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Research Article

Optimizing Wheat Yield and Biomass for Bioenergy: A Comparative Study of Multi-Sowing Techniques for Sustainable and Eco-friendly Production

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ABSTRACT

Conventional tillage is more laborious, more time consuming and more water consuming for wheat production. On the other hand, zero tillage is less time, and less water consumed with minimum labor requirement. Zero tillage also has a lesser environmental impact as it reduces soil erosion, greenhouse gas emissions, and the overall consumption of resources such as fuel and water. In the rice wheat cropping system, there is minimum time available for sowing of wheat after the harvest of paddy rice. Due to delay in sowing wheat, losses of yield are 35 to 60 kg/day/ha. To increase the production of food and to meet the needs of food security are the key challenges for scientists. The demand for food is still increasing, not only to meet food security for a growing population, but also to provide more nutritious food that makes protein quality, vitamins, and some essential minerals (iron and zinc) more available. With the help of zero tillage, we can sow wheat at a minimum time after the harvest of paddy rice, by utilizing the moisture contents of rice straw for the germination of wheat. The aim of research was to compare these two sowing techniques for wheat production by considering the parameters like emerging rate index of wheat seed and crop yield along with some suitable statistical technique. The value of the moisture content was highest in zero tillage technique was 18.55%. On the other hand, the smallest value of the moisture content was found with conventional tillage system (16.59%). The highest value of the emergence rate index was found for zero tillage technique (14.11 %/day) and lowest value of the emergence rate index was found with conventional tillage technique was 11.8 %/day. The total dry biomass recorded was 420 g/m² for zero tillage and 360 g/m² for conventional tillage suggesting a greater potential for bioenergy applications. Therefore, zero tillage practices are more environmentally sustainable and beneficial for farmers compared to conventional tillage systems in the rice-wheat cropping system.

Keywords: Zero tillage, Moisture content, Emerging rate index, Sustainable wheat production, Biomass, Eco-friendly.

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INTRODUCTION

The agricultural history is divided into prehistoric, ancient, middle and modern ages (Balkrishna et al., 2021). The agricultural sector was limited during the prehistoric duration with limited family members. Woodland cleaning and drainage of wetland was performed during the Middle Ages. Mould board plough and scratch plough were developed. In the 19th century crop yield had raised many times more than the previous ages by use of agricultural implements and innovation of tractor (Reddy, 2022). Proper time is required for sowing and harvesting crops. It is because time management is more essential for the next crop. This objective was achieved with the innovation of tractor in 19^{th} century. In this century more people were interested in agriculture as compared to the ancient Middle Ages because of ease of work (Baur and Iles, 2023).

With the passage of time, it was observed that wide-ranging tillage was the main reason for decreasing soil fertility (Shaheb et al., 2021). In addition, conventional tillage practices contribute to environmental degradation by increasing soil erosion, greenhouse gas emissions, and water consumption. It is because fertile layer of soil is removed by wind during extensive tillage operations. Tillage costs were also increased in the form of fuel, wear and tear of agricultural equipment and the cost of operator. If animals are used for tillage purposes to remove the cost of fuel consumption by tractor in agriculture, the cost of feeding and caring for animals also increased over the year. Due to the consumption of diesel by tractor to perform tillage operation, greenhouse gas emissions from the burning of diesel fuel to create global warming. Tillage also disrupts the microbial activity of soil microorganisms (O'Callaghan et al., 2022). Tractor wheels also compact the soil below the surface (Zhang et al., 2024).

For the removal of extensive tillage concept that creates many problems in soil, zero tillage practices were introduced (Carrara et al., 2024). Zero tillage is an environmentally sustainable practice that helps conserve soil structure, reduce greenhouse gas emissions, and improve water retention (Bezboruah et al., 2024). Zero tillage is that type of technology which has direct seedlings of crops after the harvesting of the previous crop. For example, after the harvest of rice, with the help of zero tillage drill direct seedling of wheat crops without tillage practices or no till. In this method, there is the benefit of time saving, reduced fuel consumption, reduced soil erosion and number of irrigations (Kienzler et al., 2012). Numerous investigations show the supremacy of conservation tillage above unadventurous tillage practices (Hassan et al., 2022).

In the cropping system of rice-wheat, there is main problem for the sowing of wheat after the harvest of rice as the availability of time is very less because of delayed harvest of paddy (Debangshi and Ghosh, 2022). According to a study the delayed sowing of wheat can pose a potential loss in yield i.e. 35 to 60 kg/day/ha, ultimately it results in lesser production of biomass which leads to a reduction in the bioenergy production. Biomass to bioenergy conversion is a sustainable approach to reduce the dependance of fossil fuels which also ensure to play a major role to enhance the economy of one's country (Dhanda et al., 2022; Asif et al., 2024). To tackle these challenges and positive contribution of biomass to bio-energy conversion, zero tillage is the solution to minimize time required for sowing, minimize labor requirement as compared to conventional tillage for wheat production after the harvest of paddy (Kumar et al., 2021). Rice consumed around 80 percent of the application of total water in the rice-wheat cropping system. The objective of the current study was to compare multi sowing techniques used for wheat crop production.

MATERIALS AND METHODS

Research involved comparative study of multi-sowing techniques to check the variability in wheat production. The research was carried in two phases. The first phase includes crop production and yield estimation. In the second phase cost analysis was carried out. The area of research was comprised of two acres of agriculture land. One acre was sown by zero tillage method for wheat production and other acre was sown by conventional tillage system for wheat production. Input cost and number of irrigations were same for both research plots. The foremost objective of this research was to compare crop yield and cost analysis regarding parameters of soil moisture content, emerging rate index by zero tillage and conventional tillage run-through for wheat production at the village of Hasilpur, tehsil Chishtian and district Bahawalnagar-Pakistan. In cost analysis, cost was included from the initial stage of wheat sowing up to wheat harvest. Cost analysis was carried out including labor cost and fuel cost. In conventional tillage the use of rotavator, cultivator and seed broadcasting followed by planker. With the help of zero tillage, we can sow the wheat in minimum time after the harvest of paddy rice, by utilizing the moisture contents of rice straw for the germination of wheat crop. The research aimed to compare these two sowing techniques for wheat production by considering the parameters like emerging rate index and crop yield along with some suitable statistical techniques.

Study Area Description

Study of research was conducted at the agriculture farm of Division Bahawalpur, Punjab-Pakistan during winter season.

Climate

The climate of the study area of my research touched two extremes. The minimum temperature during the winter season was 12 degrees calcius and the maximum temperature during summer season was recorded 51 degree calcius. Start of summer season from April that continue till October. During the summer season June and July are the warmest months. The winter season starts in November and continues till March. During the winter season January and February are the coldest months.

Topography

The topography of study zone is comparatively flat, ranging of the land shallow gradient from 0.26 m/km in the North and North-East to lower than 0.22m/km to South and South-West. The research area is most appropriate at 182 m beyond sea level (ASP, 2004).

Soil

Soil investigation of Pakistan is totally dependent on the clarification of the availability of aerial shooting for that area which categorized the soil on the origin of general features. Soil of the research area is coarse with suitable characteristics of permeability and the whole area is shown similar. The nature of the research area soil is lower in organic matter and PH range of the soil is 7 to 7.8. The soil is most appropriate for a multi variety of crops.

Materials and Machines Description

Zero tillage drill

Zero tillage drill only tills that part of soil which undergoes planting of seed. It improves the soil condition, water requirements and controls the production cost. The inter crop gap is reduced by the zero tillage technique as compared to the conventional tillage system.

Figure 1. (a) Zero tillage machine in the research area. (b) Physical observation of wheat. (c) Mixing of fertilizer into the soil along with wheat sowing. (d) Wheat sowing using a zero tillage machine.

Firstly, zero tillage machine was taken to the research area with the help of three pin linkage of tractor as shown in figure 1 in (a) Machine was checked in the field for the seeds of wheat physically that how the seeds placed into the soil by the movement of zero tillage machine in field by three pin linkage of tractor as shown in (b). It was observed that when the tractor moved forward, wheat seed and fertilizer were mixed and placed into the soil at a time that is shown in (c) Sowing of wheat with the help of zero tillage machine was completed in my research area and it was observed at that time the placement of wheat seed was in straight line that is shown in (d).

Rotavator

Rotavator is neither a primary tillage implement, nor secondary tillage implement. But it is described as a special purpose type of implement. It is used for the purpose of pulverization and inversion of soil. Rotavator was taken to field by three pin linkage of tractor in research area. The application of rotavator was at watter condition of soil. The use of rotavator in the field is included in conventional tillage practices. Rotavator is used in fields to pulverize the soil that is more appropriate for sowing wheat as shown in Figure. 2.

Figure 2. Rotavator in field (Conventional tillage system).

Cultivator

Cultivator was also taken to research area with the help of tractor three pin linkage. The use of the cultivator into the field is to break the hard pan of the soil that is shown in Figure. 3. The main objective of the cultivator into the field is to break the hard pan of the soil. Than after, planker was used to stable the wheat seeds into soil as well as to plain the surface of soil as shown in Figure. 3.

Figure 3. (a) Cultivator in Field. (b) After the utilization of cultivator with planner in field.

Parameters

The following parameters were included to compare the multi sowing techniques for wheat crop production:

Emerging rate index

Crop yield

Moisture content

Emergence rate index (ERI)

It is the value of readings that how many plants are emerging every day in unit area. In each treatment of one-meter square, three readings are taken and continue to take readings every day until ERI is constant. ERI will be intended by means of the formula (Noorka and Khaliq, 2007).

Emerging rate index (ERI) = Plants emerged in a day (DAP) / Plants emerged by (DAP)
DAP stands for day after planting

Moisture Content

It is the total quantity of water present in the soil. For appropriate ERI, proper moisture content is required. Water can be absorbed into the body of soil particles or retained on the soil surface as a film of moisture content.

Percentage of moisture = Initial weight-oven dry weight/Initial weight*100

Crop yield

Crop was harvested by combine harvester from both type of plots that were sown by zero ploughing as well as conventional ploughing performs. The total area of both plots was 2 acres. 1 acre was sown by zero tillage system and other acre was sown by conventional tillage practices. Crop yield would be calculated by using the given equation below:

$$Y=Wg/CA$$

Where,
Y= Grain yield of crop, t/ha.
Wg= Grain weight of grains (g)
A= cultivated Area, $1m^2$
C= 100 (constant)

Moreover, the scrutiny of soil moisture, soil type and irrigation water had been done to create a similar environment for both research plots for conventional and zero tillage techniques. After that, a cost analysis of both techniques was carried out to check the feasibility of both techniques.

RESULTS AND DISCUSSION

Research was focused on zero tillage system and conventional tillage techniques for wheat production. The collection of the data was started from the first day of plant emergence in the field. The date wise collection of data was done for zero tillage (figure 4) and conventional tillage (figure 5). The value of the measured ERI for cultivator plus rotavator (conventional tillage techniques) and zero tillage system were 11.7, 14.12 %/day respectively. The highest value of the ERI was measured as 14.12 %/day for zero tillage drill. While the smallest value of the ERI for conventional tillage practices was observed 11.7 %/day (table 1).

Table 1. Emerging rate index of zero tillage and conventional tillage techniques.

Techniques	Emerging rate index (% / day)
Zero tillage	14.12
Conventional tillage	11.7

The highest value of the ERI for zero tillage system was due to the placement of the seeds at proper depth (Karayel, 2009). On the other hand, the value of the ERI was lowest with conventional tillage system as compared to the value of the ERI with zero tillage system. This was due to the imbalance placement of the seeds at irregular depth.

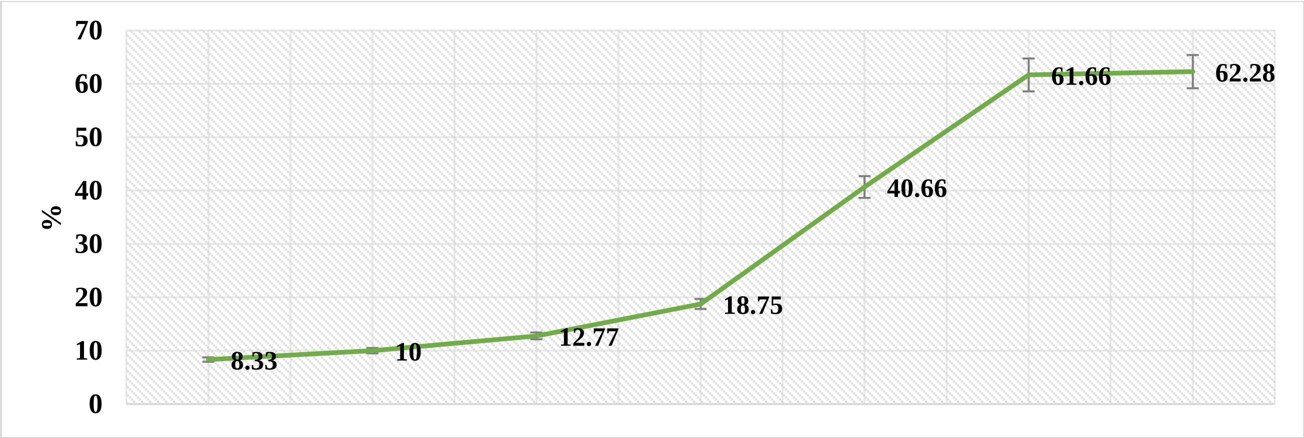

Figure 4. Emerging rate index of zero tillage vs date.

In case of the zero-tillage system, there were crop residues also left on the soil surface that results in the case of the crop yield increased due to an increase in the rate of plant emergence which leads to increase in the biomass production (Zhang and Wu, 2021). Results were observed by the (Ramírez et al., 2022) the rate of the plant emergence was more in case of zero ploughing actions as compared to the unadventurous tillage methods.

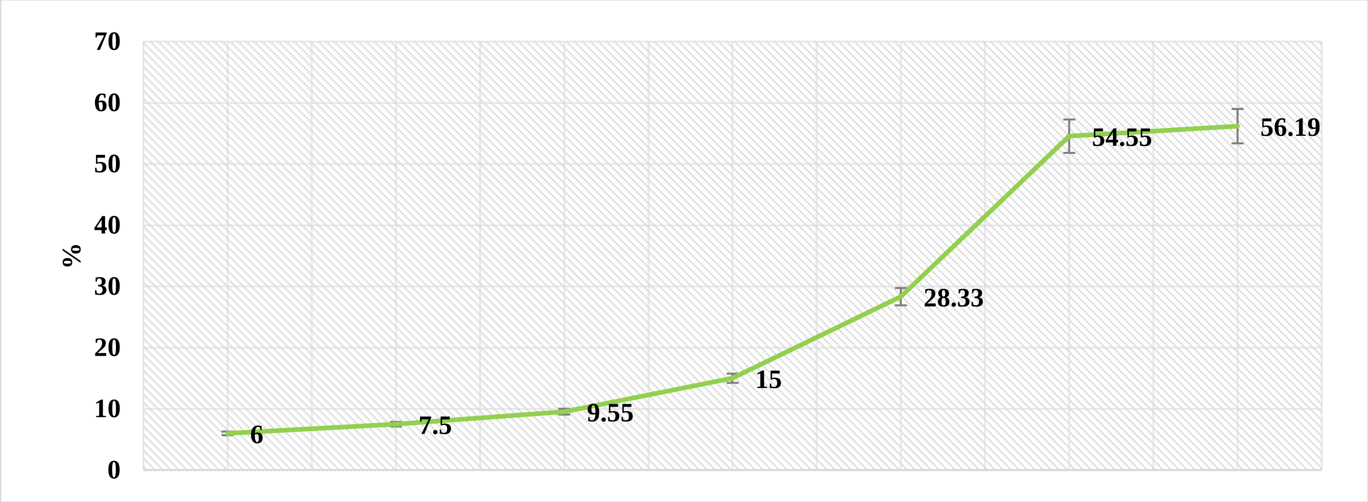

Figure 5. Emerging rate index during different wheat growth period under conventional tillage.

Moisture Content

Moisture content = Initial weight-oven dry weight / Initial weight * 100

Firstly, 1000 g of soil sample after wheat sowing from both types of tillage plots like zero tillage as well as conventional tillage to the laboratory of Degree College Hasilpur. Place the soil sample of both practices into the oven dry instrument for 24 hours. After 24 hours, took the soil sample of both practices and weight it again. The weight of the soil sample of zero tillage was 815g and the weight of the soil sample of conventional tillage practices was 847g.

Moisture content (Zero tillage) = 1000-815 / 1000 * 100 = 18.5%

Moisture content (Conventional tillage) = 1000-847 / 1000 * 100 = 15.3%

The value of the moisture content was highest in zero tillage technique of T2 treatment was 18.55%. On the other hand, the smallest value of the moisture content was found with conventional tillage system of T1 treatment was 16.59% (figure 2). Similar results were also observed by (Ali et al., 2019; De Vita et al., 2007).

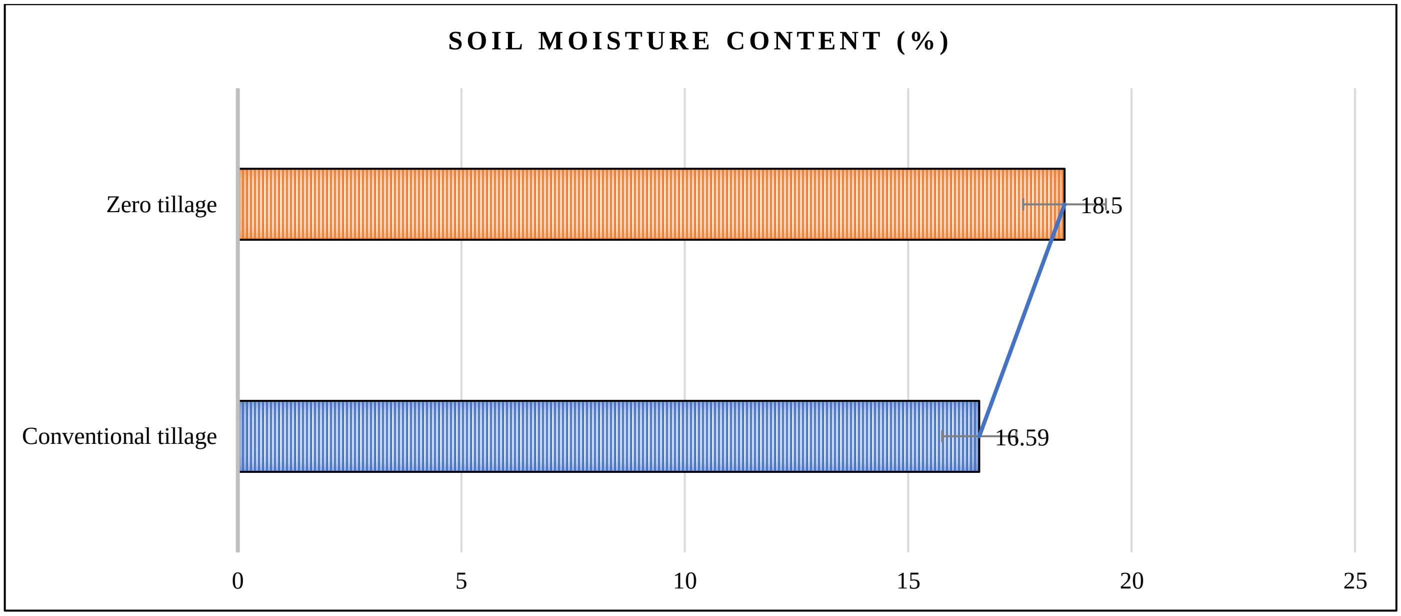

Figure 6. Soil moisture content of conventional tillage and zero tillage.

Crop Yield

Crop yield of wheat crop that had been sown by zero tillage techniques and conventional tillage system was recorded 44 mounds / acre and 35 mounds / acre respectively (figure 6). Crop yield of wheat crop that had sown by zero tillage method was higher as compared to the crop yield of wheat crop that had sown by conventional tillage system as shown in Figure 10.

Zero tillage practices are the best and most suitable for the farmers as time saving, labor saving and minimum input cost to get maximum output of wheat crop in terms of yield and biomass production as compared to the conventional tillage system in rice-wheat cropping system (Erenstein and Laxmi, 2008). In conventional tillage system, there is maximum input cost in case of cultivating the land before the time of irrigation application to obtain water condition (Erenstein and Laxmi, 2008). Irrigated the land before the time of sowing to get water condition. Than after gaining water condition, plough the land two times by cultivator to pulverize the soil before sowing. Than after broadcasting wheat seed and used third time cultivator with planner to obtain plain surface of soil as well as mix the seed and DAP fertilizer into the soil (Erenstein and Laxmi, 2008).

In zero tillage practices, there is no need to plough the land or harrow the land by cultivator or rotavator. There is also no need for any irrigation application before sowing time like to get water condition that are used in conventional tillage system (Keil et al., 2015). Zero tillage drill only tills that part of soil which undergoes planting of seed. It improves the soil condition, water requirements and controls the production cost. The inter crop gap is reduced by the zero tillage technique as compared to the conventional tillage system. Residue of the leaves are located on the superficial soil only in the center of the rows that are under planting. It is more beneficial practice to reduce soil water and wind erosion. Thus, storage of water in the soil profile.

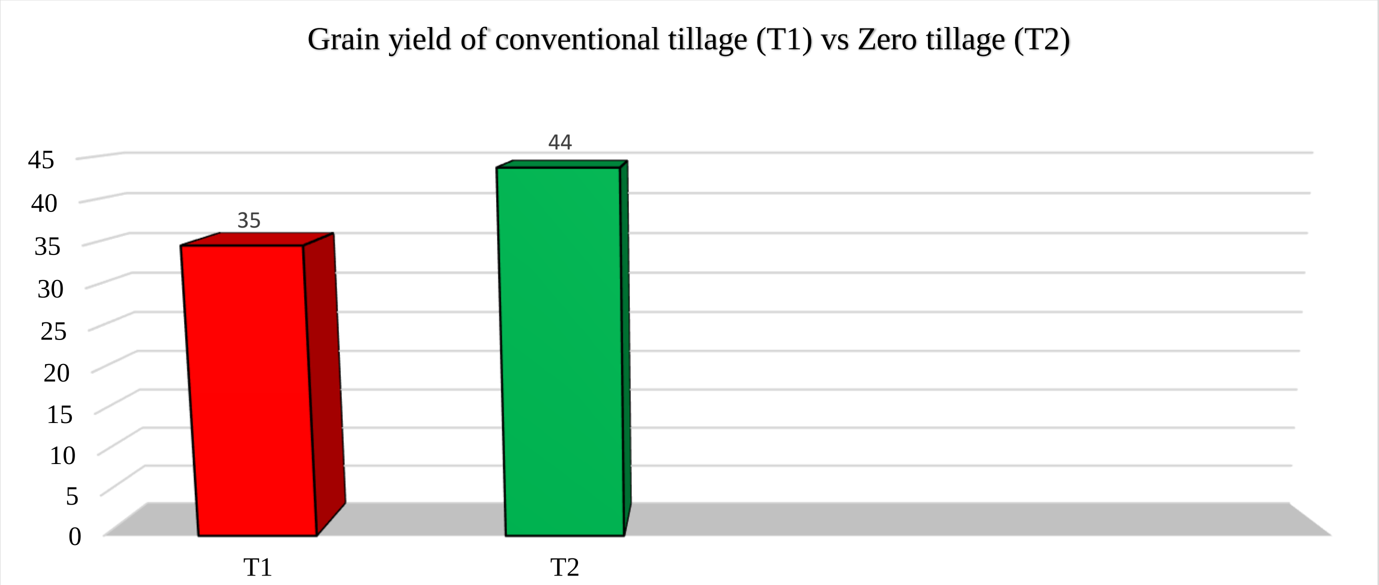

Figure 7. Grain yield of conventional tillage vs zero tillage.

I observed that crop yield by zero tillage technique was 44 mounds/acre and crop yield by conventional tillage system was 35 mounds/acre. So that’s why Zero tillage practices is most appropriate and beneficial for the farmers as compared to the conventional tillage system in rice-wheat cropping system (Erenstein and Laxmi, 2008).

Biomass Accumulation and Measurement

Biomass accumulation is a crucial factor in determining crop productivity and its potential for bioenergy production. In this study, biomass was measured at different growth stages by collecting plant samples from both zero tillage and conventional tillage plots. The collected biomass was dried to a constant weight and expressed in terms of dry matter production per unit area (g/m^2).

The results indicated that zero tillage plots had a higher biomass accumulation compared to conventional tillage plots due to better soil moisture retention and optimal seed placement. The total dry biomass recorded was 420 g/m^2 for zero tillage and 360 g/m^2 for conventional tillage, showing a 16.7% increase in biomass production under zero tillage conditions (figure 8).

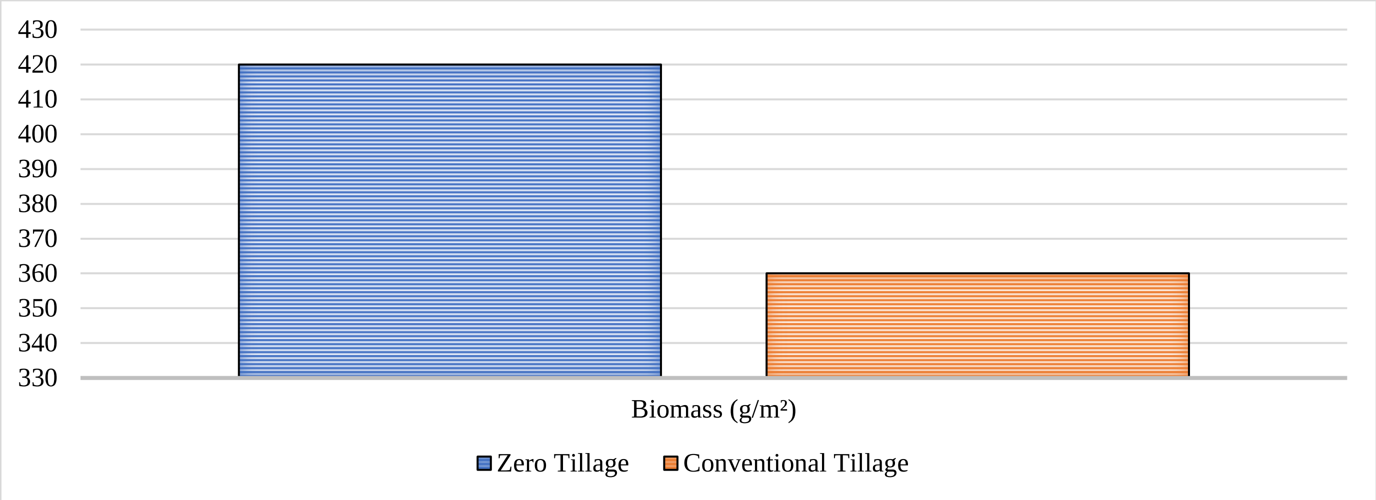

Figure 8. Estimation of biomass of conventional tillage vs zero tillage.

Biomass Utilization for Bioenergy

Enhanced biomass production under zero tillage systems suggests greater potential for bioenergy applications. Wheat biomass, particularly straw and stubble, can be converted into biofuels through conversion technologies like biofuel pellets, Biochar from pellets, gasification, and pyrolysis. Studies indicate that wheat straw has an energy potential of approximately 15-17 MJ/kg, making it a viable feedstock for bioenergy production.

The increased biomass under zero tillage contributes to sustainable energy production by reducing dependency on fossil fuels. Moreover, the retention of crop residues in zero tillage further supports soil carbon sequestration, which enhances soil health and mitigates greenhouse gas emissions.

CONCLUSIONS

Crop yield of the zero-tillage technique was found to be highest at 44 mounds/acre, while the lowest yield was 35 mounds/acre with the conventional tillage technique. Beyond higher yields, zero tillage practices also provide significant environmental benefits by reducing soil erosion, conserving moisture, and decreasing overall water and fuel consumption. Along with larger production of biomass in terms of the number of healthy plants per acre having greater leaf area index which leads to ensure the greater availability of biomass for bioenergy conversion. Therefore, zero tillage techniques are more suitable for sustainable farming in the rice-wheat cropping system. Conventional tillage, on the other hand, demands higher input costs, including labor, fuel, and water, and has a higher environmental footprint. Considering increasing environmental concerns and energy crises, zero tillage practices emerge as an eco-friendly and more cost-effective alternative to conventional tillage systems for wheat production.

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AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

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