in M7. The input output energy ratio, specific energy and energy productivity was significantly higher with $M_1$ which was statistically at par with $M_7$.
- Among weed control treatments the $W_2$ has the lowest energy input and $W_1$ has the maximum output energy. The input-output energy ratio, specific energy and energy productivity was significantly higher in tembotrione @120 g/ha at 15 DAS which was statistically at par with topramezone @25.2 g /ha at 15 DAS in both the year in maize-wheat cropping system.

**Future scope of the study**

The present study can be directed towards optimization of energy input in the maize wheat cropping system. This includes the study of energy use efficiency in maize wheat cropping system with different planting metods and weed management practices. Develop comprehensive energy auditing protocols to evaluvate the energy consumption and efficiency of different management practices including those involving paddy resdue and weed management. This sudy can be further extended to explore the potential use of paddy residue as a bioenergy source.

**Declaration of competing interest**

The author declare that they have no conflict of intrest

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