Farming System 2 (2024) 100085

Contents lists available at ScienceDirect

Farming System

journal homepage: www.journals.elsevier.com/farming-system

Productivity, profitability and energy use efficiency of wheat-maize cropping under different tillage systems

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ARTICLE INFO

Keywords:
Conservation practices
Cropping system
Crop productivity
Energy efficiency
Profitability
Energy utilization

ABSTRACT

The energy consumption of intensive tillage practices is higher, decreasing soil and environment sustainability. Conservation agriculture practices i.e. reduced or no-tillage could be suitable options to conserve energy and environment and increase profitability. However, previous studies evaluated the energy consumption, productivity and profitability in two or three tillage systems, a comprehensive assessment of multiple tillage systems is needed. Therefore, six tillage i) conventional (CT), ii) conventional with bed (CTB), iii) reduced (RT), iv) reduced with bed (RTB), v) zero (ZT), and vi) zero with bed (ZTB) were practiced to evaluate the energy consumption, productivity of wheat-maize and their economic returns. The results showed that CT, RTB, RT, ZTB, and ZT reduced 21% and 13%, 81% and 93%, 36% and 56%, 169% and 263%, and 81% and 152% energy consumption than CTB in wheat and maize, respectively. Considering mean productivity, CT and CTB increased by almost wheat (953.43 kg ha^{-1}) and maize (466.66 kg ha^{-1}) yields. However, ZT, and RT had higher EP (energy productivity, 32%) and EUE (energy use efficiency, 30%) in wheat, 14% EP and 10% EUE as compared to CTB in maize. The lower EP and EUE in maize were mainly due to higher inputs/energy consumption in comparison to wheat. The input cost of CT, and CTB was higher in wheat than in other tillage practices, but the wheat yield was statistically similar in CT, CTB, RT, and RTB in both years. The RT had a higher benefit-cost ratio (BCR) in wheat (1.52) and maize (0.74) than intensive CT practice (1.44 (wheat), 0.61 (maize)). In wheat, EUE and EP were significantly higher under RT and ZT treatments, however, both were significantly reduced under bed plantation, contrarily no specific trends were observed in maize. In conclusion, RT could be used for wheat cultivation that consumed lower energy inputs and produced higher EUE, EP, and statistically equal grain yield as compared to CT. However, this practice might not be useful for maize cultivation and needs further evaluation.

1. Introduction

Crop production practices contribute ~5% of total global energy consumption (Yadav et al., 2018; Malhi et al., 2021). In different agriculture production systems, tillage has been identified as a major energy consumer and source of greenhouse gas production (Choudhary et al., 2020; Ahmad et al., 2024). Compared to no-tillage (NT), conventional tillage (CT) inverts the soil surface, and increases water infiltration and nutrient availability (Babu et al., 2020; Ahmad et al., 2023), which facilitates crop growth and yield enhancement in different cropping systems (Nisar et al., 2021). However repetitive CT practices often decrease soil structure stability and energy use efficiency (Liu et al., 2021). The CT practices in South Asia (Pakistan, India, Nepal, Bangladesh, and China) had an indirect effect on environmental pollution and production system

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https://doi.org/10.1016/j.farsys.2024.100085
Received 28 July 2023; Received in revised form 11 February 2024; Accepted 13 February 2024
Available online 2 April 2024

Table 1
Description of tillage operations used in different tillage treatments.

Treatment	Crop	Tillage particulars (number of operations)				
		Cultivation	Rotavator/straw chopper	Planking	Bed making via ridger	Seeding drill
CT	Wheat	3	1	2	–	–
	Maize	3	2	2	–	1
CTB	Wheat	3	2	2	1	1
	Maize	3	2	2	1	1
RT	Wheat	1	1	1	–	–
	Maize	1	1	1	–	1
RTB	Wheat	1	1	1	1	1
	Maize	1	2	1	1	1
ZT	Wheat	–	1	–	–	1
	Maize	–	–	–	–	1
ZTB	Wheat	–	–	–	1	1
	Maize	–	2	–	1	1

sustainability (Bhatt, 2017; Singh et al., 2019).

NT requires less fuel energy, decreasing carbon dioxide emissions and global warming (Yadav et al., 2021a). Eco-environment management practices and cropping cultivation are important factors for a sustainable crop production system and ultimately food security (Kumar et al., 2018). Intensive crop cultivation practices decline productivity factors, resource use efficiency, natural resource degradation and nutrient depletion in comparison with conservation agriculture practices like reduced (RT) and NT in different cropping systems (Zhao et al., 2020; Guo et al., 2021). Similarly, Yadav et al. (2018) reported that conservation tillage practices enhance soil health quality, profitability, and resource utilization efficiency under rice-mustard production patterns in Indo-Gangetic plains of India. The over-exploitation of natural resources increased environmental challenges by reducing energy use efficiency (EUE) and increasing emissions of greenhouse gases (Kumar et al., 2013; Gathala et al., 2016). Globally in the last four decades, the allocation of agricultural farmlands per person decreased significantly, mainly due to rapidly increasing population, urbanization, changing climatic conditions and soil degradation (Gomiero, 2016; Wily, 2018). It has decreased from 0.44 to 0.18 ha^{-1} and is expected to decrease by 0.1 ha by 2050 (Mobtaker et al., 2010). Moreover, farming communities in Asian and African continents have poor resources mainly due to less institutional access (enormously affects resource use efficiency) as well as high input costs of agricultural production systems that substantially decrease economic returns (Mehmood et al., 2015; Ndayisaba et al., 2023). The low profitability and high energy input cost ultimately lower the living standards of farming communities in developing countries (Chaudhary et al., 2009; Tuti et al., 2012).

Farmers mainly adopt conventional cropping systems despite assessing regional resources (Jat et al., 2018). Furthermore, intensive usage of tillage, fertilizer, chemicals and irrigation water increased production cost and decreased the benefit margin (Li et al., 2021a). Increasing the input energy for cultivation does not give maximum profit due to increased production costs that also reduce EUE and increase greenhouse gas emissions (Meena et al., 2015; Gathala et al., 2016). Crop production is an active source and sink of bioenergy (Chaudhary et al., 2009). Higher energy output and lower energy input in crop production systems increased net energy gain (Bhunia et al., 2021). However, to estimate the effectiveness of different cropping systems in energy conservation, the use of various patterns of energy must be evaluated, and analysis of energy budgeting is required for appropriate management to enhance agricultural productivity (Sharma, 1991). Energy analysis of agricultural ecosystems is a useful method to determine energy sustainability and environmental influence (Gong et al., 2021). Furthermore, optimizing natural resources, with more energy-efficient crop cultivation technologies, is needed to enhance cost benefits and mitigate environmental consequences (Kumar, 2011). The economics, energy and the environment are all interlinked and must be evaluated to increase resource allocation (Gathala et al., 2016). Tillage operations, amount of organic manure and chemical fertilizers, plant protection measures, harvesting and threshing, yield and biomass production affect energy input-output relationships in cropping systems (Kumar et al., 2013; Elhami et al., 2016; Bhatt, 2017; Ahmad et al., 2024). Considering the energy input-output relationship, sustainable productivity is a major issue in all production systems. Likewise, Singh et al. (2021) have evaluated the input and output energy relationship in wheat cropping systems. Similarly, Chaudhary et al. (2009) analyzed EUE in rice-wheat cropping in four different tillage systems. However, this could not reflect the energy use efficiency scenario of multiple tillage practices for different regions. Efficient energy utilization in agroecosystems can be helpful in reducing production cost and associated environmental issues leading to agronomic and environmental sustainability of crop production.

This study aimed to provide valuable insights into the impact of tillage practices on yield, profitability, and energy efficiencies of wheat-maize cropping systems, thus facilitating the adoption of sustainable and conservation agricultural practices. Therefore, this study was conducted to compare six different tillage practices to comprehensively elevate the energy consumption, yield productivity and economic returns under the maize-wheat cropping system. The specific objectives of this study were to (1) compare the EUE of different tillage systems in maize-wheat cropping (2) evaluate the productivity and profitability of various tillage practices of whole cropping system (3) analyze the relationship of energy indices with yield productivity and economic returns.

2. Materials and methods

2.1. Experimental site

A field experiment was conducted during 2019–2020 at Agronomy Research Farm (31.45° N, 73.13° E at an altitude of ~186 m above sea level) at the University of Agriculture Faisalabad, Pakistan. The region has semi-arid, hot and humid summers (26.9–45.5 °C) and dry cool winters (4.1–19.4 °C). Rainfall dominates during monsoon seasons (July–August) with a mean annual value of 230 mm.

2.2. Experimental details

The experiment was laid out in a randomized complete block design (RCBD) with six different tillage treatments conducted in triplicate, and plot size of wheat and maize was 120 m^2 (8 m × 15 m). Tillage treatments consist of (i) conventional tillage (CT) (ii) conventional tillage with bed planting (CTB) (iii) reduce tillage (RT) (iv) reduced tillage with bed planting (RTB) (v) zero tillage (ZT) (vi) zero tillage with bed (ZTB). The bed width was 75 cm and the bed-to-bed distance was 30 cm in each tillage treatment. All the details of field sowing operations are given in Table 1. Wheat or maize was sown with seed cum fertilizer drill in each tillage treatment. Wheat (variety Anaaj-2017) at 100 kg ha^{-1} was sown on November 07, 2018, and November 09, 2019, by maintaining a 23 cm

Table 2
Energy equivalents of inputs and outputs used in cultivation operations.

Particulars	Unit	Energy co-efficient (MJ unit $^{-1}$)	References
Tractor	kg	64.8	Devasenapathy et al. (2009)
Cultivator	kg	62.7	Devasenapathy et al. (2009)
Planking	kg	62.7	Devasenapathy et al. (2009)
Levelling	kg	149	Devasenapathy et al. (2009)
Seed cum fertilizer drill	kg	133	Devasenapathy et al. (2009)
Sprayer	kg	129	Devasenapathy et al. (2009)
Combine harvester	kg	83.5	Devasenapathy et al. (2009)
Irrigation water	m^3	1.02	Devasenapathy et al. (2009)
Human (adult man)	Man-h	1.96	Devasenapathy et al. (2009)
Diesel	L	56.31	Singh et al. (2008b)
Wheat grain	kg	15.1	Nisar et al. (2021)
Maize grain	kg	15.7	Nisar et al. (2021)
N	kg	60.6	Devasenapathy et al. (2009)
P	kg	11.1	Devasenapathy et al. (2009)
K	kg	6.7	Devasenapathy et al. (2009)
Herbicide	kg (a.i)	238	Pimentel (1980)
Fungicide	kg (a.i)	216	Pimentel (1980)
Insecticide	kg (a.i)	199	Pimentel (1980)
Electricity	kWh	11.93	Esengun et al. (2007)
Wheat straw	kg	12.50	Nisar et al. (2021)
Maize straw	kg	12.50	Nisar et al. (2021)

a.i: active ingredient.

row-row distance in flat sowing and bed planting. Wheat was fertilized with 115-75-62.5 N, P_2O_5, and k_2O kg ha^{-1} using urea (46% N), diammonium phosphate (18% N, 46% P) and sulfate of potash (50% K_2O), respectively. N fertilizer was applied with three equal splits at the sowing, anthesis and grain formation stages. A total of four irrigations (each of 3-acre inches or 308.37 m^3) were applied during the wheat growth cycle. Crop was harvested on 22nd April and 24th April during the 1st and 2nd year of study respectively. Maize (variety Sahiwal gold) was sown at 30 kg ha^{-1} on June 04, 2019, and June 06, 2020, by maintaining a 25 cm plant-plant and 75 cm row-row distance. Maize was fertilized with 187-115-62.5 N, P_2O_5 and K_2O kg ha^{-1} using urea (46% N), diammonium phosphate (18% N, 46% P) and sulfate of potash (50% K_2O), respectively (Hakeem et al., 2016). Fertilizer was applied with three equal splits at the sowing, knee height and pre-tasseling stages. A total of 10 irrigations (308.37 m^3 each time) were applied during the maize growth crop period. Crop was harvested on the 12th and 15th of September during the 1st and 2nd year of study, respectively.

2.3. Energy analysis

2.3.1. Energy inputs

Energy input estimations were based on the human labor requirement, use of different types of machinery and quantity of materials, energy calculation was computed using different input and output energy equivalents (Table 2).

2.3.2. Seed energy

Seed energy was calculated by the multiplication of quantity (Qs) of seed (kg ha^{-1}) used at the time of sowing with the amount of energy stored (SE) in each seed unit (equation (1)).

$$SE\ \left(MJ\ ha^{-1}\right) = Q_{s \times S_e} \tag{1}$$

2.3.3. Fuel energy

Total fuel was quantified using volumetric methods such as tillage, sowing, harvesting and threshing operations. Total fuel (Fuel Energy, FE) was calculated by the multiplication of quantity of diesel (Q_d) with the energy present (L_e) in each liter (equation (2)).

$$FE\ \left(MJ\ ha^{-1}\right) = Q_{d\times}L_e \tag{2}$$

2.3.4. Human labor energy

Human labor (HL) is required individually in each tillage, fertilizer, irrigation, chemicals, harvesting and threshing operation during the crop growth period. It was calculated by multiplication of total hours (H_d) per day needed with the human energy used (E_h) per hour (equation (3)).

$$HL\ \left(MJ\ ha^{-1}\right) = H_{d\times}E_h \tag{3}$$

2.3.5. Irrigation energy

Irrigation applied to the field, during crop growth period, was measured with a water flow meter. It was calculated by multiplication of total quantity of water (Q_w) to field with the water energy (W_e) used during irrigations (equation (4)).

$$WE\ \left(MJ\ ha^{-1}\right) = Q_{w\times}W_e \tag{4}$$

2.3.6. Electric energy

Electricity energy (EE) was calculated by the multiplication of total electricity (T_e) used during irrigation applied to the fields with the amount of energy present in electricity (E_h) per hour (equation (5)).

$$EE\ \left(MJ\ ha^{-1}\right) = T_{e\times}E_h \tag{5}$$

2.3.7. Fertilizer energy

Fertilizer energy (FE) was calculated by the multiplication of fertilizers applied (A_N, A_P and A_K in kg ha-1) to the field with the amount of energy present in chemical fertilizer (C_N, C_P and C_K in MJ kg^{-1}) in each fertilizer unit (equation (6)).

$$FE\left(MJ\ ha^{-1}\right) = \left(A_{N\times}C_N\right) + \left(A_{P\times}C_P\right) + \left(A_{K\times}C_K\right) \tag{6}$$

2.3.8. Chemical energy

Chemical energy (CE) was calculated by the multiplication of amount of chemicals applied (A_H, A_I and A_F in kg ha^{-1}) to crop with the quantity of energy present in (Q_H, Q_F and Q_I in MJ kg^{-1}) in each chemical (equation (7)).

$$CE\left(MJ\ ha^{-1}\right) = \left(A_{H\times}Q_H\right) + \left(A_{I\times}Q_F\right) + \left(A_{F\times}Q_I\right) \tag{7}$$

2.3.9. Machine energy

The different agriculture operations run by machinery utilize their respective energy i.e., machine energy (ME). The total duration of the tractor (D_m h ha^{-1}) of each implement was multiplied by the total amount of energy (T_{mi}, MJ ha^{-1}) present in each machinery unit (equation (8)).

$$ME\left(MJ\ ha^{-1}\right) = \sum_{i=1}^{n} D_{mi\times}T_{mi} \tag{8}$$

2.3.10. Total input energy

The total input energy (TIE) was calculated by adding all external inputs applied during the whole crop period (equation (9)).

$$TIE\left(MJ\ ha^{-1}\right) = ME + FE + HE + SE + FE + CE + WE + EE \tag{9}$$

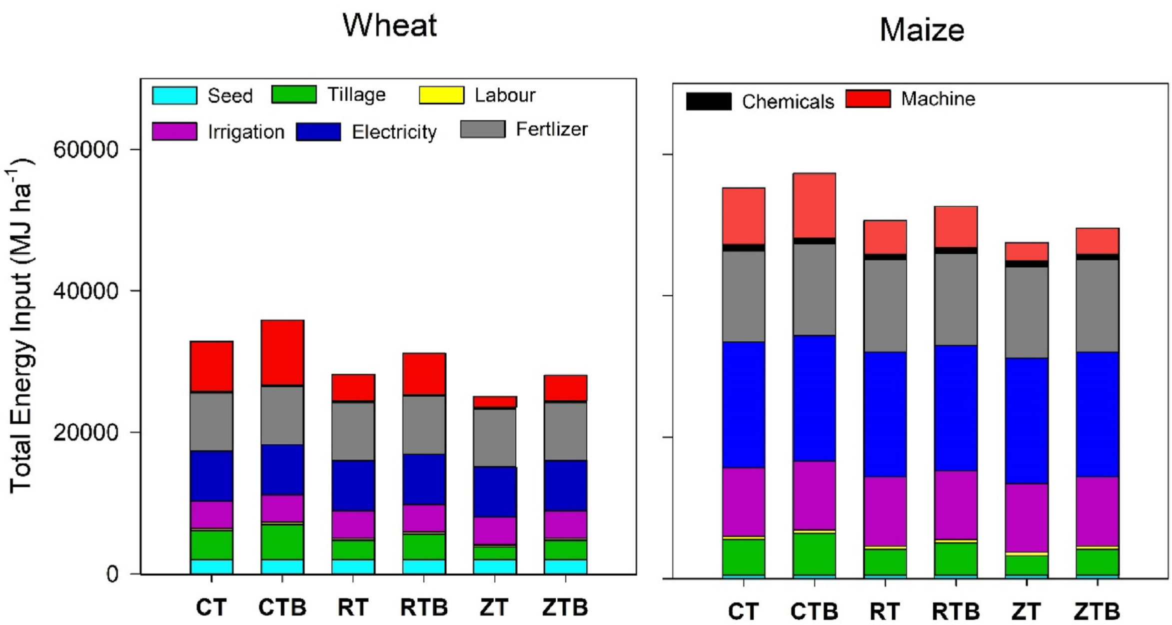

Fig. 1. Mean energy inputs from seed, fertilizer, irrigation, machines and chemicals in maize and wheat in both years in different tillage practices (2019, 2020).

2.3.11. *Energy outputs*

Yield energy (YE) was calculated by the multiplication of the yield rate (Y_r) with the amount of energy (E_y) present in wheat and maize crops (equation (10)).

$$YE\left(MJ\ ha^{-1}\right) = Y_{r\times}E_y \quad (10)$$

Straw energy (StE) of wheat and maize was calculated by the multiplication of the amount of straw (A_{st}, kg ha^{-1}) and straw energy present (E_{st}, kg ha^{-1}) after crop harvest (equation (11)).

$$StE\left(MJ\ ha^{-1}\right) = A_{st\times}E_{st} \quad (11)$$

Total output energy (TOE) was calculated by combining yield energy (YE) and straw energy (StE) (equation (12))

$$TOE\left(MJ\ ha^{-1}\right) = YE + StE \quad (12)$$

2.3.12. *Energy indices*

Energy indices include different parameters such as specific energy (SE, equation (13)), energy productivity (EP, equation (14)), energy use efficiency (EUE, equation (15)), net energy gain (NEG, equation (16)) and energy profitability (PE, equation (17)) involving all parameters during energy consumption in the farm operation and energy production from straw and grain were calculated from given equations.

$$SE = \frac{TEI}{GY} \quad (13)$$

Where SE is specific energy (MJ kg^{-1}); TIE, total input energy (MJ kg^{-1}); GY, grain yield (kg ha^{-1})

$$EP = \frac{GY}{TEI} \quad (14)$$

Where EP is energy productivity (kg ha^{-1}); GY, grain yield (kg ha^{-1}); TIE, total input energy (MJ kg^{-1}).

$$EUE = \frac{TOE\ \left(MJha^{-1}\right)}{TIE\ \left(MJha^{-1}\right)} \quad (15)$$

Where EUE is energy use efficiency; TOE, total output energy (MJ ha^{-1}); TIE, total input energy (MJ ha^{-1})

$$NEG\left(MJ\ ha^{-1}\right) = TOE - TEI \quad (16)$$

Where NEG is net energy gain (MJ ha^{-1}); TOE, total output energy (MJ ha^{-1}); TIE, total input energy (MJ ha^{-1})

$$PE = \frac{NEG\left(MJha^{-1}\right)}{TIE\ \left(MJ\ ha^{-1}\right)} \quad (17)$$

Where PE is energy profitability; NEG, net energy gain (MJ ha^{-1}); TIE, total input energy (MJ ha^{-1}).

2.4. *Economic analysis*

The economic capability of different treatments was calculated from the cost of cultivation (CC) including labor wages, cost of farm inputs (pesticides, seed and fertilizers), harvesting and threshing operations. The total economic revenue based on the market value of crop (MP) and net profit (NP) was obtained by using equation (19). The benefit-cost ratio (BCR) was calculated following Iqbal et al. (2019), based on the given equations.

$$GR = GY \times MP \quad (18)$$

Whereas GR is gross revenue, GY is the grain yield of the crop (kg ha^{-1}) and MP is the latest market price (US \$ ha^{-1}) in the local market.

$$NP = GR - CC \quad (19)$$

Where NP is net profit; GR, gross revenue; CC, cost of production.

$$BCR = \frac{NP}{CC} \quad (20)$$

Where BCR is benefit-cost ratio; NP, net profit; CC, cost of production.

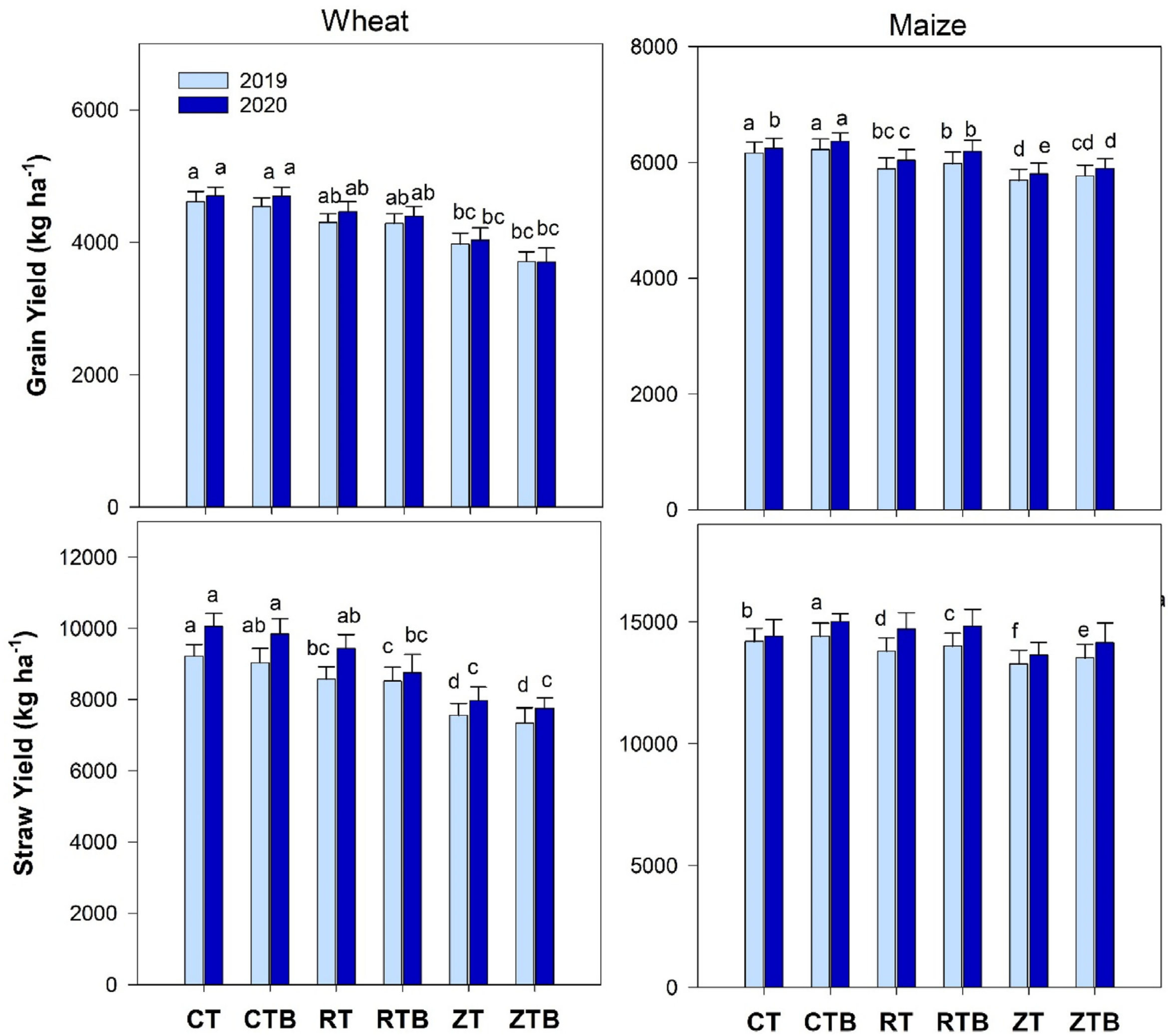

Fig. 2. Effects of different tillage systems (conventional tillage (CT), conventional tillage with bed planting (CTB), reduce tillage (RT), reduce tillage with bed planting (RTB), zero tillage (ZT), zero tillage with bed (ZTB)) on yield and straw production of wheat and maize in two years (2019, 2020).

2.5. Statistical analysis

All the obtained data were statistically analyzed using Statistix 8.1 software with one-way analysis of variance (ANOVA). Treatment means were compared using the least significance difference (LSD) test at $p = 0.05$.

3. Results

3.1. Energy input

The energy inputs were different in wheat and maize crops. The difference in energy inputs between maize and wheat was mainly attributed to fuel, labor, irrigation, fertilizer, electricity, chemical and machine energy (Fig. 1). Different tillage treatments consumed different energy, mainly higher in CTB. In wheat crop CT, RTB, RT, ZTB, and ZT reduce fuel energy consumption by about 21%,81%, 36%,169% and 81% as compared to CTB respectively. The difference in energy consumption was due to lower tillage and machine operations. Briefly, 17%, 61%, 29%,114% and 61% lower tillage implementation was done for CT, RTB, RT, ZTB, and ZT than CTB in maize crop. The labor energy in wheat and maize crops was maximum in CTB ranging from 313 to 329 MJ ha^{-1} and 470–486 MJ ha^{-1}, respectively. In the wheat crop irrigation energy requirement was the same for all treatments (3886.2 MJ ha^{-1}) and maize crop had more irrigation energy than wheat (9715 MJ ha^{-1}). Electrical energy consumption in wheat crop followed the same pattern as water energy input, maize crop had more (149%) electric energy requirements as compared to wheat. The fertilizer input energy was 8151.25 MJ ha^{-1} in wheat, and 12945.25 MJ ha^{-1} in maize. In wheat crop chemical energy for CT, RTB, RT, ZTB, ZT and CTB was same because the herbicide, fungicide, and insecticide application rates were the same for all treatments. However, maize consumed about 231% higher chemical energy as compared to wheat. Among tillage systems CTB consumed higher energy inputs than CT, RTB, RT, ZTB, ZT and CTB in wheat and maize crops, for wheat, CT, RTB, RT, ZTB, and ZT reduced machine energy consumption by about 29%, 144%, 56%, 499% and 152% as compared to CTB respectively. Similarly, 13%,93%,56%,263% and 152% lower energy was consumed for CT, RTB, RT, ZTB, and ZT than CTB in maize crop. The mean energy consumption difference in wheat and maize was 29% (fuel), 49% (labor), 150% (irrigation), 149% (electricity), 58% (fertilizer) and 49% (machine energy) (Fig. 1). Overall maize crop consumed almost 83% higher energy as compared to wheat.

3.2. Grain and straw yield

Maximum wheat grain yield was observed in CT (4703 and 4615 kg ha^{-1}) followed by RT and ZT and minimum grain yield was obtained in ZTB (3701 and 3709 kg ha^{-1}) in 2019 and 2020, respectively. Maize maximum yield was found in CTB (6366 and 6226 kg ha^{-1}) that was followed by RT and ZT and minimum grain yield was obtained in ZT

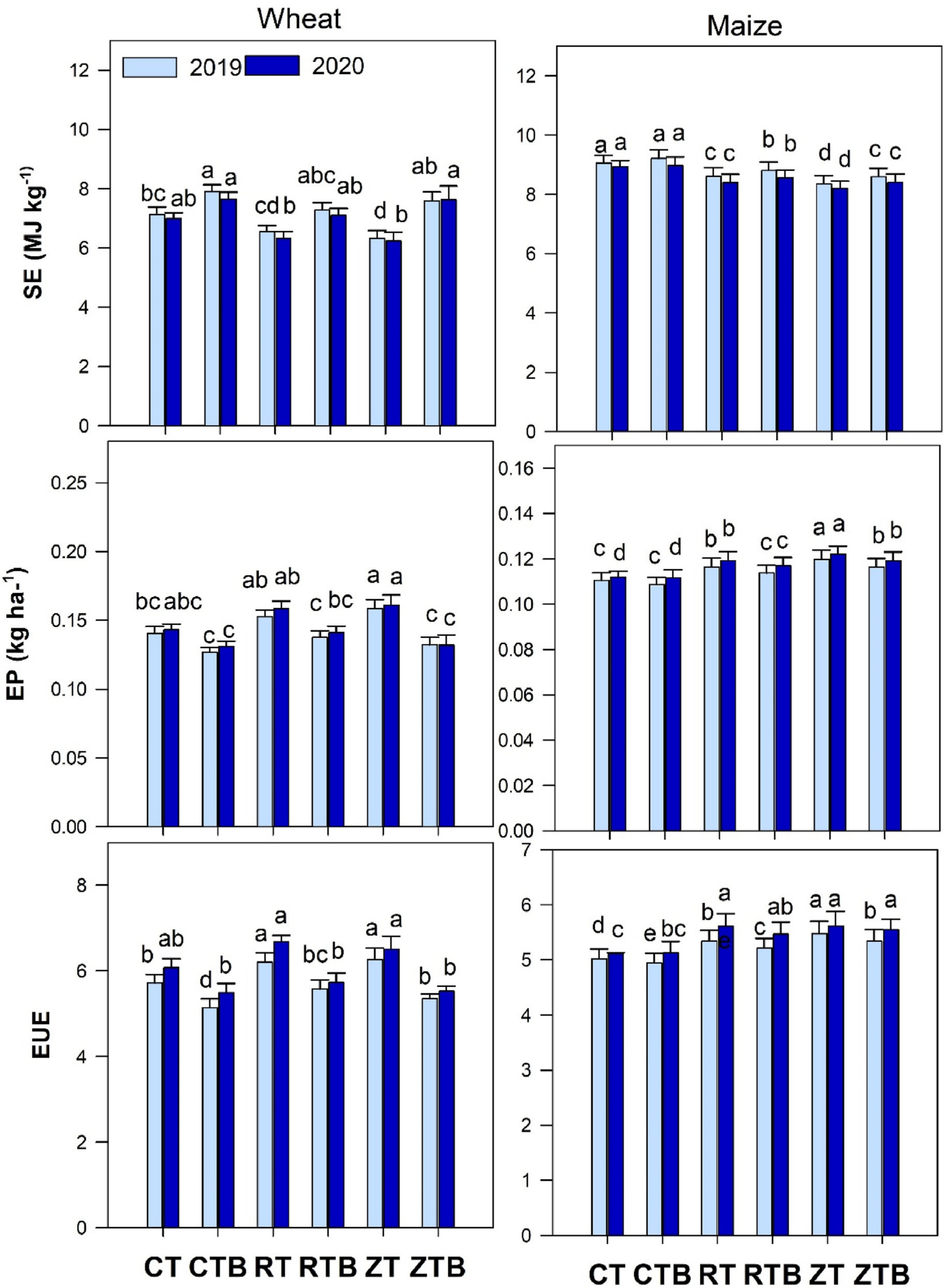

Fig. 3. Effects of different tillage systems (conventional tillage (CT), conventional tillage with bed planting (CTB), reduce tillage (RT), reduce tillage with bed planting (RTB), zero tillage (ZT), zero tillage with bed (ZTB)) on specific energy (SE), energy productivity (EP), energy use efficiency (EUE) of wheat and maize in two years (2019, 2020).

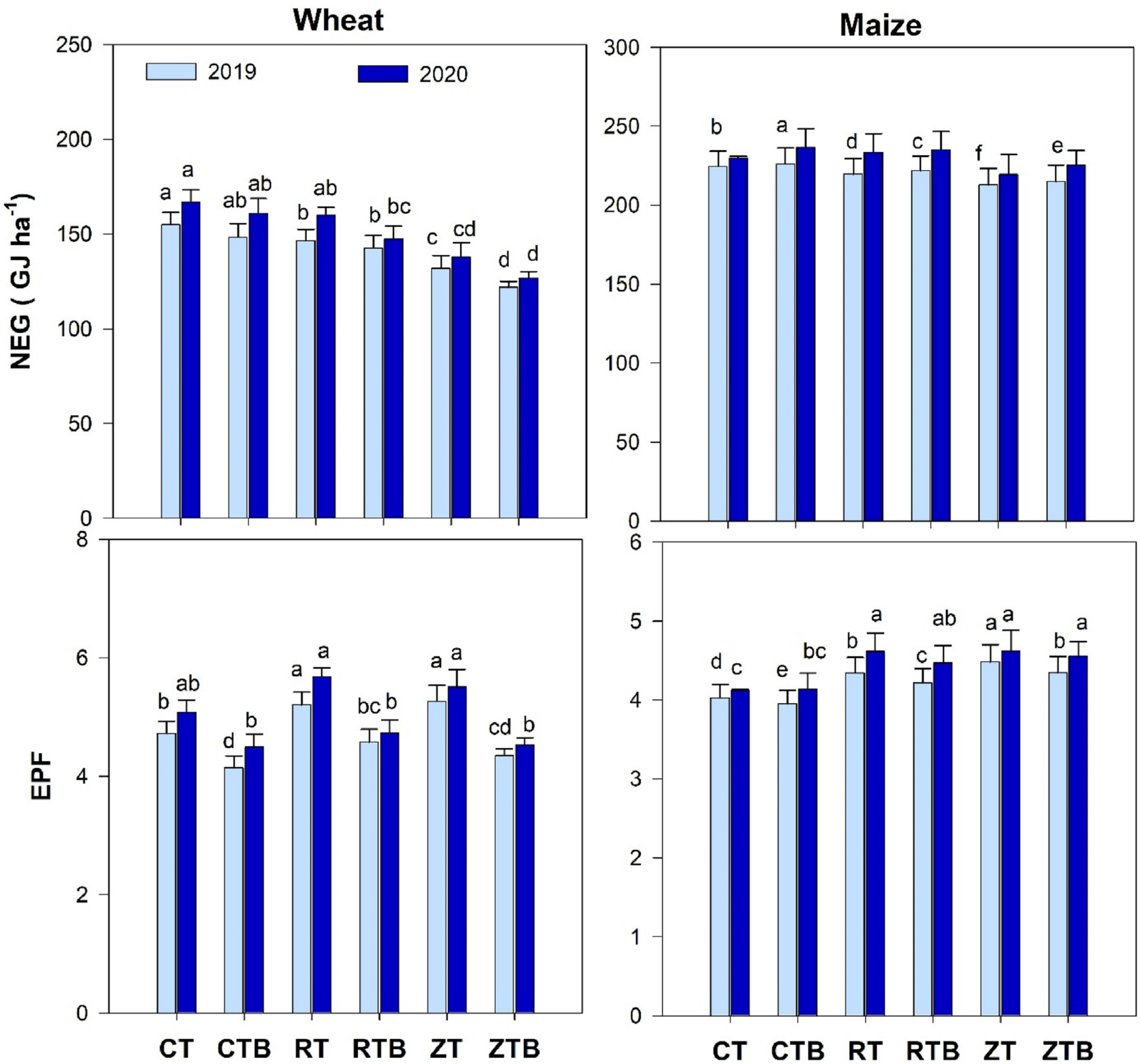

Fig. 4. Effects of different tillage systems (conventional tillage (CT), conventional tillage with bed planting (CTB), reduce tillage (RT), reduce tillage with bed planting (RTB), zero tillage (ZT), zero tillage with bed (ZTB)) on net energy gain (NEG), energy profitability (EPF) of wheat and maize in two years (2019, 2020).

(5800 and 5693 kg ha^{-1}) in 2019 and 2020, respectively. Wheat straw yield was higher under CT 10059–9225 kg ha^{-1} and the minimum was observed in ZTB 7338–7753 kg ha^{-1} in both years. Maize straw yield was higher under CTB 15020–14416 kg ha^{-1} and minimum maize straw yield was obtained in ZT ranged about 13650-13266 kg ha^{-1} in 2019 and 2020, respectively (Fig. 2).

3.3. Energy indices

The energy outputs were different in wheat and maize crops. Specific energy (SE) was significantly higher in CTB (7.90–7.646 MJ kg ha^{-1}) and the minimum was obtained in ZT (6.32–6.23 MJ kg ha^{-1}) in wheat during both experimental years. With regards to energy productivity (EP), higher EP (0.158–0.161 kg ha^{-1}) was observed in ZT, while lower under CTB (0.126–0.131 kg ha^{-1}) in 2019–2020 respectively. Maximum wheat energy use efficiency (EUE) was ~6.68 in ZT and RT and minimum 5.13 in CTB (Fig. 3). Net energy gain (NEG) was higher in CT (154.94–166.75 GJ ha^{-1}) and minimum (121 0.92–126.98 GJ ha^{-1}) in ZTB followed by CTB, RT, RTB and ZT in 2019 and 2020 respectively. Mean maximum wheat energy profitability (EPF) under ZT and RT (5.68) and minimum in CTB (4.30) during both seasons were observed, respectively. About maize SE, the amount of energy required for a unit of production was significantly higher (9.21 MJ kg ha^{-1}) in CTB and lower (8.36 MJ kg ha^{-1}) in ZT in 2019 and 2020 respectively. In maize, maximum EP ranged from 0.1087 to 0.1221 kg ha^{-1} followed by CT, CTB, RT, RTB, ZT and ZTB in both years, respectively. Maximum maize energy use efficiency (EUE) was observed in ZT (5.48–5.61) and minimum was obtained in CTB (5.13–4.94) that was followed by CT, RT, RTB and ZTB in both years respectively (Fig. 3). In maize, ZT, ZTB, CT, RT, RTB showed less NEG almost 0.77–2.98%,2.98–1.39%,1.98–0.71%,6.30–7.88% and 5.19–4.19% as compared to CTB in 2019 and 2020, respectively (Fig. 4). Mean maximum maize EPF was (4.61) in ZT and RT and minimum was recorded in CTB and CT (4.11) during both years.

3.4. Economics and benefit-cost ratio

The total cost under CTB through different inputs was higher than for all other treatments. On average ZT had 31.10% less cultivation cost than CTB. Among the various cost components such as labor cost, irrigation, fertilizer, chemicals, and acquisition of machinery were the primary sources of expenditure and it was greater under CTB in comparison to all other treatments however, the minimum cost induced for all farm operations was observed for the ZT system (Fig. 5). The cost of production of wheat was lower by 31-11% in CT, RT, RTB, ZT, ZTB than CTB. The

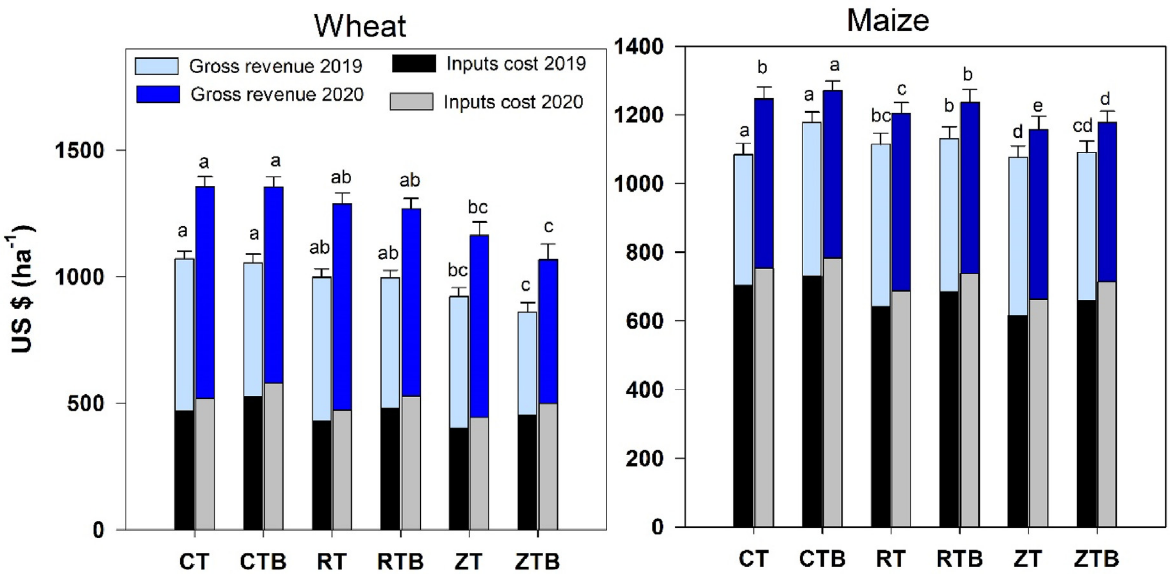

Fig. 5. Effects of different tillage systems (conventional tillage (CT), conventional tillage with bed planting (CTB), reduce tillage (RT), reduce tillage with bed planting (RTB), zero tillage (ZT), zero tillage with bed (ZTB)) on input cost and gross revenue of wheat and maize in two years (2019, 2020).

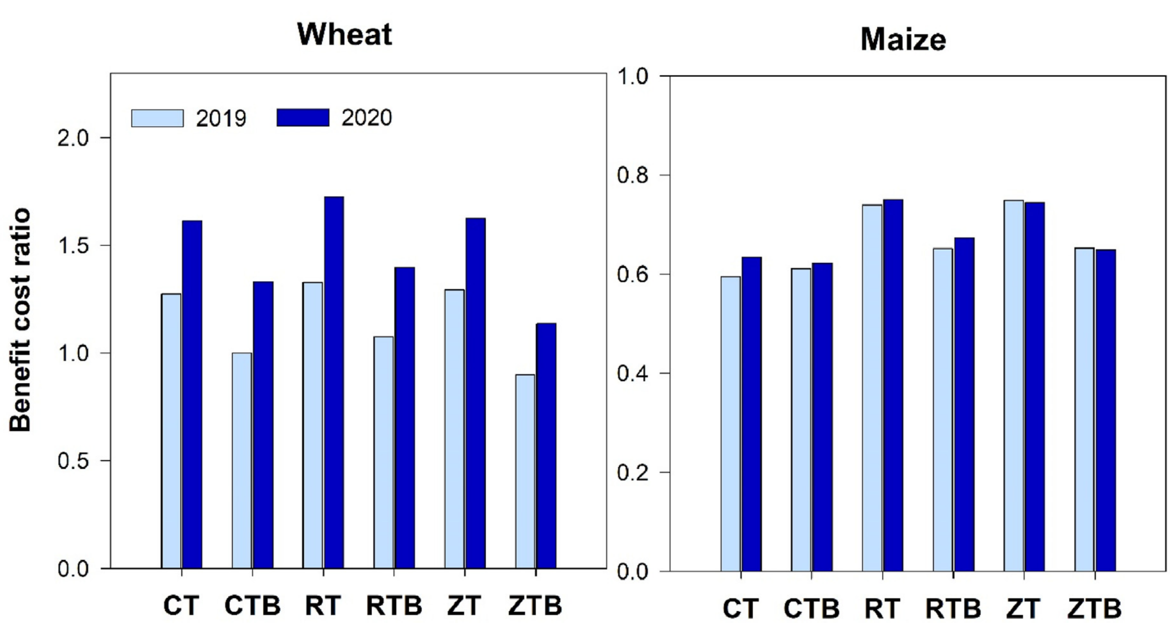

Fig. 6. Effects of different tillage systems (conventional tillage (CT), conventional tillage with bed planting (CTB), reduce tillage (RT), reduce tillage with bed planting (RTB), zero tillage (ZT), zero tillage with bed (ZTB)) on benefit cost ratio (BCR) of wheat and maize in two years (2019, 2020).

mean net income was highest in CTB (580 US $ ha^{-1}) followed by RTB (528 US $ ha^{-1}), CT (518 US $ ha^{-1}), ZTB (499 US $ ha^{-1}), RT (472 US $ ha^{-1}) and ZT (442 US $ ha^{-1}). The maximum benefit-cost ratio (BCR) of wheat was found in RT (1.32–1.72) and the minimum was recorded (0.90–1.13) in ZTB during both years, respectively. Different tillage treatments also consumed different energy, mainly higher in CTB and lower in ZT. The production cost of maize was lower by 18-3% in CT, RT, RTB, ZT and ZTB than in CTB. The mean net income was maximum in CTB (782 US $ ha^{-1}) followed by CT (752 US $ ha^{-1}), RTB (738 US $ ha^{-1}), ZTB (713 US $ ha^{-1}), RT (687 US $ ha^{-1}) and ZT (663 US $ ha^{-1}), respectively. In maize, BCR was found maximum in ZT and RT (0.75), while the minimum was recorded in ZTB (0.64–0.65) during 2019 and 2020, respectively (Fig. 6).

4. Discussion

The energy consumption pattern stated that input energy was maximum for CT and minimum for NT. The total energy used in each treatment was determined by the intensity, quantity, and type of tillage operations (Choudhary et al., 2020; Kan et al., 2020). In this study, maximum fuel consumption was observed in CTB, and minimum was recorded in ZT in both crops (wheat and maize). The data presented in the study exhibit an energy saving of 9575, 8221, 6419, and 4617 MJ ha^{-1} in CT, RTB, RT and ZT than that of CTB (35846 MJ ha^{-1}), respectively. The previous study shows that almost 50–70% of fuel energy contributed to the TIE of CT during seedbed preparation (Singh et al., 2019; Choudhary et al., 2020; Kan et al., 2020; Meena et al., 2021).

Similar findings have been observed in our study, revealing most of the energy difference due to fuel consumption in different tillage treatments (Fig. 1) Furthermore, Yadav et al. (2021b) reported that decreased tillage operations under ZT/RT reduce fuel consumption than CT. For wheat and maize comparison, wheat had almost 83% less energy inputs than that of maize, this is mainly attributed to lower fertilizer, irrigation and electricity costs. Consistent with these findings, Kumar et al. (2021) explained that fertilizer, water and diesel consumption contributed almost 60%, 25% and 10% for TIE in wheat-maize cropping systems in comparison to conservation practices.

Experimental plots treated with ZT, ZTB produced lesser wheat yield as compared to CT, CTB, RT and RTB. However, wheat yield produced in experimental plots where wheat crop was treated with CT, CTB, RT and RTB was statistically at par with each other, whereas significant differences were observed in TIE. Observed energy input differences can be attributed to variations in diesel consumption under different tillage treatments. This indicates less energy inputs used in reduced tillage treatments could be sufficient to produce equivalent yield. Gathala et al. (2016) reported less inputs/energy consumption as a sustainable practice to improve crop yield. In contrast to maize yield, CTB had higher productivity as compared to other treatments. The higher maize yield in CTB was possibly due to a raised bed that facilitates maize roots to establish better, and absorb water and nutrients efficiently than that of other treatments (Fiorini et al., 2018). Moreover, the EP and EUE in maize and wheat were higher in RT and ZT in both growing years, and this was mainly due to lower energy inputs and optimum yield production (Li et al., 2002; Singh et al., 2008a; Ghosh et al., 2016). In the same way, RT and ZT had higher EPF which was confirmed by previous energy indices. Nisar et al. (2021) also reported that various energy indices such as EUE, EP and NEG are important parameters to distinguish efficient energy practices without compromising crop productivity. Similarly, our study results showed that less energy inputs via RT, ZT and RTB are useful tillage practices to conserve energy, but only RT and RTB could be used to conserve energy without compromising wheat and maize yield (Fig. 2).

The input cost was lesser in wheat as compared to maize (Fig. 5), which was mainly attributed to the different amounts of inputs in both crops which have been indicated in Fig. 1. The main difference in inputs between maize and wheat was fertilizer, water, and electricity cost (Fig. 1). The highest input cost was noted under CTB in both crops. However, a lesser amount of irrigation, fertilizer and electricity reduced input cost in wheat in comparison to wheat. The higher input cost in bed tillage was mainly due to the extra consumption of diesel for preparing seed beds (Li et al., 2021b; Sarwar et al., 2021). Noticeably, gross revenue of RT, RTB was statistically equal to CT and CTB in wheat and RTB was statically equal to CT for maize gross revenue. This indicated that all these compared treatments had statistically equal yields in wheat and maize. Similarly, Elhami et al. (2016) also reported that bed planting consumed more diesel, increased cost and reduced BCR. In addition, net revenue was higher in wheat than in maize, which significantly affected BCR. The higher BCR was mainly attributed to lower input costs with a higher yield. Contrarily, lower BCR in maize was possibly due to higher input cost and lower net revenue generated by maize grains and straw yield. The BCR in 2020 under wheat was higher than in 2019 owing to the higher market price of wheat yield. These results are consistent with Sarwar et al. (2021) which showed higher market value and lower input prices enormously increased BCR. However, consistent market values of yield could be a useful tool to predict better crop economics. Furthermore, BCR with other energy indices should be evaluated to maintain sustainable production systems in relation to environment conservation.

5. Conclusions

Input and output energy balance in crop cultivation is a major determinant factor for a sustainable and environment-efficient crop production system. The study confirmed the hypothesis that conservation tillage practices i.e. RT, RTB, ZT and ZTB reduced energy input and input cost than intensive tillage systems (CT, CTB). Noticeably, RT significantly decreased energy inputs, increased energy utilization and wheat yield as compared to CT. More importantly, RT had a statistical mean equal wheat grain yield (4382.36 kg ha^{-1}) in comparison to CT (4659.13 kg ha^{-1}) that significantly increased economic returns and BCR as compared to conventional tillage (CT). However, maize yield was higher under CTB than other tillage practices, in return, CTB consumed more energy and reduced EUE. Higher (+94%) profitability of wheat than maize, was mainly due to higher (+83%) inputs (fertilizer, electricity, water). Overall, RT shows potential for enhancing wheat productivity and profitability by increasing energy use efficiency, as compared to intensive tillage system. Obtained results can show signs of substantial assistance for farmers suffering from escalating fuel expenses. However, further investigation into maize cultivation under reduced inputs is required to maximize yield and profitability. This study offers valuable insights into the adoption of sustainable and conservation agricultural practices, such as reduced tillage, and their implications for wheat-maize cropping systems.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors are grateful to Master's students at Agro-climatology Lab, University of Agriculture, Faisalabad, Pakistan for their assistance during data collection.

References

Ahmad, N., Virk, A.L., Hafeez, M.B., Ercisli, S., Golokhvast, K.S., Qi, Y., Guo, X., Zhang, Y., Wang, R., Wang, X., Rehmani, M.I.A., Li, J., 2024. Effects of different tillage and residue management systems on soil organic carbon stock and grain yield of rice–wheat double cropping system. Ecol. Indic. 158, 111452. https://doi.org/10.1016/j.ecolind.2023.111452.

Ahmad, N., Virk, A.L., Hafeez, M.B., Kan, Z.-R., Shi, Z., Wang, R., Iqbal, H.M.W., Rehmani, M.I.A., Wang, X., Lal, R., Li, J., 2023. Soil carbon mineralization and aggregate distribution in various tillage practices of rice–wheat cropping system: a field and laboratory study. J. Soil Sci. Plant Nutr. https://doi.org/10.1007/s42729-023-01555-2.

Babu, S., Mohapatra, K.P., Das, A., Yadav, G.S., Tahasildar, M., Singh, R., Panwar, A.S., Yadav, V., Chandra, P., 2020. Designing energy-efficient, economically sustainable and environmentally safe cropping system for the rainfed maize–fallow land of the Eastern Himalayas. Sci. Total Environ. 722, 137874. https://doi.org/10.1016/j.scitotenv.2020.137874.

Bhatt, R., 2017. Zero tillage impacts on soil environment and properties. J. Environ. Agric. Sci. 10, 1–19.

Bhunia, S., Karmakar, S., Bhattacharjee, S., Roy, K., Kanthal, S., Pramanick, M., Baishya, A., Mandal, B., 2021. Optimization of energy consumption using data envelopment analysis (DEA) in rice-wheat-green gram cropping system under conservation tillage practices. Energy 236, 121499. https://doi.org/10.1016/j.energy.2021.121499.

Chaudhary, V.P., Gangwar, B., Pandey, D.K., Gangwar, K.S., 2009. Energy auditing of diversified rice-wheat cropping systems in Indo-gangetic plains. Energy 34, 1091–1096. https://doi.org/10.1016/j.energy.2009.04.017.

Choudhary, M., Panday, S.C., Meena, V.S., Singh, S., Yadav, R.P., Pattanayak, A., Mahanta, D., Bisht, J.K., Stanley, J., 2020. Long-term tillage and irrigation management practices: strategies to enhance crop and water productivity under rice-wheat rotation of Indian mid-Himalayan Region. Agric. Water Manag. 232, 106067. https://doi.org/10.1016/j.agwat.2020.106067.

Devasenapathy, P., Senthilkumar, G., Shanmugam, P.M., 2009. Energy management in crop production. Indian J. Agron. 54, 80–89.

Elhami, B., Akram, A., Khanali, M., 2016. Optimization of energy consumption and environmental impacts of chickpea production using data envelopment analysis (DEA) and multi objective genetic algorithm (MOGA) approaches. Inf. Process. Agric. 3, 190–205. https://doi.org/10.1016/j.inpa.2016.07.002.

Esengun, K., Erdal, G., Gündüz, O., Erdal, H., 2007. An economic analysis and energy use in stake-tomato production in Tokat province of Turkey. Renew. Energy 32, 1873–1881. https://doi.org/10.1016/j.renene.2006.07.005.

Fiorini, A., Boselli, R., Amaducci, S., Tabaglio, V., 2018. Effects of no-till on root architecture and root-soil interactions in a three-year crop rotation. Eur. J. Agron. 99, 156–166. https://doi.org/10.1016/j.eja.2018.07.009.

Gathala, M.K., Timsina, J., Islam, M.S., Krupnik, T.J., Bose, T.R., Islam, N., Rahman, M.M., Hossain, M.I., Harun-Ar-Rashid, M., Ghosh, A.K., Hasan, M.M.K., Khayer, M.A., Islam, M.Z., Tiwari, T.P., McDonald, A., 2016. Productivity, profitability, and energetics: a multi-criteria assessment of farmers' tillage and crop establishment options for maize in intensively cultivated environments of South Asia. Field Crops Res. 186, 32–46. https://doi.org/10.1016/j.fcr.2015.11.008.

Ghosh, B.N., Dogra, P., Sharma, N.K., Alam, N.M., Singh, R.J., Mishra, P.K., 2016. Effects of resource conservation practices on productivity, profitability and energy budgeting in maize–wheat cropping system of Indian sub-himalayas. Proc. Natl. Acad. Sci. India B Biol. Sci. 86, 595–605. https://doi.org/10.1007/S40011-015-0492-2.

Gomiero, T., 2016. Soil degradation, land scarcity and food security: reviewing a complex challenge. Sustainability 8, 281. https://doi.org/10.3390/su8030281.

Gong, X., Qiu, R., Zhang, B., Wang, S., Ge, J., Gao, S., Yang, Z., 2021. Energy budget for tomato plants grown in a greenhouse in northern China. Agric. Water Manag. 255, 107039. https://doi.org/10.1016/J.AGWAT.2021.107039.

Guo, Y., Yin, W., Chai, Q., Yu, A., Zhao, C., Fan, Z., Fan, H., Coulter, J.A., 2021. No tillage and previous residual plastic mulching with reduced water and nitrogen supply reduces soil carbon emission and enhances productivity of following wheat in arid irrigation areas. Field Crops Res. 262, 108028. https://doi.org/10.1016/j.fcr.2020.108028.

Hakeem, A., Liu, Y., Xie, L., Tahir Ata-Ul-Karim, S., Huang, J., 2016. Comparative effects of alternate partial root-zone drying and conventional deficit irrigation on growth and yield of field grown maize (Zea mays L.) hybrid. J. Environ. Agric. Sci. 6, 23–31.

Iqbal, S., Khalid, U.B., Saleem, M.U., Iram, A., Ahmad, N., Iqbal, N., Sabar, M., Awan, T.H., 2019. Agronomic efficiency and economics of crop establishing techniques and nitrogen application in fine aromatic rice (*Oryza sativa*). Int. J. Agric. Biol. 22, 1347–1355.

Jat, R.D., Jat, H.S., Nanwal, R.K., Yadav, A.K., Bana, A., Choudhary, K.M., Kakraliya, S.K., Sutaliya, J.M., Sapkota, T.B., Jat, M.L., 2018. Conservation agriculture and precision nutrient management practices in maize-wheat system: effects on crop and water productivity and economic profitability. Field Crops Res. 222, 111–120. https://doi.org/10.1016/j.fcr.2018.03.025.

Kan, Z. Rong, Virk, A.L., He, C., Liu, Q.Y., Qi, J.Y., Dang, Y.P., Zhao, X., Zhang, H.L., 2020. Characteristics of carbon mineralization and accumulation under long-term conservation tillage. Catena 193, 104636. https://doi.org/10.1016/j.catena.2020.104636.

Kumar, Adarsh, Rana, K.S., Choudhary, A.K., Bana, R.S., Sharma, V.K., Prasad, S., Gupta, G., Choudhary, M., Pradhan, A., Rajpoot, S.K., Kumar, Abhishek, Kumar, Amit, Tyagi, V., 2021. Energy budgeting and carbon footprints of zero-tilled pigeonpea–wheat cropping system under sole or dual crop basis residue mulching and Zn-fertilization in a semi-arid agro-ecology. Energy 231. https://doi.org/10.1016/J.ENERGY.2021.120862.

Kumar, M., 2011. Yield production and energy budget of traditional agricultural crops in garhwal himalaya. Agric. Sci. China 10, 78–85. https://doi.org/10.1016/S1671-2927(11)60309-X.

Kumar, V., Jat, H.S., Sharma, P.C., Balwinder-Singh, Gathala, M.K., Malik, R.K., Kamboj, B.R., Yadav, A.K., Ladha, J.K., Raman, A., Sharma, D.K., McDonald, A., 2018. Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. Agric. Ecosyst. Environ. 252, 132–147. https://doi.org/10.1016/j.agee.2017.10.006.

Kumar, V., Saharawat, Y.S., Gathala, M.K., Jat, A.S., Singh, S.K., Chaudhary, N., Jat, M.L., 2013. Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic Plains. Field Crops Res. 142, 1–8. https://doi.org/10.1016/j.fcr.2012.11.013.

Li, F.R., Gao, C.Y., Zhao, H.L., Li, X.Y., 2002. Soil conservation effectiveness and energy efficiency of alternative rotations and continuous wheat cropping in the Loess Plateau of northwest China. Agric. Ecosyst. Environ. 91, 101–111. https://doi.org/10.1016/S0167-8809(01)00265-1.

Li, S., Wu, J., Ma, L., 2021a. Economic, energy and environmental consequences of shifting from maize-wheat to forage rotation in the North China Plain. J. Clean. Prod. 328, 129670. https://doi.org/10.1016/j.jclepro.2021.129670.

Li, S., Wu, J., Ma, L., 2021b. Economic, energy and environmental consequences of shifting from maize-wheat to forage rotation in the North China Plain. J. Clean. Prod. 328, 129670. https://doi.org/10.1016/j.jclepro.2021.129670.

Liu, Q.Y., Xu, C.T., Han, S.W., Li, X.X., Kan, Z.R., Zhao, X., Zhang, H.L., 2021. Strategic tillage achieves lower carbon footprints with higher carbon accumulation and grain yield in a wheat-maize cropping system. Sci. Total Environ. 798, 149220. https://doi.org/10.1016/j.scitotenv.2021.149220.

Malhi, G.S., Rana, M.C., Kumar, S., Rehmani, M.I.A., Hashem, A., Abd_Allah, E.F., 2021. Efficacy, energy budgeting, and carbon footprints of weed management in blackgram (*Vigna mungo* L.). Sustainability 13 (23), 13239. https://doi.org/10.3390/su132313239.

Meena, B.P., Biswas, A.K., Singh, M., Das, H., Chaudhary, R.S., Singh, A.B., Shirale, A.O., Patra, A.K., 2021. Energy budgeting and carbon footprint in long-term integrated nutrient management modules in a cereal- legume (Zea mays – cicer arietinum) cropping system. J. Clean. Prod. 314. https://doi.org/10.1016/J.JCLEPRO.2021.127900.

Meena, J.R., Behera, U.K., Chakraborty, D., Sharma, A.R., 2015. Tillage and residue management effect on soil properties, crop performance and energy relations in greengram (Vigna radiata L.) under maize-based cropping systems. Int. Soil Water Conserv. Res. 3, 261–272. https://doi.org/10.1016/j.iswcr.2015.11.001.

Mehmood, S., Iqbal, M., Shahid, M., Zamir, I., Rasool, T., Ul Haq, I., Sohail, M., 2015. Effect of plastic mulch and different irrigation practices on soil properties, nutrient contents and their availability in maize and their availability in maize. J. Environ. Agric. Sci.

Mobtaker, H.G., Keyhani, A., Mohammadi, A., Rafiee, S., Akram, A., 2010. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. Agric. Ecosyst. Environ. 137, 367–372. https://doi.org/10.1016/j.agee.2010.03.011.

Ndayisaba, P.C., Kuyah, S., Midega, C.A.O., Mwangi, P.N., Khan, Z.R., 2023. Push-pull technology enhances resilience to climate change and prevents land degradation: perceptions of adopters in western Kenya. Farming Syst 1, 100020. https://doi.org/10.1016/J.FARSYS.2023.100020.

Nisar, S., Benbi, D.K., Toor, A.S., 2021. Energy budgeting and carbon footprints of three tillage systems in maize-wheat sequence of north-western Indo-Gangetic Plains. Energy 229, 120661. https://doi.org/10.1016/j.energy.2021.120661.

Pimentel, D., 1980. Energy inputs for the production, formulation, packaging, and transport of various pesticides. In: Handbook of Energy Utilization in Agriculture. CRC, Boca Raton, pp. 45–48.

Sarwar, N., Atique-ur-Rehman, Farooq, O., Wasaya, A., Hussain, M., El-Shehawi, A.M., Ahmad, S., Brestic, M., Mahmoud, S.F., Zivcak, M., Farooq, S., 2021. Integrated nitrogen management improves productivity and economic returns of wheat-maize cropping system. J. King Saud Univ. Sci. 33, 101475. https://doi.org/10.1016/j.jksus.2021.101475.

Sharma, S., 1991. Energy budget studies of some multiple cropping patterns of the Central Himalaya. Agric. Ecosyst. Environ. 36, 199–206. https://doi.org/10.1016/0167-8809(91)90017-R.

Singh, K.P., Prakash, V., Srinivas, K., Srivastva, A.K., 2008a. Effect of tillage management on energy-use efficiency and economics of soybean (Glycine max) based cropping systems under the rainfed conditions in North-West Himalayan Region. Soil Till. Res. 100, 78–82. https://doi.org/10.1016/j.still.2008.04.011.

Singh, K.P., Prakash, V., Srinivas, K., Srivastva, A.K., 2008b. Effect of tillage management on energy-use efficiency and economics of soybean (Glycine max) based cropping systems under the rainfed conditions in North-West Himalayan Region. Soil Till. Res. 100, 78–82. https://doi.org/10.1016/j.still.2008.04.011.

Singh, P., Singh, G., Sodhi, G.P.S., 2019. Energy auditing and optimization approach for improving energy efficiency of rice cultivation in south-western Punjab, India. Energy 174, 269–279. https://doi.org/10.1016/j.energy.2019.02.169.

Singh, P., Singh, G., Sodhi, G.P.S., Sharma, S., 2021. Energy optimization in wheat establishment following rice residue management with Happy Seeder technology for reduced carbon footprints in north-western India. Energy 230, 120680. https://doi.org/10.1016/j.energy.2021.120680.

Tuti, M.D., Prakash, V., Pandey, B.M., Bhattacharyya, R., Mahanta, D., Bisht, J.K., Kumar, M., Mina, B.L., Kumar, N., Bhatt, J.C., Srivastva, A.K., 2012. Energy budgeting of colocasia-based cropping systems in the Indian sub-Himalayas. Energy 45, 986–993. https://doi.org/10.1016/J.ENERGY.2012.06.056.

Wily, L.A., 2018. Collective land ownership in the 21st century: overview of global trends. Land 7 (2), 68. https://doi.org/10.3390/land7020068.

Yadav, G.S., Babu, S., Das, A., Datta, M., Mohapatra, K.P., Singh, R., Singh, V.K., Rathore, S.S., Chakraborty, M., 2021a. Productivity, soil health, and carbon management index of Indian Himalayan intensified maize-based cropping systems under live mulch based conservation tillage practices. Field Crops Res. 264. https://doi.org/10.1016/j.fcr.2021.108080.

Yadav, G.S., Das, A., Kandpal, B.K., Babu, S., Lal, R., Datta, M., Das, B., Singh, R., Singh, V.K., Mohapatra, K.P., Chakraborty, M., 2021b. The food-energy-water-carbon nexus in a maize-maize-mustard cropping sequence of the Indian Himalayas: an impact of tillage-cum-live mulching. Renew. Sustain. Energy Rev. 151, 111602. https://doi.org/10.1016/j.rser.2021.111602.

Yadav, G.S., Das, A., Lal, R., Babu, S., Meena, R.S., Saha, P., Singh, R., Datta, M., 2018. Energy budget and carbon footprint in a no-till and mulch based rice–mustard cropping system. J. Clean. Prod. 191, 144–157. https://doi.org/10.1016/j.jclepro.2018.04.173.

Zhao, X., Virk, A.L., Ma, S.T., Kan, Z.R., Qi, J.Y., Pu, C., Yang, X.G., Zhang, H.L., 2020. Dynamics in soil organic carbon of wheat-maize dominant cropping system in the North China Plain under tillage and residue management. J. Environ. Manag. 265, 110549. https://doi.org/10.1016/j.jenvman.2020.110549.