Policy Journal of Social Science Review
ISSN (Online): 3006-4635
ISSN (Print): 3006-4627
https://journalofsocialsciencereview.com/index.php/PJSSR
Vol. 2 No. 4 ,(Fall-2024)

Policy Journal of
Social Science Review

Let's Start!

Optimizing Wheat Yield through Sowing and Tillage Management in Silty Loam Soils

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Abstract

The productivity of wheat crops may be affected by a multitude of factors including soil moisture, seed quality, soil fertility, rainfall pattern, and field management practices. However, this study is focused on evaluating the impact of different tillage and sowing methods on the yield of wheat in silty loam soil. Over two consecutive wheat growing seasons (2021-22 and 2022-23), the research focused on comparing Conventional Tillage (CT) and No-Tillage (NT) with four sowing methods: Flat Basin with Broadcasting (FB-B), Flat Basin with Line sowing (FB-L), Narrow Bed with Line sowing (NB-L) and Wide Bed with Line sowing (WB-L). The study utilized a Randomized Complete Block Design (RCBD) to ensure robust experimental design and data collection. Results revealed that NT practice yields 4.79% better results than CT treatments. Statistical analysis revealed that the NB-L method consistently outperformed other methods, demonstrating superior crop growth and maximizing grain yield. On average, NB-L exhibited an increase of 4.20% in crop height, 25.18% in dry biomass production, and 26.10% increase in grain yield compared to the conventional broadcasting method for sowing. Conversely, flat basin line sowing (FB-L) exhibited mixed performance, with advantages in grain quality metrics having 5.43% higher grain weight and 6.59% harvesting index compared to broadcasting method, but shorter spikes and lower dry biomass production compared to other sowing methods. WB-L has 32.92% higher water productivity compared to the broadcasting method. NB-L treatments exhibited higher irrigation demand but

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PJSSR
Vol. 2 No. 4 ,(Fall-2024)

demonstrated efficient water utilization and higher water productivity, with a 26.41% higher compared to the broadcasting method. The findings suggest that the wide beds sowing method is considered the most suitable technique in water-scarce regions to reduce water usage and produce optimum yield. The study's findings provide crucial insights for agricultural practices, suggesting the robustness and adaptability of the NB-L method across different tillage conditions and the potential of WB in water-efficient farming. This research offers valuable insights for farmers and policymakers, guiding the adoption of more efficient and sustainable wheat cultivation practices like narrow beds, and no-tillage practices. Future research should investigate the long-term effects of these practices on soil health and assess their adaptability across various soil types and climatic conditions.

Keywords: Management, Optimizing, Silty Loam Soil, Sowing, Tillage, Wheat and Yield

INTRODUCTION

Global crop yields for major staples like maize, rice, wheat, and soybean are rising; however, the pace of this increase is insufficient to meet the projected demands by 2050 (Ray et al., 2013). Current yield growth rates fall below the required 2.4% annually needed to double global production by 2050, posing a significant challenge to future agricultural needs (Negro et al., 2019). Thus, increasing crop yields and combating yield stagnation is essential to meet growing global agricultural demands.

In Pakistan, agriculture is of immense significance, particularly the cultivation of wheat—a crucial staple crop for food security and economic stability. Wheat production plays a vital role in the country's economy, contributing substantially to GDP, employment, and exports (Shar et al., 2021). However, this sector faces numerous challenges and has significant potential for growth. Aslam (2016) highlighted a significant yield gap between actual and potential yields for major crops in Pakistan. For instance, the actual wheat yield is 2.26 tons per hectare compared to a potential yield of 6.80 tons per hectare, resulting in a 66.76% gap. Wheat, as a winter crop, benefits from cool temperatures and relatively dry conditions during its growth phase (Fang et al., 2017). Despite significant advancements in wheat cultivation, particularly in Sindh, Pakistan's yield levels still lag behind those of major producers like China, India, and Bangladesh (Abid et al., 2018; Ahmad et al., 2021).

Suboptimal farming practices, such as intensive tillage, broadcasting, and conventional flooding methods, present significant challenges to wheat cultivation in Pakistan. Intensive tillage, involving excessive plowing, contributes to soil erosion, decreased soil fertility, and reduced water retention capacity (Zhang et al., 2023). Broadcasting, where seeds are scattered manually, leads to uneven crop emergence and lower yields (Shahid et al., 2023). Conventional flooding methods also result in water wastage, waterlogging, and salinity issues, further impacting crop productivity (Qasim et al., 2022).

Addressing these challenges requires a shift towards more sustainable agricultural practices, such as no-tillage and precision seeding techniques. No-tillage has been shown to improve soil health, conserve moisture, and control erosion (Asif et al., 2016; Akhtar & Rasool, 2020). Precision seeding methods, like GPS-guided seed placement, can optimize seed distribution, improve crop uniformity, and enhance yields (Ikram et al., 2023).

Wheat sowing methods have been extensively studied, with evidence suggesting that drilling methods yield better results than broadcasting (Shahid et al., 2023). Techniques like narrow and wide bed sowing have shown potential for increasing yields by 4.5% and 5.8%, respectively, compared to broadcasting (Akbar et al., 2007).

This study aims to explore the specific gaps in wheat cultivation practices in silty loam soil. It evaluates the effectiveness of different tillage techniques (no-tillage vs. conventional tillage) and sowing methods (narrow bed, wide bed, line sowing, and broadcasting) to identify practical solutions for enhancing wheat productivity. By focusing on these critical factors, the research seeks to provide actionable insights to address the challenges faced by wheat farmers in Pakistan, contributing to sustainable agricultural practices and ensuring food security.

This research is crucial for improving wheat productivity in silty loam soils by identifying the most effective tillage and sowing techniques. The findings will guide farmers and policymakers in adopting practices that enhance yield, ensure food security, and promote sustainable agriculture in Pakistan.

METHODOLOGY

EXPERIMENTAL SITE/STUDY AREA

The Climate, Energy and Water Research Institute (CEWRI) of National Agricultural Research Center (NARC) having coordinates 33.67531° N, 73.13770° E was selected as our experimental site for this research study as shown in Figure 1. The altitude of NARC-CEWRI field station is 498 m, where temperature ranges from 0 to 45 degree Celsius and annual rainfall of 1200 mm out of which 70% occurs in monsoon.

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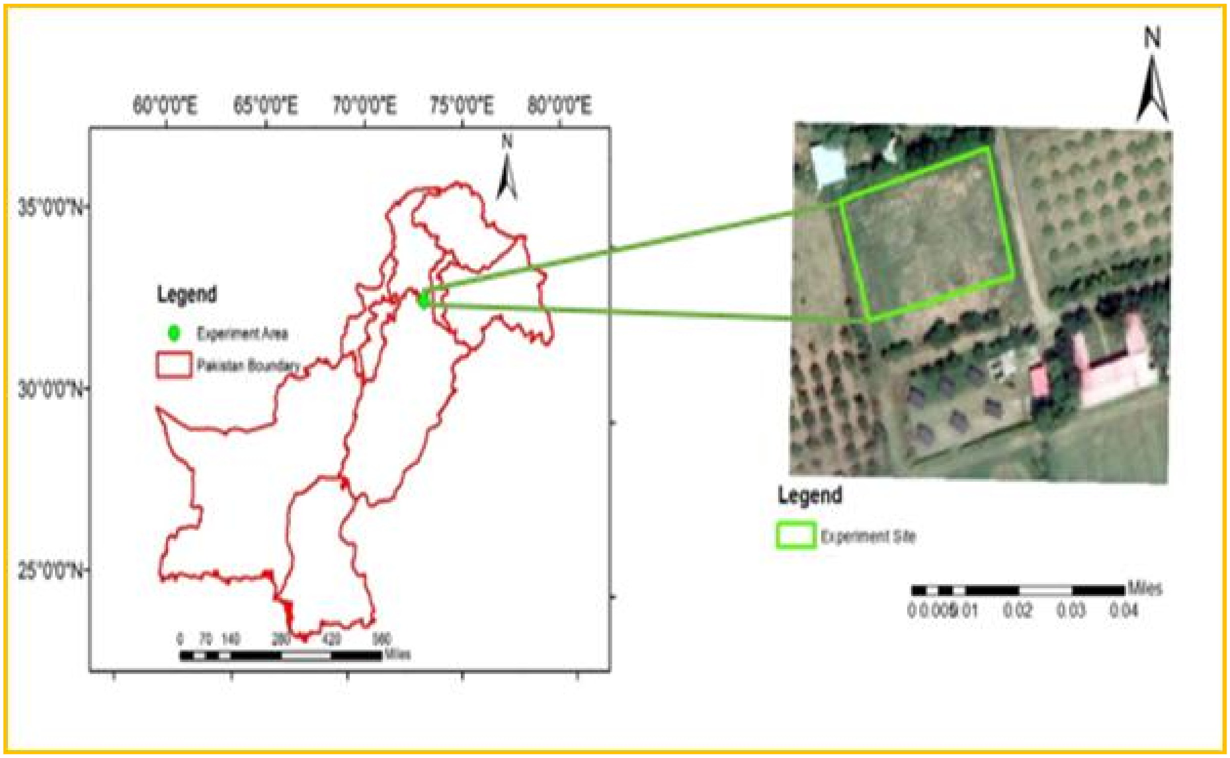

Figure 1 Experimental site 'CEWRI Field Station NARC' location on Pakistan map

TREATMENTS APPLIED

Experimental plot was established at NARC under irrigated conditions. The experiment was comprised of two main treatments of tillage methods and four sub-plots of sowing methods with three replications at NARC Islamabad. The main tillage methods were:

1. Zero/No-Tillage (NT)
2. Conventional Tillage (CT)

Four sowing methods as sub-plots of each main treatment were:

i. Flat basin with Broadcasting (FB-B)
ii. Flat basin with Line sowing (FB-L)
iii. Narrow Beds (NB) with Line sowing
iv. Wide Beds (WB) with Line sowing

Each treatment with its basic details, like plot size, no. of beds, no. of lines, and seed rate are listed in Table 1

Table 1 Treatments with their basic details

Treatments	Plot Size	No. of Beds	No. of Lines	Seed Rate	
FB-Broadcasting	29.26 m^2	0	0	365 g/plot	
FB-Line Sowing	29.26 m^2	0	15	365 g/plot	**123.55 kg/ha**

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Vol. 2 No. 4 ,(Fall-2024)

NB-Line Sowing	29.26 m^2	4	8	365 g/plot	**(50 kg/Acre)**
WB-Line Sowing	29.26 m^2	2	10	365 g/plot	

EXPERIMENTAL LAYOUT

The experimental layout follows a Randomized Complete Block Design (RCBD) comprising two tillage methods as major treatments and four sowing methods as secondary treatments, resulting in eight treatments, shown in Figure 2 below. Each treatment is replicated three times, totaling twenty-four subplots distributed randomly within the experimental plot to minimize error and enhance result accuracy.

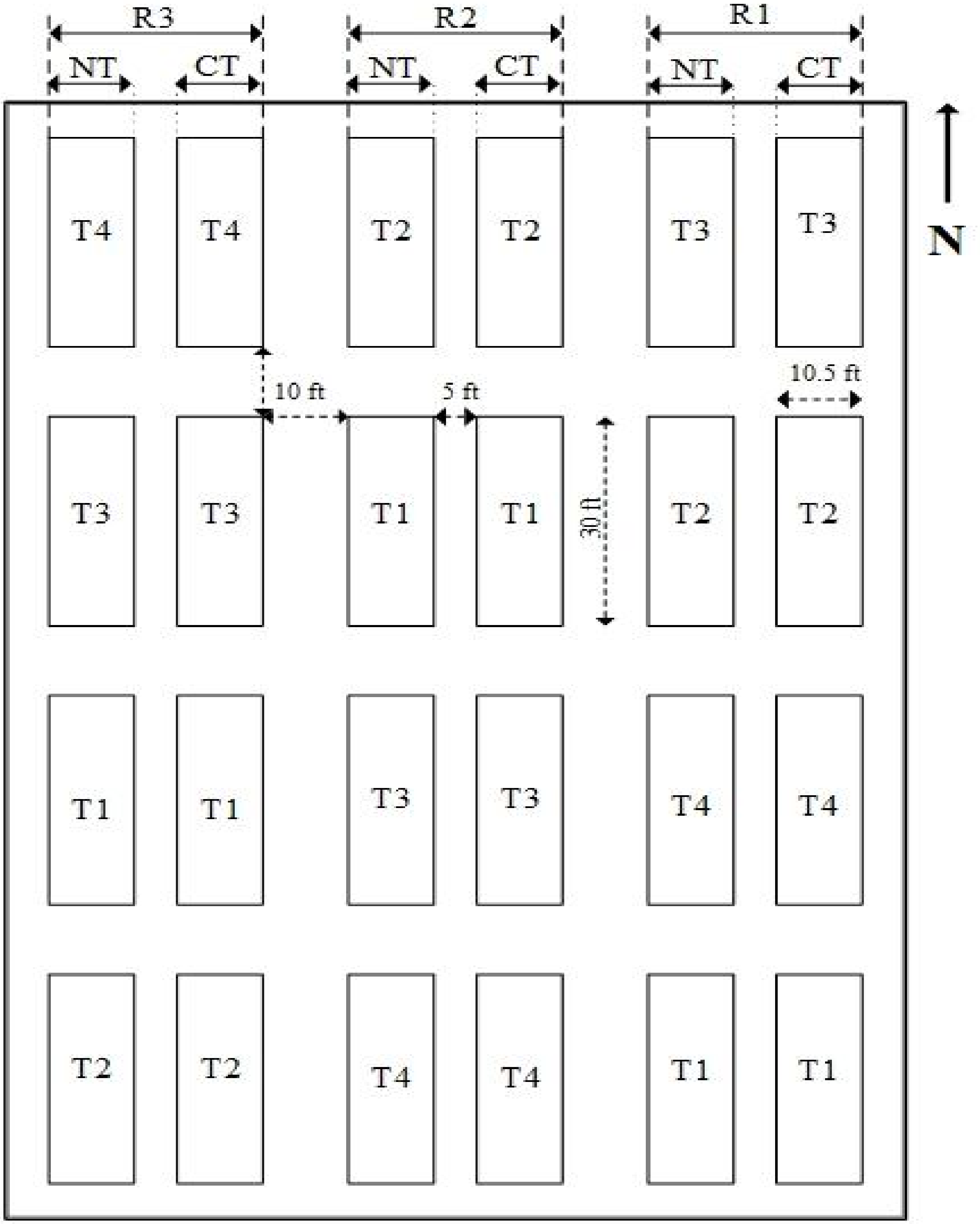

Figure 2 Randomized Complete Block Design for our experimental plot

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PJSSR
Vol. 2 No. 4 ,(Fall-2024)

The experimental plot is fully equipped with the necessary resources. An irrigation pump, powered by a 20 kw solar system, is installed on site. Two types of pipes, for flood and drip irrigation, are laid underground with water meters to measure the water supply to each plot.

DATA COLLECTION

The required weather data on the site was recorded and noted from a weather station situated at the "Climate Energy and Water Research Institute" (CEWRI) field station, NARC. The weather station at NARC records the daily minimum and maximum temperature in degree Celsius, wind speed in km/day, evaporation by pan evaporation method in mm/day, rainfall in mm/day and relative humidity in percentage. The data available was enough for this research study.

WEATHER DATA

The weather data encompassing rainfall and temperature, during the wheat growing seasons of 2021-22 and 2022-23 was gathered from the weather station situated at CEWRI field station of NARC. The data has been organized and presented in Table 2.

Table 2 Monthly weather (rainfall and temperature) data obtained from CEWRI field station of NARC Islamabad for two consecutive wheat-growing seasons of 2021-22 and 2022-23

Month-Year (2021-22)	Rainfall (mm)	Temperature (°C)		Month-Year (2022-23)	Rainfall (mm)	Temperature (°C)	
		Max	Min			Max	Min
Nov-21	0.00	24.63	7.3	Nov-22	64.26	23.77	8.63
Dec-21	9.59	19.39	3.42	Dec-22	8.47	20.68	4.13
Jan-22	164.92	15.84	5.35	Jan-23	45.48	16.61	3.26
Feb-22	22.18	19.43	6.36	Feb-23	14.94	23.11	6.93
Mar-22	53.94	28.74	13	Mar-23	94.80	24.32	10.77
Apr-22	5.11	35.3	16.33	Apr-23	70.05	28.63	14.43

SOIL PHYSICAL PROPERTIES

Soil samples were collected from the top 15 cm depth at randomly selected locations within each block using soil auger method prior to field preparation for determining its physical, chemical and hydraulic properties. The samples are weighted and then dried. The dried samples were weighted again. The soil tests have been done and the obtained results are shown in the Table 3 below.

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PJSSR
Vol. 2 No. 4 ,(Fall-2024)

Table 3 Physical properties of soil at experimental site

Texture	Permanent Wilting Point (%)	Field Capacity (%)	Saturation (%)	Hydraulic Conductivity (mm/day)
Silt Loam	13.0	33.0	46.0	575.0

Field Activities

In the Wheat growing seasons, a detailed log of field activities was maintained; capturing critical factors such as plot size, sowing date, seed variety, urea, and applications of weed control measures. These recorded activities provide invaluable insights into the management practices employed and their influence on crop development and yield outcomes. The activities detailed for both wheat-growing seasons, 2021-22 and 2022-23 are given in Table 4 below.

Table 4 Record of field activities performed in wheat growing seasons 2021-22 and 2022-23

S. No	Input/Activity	Date/year (Season 2021-22)	Date/year (Season 2022-23)
1	Plot size	29.26 m^2	29.26 m^2
2	Sowing date	12th Nov 2021	4th Nov 2022
3	Urea 178 kg/ha	24/1/2022	02/11/2022
4	DAP 170.5 kg/ha	09/12/2021	02/11/2022
5	Zinc 18.8 kg/ha	29/03/2022	02/11/2022
6	Weedicides (Ally Mix, Axial)	30/12/2021	03/01/2023
7	Harvesting	26/4/2022	27/04/2023

FIELD PREPARATION

The entire area spans 37.79 m (124 feet) by 48.15 m (158 feet), totaling 1820.15 square meters. Within this space, twenty-four plots are demarcated, each measuring 3.20 m (10.5 feet) in width and 9.14 m (30 feet) in length, equivalent to 29.26 square meters. To maintain separation between the plots and prevent water seepage, a 1.52 m (5 feet) buffer zone is delineated. Additionally, a designated pathway, 3.04 m (10 feet) wide, is established to facilitate easy movement and field operations.

The land preparation process commences with an initial plowing phase to break and loosen the soil, followed by careful use of a Rotavator to further refine and prepare the seedbed. These sequential steps are executed with precision to create an optimal environment conducive to wheat crop growth and development, ensuring a well-prepared area for the experiment.

FERTILIZER APPLICATION

After the field preparation, fertilizers (Urea, DAP, and Potash) at the rate of 123.55 kg/ha were applied to each subplot. To apply fertilizer equally to each plot, the quantity was assured using an electronic weighing balance. Details of fertilizer applied to each plot are shown in Table 5.

Table 5 Details of the fertilizer applied to the field

Fertilizer	Quantity/Plot	Quantity/Per Area
NPK	500 g per plot	123.55 kg/ha (50 kg/acre)
DAP	500 g per plot	123.55 kg/ha (50 kg/acre)
Potash K2O	500 g per plot	123.55 kg/ha (50 kg/acre)

SOWING

The sowing process involved the careful application of various techniques, using both hand drills and manual broadcasting methods. To ensure precision, flat basin line sowing, narrow bed line sowing, and wide bed line sowing were conducted using hand drills. The broadcasting technique was utilized for sowing on flat basins.

Each plot received a consistent seed rate of 365 grams (equivalent to 123.55 kg/ha), which remained uniform across all plots. This standardized approach ensured consistency and comparability in the sowing process across the experimental setup.

WEEDICIDES APPLICATION

The weedicides were applied to the wheat crop using manual hand pump spraying to target both narrow-leaved and broad-leaved weeds. This precise application, timed strategically to coincide with weed growth stages, effectively controlled weed infestation while safeguarding wheat plants. The following Weedicides were applied and their details are listed in Table 6.

Table 6 Weedicide applied to the experimental field and their details

Weedicides	Quantity
Ally Mix (Broad leaves weedicides)	4 g with 20 liters of water
Axial (Narrow leaves weedicides)	66 ml with 20 liters of water

IRRIGATION APPLICATION

Irrigation was applied based on the crop water requirements of the experimental plots. The installed 20kW solar power plant at the CEWRI field station of NARC, was used for pumping irrigation water. This system incorporated irrigation pipes equipped with two distinct flow meters dedicated to flood and drip irrigation management within the experimental plots. These flow meters facilitated detailed and accurate measurements, offering essential insights into the

POLICY JOURNAL OF SOCIAL SCIENCE REVIEW
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https://journalofsocialsciencereview.com/index.php/PJSSR
PJSSR
Vol. 2 No. 4 ,(Fall-2024)

precise quantity of water dispensed to the wheat crop. By aligning the irrigation process with crop water requirements and utilizing advanced technology for monitoring, the study ensured optimal water management strategies, contributing crucial data for evaluating the impact of irrigation techniques on wheat crop growth and productivity.

AGRONOMIC PARAMETERS

The collection of agronomic parameters involved a systematic and comprehensive approach throughout the wheat crop's growth stages in the experimental plots. Regular field visits were conducted, during which various parameters including plant height, tiller count, flowering stages, and maturity were meticulously observed and recorded at predetermined intervals. Additionally, measurements of yield-related traits such as spike length, number of grains per spike, and grain weight were gathered during harvest. This diligent and consistent data collection process aimed to capture crucial information regarding the growth, development, and yield components of the wheat crop under different sowing and tillage methods. These parameters are pivotal in assessing the effects of agronomic practices on wheat productivity, facilitating an in-depth analysis of the experimental outcomes.

PLANT HEIGHT

Plant height measurements were taken during the harvesting stage using a measuring tape in the experimental plots. The height of wheat plants was systematically recorded from the base to the tip of the main stem, employing standardized measurement techniques. The data collected at harvest regarding plant height served as a fundamental parameter for evaluating the overall growth performance and stature of the wheat crop, facilitating an in-depth analysis of the agronomic practices' impact on the crop's vertical development.

SPIKE LENGTH

Spike length measurements were carried out at the harvesting stage across the experimental plots, employing a measuring tape to determine the length of wheat spikes. This systematic approach ensured consistent and accurate recording of spike length, measuring from the base to the tip of the spikes.

NUMBER OF TILLERS

Tiller quantification was conducted meticulously across the experimental wheat plots, encompassing both the counting of tillers per individual plant and the assessment of tiller density within a one-meter square area.

WET WEIGHT (PLANTS/M^2)

Using a one-meter square frame, the wheat crop within the frame was carefully harvested, and its biomass was measured using an electronic measuring balance. By employing this method, precise measurements of the crop's biomass per square meter were obtained, providing

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https://journalofsocialsciencereview.com/index.php/PJSSR
Vol. 2 No. 4 ,(Fall-2024)

essential data regarding the yield potential and biomass production of the wheat crop under various sowing and tillage methods.

THOUSAND GRAIN WEIGHT

The grain weight analysis was conducted by meticulously counting and weighing 1000 grains from each sample of the wheat crop, employing a precise measuring balance for accurate measurements.

NUMBER OF GRAINS PER SPIKE

In the evaluation of the wheat crop, an examination was conducted by randomly selecting three spikes from each plot sample. The primary objective was to precisely count the number of grains present on each spike, while concurrently noting the count of unfilled grain spaces, a measure indicating sterility. This detailed assessment aimed to provide comprehensive insights into the reproductive success and potential yield of the wheat crop under varying sowing and tillage methods. Assessing both the abundance of grains per spike and the presence of unfilled grain spaces allowed for a comprehensive understanding of the crop's reproductive health and grain development dynamics. The data acquired from these observations significantly contributed to the assessment of the wheat crop's overall productivity and reproductive efficiency, essential components crucial to the comprehensive analysis within the framework of my thesis.

RESULTS AND DISCUSSION

YIELD AND YIELD COMPONENTS

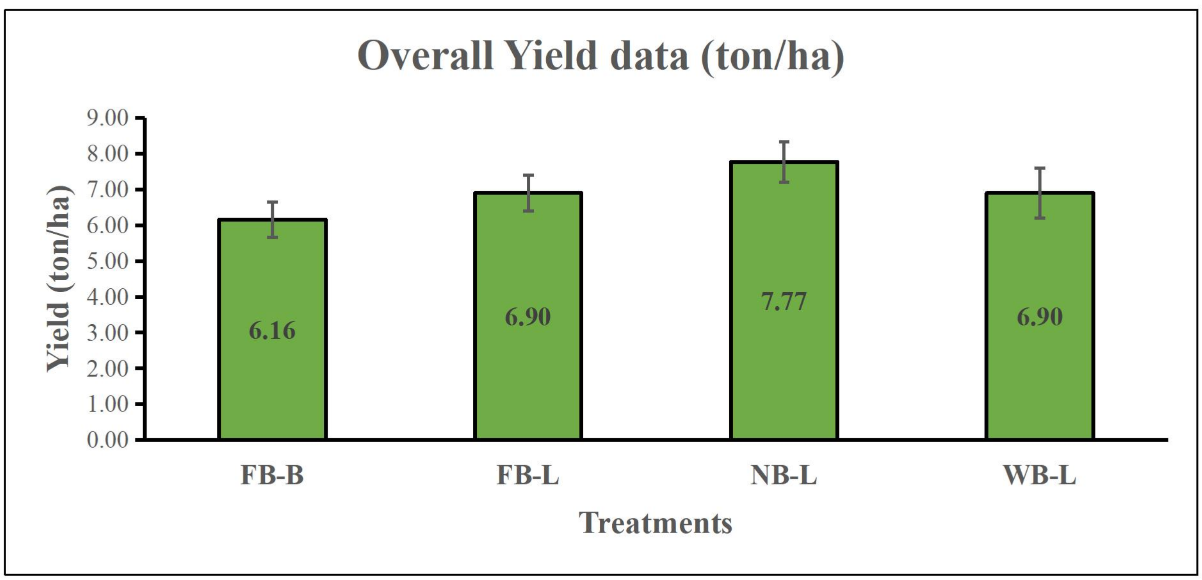

Figure 13 Two years' average wheat yield under different treatments

The provided graph illustrates the overall yield data (ton/ha) for wheat under different treatments labeled as FB-B, FB-L, NB-L, and WB-L, each with respective yield values and error bars. FB-B (Flat Bed - Broadcasting) yielded 6.16 tons per hectare, the lowest among the treatments, while FB-L (Flat Bed - Line sowing) yielded 6.90 tons per hectare, showing a higher yield. NB-L (Narrow Bed-Line sowing) yielded the highest at 7.77 tons per hectare, indicating significant improvement with this method. WB-L (Wide Bed-Line sowing) also yielded 6.90 tons per hectare, suggesting that bed width does not significantly affect yield when line sowing is used. The error bars indicate variability, with shorter bars suggesting more data that are consistent. Line sowing methods clearly outperform broadcasting, with narrow bed line sowing (NB-L) being the most effective. These findings suggest that adopting narrow bed line sowing could significantly benefit wheat farmers aiming to enhance productivity.

WATER PRODUCTIVITY

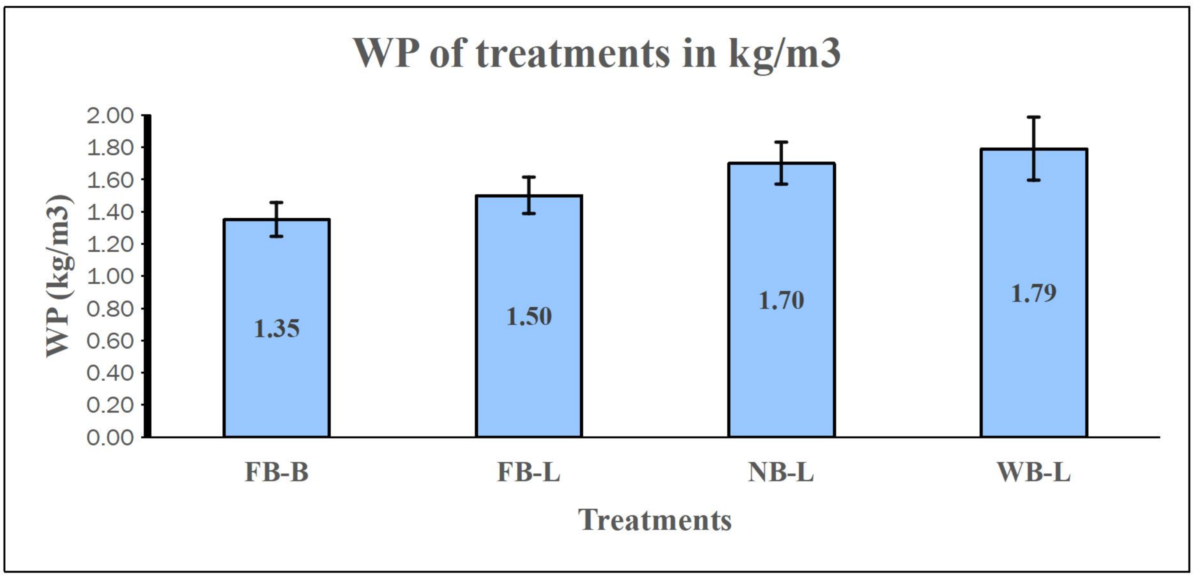

Figure 19 Overall average Water Productivity of wheat crop under different sowing methods

Figure 19 illustrates the overall average Water Productivity (WP) of both consecutive wheat growing seasons 2021-22 and 2022-23 under different treatments measured in kilograms per cubic meter (kg/m³), showcasing the efficiency of water use in producing crop biomass or yield. The Y-axis represents WP, ranging from 0.00 to 2.00 kg/m³, while the X-axis lists the treatments: FB-B, FB-L, NB-L, and WB-L. Each bar denotes the WP for a specific treatment, with FB-B having the lowest WP at 1.35 kg/m³, followed by FB-L at 1.50 kg/m³. The NB-L treatment shows a significant improvement in WP at 1.70 kg/m³, and WB-L has the highest WP at 1.79 kg/m³. The error bars on each column indicate the variability or standard error of the WP measurements, with relatively small error bars suggesting consistent measurements. The results suggest that

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ISSN (Print): 3006-4627
https://journalofsocialsciencereview.com/index.php/PJSSR
Vol. 2 No. 4 ,(Fall-2024)

WB-L is the most efficient treatment for water use in crop production, followed by NB-L, FB-L, and FB-B, in descending order of efficiency. This indicates that the irrigation techniques or management practices represented by these treatments can greatly influence water use efficiency in agriculture.

DRY BIOMASS AND HARVEST INDEX

The table presents data comparing the effects of two tillage methods, Conventional Tillage (CT) and No-Tillage (NT), on dry biomass (ton/ha) and harvest index (%) for four different treatments: FB-B, FB-L, NB-L, and WB-L.

Under Conventional Tillage (CT), the FB-B (Flat Bed - Broadcasting) treatment produces 15.35 tons per hectare of dry biomass with a harvest index of 40.05%, indicating the proportion of harvested grain to total biomass. The FB-L (Flat Bed-Line sowing) treatment shows an improvement in dry biomass to 16.00 tons per hectare and a higher harvest index of 41.70%, suggesting better efficiency in grain production. The NB-L (Narrow bed-line sowing) treatment achieves the highest dry biomass of 18.39 tons per hectare among the treatments with a harvest index of 41.06%, indicating a substantial amount of biomass with good grain yield. The WB-L (Wide Bed-Line sowing) treatment produces 16.53 tons per hectare of dry biomass with a harvest index of 39.34%, showing a moderate increase in biomass but slightly lower efficiency in grain yield compared to FB-L.

Under No-Tillage (NT), the FB-B (Flat Bed - Broadcasting) treatment slightly reduces dry biomass to 15.29 tons per hectare with a harvest index of 39.87%, showing marginally lower efficiency compared to conventional tillage. The FB-L (Flat Bed-Line sowing) treatment increases dry biomass to 16.35 tons per hectare with a harvest index of 43.48%, the highest harvest index among all treatments, indicating excellent grain production efficiency. The NB-L (Narrow Bed - Line sowing) treatment shows a significant increase in dry biomass to 19.97 tons per hectare, the highest among all treatments, with a harvest index of 39.73%, suggesting that No-Tillage combined with narrow bed line sowing maximizes biomass production. The WB-L (Wide Bed - Line sowing) treatment produces 18.57 tons per hectare of dry biomass with a harvest index of 38.10%, indicating good biomass production but lower efficiency in converting biomass to grain.
Overall, the data indicates that NB-L under NT shows the highest dry biomass production, suggesting that No-Tillage with narrow bed line sowing maximizes overall biomass. FB-L under NT achieves the highest harvest index, indicating the most efficient grain production relative to biomass. No-Tillage generally improves dry biomass production compared to conventional tillage for most treatments, except FB-B, where the difference is minimal. The choice of tillage method and sowing technique significantly affects both dry biomass and harvest index, with narrow bed line sowing and no-tillage emerging as effective practices for maximizing yield.

POLICY JOURNAL OF SOCIAL SCIENCE REVIEW
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ISSN (Print): 3006-4627
https://journalofsocialsciencereview.com/index.php/PJSSR
PJSSR
Vol. 2 No. 4 ,(Fall-2024)

Table 9 Average dry biomass and harvest index under CT and NT for 2021-22 and 2022-23

Treatment	CT		NT	
	Dry Biomass (ton/ha)	Harvest Index (%)	Dry Biomass (ton/ha)	Harvest Index (%)
FB-B	15.35	40.05	15.29	39.87
FB-L	16.00	41.70	16.35	43.48
NB-L	18.39	41.06	19.97	39.73
WB-L	16.53	39.34	18.57	38.10

CONCLUSION AND DISCUSSION

This study offers valuable insights into optimizing wheat cultivation through the comparative analysis of various sowing and tillage practices in silty loam soil. The research underscores the superior performance of the narrow bed line (NB-L) sowing method, which demonstrated significant increases in crop height, spike length, dry biomass production, and grain yield compared to traditional broadcasting methods. NB-L consistently showed a 4.20% increase in crop height, a 2.28% increase in spike length, a 25.18% increase in dry biomass production, and a 26.10% increase in grain yield, highlighting its potential as a preferred method for maximizing wheat productivity.

Conversely, flat basin line (FB-L) sowing exhibited mixed results, with advantages in grain quality metrics such as 1000-grain weight and harvest index but consistently shorter spikes and lower dry biomass production compared to NB-L. The wide bed line (WB-L) sowing method demonstrated notable improvements in water productivity, with a 32.92% increase compared to broadcasting, indicating its efficacy in resource-efficient wheat cultivation. The study also revealed that no-tillage (NT) practices resulted in a 4.79% improvement in overall yield compared to conventional tillage (CT), underscoring the benefits of NT in promoting soil health and conserving resources.

The dynamic nature of agricultural systems necessitates the adoption of innovative and sustainable practices to enhance crop productivity and resource efficiency. This study has highlighted the critical role of sowing methods and tillage practices in optimizing wheat yields in silty loam soil. The NB-L sowing method consistently outperformed other methods across multiple agronomic metrics, demonstrating its effectiveness in promoting robust crop growth and maximizing grain production. This method's superior performance in crop height, spike length, dry biomass production, and grain yield underscores its potential as a preferred sowing method for sustainable wheat cultivation.

Conversely, the FB-L sowing method showed mixed results, with advantages in grain quality but consistently shorter spikes and lower dry biomass compared to NB-L. These observations suggest that while FB-L may be beneficial for improving grain quality, it may not be the best method for maximizing overall crop productivity. Further investigation into the underlying mechanisms influencing FB-L performance is warranted to assess its comprehensive suitability for wheat cultivation.

The analysis of water productivity revealed significant improvements associated with the WB-L sowing method, which demonstrated a 32.92% increase in water productivity compared to broadcasting. This finding underscores the importance of efficient water utilization practices in achieving sustainable wheat production, particularly in regions with limited water resources. The study also indicated that NT practices resulted in a 4.79% improvement in overall yield compared to CT, highlighting the benefits of minimal soil disturbance in promoting soil health and conserving resources.

As climate change continues to impact agricultural landscapes, the development of resilient and sustainable practices becomes increasingly critical. The findings of this research provide evidence-based recommendations for optimizing wheat cultivation, advocating for the integration of NB-L and NT practices to enhance productivity and resource efficiency. Continued research, collaboration, and innovation are essential to advance the adoption of sustainable agricultural practices, ensuring food security and environmental sustainability in the face of changing climatic conditions.

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