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RESPONSE OF TILLAGE, RESIDUE MANAGEMENT, AND SEED RATES ON PRODUCTIVITY OF WHEAT

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Abstract

In Nepal, the lack of appropriate agronomic practices and soil health maintenance are major factors contributing to low wheat yield. Utilizing suitable agronomic practices not only enhances wheat productivity but also helps sustain soil health. A field experiment was conducted during the winter season of 2019 and 2020 at the National Wheat Research Program (NWRP), Bhairahawa, Rupandehi, Nepal, to assess the effect of tillage practices, residue management, and seed rates on wheat growth, yield attributes, yield, and soil health. The experiment was conducted in a strip-split plot design with three replications. Three tillage practices (conventional tillage, reduced tillage, and zero tillage) were assigned to the vertical factor, two residue levels (residue removal, and residue retention at 30 cm) were assigned to the horizontal factor, and seed rates of 80, 120, and 160 kg ha^{-1} were used as subplots. The recommended dose of fertilizers at the rate of 100: 50: 50 N: P_2O_5:K_2O kg ha^{-1} was applied. The experimental plot was 12 m^2 with a 25 cm row spacing. The released variety Vijay was planted, and data on growth, yield attributes, and yield were collected and analyzed using the Genstat 15th Edition. Results showed a significant difference in plant height and number of tillers per square meter between tillage practices in 2019 but were significantly higher for zero tillage in 2020. Residue management treatments showed similar effects on plant height, number of tillers per square meter, dry matter production, and leaf area index in both years. Seed rates were not significant for plant height but significantly increased the number of tillers per square meter, dry matter production, and leaf area index due to the increase of seed rate up to 160 kg ha^{-1} during both years of experimentation. Days to flowering and maturity days were not influenced by tillage and residue management treatments in both years. In 2020, zero tillage resulted in longer spikes and more grains per spike than conventional and reduced tillage, though tillage had no effect in 2019. Residue management had no significant impact on spike length, grains per spike, and 1000-grain weight. The lower seed rate (80 kg ha^{-1}) produced significantly longer spikes only in 2020, and more grains per spike only in 2019, compared to higher rates (120 and 160 kg ha^{-1}). Zero tillage also showed lower sterility percentages than other tillage methods, while residue levels and seed rates did not affect sterility. Grain yield was significantly affected by tillage practices and seed rates but not by residue management. Zero tillage produced a higher grain yield than conventional tillage and reduced tillage. The higher levels of seed rate 160 kg ha^{-1} registered more grain yield than its lower levels of 80 and 120 kg ha^{-1}. The harvest index was not influenced by different tillage and residue levels but seed rates affected the harvest index during 2019. The lower levels of seed rate 80 kg ha^{-1} produced more harvest index. Zero tillage resulted in higher organic matter compared to conventional and reduced tillage. Residue retention increased organic matter and reduced bulk density compared to residue removal. Based on two years' results, it can be concluded that adopting zero tillage, retaining residue, and using a recommended rate of seed rate of 120 kg ha^{-1} can enhance wheat yield and sustain soil fertility.

Keywords: Residue, Seed Rate, Soil Fertility, and Zero Tillage Wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L) is the third important cereal after rice and maize in Nepal. It plays an important role in national food security [1]. It is grown in the Terai, mid-hill, and high hills during the winter season. Wheat crop covers nearly 7,07,505 hectares in Nepal [2] with a total production of 21,85,289 metric tons and 3.08 t ha^{-1} average productivity.

Wheat yield is stagnant due to late sowing, unwise tillage operations, water shortage, lack of organic matter, and unbalanced application of nutrients. Some farmers give intensive tillage to rice fields besides burning the residues, while others incorporate the residues deep into the soil to have favorable land preparation for succeeding wheat crops. Both excessive tillage and residue burning deteriorate soil quality and have adverse effects on the environment.

There are huge losses of nutrients from conventional tillage (CT) and residue burning [3]. Burning of crop residue is increasing in the Terai region of Nepal to facilitate the tillage operation for the preparation of fields and sowing of wheat. More than 43% of crop residue is burned in Western Terai of Nepal [4].

Tillage practices could affect crop growth and yield due to their effect on water conservation, and soil chemical and physical properties [5]. Tillage plays an important role in the management of soil tilth. Soil tilth is the physical conditions of a soil described by its bulk density, porosity, structure, unevenness, and aggregate characteristics, related to water, nutrients, heat and air transport, stimulation of microbial and micro-fauna populations and processes, and impedance to seedling emergence and root penetration [6]. Wheat production can be improved by using better inputs, proper production technology, and proper tillage practices. Crop yield is affected by these field operations due to their effect on the chemical and physical characteristics of soil and water conservation [7].

Proper tillage and timing promote and maintain good soil tilth while improper tillage and timing destroy soil structure, produce poor tilth, establish conditions unfavorable to seed germination and plant growth, and are favorable for soil erosion. Tillage practices vary from no-tillage to inversion of soil by deep tillage and mould board plow. Not enough attention has been paid to developing a systematic approach for matching tillage practices with the physical condition of soil [8]. Zero tillage and reduced tillage with crop residue retention reduce soil erosion, enhance soil biological activity, provide better economic returns [9], save labor and time [10], reduce management-related yield gap by 14–47% for wheat [11].

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Recycling crop residues into agricultural land improves soil health and crop productivity. Crop residues return carbon (C) to the soil, which improves soil structures, and improves the ability of the soil to hold nutrients and water-holding capacity. Returning crop residues to the soil is the most economical and ecological means of conserving soil and water and sustaining crop production [12].

Optimum seed rate is a key to maximize yield in most crops. To make a wheat canopy more effective, an optimum seed rate is necessary. Together with an optimal seed rate, the uniform distribution of the crop plants increases the vigor of the individual plants and their grain yield, because too high or too low plant population results in low grain yield [13]. Keeping these in view a field was planned to address the afore-mentioned problem.

MATERIALS AND METHODS

Experimental site

A field experiment was conducted during the winter seasons of 2018/19 and 2019/20 at the C block of the National Wheat Research Program (NWRP) in Bhairahawa, Rupandehi, Nepal. This site, situated at an elevation of 104 meters above sea level (masl), lies at 27°32' North latitude and 83°25' East longitude. The region experiences a subtropical climate, characterized by warm summers and mild winters, which is typical of the Terai region of Nepal.

These climatic conditions, combined with the fertile alluvial soils of the region, provide a conducive environment for winter wheat cultivation. The experiment site, managed by the NWRP, serves as an important research hub for advancing wheat production technologies and strategies in Nepal, specifically in response to the region's unique agro-ecological conditions.

Soil physio-chemical properties and weather data of experimental soil

Soil samples were collected before the experimentation diagonally from three spots of the experimental plot at a depth of 0-20 cm using a tube auger and the composite sample was prepared which was air-dried, ground, and sieved through a 2 mm sieve for analysis. Soil samples were analyzed for texture, organic matter, pH, N, P_2O_5, and K_2O.

The experimental soil pH was alkaline (7.84); low in organic matter (1.88%), low in total nitrogen (0.09 %); high in available phosphorus (97.03 kg ha^{-1}); and medium in available potassium (179.12 kg ha^{-1}).

The soil texture was silt loam. The total rainfall during the research period was recorded as 138 mm, and weekly maximum and minimum temperatures ranged from 23 to 39^oC and 7 to 25^oC respectively during 2018/19. During 2019/20, the total rainfall during the research period was recorded as 333.9 mm, and weekly maximum and minimum temperatures ranged from 15.2 to 36^oC and 7.3 to 21^oC respectively.

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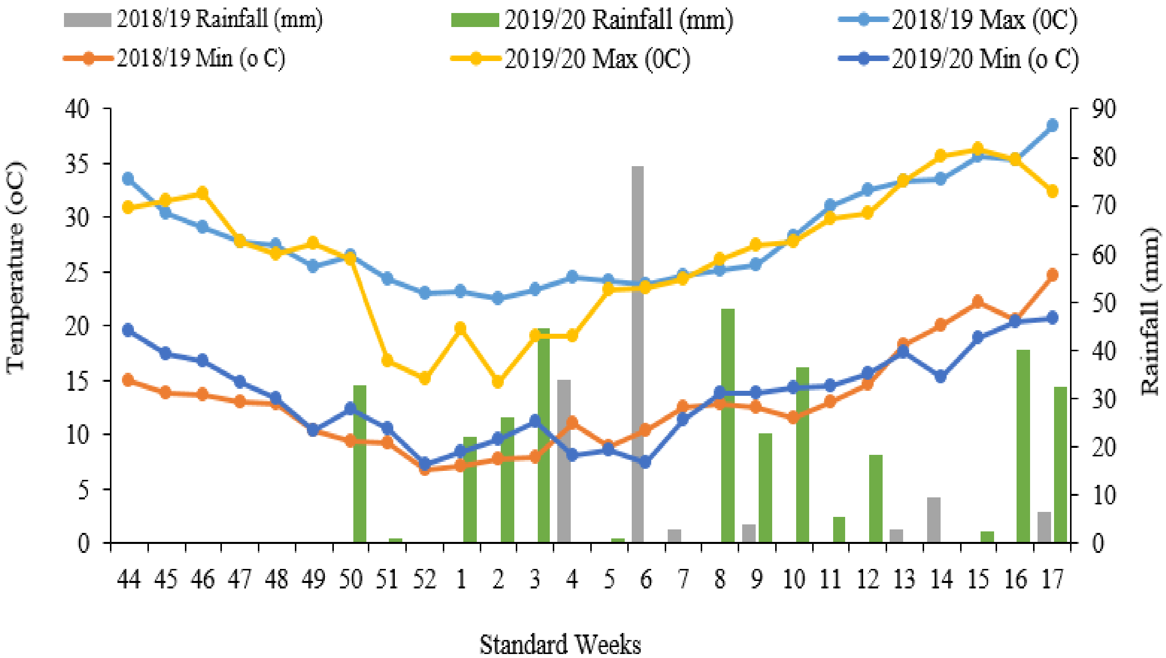

Fig 1: Weather conditions (average of two years) during the Experimental season during 2018/2019- 2019/2020

Notes:

Experimental details

The experiment was conducted in a strip split plot design. Three tillage practices viz. conventional tillage (3 passes plowing with 4 wheeler tractor drawn 9 tine cultivator and two planking), zero tillage (seeding of the wheat crop after harvesting rice under zero tillage condition) and reduced tillage (single pass plowing with rotavator) were allotted to vertical treatment, two residue levels such as residue retention (30 cm crop residue were left in the field) and residue removal (crop residue were removed close to the ground) were allotted to horizontal treatment and three seed rates such as 80, 120 and 160 kg ha^{-1} were assigned to subplot treatment with three replications.

Wheat variety Vijay was used in the experiment. The experiment was planted on the 22nd and 23rd of November 2018 and 2019 respectively. The size of individual plots was (4 m x 3 m) 12 m^2. 12 rows of 4-meter length were sown in each plot. Sulfosulfuron @ 30 gm a.i. ha^{-1} herbicide was applied to control weed populations in all experimental plots at 35 days after sowing (DAS). The fertilizer dose 100:50: 50 N: P_2O_5: K_2O kg ha^{-1} was applied. 50% N and full P and K doses were applied as basal doses. The remaining N dose was split and applied at 30 DAS and 50 DAS respectively, in equal amounts.

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Measurements

Ten plants were randomly selected to measure plant height in each plot. The height was measured from the ground to the tip of the spike excluding the awn, and the average was expressed in centimeters. The plant samples from 40 cm row length were collected from crop rows marked for destructive sampling. The roots were clipped off from each selected plant; the remainder was cleaned, transferred to properly labeled brown paper bags, and then partially sun-dried. Later on, they were subjected to oven drying at 65 ± 2˚C until constant weight was obtained and expressed as dry matter production (g m^{-2}).

Spike per square meter was recorded from the net plot area, with two quadrats sampled in each plot. Grains per spike was taken from 20 randomly selected spikes. Each spike was threshed separately and grains were counted then an average grain of 20 spikes was used as grains per spike. Thousand grains were counted from each net plot yield and weighted with an automatic electronic balance. The total biomass yield of each net plot was recorded at harvest. Grain yield was recorded from a net plot area of 7.0 m^2, and expressed in kg ha^{-1} at 12 % moisture content. The Harvest index was calculated by dividing grain yield by total biological yield and multiplying by hundred to express in percent.

Data Analysis

All the collected data were analyzed using the Genstat statistical package (15th Edition). Analysis of variance was done for all the variables and Duncan's multiple range test (DMRT) was used for mean separations at $p<0.05$.

RESULTS

Plant height

The plant height was significantly ($p<0.05$) influenced by different tillage practices during 2019 but there was no significant difference among the tillage practices in 2020. Zero tillage produced the highest plant height (95.7 cm) compared to conventional and reduced tillage in 2019. In comparison, the plant height was not significantly different in residue removal and residue retention treatments during 2019 and 2020. The plant height was not influenced ($P< 0.05$) due to the use of different levels of seed rates 80, 120, and 160 kg ha^{-1}. The average plant height was 93.37 cm and 91.21 cm during 2019 and 2020 respectively as presented in Table 1.

Dry matter production

Dry matter production was statistically different for tillage practices during 2019. The dry matter production was highest in zero tillage (1002 g m^{-2}) over conventional tillage (797.0 g m^{-2}) and reduced tillage (755.0 g m^{-2}). During 2020 dry matter production was in a similar trend as in 2019 in different tillage practices. The residue removal and retention (30 cm) had no significant response on dry matter production in 2019 and 2020.

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The dry matter production was increased significantly with increasing levels of seed rate up to 160 kg ha^{-1}. The average dry matter production was 851 and 637 g m^{-2} as presented in Table 1.

Leaf area index

Leaf area index significantly differed in different tillage practices and seed rates. Whereas, crop residue management did not influence the leaf area index. The leaf area index was significantly higher in zero tillage practice followed by conventional tillage and reduced tillage. The seed rates showed significant differences (P > 0.05) in the leaf area index, with the 160 kg ha^{-1} seed rate recording a higher leaf area index compared to the lower seed rates. The leaf area index increased significantly with increased levels of seed rate in both years (Table 1). The average leaf area index during 2019 and 2020 was 0.93 and 1.42 respectively.

Table 1: Growth of wheat as influenced by tillage practice, residue management, and seed rate during 2019-2020

Treatments	Plant height (cm)		Dry matter production (g m^{-2})		Leaf area index	
	2019	2020	2019	2020	2019	2020
Tillage practices						
Con. tillage	93.1^{b}	91.2	797.0^{b}	672.0	0.84^{b}	1.43^{b}
Reduced tillage	91.4^{b}	89.7	755.0^{b}	550.0	0.69^{b}	1.13^{c}
Zero tillage	95.7^{a}	92.7	1002.0^{a}	688.0	1.26^{a}	1.70^{a}
P - value	0.008	0.116	0.029	0.074	0.043	0.010
SEm (±)	0.47	0.76	42.40	32.60	0.11	0.07
LSD (p=0.05)	1.83	2.99	166.70	127.9	0.41	0.26
CV, %	1.00	1.40	8.60	8.90	19.90	8.10
Residue management						
Residue Removal	92.9	91.4	836.0	636.0	0.90	1.42
Residue Retention	93.8	91.0	866.0	637.0	0.96	1.42
P - value	0.396	0.765	0.676	0.958	0.671	0.985
SEm (±)	0.57	0.76	43.80	16.00	0.09	0.08
LSD (p=0.05)	3.46	4.62	266.30	97.20	0.56	0.47
CV, %	1.10	1.40	8.90	4.30	17.20	9.40
Seed rate (kg ha^{-1})						
80	93.6	90.7	701.0^{c}	491.0^{c}	0.66^{c}	1.13^{c}
120	92.9	91.1	837.0^{b}	626.0^{b}	0.89^{b}	1.40^{b}
160	93.7	91.8	1015.0^{a}	793.0^{a}	1.25^{a}	1.73^{a}
P - value	0.596	0.502	<0.001	<.001	<0.001	<.001
LSD (p=0.05)	0.61	0.65	20.70	20.60	0.040	0.049
SEm (±)	1.80	1.90	60.30	60.10	0.12	0.14
CV, %	2.80	3.00	10.30	13.70	20.20	14.70
Grand Mean	93.37	91.21	851.0	637.0	0.93	1.42

Notes: SEm (±), Standard Error of mean; CV, Coefficient of Variation; LSD, least Significant Difference; Con., Conventional; treatment means followed by a common letter(s) are not significantly different from each other based on Duncan's Multiple Range Test (DMRT) at 5% level of significance.

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Days to flowering and physiological maturity

Days to flowering and physiological maturity of wheat were non-significant in zero tillage, conventional tillage, and reduced tillage crop establishment methods during 2019 and 2020. A similar trend of days to flowering and physiological maturity was noticed in residue removal and residue retention treatments. But different seed rates, 80, 120, and 160 kg ha^{-1} had influenced flowering days during 2019.

Application of 80 kg ha^{-1} seed rate in wheat took longer days (79.4 days) for flowering and maturity (120.1 days) than 120 and 160 kg ha^{-1}. The average values of flowering and physiological maturity days ranged from 79.9 to 80.1 and 119.9 to 121.9 days respectively as presented in Table 2.

Table 2: Days to flowering and maturity of wheat as influenced by tillage practice, residue management, and seed rate

Treatments	Days to flowering (Days)		Days to maturity (Days)	
	2019	2020	2019	2020
Tillage practices				
Con. tillage	78.9	80.2	119.7	121.9
Reduced tillage	78.7	80.1	119.8	121.6
Zero tillage	79.2	80.1	120.1	122.2
P - value	0.62	0.95	0.54	0.30
SEm (±)	0.34	0.25	0.21	0.24
LSD (p=0.05)	1.35	0.98	0.83	0.93
CV, %	0.80	0.50	0.30	0.30
Residue management				
Residue Removal	78.4	80.0	119.6	121.9
Residue Retention	79.5	80.3	120.1	122.0
P - value	0.05	0.09	0.12	0.38
SEm (±)	0.17	0.07	0.14	0.09
LSD (p=0.05)	1.05	0.42	0.84	0.57
CV, %	0.40	0.10	0.20	0.10
Seed rate (kg ha^{-1})				
80	79.4^{a}	80.3	120.1^{a}	122.1
120	78.8^{b}	80.1	119.7^{b}	121.8
160	78.6^{b}	79.9	119.7^{b}	121.9
P - value	0.01	0.22	0.01	0.14
LSD (p=0.05)	0.17	0.16	0.10	0.12
SEm (±)	0.49	0.46	0.28	0.34
CV, %	0.90	0.80	0.30	0.40
Grand Mean	79.9	80.1	119.9	121.9

Notes: SEm (±), Standard Error of mean; CV, Coefficient of Variation; LSD, least Significant Difference; Con., Conventional treatment; means followed by common letter(s) are not significantly different from each other based on Duncan's Multiple Range Test (DMRT) at 5% level of significance.

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Tillers production

The different tillage practices, zero tillage, conventional tillage, and reduced tillage were not significant (P>0.05) on tillers production during 2019. However, during 2020, the different tillage practices affected significantly (P<0.05) tillers production. Though zero tillage had more number tillers in both experimentation years. In 2020, zero tillage and conventional tillage effects were similar in tiller production and both tillage practices produced higher numbers of tillers than reduced tillage (Table 3).

The effect of residue management was not significant on tillers production during 2019 and 2020 (Table 3). The use of seed rates, 80, 120, and 160 kg ha^{-1} were significantly different (P<0.05) on tiller production. The higher number of tillers was found with a 160 kg ha^{-1} seed rate followed by 120 and 80 kg ha^{-1}. The number of tillers production increased with increasing levels of seed rate up to 160 kg ha^{-1}.

Spike length

The effect of tillage practices, zero tillage, conventional tillage, and reduced tillage were not significant (P>0.05) on spike length during 2019. However, during 2020, it affected significantly (P<0.05) on spike length (Table 3). The zero-tillage practice produced a longer spike than conventional tillage and reduced tillage in both years. Residue removal and residue retention were not significant (P>0.05) on spike length (Table 3).

The use of seed rates at 80, 120, and 160 kg ha^{-1} effect on spike length was not significant (P>0.05) during 2019. But during 2020, the result was significant (p<0.05). The lower level of seed rate use of 80 kg ha^{-1} produced a longer spike than 120 and 160 kg ha^{-1} seed rates during 2019 and 2020 (Table 3).

Table 3: Yield attributes of wheat as influenced by tillage practices, residue management, and seed rate

Treatments	Effective tillers per m^2 (no.)		Spike length (cm)		No. of grains per spike		1000 grains weight (g)	
	2019	2020	2019	2020	2019	2020	2019	2020
Tillage practices								
Con. tillage	251.9	259.9[a]	10.1	9.4[b]	33.5	33.15[b]	50.8	46.6
Reduced tillage	236.8	240.3[b]	9.9	9.5[b]	33.6	32.8[b]	50.6	45.1
Zero tillage	263.8	266.6[a]	10.4	9.9[a]	36.4	35.91[a]	50.5	45.8
P - value	0.143	0.035	0.05	0.02	0.075	0.026	0.910	0.354
SEm (±)	7.47	4.62	0.087	0.084	0.70	0.53	0.40	0.62
LSD (p=0.05)	29.31	18.15	0.34	0.33	2.766	2.070	1.56	2.44
CV, %	5.20	3.10	1.50	1.50	3.50	2.70	1.40	2.40
Residue management								
Residue Removal	257.5	253.5	10.12	9.7	34.5	34.0	50.9	45.6
Residue Retention	244.2	257.6	10.11	9.6	34.5	33.9	50.4	46.1
P - value	0.10	0.38	0.86	0.25	0.90	0.92	0.41	0.56
SEm (±)	3.19	2.56	0.02	0.05	0.28	0.33	0.38	0.55
LSD (p=0.05)	19.43	15.56	0.15	0.31	1.70	2.00	2.33	3.37
CV, %	2.20	1.70	0.40	0.90	1.40	1.70	1.30	2.10

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Seed rate (kg ha^{-1})								
80	225.3^{c}	228.6^{c}	10.3	9.7^{a}	35.8^{a}	34.9	51.4^{a}	46.3^{a}
120	247.6^{b}	259.3^{b}	10.0	9.6^{ab}	34.3^{ab}	34.0	50.5^{b}	45.9^{ab}
160	279.7^{a}	278.8^{a}	10.0	9.5^{b}	33.4^{b}	33.0	50.0^{c}	45.3^{b}
P - value	<0.001	<.001	0.05	0.01	0.02	0.06	<.001	0.02
LSD (p=0.05)	5.16	2.76	0.08	0.05	0.57	0.54	0.17	0.22
SEm (±)	15.06	8.05	0.227	0.155	1.663	1.569	0.491	0.645
CV, %	8.70	4.60	3.30	2.30	7.00	6.70	1.40	2.00
Grand Mean	250.9	255.6	10.11	9.61	34.5	33.95	50.64	45.82

Notes: SEm (±), Standard Error of mean; CV, Coefficient of Variation; LSD, least Significant Difference; Con., Conventional; treatment means followed by a common letter(s) are not significantly different from each other based on Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Grains per spike

The number of grains per spike was not influenced by zero tillage, conventional tillage, and reduced tillage in 2019 (Table 3). However, tillage practices significantly affected ($P<0.05$) grains per spike in 2020. The statistically highest number of grains per spike was recorded in zero tillage compared to conventional tillage and reduced tillage. Grains per spike in conventional tillage and reduced tillage were similar. The grains per spike observed in residue removal and residue retention treatments were not significantly different ($P>0.05$) in 2019 and 2020. Seed rates of 80, 120, and 160 kg ha^{-1} showed significant differences ($P<0.05$) in grains per spike (Table 3). The use of a lower seed rate of 80 kg ha-1 in wheat resulted in higher grains per spike, but it was similar to the 120 kg ha^{-1} seed rate. Similarly, the 120 and 160 kg ha^{-1} seed rates were also similar in grains per spike in 2019. The effect of different seed rates of 80, 120, and 160 kg ha-1 was not significant ($P>0.05$) for grains per spike in 2020 (Table 3). The average number of grains per spike was 34.4 in 2019 and 33.95 in 2020.

Thousand grains weight

The thousand grains weight recorded in conventional tillage, reduced tillage, and zero tillage, was similar ($P>0.05$) during the 2019 and 2020 experimental years as presented in Table 3. Residue retention and residue removal were also at par for thousand grains weight in both years 2019 and 2020.

The thousand grains weight of wheat was significantly difference ($P<0.05$) in the use of 80, 120, and 160 kg ha^{-1} seed rates (Table 3). The use of a lower rate of seed 80 kg ha^{-1} produced the highest thousand grains weight than 120 and 160 kg ha^{-1} during 2019 and 2020.

The thousand-grain weight was found to decrease trend with increasing levels of seed rate from 80 to 160 kg ha^{-1} in both years (Table 3). The average thousand-grain weight was 50.64 g and 45.82 g during 2019 and 2020 respectively.

Sterility percentage

The sterility was significantly lower in zero tillage followed by conventional tillage and reduced tillage during 2019. Similarly, in 2020, conventional tillage and zero tillage were at par for sterility but significantly lower than reduced tillage (Table 4). The residue removal and residue retention were not significant for sterility during the 2019 and 2020 experimental years. The use of seed rates 80, 120, and 160 kg ha^{-1} were also statistically similar for sterility in both years. The mean value of sterility was 30.19 and 31.15 during 2019 and 2020 respectively.

Above-ground total biological yield

The total biological yield above ground was significantly ($P< 0.05$) influenced by different tillage practices during 2019 and 2020 (Table 4). The wheat sown under the zero till condition produced statistically ($P< 0.05$) the highest total biological yield over conventional tillage and reduced tillage during the 2019 and 2020 experimentation years.

The residue removal and residue retention treatments were not significant for total biological yield in both years. The use of seed rates 80, 120, and 160 kg ha^{-1} significantly ($P< 0.05$) responded to total biological yield during 2019 and 2020 (Table 4). The use of 160 kg ha^{-1} seed rate produced the highest total biological yield followed by 120 and 80 kg ha^{-1} seed rates.

The grain yield

The average grain yield for the experiment was 3,508 kg ha^{-1} in the first year and 3,290 kg ha^{-2} in the second year (Table 4). This slight decline in yield during the second year may be attributed to varying environmental conditions. Despite the difference, these yields reflect typical production levels for wheat in the subtropical climate of the region. The wheat grain yield was significant ($P<0.05$) among the tested tillage practices during 2019 and 2020.

The wheat grain yield sown under zero tillage practice was statistically highest over conventional tillage and reduced tillage. However, wheat grain yield obtained under conventional tillage and reduced tillage was statistically similar during the 2019 and 2020 experimental years. The residue removal and residue retention treatments were not significant for grain yield production during 2019 and 2020. The varying seed rates showed a statistically significant difference ($P<0.05$) in grain yield throughout both years of the experiments.

During 2019, the highest grain yield was noticed in 160 kg ha^{-1} seed rate over 120 and 80 kg ha^{-1} seed rate, meanwhile, the grain yield difference between 120 and 80 kg ha^{-1} seed rate was also significant. The grain yield increased with increasing levels of seed rate from 80 to 160 kg ha^{-1} during 2019. During 2020, the grain yield obtained at 120 and 160 kg ha^{-1} seed rates, was statistically at par but these two levels of seed rate produced significantly higher grain yield than the 80 kg ha^{-1} seed rate.

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Table 4: Sterility, total biological yield, grain yield, and harvest index of wheat as influenced by tillage practices, residue management, and seed rate

Treatments	Sterility (%)		Total biological (kg ha^{-1})		Grain yield (kg ha^{-1})		Harvest Index (HI%)	
	2019	2020	2019	2020	2019	2020	2019	2020
Tillage practices								
Con. tillage	30.6^b	30.8^b	7459^b	7136^b	3466^b	3248^b	46.4	45.6
Reduced tillage	31.5^a	33.0^a	6875^b	6772^b	3186^b	3022^b	46.4	44.6
Zero tillage	28.4^c	29.7^b	8440^a	7854^a	3870^a	3600^a	45.8	45.9
P - value	0.001	0.024	0.007	0.03	0.009	0.025	0.067	0.224
SEm (±)	0.209	0.516	169.4	177.4	79.10	88.9	0.136	0.439
LSD (p=0.05)	0.819	2.025	665.2	696.5	310.40	349	0.532	1.723
CV, %	1.20	2.90	3.90	4.20	3.90	4.70	0.50	1.70
Residue management								
Residue Removal	30.06	30.6	7725	7103	3587	3263	46.4	46.0
Residue Retention	30.32	31.7	7458	7405	3428	3317	46.0	44.7
P - value	0.78	0.04	0.60	0.41	0.56	0.50	0.42	0.43
SEm (±)	0.57	0.15	306.30	208.10	162.30	47.40	0.32	0.88
LSD (p=0.05)	3.47	0.90	1863.70	1266.50	987.80	288.20	1.92	5.33
CV, %	3.30	0.80	7.00	5.00	8.00	2.50	1.20	3.30
Seed rate (kg ha^{-1})								
80	29.05	31.1	7277^c	6908^c	3367^c	3123^b	46.3^a	45.2
120	30.35	31.5	7556^b	7331^b	3519^b	3359^a	46.6^a	45.8
160	31.17	30.9	7941^a	7522^a	3637^a	3388^a	45.8^b	45.0
P - value	0.39	0.66	<.001	<.001	<.001	0.001	0.01	0.5
LSD (p=0.05)	1.08	0.49	75.80	58.90	34.60	47.70	0.16	0.48
SEm (±)	3.157	1.424	221.1	172	101.1	139.2	0.4705	1.385
CV, %	15.20	6.60	4.20	3.40	4.20	6.10	1.50	4.40
Grand Mean	30.19	31.15	7591	7254	3508	3290	46.21	45.35

Notes: SEm (±), Standard Error of mean; CV, Coefficient of Variation; LSD, least Significant Difference; Con., Conventional; treatment means followed by a common letter(s) are not significantly different from each other based on Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Harvest Index (HI)

The harvest index was not significant due to conventional tillage, reduced tillage, and zero tillage during 2019 and 2020 (Table 4). Similarly, the effect of residue removal and residue retention on harvest index was also not significant in both experimental years. The harvest index was significant ($P<0.05$) due to 80, 120, and 160 kg seed rate application during 2019. The use of 80 and 120 kg ha^{-1} seed rates was similar for the harvest index but significantly higher than the 160 kg seed rate. Similarly, these seed rates were not significant for the harvest index during 2020.

Organic matter (%)

The initial organic matter content of the experimental plot was 2.5%. After completing a season of crop experiments, an increasing trend in organic matter was observed, with

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zero tillage showing the highest organic matter content, followed by conventional tillage and reduced tillage. This trend continued after two seasons of wheat and rice crops, as shown in Figure 3. After three crop seasons, zero tillage still had the highest organic matter content compared to conventional and reduced tillage. In addition, soil organic matter showed an increasing trend in the residue retention plot compared to the residue removal plot, as depicted in Figure 3.

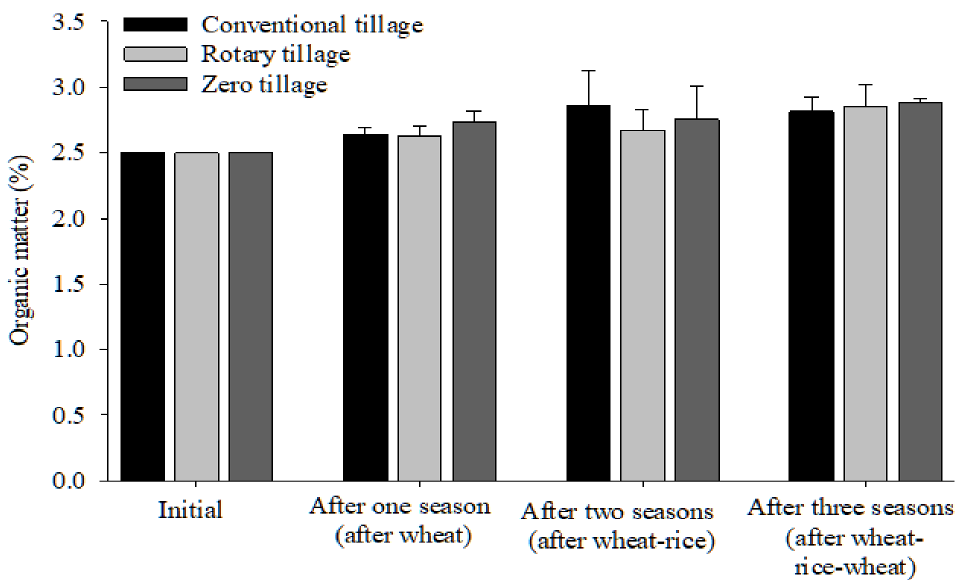

Fig 2: Organic matter percentage influenced by tillage practices

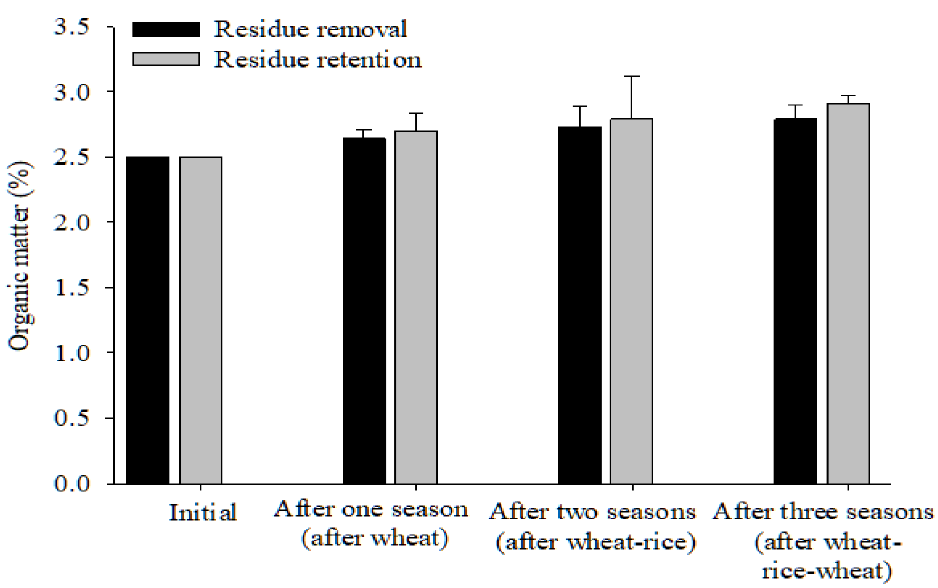

Fig 3: Organic matter (%) influenced by residue management strategies

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Bulk density

The bulk density was not significantly different due to tillage practices and residue management treatments (Figure 4). The soil bulk density was slightly high in reduced tillage practice in comparison to conventional tillage and zero tillage practice. Similarly, residue removal and residue retention treatments were found similar for bulk density and porosity at the initial stages but after three seasons crop residue retention resulted in lower bulk density.

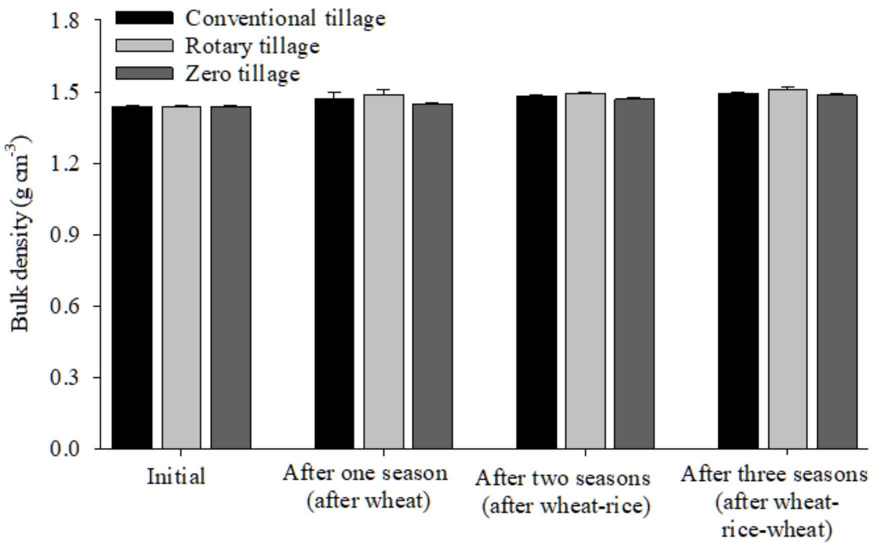

Fig 4 (a): Bulk density (g cm^{-3}) influenced by tillage practices

Fig 4 (b): Bulk density (g cm^{-3}) influenced by residue management strategies

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DISCUSSION

The experiment was conducted in 2019 and 2020, indicating that zero tillage practices had a significant influence on growth, yield attributes, and yield compared to conventional tillage and reduced tillage practices. However, residue did not have a significant influence on the growth, yield attributes, and yield of wheat. The use of different levels of seed rates, 80, 120, and 160 kg ha^{-1}, had a significant influence ($P< 0.05$). Wheat yield increased with increasing levels of seed rate up to 160 kg ha^{-1}. Higher percentage of organic matter and lower bulk density were observed in zero tillage treatment compared to both tillage practices. Similarly, residue retention also had a positive influence on organic matter and reduced bulk density compared to residue removal treatment.

Plant height is an important factor in development that provides insight into predicting biomass and crop productivity. Higher plant height was observed in zero tillage compared to reduced tillage and conventional tillage. Hakim et al. [14] reported that zero tillage recorded the maximum plant height, significantly higher than the conventional method. This may be due to enhanced soil health and micro-environment through the implementation of conservation-based management practices [15]. In contrast, Sardana et al. [16] and Singh et al. [17] observed no significant difference in plant height when comparing zero tillage with conventional methods. Meena [18] observed significantly higher plants under zero tillage compared to farmers' practices and conventional tillage. However, Yadav et al. [19] reported marginally higher growth parameters of wheat crops under zero tillage compared to conventional tillage. Plant height was similar in both residue retention and residue removal treatments. Qamar et al. [20] also reported no significant effect of residue removal and retention on plant height in wheat. Different levels of seed rates, 80, 120, and 160 kg ha^{-1}, did not show a significant effect on plant height. Singh [21] found no significant difference in plant height due to different seeding densities. Kabir et al. [22] reported the highest plant height at a seed rate of 140 kg ha^{-1} compared to lower and higher seed rates.

Biomass accumulation is positively correlated with the number of tillers and plant height. Zero tillage practices had a significant influence ($P<0.05$) on dry matter production compared to reduced tillage and conventional tillage. This may be due to the higher plant height and number of tillers in zero tillage treatments contributing to higher dry matter production. Timalsina et al. [23] found higher dry matter accumulation in wheat under zero tillage compared to conventional tillage. Residue retention and residue removal did not have a significant influence ($P>0.05$) on plant height, possibly due to similar growth parameters in both treatments. A similar result was found by Timalsina et al. [23]. Dry matter production was significantly higher in the seed rate of 160 kg ha^{-1} compared to 120 and 80 kg ha^{-1}. This may be due to a higher number of tillers in the higher seed rate resulting in higher dry matter production. This could also be due to higher evaporation and dryness under a lower seed rate due to more soil exposure [24, 25]. Kumar et al. [26] also reported higher dry matter under a higher seed rate of 125 kg ha^{-1} compared to 75 kg ha^{-1}.

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The higher leaf area index in zero tillage practices may be attributed to greater plant height and number of tillers compared to reduced tillage and conventional tillage. Timalsina et al. [23] also found a higher leaf area index (LAI) in zero tillage crop establishment methods compared to conventional tillage and surface seeding methods. In contrast, Shahzad et al. [27] and Thapa et al. [28] reported a lower leaf area index in zero tillage wheat compared to conventional tillage. The similar leaf area index in residue retention and residue removal plots may be due to a non-significant response in growth parameters. Timalsina et al. [23] also reported a non-significant response in leaf area index due to residue removal and retention. The higher leaf area index of 160 kg ha^{-1} compared to 80 and 120 kg ha^{-1} may be due to a higher number of tillers with higher seed rates. Laghari et al. [34] also found a higher leaf area index (LAI) with higher seed rates.

Days to flowering and physiological maturity in zero tillage, reduced tillage, and conventional tillage practices were not significant. A similar trend was observed in residue removal and retention treatments. This may be due to uniform fertility levels in all treatments. However, lower seed rates (80 kg ha^{-1}) took longer for flowering and maturity compared to 120 and 160 kg ha^{-1} of seed application. This could be due to lower inter and intra-plant competition compared to higher seed rates.

Proper plant population is essential for achieving higher productivity. The number of tillers per unit area is a key indicator for predicting crop productivity. Zero tillage practice resulted in a higher number of tillers compared to reduced tillage and conventional tillage. This could be attributed to better resource utilization under zero tillage, leading to a greater number of tillers. Kumar et al. [26] also found a higher number of tillers in zero-till sown wheat compared to other tillage practices tested. Residue removal and retention did not have a significant effect on tiller production, possibly due to similar resource utilization. Saini and Walia [29] reported no noticeable growth differences between residue retention and removal situations. Similarly, Timalsina et al. [23] observed no significant differences in tiller production between residue removal and retention conditions in wheat. A higher number of tillers was observed with a seed rate of 160 kg ha^{-1} compared to 80 and 120 kg ha^{-1}. This could be because a higher seed rate resulted in a greater plant population per unit area. Singh et al. [30] noted that the number of tillers per m2 was highest with a seed rate of 80 kg/ha, outperforming lower seed rates of 60 kg ha^{-1} and 40 kg ha^{-1}. Kabir et al. [22] reported the highest total tillers per plant with a seed rate of 140 kg ha^{-1} compared to higher and lower seed rates.

Spike length is an indicator of the number of grains and spikelets, with higher spikelets leading to higher grain yield. Zero tillage practice resulted in longer spikes compared to reduced tillage and conventional tillage, possibly due to improved soil health and micro-environment from conservation-based management practices [15]. Alijani et al. [31] conducted a two-year field experiment to assess the impact of different levels of soil disturbance through three tillage practices (conventional tillage, zero tillage, and deep tillage) on wheat. Longer spike lengths were observed in no-tillage and deep tillage compared to traditional methods. Spike length was similar between residue removal and

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retention treatments, likely due to similar resource utilization. Khatri et al. [32] found no significant difference in spike length between residue removal and retention treatments. However, Raghavendra et al. [33] noted longer spike lengths in the residue retention treatment compared to no residue treatment. The longer spike length with a seed rate of 80 kg ha^{-1} over 120 and 160 kg ha^{-1} may be due to reduced competition between plants. Laghari et al. [34] also reported longer spike lengths with lower seed rates, with a significant decrease in spike length as seed rates increased up to 200 kg ha^{-1}.

A higher number of grains per spike was observed under zero tillage conditions compared to reduced and conventional tillage practices. This could be attributed to better soil health and microenvironment under zero tillage conditions. Timalsina et al. [23] also found a higher number of grains per spike in zero tillage compared to conventional tillage and surface-seeding wheat. In contrast, Leghari et al. [35] noted the maximum number of grains per spike under conventional tillage. The similar number of grains per spike in residue removal and residue retention plots may be due to the insignificant difference in resource utilization between the two treatments. This result is consistent with Khatri et al. [32], who observed no significant effect of residue removal and retention on grains per spike. A lower seed rate (80 kg ha^{-1}) resulted in a higher number of grains compared to 120 and 160 kg ha^{-1}, possibly due to the longer spike length contributing to a higher number of grains per spike. Laghari et al. [34] also found a higher number of grains per spike with a lower seed rate.

The thousand grain weight recorded in zero tillage, reduced tillage, and conventional tillage was similar. Timalsina et al. [23] also found no significant response in thousand grain weight in zero tillage, conventional tillage, and surface-seeding wheat. In contrast, Chokkar et al. [36] found that thousand grain weight was affected by tillage systems, with the maximum weight achieved in zero tillage compared to other practices. The thousand grain weight was also similar in residue removal and residue retention plots. Meena et al. [37] and Khatri et al. [32] reported that residue retention did not statistically affect thousand grain weight compared to residue removal. The lower seed rate (80 kg ha^{-1}) resulted in a higher thousand grain weight compared to 120 and 160 kg ha^{-1}, possibly due to more efficient resource utilization resulting in bold grains, while higher seed rates led to competition resulting in shriveled grains. Laghari et al. [34] also found higher thousand grain weight with a lower seed rate.

The sterility percentage was lower in zero tillage compared to reduced and conventional tillage, possibly due to more efficient resource utilization. Residue management and different levels of seed rate showed similar sterility percentages in wheat. Timalsina et al. [23] found no significant response in sterility among different tillage practices and residue removal and retention treatments in wheat crops.

The total biological yield above ground is higher under zero tillage compared to reduced and conventional tillage. This could be due to more efficient nutrient utilization by plants in zero tillage practices. Hussain et al. [38] and Iqbal et al. [39] also found higher biological yield in zero-till sown wheat compared to other tillage practices. The management of

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residue did not affect the total biological yield above ground, possibly because there was no significant difference in resource utilization between residue removal and retention treatments. Khatri et al. [32] discovered a higher biological yield in residue-kept treatments than in residue-removal treatments.

A significantly higher total biological yield above ground was observed with a seed rate of 160 kg ha^{-1} compared to 120 and 80 kg ha^{-1}. This could be due to better growth and yield attributes with higher seed rates. Ahmad et al. [40] also found higher biological yield with increased seed rates. Huang et al. [41] and Hiltbrunner et al. [42] suggested that the increase in biological yield with higher seed rates may be because of a greater number of plants per unit area, even though there are fewer tillers.

The higher number of tillers, longer spikes, more grains per spike, and lower sterility percentage in zero tillage practices compared to reduced and conventional tillage could be the reason for higher grain yield in wheat. The lower yield under conventional tillage may be due to higher weed density, leaching of nitrogen fertilizer, and immobilization due to crop residue incorporation. On the other hand, the higher yield under zero tillage may be attributed to reduced weed growth, minimal nutrient loss, and efficient moisture conservation leading to more productive tillers of wheat. Kumar et al. [26] also observed higher grain yield in wheat under zero tillage.

The yield produced under residue removal and retention was similar, possibly due to similar yield attributes in both residue treatments. Khatri et al. [32] reported a non-significant response of residue removal and retention on grain yield. In contrast, Yadav and Singh [52] reported higher grain yield in residue retention treatments. The increased wheat yield with a seed rate of 160 kg ha^{-1} over 120 and 80 kg ha^{-1} could be due to a higher number of tillers with a higher seed rate. Sharma and Singh [43] also noted an increasing trend in wheat grain yield with increasing seed rates up to 125 kg ha^{-1}. Ahmad et al. [40] found that a seed rate of 115 kg ha^{-1} resulted in the desired plant population, ensuring maximum tillers, longest spikes, and more spikelets per spike, leading to the highest grain production from wheat crops. This aligns with the findings of Sayre and Moreno [44], Talukder et al. [45], and Waraich et al. [46] who reported the highest grain yield by using the optimal seed rate to produce the longest spike and a greater number of spikelets per spike, resulting in the highest grain production from wheat crops. Tripathi et al. [50] reported similar wheat grain yield between 100 and 125 kg ha^{-1} seed rates.

The harvest index depicts the physiological efficiency of plants in converting assimilates into grain yield. A higher harvest index indicates a greater capability of plants to convert dry mass into economic parts. Different agronomic practices, such as sowing time, method, seed rate, fertilizer application, and irrigation application, influence the harvest index. Zero tillage, reduced tillage, and conventional tillage practices were not significant. Ali et al. [47] and Bartaula et al. [48] found a non-significant response of tillage on the harvest index. In contrast, Thapa et al. [28] reported a significantly higher harvest index in conventional tillage than zero tillage.

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The Harvest index was similar in residue removal and residue retention treatments. Netam et al. [49] also reported non-significant results of residue management on the harvest index in wheat crops. In contrast, Thapa et al. [28] reported a higher harvest index in zero tillage (ZT) than in conventional tillage (CT) wheat. Seed rates of 80, 120, and 160 kg ha^{-1} were significant in 2019, but in 2020, the response of the harvest index was not significant. Tripathi et al. [50] also reported a non-significant response on the harvest index of wheat between 100 and 125 kg ha^{-1} seed rate.

The soil organic matter showed an increasing trend in zero tillage practices. Organic matter levels of 8%, 14.4%, and 15.6% were observed after one season crop, two season crop, and three season crops respectively. In conventional tillage, organic matter levels of 6%, 9.2%, and 12.8% were found after one-season crop, two-season crop, and three-season crops respectively. Similarly, in reduced tillage, organic matter levels of 5.2%, 6.8%, and 14% were observed after the completion of one-season crop, two-season crop, and three-season crops respectively.

The higher organic matter in zero tillage practice might be due to the deposition of organic matter. Alam et al. [51] observed that after four years, soil organic matter increased by 50% in ZT compared to the initial status. The soil organic matter showed an increasing trend in the residue retention plot compared to the residue removal plot. After completion of three season crops, 16.4% higher organic matter was observed in the residue retention plot than the initial value. Singh and Yadav [52] also found higher organic carbon levels in residue retention and incorporation plots than in residue removal plots.

The bulk density was lower in zero tillage and residue retention plots, possibly due to the deposition of organic matter. Alam et al. [51] found that bulk density and porosity varied significantly ($P<0.05$) among the tillage practices. After four years, bulk density decreased due to tillage practices, with a greater decrease found in ZT than in other tillage practices. After four years of cropping cycles, porosity increased from the initial value (6.2%, 2.9%, and 0.69% increase in ZT, MT, and CT). Singh and Yadav [52] found significantly lower bulk density in residue retained and incorporation treatments than in residue removal treatment.

CONCLUSION

Based on two-year results, the wheat growth, yield attributes, and yield variables were higher under zero tillage conditions than reduced and conventional tillage. Residue removal and residue retention were similar for growth, yield attributes, and yield of wheat. But the higher rate of seed, 160 kg ha^{-1} had higher yield attributes and yield than 80 and 120 kg ha^{-1}. The yield difference between the seed rate of 120 and 160 kg ha^{-1} was 118 and 29 kg ha^{-1} during 2019 and 2020 respectively. The soil health parameters, higher organic matter, and lower bulk density were found in zero tillage and residue retention treatments. Based on the obtained results, it could be concluded that wheat can be grown under zero tillage with residue retention and use of the recommended rate of seed rate 120 kg ha^{-1} for optimum yield and sustain soil fertility.

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