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Performance of conservation agriculture practices on the physical growth and yield of broccoli (*Brassica oleracea L. var. italica*) in Nyabihu District

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Abstract

This study aims to investigate the effect of various tillage methods on physical growth and yield of broccoli (*Brassica oleracea L. var. italica)*. The experiment was conducted in farmers'field during seasons 2022B (March-June) and 2023A (September-February). Experiment was laid out in a Randomized Complete Block Design (RCBD) in Nyabihu District in four replications and five treatments which were T1(Conventional tillage), T2(zero tillage), T3(minimum tillage), T4(medium tillage) and T5(maximum tillage). Data were collected on physical growth at 15 days after planting (DAP) with interval of 15 days up to 45 DAP, while yield data were collected after harvesting. The Analysis of variance (ANOVA) was done following OPSTAT, statistical analysis tool, at $P<0.05$ and Least Significant Difference (LSD) was used for mean separation. There was a significant difference in physical growth and yield of broccoli. Minimum tillage outperformed other treatments both in growth and yield while zero tillage was the least. Yield was the highest with 31.32t/ha for minimum tillage and the lowest for maximum tillage with 10.18t/ha both in 2023A.Yield increment was highest for minimum tillage and lowest for zero and maximum tillage. Minimum tillage is advised to increase yield of broccoli and environmental conservation.

***Keywords*:** *Broccoli, conservation agriculture, physical growth, tillage, yield increment*

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Introduction

Broccoli is an open branching form of cauliflower that bears young flowering shoots which are used as vegetables and is classified in the Italica cultivar group of the species Brassica Oleracea (*Brassica Oleracea Var. Corato)*. It belongs to the Brassicacea family which consists of several cole vegetable crops such as cauliflower, cabbage, Chinese cabbage, broccoli, Brussels sprouts and kohlrabi (Abou El- Magd *et al.,* 2006). It originated from Mediterranean and Asia Minor (Das and Ghosh, 2021). The common English name 'broccoli' is derived from the Italian word 'broccolo', meaning 'the flowering crest of a cabbage' (Das and Ghosh, 2021). Broccoli (*Brassica oleracea* var. italic) is one of the many vegetables grown in Rwanda and it is among the most nutritious vegetables grown in the world.

Fresh broccoli is dark green in color with firm stalks and compact bud clusters and it has a variety of nutrients. It is grown for its edible flower buds and stalk (Das and Ghosh, 2021). Broccoli contains 90% of water, 7% of carbohydrates, and zero fat content (Das and Ghosh, 2021). It contains minerals like Fe, Zn, Ca, and Mg as well as vitamins such as E, A, B1, B2, B5, and B6 (Abou El-Magd *et al*., 2006). Broccoli is a rich source of antioxidant substances with powerful anticancer properties (Abou El-Magd *et al*., 2006; Al-jaf*et al.,* 2018; Das and Ghosh, 2021). Consumption of broccoli can help to meet nutritional requirements and body protection due to its nutrients and phytonutrients.

Broccoli is a cold weather crop and it is cultivated in different methods. It grows better at temperature of 10 to 20^{0}C (Wikifarmer, 2023). Different tillage methods are used for growing broccoli. Tillage is an important method that is used to grow this crop. It changes soil characteristics, improve soil physical and chemical properties, and create a good environment for crop growth (Shan *et al.,* 2022). Tillage usually means reducing soil hardness, improving soil structure, and improving soil water storage capacity through interactions between machines and the soil (Shan *et al.,* 2022). Studies have also reported that deeper tillage can alleviate subsoil compaction, thereby improving crop yield (Mochizuki *et al.,* 2007). Tillage reduces soil compaction which allows roots to penetrate deeper in the soil and it contributes to the crop yield.

Growing broccoli is predominated using conventional tillage method which adds burden to the ecosystem and environmentally friendly methods are needed to cope with the changing climate. According to Darley *et al.* (2019), a problem faced in the cultivation of vegetables including

broccoli spp is soil management, which is due to intensive conventional tillage, revolting with plow, grid, and enchantment, causing environmental damage and mainly soil loss due to erosion, as well as degradation of organic matter and reduction of fertility. On the other hand, conservation agriculture acts as a resource-saving agricultural crop production system that serves to achieve acceptable profits and sustain production while conserving the environment (Dlamini *et al*., 2019). The use of conservation farming has gained momentum in recent years. This is attributed mainly to the Food and Agriculture Organization (FAO) which has been actively promoting Conservation Agriculture (CA), especially in the developing and emerging economies (FAO, 2017). It holds tremendous potential for all sizes of farms and agroecological systems, but its adoption is perhaps mostly urgently required by small-scale farmers (FAO, 2017; Dlamini *et al*., 2019) especially those facing acute labor shortages. It is a way of combining profitable agricultural production with environmental concerns and sustainability and it has been proven to work in a variety of agro-ecological zones and farming systems. It is being perceived by practitioners as a valid tool for Sustainable Land Management (SLM) (Dlamini *et al*., 2019). Therefore, this study aims at investigating effect of conservation agriculture practices namely zero tillage, reduced, minimum and maximum tillage on growth and yield of broccoli.

Materials and Methods

Experimental site

The experiments were conducted in farmers' fields in Nyabihu District, Jenda sector during the agricultural seasons 2022B and 2023A.Nyabihu District is located on a volcanic mountain range whose altitude varies between 1800 and 2450 meters above sea level, 1°29' of Latitude S and 29°39' of Longitude E. It is characterized by volcanic soil. Precipitation was almost uniform throughout the 2 seasons, which was around 1400 mm and the average temperature was 15^{0}C (Nyabihu District, 2019).

Experimental design and field layout

The experiment was laid out in Randomized Complete Block Design (RCBD) in two agricultural seasons 2022B and 2023A with five treatments and four replications. The elementary plots had a dimension of 4x3m, spaced 1m within the blocks and 2m between the blocks. The planting density of 50 cm x 30 cm (0.15 sqm per plant) between and within rows respectively recommended by RAB (Rwanda Agriculture and Animal Resources Development Board) was used which gave a total of 80 planting holes per elementary plot, and the total plant population was 66,667 plants/ha. Five

treatments were assigned to each block and their identifications are as follow:

- T1: Conventional tillage method (depth varies up to 30cm),
- T2: Zero tillage (0 cm),
- T3: Minimum tillage (5 cm),
- T4: Medium tillage (10 cm), and
- T5: Maximum tillage (20 cm)

Data collection

In each agricultural season, five plants were randomly selected from each elementary plot excluding border plants, and the data were used to measure various growth and yield parameters. Data were collected at the period interval of 15Days After Planting (DAP) starting from 15th day after planting up to 45 days and technical data collection sheets, rulers, weighing scales, and pair calipers were availed for that purpose. Growth parameters measured were plant leaf development (number of leaves), plant height and plant stem diameter. The yield was measured as head weight t/ha.

Statistical data analysis

Collected data were subjected to Analysis of Variance (ANOVA) appropriate to the RCBD following OPSTAT, statistical analysis tool at $P < 0.05$ levels of probability test and the treatment means were separated into homogeneous groups using the Least Significant Difference (LSD).

Results and Discussion

Broccoli plant leaf development (number) as influenced by conservation agriculture practices

The results of ANOVA showed that there was a significant difference in number of leaves in all treatments and in both seasons at $P< 0.05$ as presented in Table 1. Broccoli leaves development was evaluated on different tillage methods at 15, 30, and 45 days after planting (DAP) across two growing seasons, 2022-B and 2023-A. Conventional Method showed moderate performance across both seasons. The leaf development was consistent, but not outstanding compared to other methods. At 15 DAP, it had similar values in both seasons but was generally outperformed by other tillage methods, especially minimum tillage. By 45 DAP, it recorded lower leaf development compared to other methods, particularly in the 2023-A season. Maximum Tillage displayed varying results between the two seasons. In season 2022-B, it performed well at 30 DAP but had a notable drop at 45 DAP. Season 2023-A saw inconsistent results, with higher values at 15 DAP but a decline at 30 DAP, and slight recovery at 45 DAP. Medium Tillage generally performed well, with good leaf development at 30 and 45 DAP in both seasons. The values were competitive with minimum tillage, especially at 45 DAP,

indicating that moderate tillage depths may be beneficial for sustained leaf development. Minimum Tillage consistently outperformed all other treatments across both seasons and all time points. At 15 DAP, it had the highest values, showing the most robust early leaf development. This trend continued at 30 and 45 DAP, making it the most effective tillage method for broccoli leaf development. Regarding Zero Tillage recorded the lowest values across all time points in both seasons. The lack of tillage seems to significantly hinder early and late leaf development, making it the least favorable method. For **Season 2022-B, t**he general mean leaf development shows that the methods, particularly minimum tillage, were effective, with consistent results.

Table 1. ***Response of various depths of tillage on broccoli leaf development in seasons 2022-B and 2023-A***

Treatments	Season 2022-B			Season 2023-A		
	15 DAP	**30 DAP**	**45DAP**	**15 DAP**	**30 DAP**	**45DAP**
Conventional method	9.47^{bc}	10.54^{bc}	14.50^{cd}	9.28^{d}	10.44^{c}	13.48^{d}
Maximum tillage	9.63^{b}	11.35^{ab}	13.88^{d}	11.06^{bc}	9.83^{de}	13.93^{cd}
Medium tillage	8.56^{bcd}	12.27^{a}	14.55^{bcd}	9.99^{cd}	10.94^{bc}	14.60^{bc}
Minimum tillage	11.00^{a}	12.78^{a}	15.90^{a}	13.23^{a}	12.88^{a}	18.60^{a}
Zero tillage	5.90^{e}	8.43^{d}	9.85^{e}	7.90^{e}	9.33^{e}	12.05^{e}
General Mean	**8.90**	**11.10**	**13.70**	**10.30**	**10.70**	**14.50**
CV (%)	0.096	0.055	0.036	0.098	0.034	0.034
LSD (5%)	1.31	0.94	0.76	1.55	0.57	0.76

Means followed by the same letter(s) in a column are not significantly different by LSD at a 5% level of significance, CV=Coefficient of variation, LSD=Least Significant Differences.

The CV (Coefficient of Variation) values indicate moderate variability in leaf development across treatments. For Season 2023-A**, t**he results are somewhat similar to 2022-B, but with higher values in general for the 15 and 30 DAP stages, particularly for minimum tillage. CV values are lower, indicating less variability and more consistency in the results. The LSD values at the 5% significance level indicate that there are significant

differences between treatments at all stages and for both seasons. The differences observed, especially in minimum and zero tillage, are statistically significant, highlighting the reliability of the results. Minimum Tillage is consistently the best method for promoting broccoli leaf development in both seasons. This suggests that a shallower tillage depth might be more conducive to optimal leaf growth. Conventional and Maximum Tillage methods also provide decent results but are not as effective as minimum tillage. Zero Tillage is the least effective, significantly limiting leaf development. These results suggest that while traditional tillage practices are beneficial, adjusting the depth of tillage, specifically adopting a minimum tillage approach, could enhance broccoli leaf growth. It was reported that reduced tillage limit root development which can affect the entire development of the plant (Mochizuki *et. al.*, 2007). A study conducted by Jokela, and Nair (2016) on non-tillage, strip tillage and convention tillage showed no significant difference in leaves development in 2014, while there was a significant difference in 2015. Furthermore, Schellenberg *et al.* (2009) reported no significant difference on number of leaves for broccoli grown in spring and fall under conventional tillage and no tillage. Number of leaves increase as the plant grows and it depends on type of tillage and season.

Broccoli plant height (Cm) as influenced by conservation agriculture practices

The results of ANOVA revealed that there was a significant difference in plant height in both seasons for all treatments at $P < 0.05$ as presented in Table 2 at 15, 30, and 45 days after planting (DAP) across two growing seasons, 2022-B and 2023-A. Conventional Method showed lower growth heights across both seasons compared to other tillage methods. Growth was relatively consistent between the two seasons but consistently lagged behind the other tillage methods, particularly in the later stages (30 and 45 DAP). Maximum Tillage provided moderate growth height results. In season 2022-B, the results improved from 15 DAP to 45 DAP but still trailed behind minimum tillage. In season 2023-A, the growth height was slightly lower than in 2022-B at 15 and 30 DAP, but it showed a significant increase by 45 DAP, though still not reaching the levels of minimum tillage. Medium Tillage showed good performance across both seasons. Growth height at 15 DAP was similar to maximum tillage but showed a slight advantage at 30 and 45 DAP in both seasons. The results indicate that medium tillage supports consistent growth, particularly in the mid to late stages.

Minimum Tillage Produced the highest growth heights consistently across all DAP stages in both seasons. In season 2022-B, it reached a height of 48.03 cm by 45 DAP, significantly higher than other methods. In season 2023-A, the trend continued with even better results, reaching 50.83 cm by 45 DAP, indicating the superior efficacy of minimum tillage for broccoli growth. Zero Tillage consistently resulted in the lowest growth heights. There was a noticeable drop in growth height at all stages compared to the other methods, particularly at 15 and 30 DAP. The results suggest that the absence of tillage severely restricts broccoli growth, especially in the early and middle stages. During Season 2022-B, the general mean for growth height shows reasonable growth, with minimum tillage standing out.

Table 2. ***Response of the various tillage depth on the broccoli growth height in cm for seasons 2022 B and 2023A***

Treatments	Season 2022-B			Season 2023-A		
	15DAP	**30 DAP**	**45 DAP**	**15 DAP**	**30 DAP**	**45 DAP**
Conventional method	9.74^{de}	25.65^{d}	40.7^{d}	9.74^{d}	23.20^{cd}	39.18^{e}
Maximum tillage	11.18^{c}	26.2^{cd}	41.38^{cd}	11.17^{c}	22.80^{d}	42.98^{cd}
Medium tillage	11.50^{bc}	26.54^{bc}	41.75^{bcd}	11.50^{bc}	23.48^{bcd}	43.35^{bcd}
Minimum tillage	13.14^{a}	32.38^{a}	48.03^{a}	13.59^{a}	25.98^{a}	50.83^{a}
Zero tillage	9.34^{e}	22.38^{e}	34.50^{e}	7.34^{e}	18.48^{e}	41.54^{d}
General Mean	**10.98**	**26.63**	**41.27**	**10.67**	**22.79**	**43.57**
CV (%)	0.04	0.018	0.048	0.042	0.027	0.036
LSD (5%)	0.68	0.73	3.04	0.69	0.93	2.43

Means followed by the same letter(s) in a column are not significantly different by LSD at a 5% level of significance, CV=Coefficient of variation, LSD=Least Significant Differences.

The results indicate some variability in growth heights, as reflected by the CV values. During Season 2023-A, the general mean growth height was slightly lower at the early stage (15 DAP) but improved significantly by 45 DAP. The higher growth heights observed for minimum tillage in this season suggest a strong response to this tillage method, particularly in the later stages. The LSD values at the 5% significance level indicate significant

differences in growth heights across the different treatments. The differences observed, particularly between minimum tillage and zero tillage, are statistically significant, underscoring the reliability of the results. Minimum Tillage is the most effective method for enhancing broccoli growth height, particularly in the later stages of development. This trend is consistent across both seasons, making it a superior tillage method for this aspect of broccoli cultivation. Conventional, Maximum, and Medium Tillage methods are moderately effective but do not match the performance of minimum tillage. However, they are still better than zero tillage. Zero Tillage is the least effective, leading to significantly lower growth heights, which could impact overall yield and crop quality. These results suggest that for optimal broccoli growth height, particularly as the plant matures, minimum tillage should be the preferred method. The consistency of these findings across two seasons reinforces the importance of tillage depth in crop management strategies. It was reported that increase of tillage depth from 10 cm to 30 cm increased cabbage development by 28% and growth at 30 cm depth was similar to convention tillage (Mochizuki *et al.*, 2007). A study conducted by Jokela, and Nair (2016) on plant height showed that broccoli grown in convention tillage grew more rapidly than the ones grown with no tillage and strip tillage in 2014, while there was no significant difference in 2015. Type of tillage has effect of how plant access the nutrients from soil and its development (Mochizuki *et. al.*, 2007). The increase of plant height is affected by the nature of tillage and weather conditions.

Broccoli stem diameter (Cm) as influenced by conservation agriculture practices

The results from ANOVA showed that there was a significant difference of plant stem diameter in both seasons for all treatments at $P<0.05$ as illustrated in Table 3 at 15, 30, and 45 days after planting (DAP) during the 2022-B and 2023-A growing seasons. Conventional Method, in season 2022-B, the broccoli diameter was moderate, with values gradually increasing from 1.52 cm at 15 DAP to 2.81 cm at 45 DAP. In season 2023-A, the diameter started slightly higher at 15 DAP (1.75 cm) and reached 2.43 cm at 45 DAP, but the growth was slower compared to 2022-B. Overall, this method resulted in moderate diameters, but it was outperformed by other methods at various stages, especially by minimum tillage. Maximum Tillage, produced relatively good results, particularly at 15 and 30 DAP in both seasons. In 2022-B, the broccoli diameter grew from 1.81 cm at 15 DAP to 2.97 cm at 45 DAP, indicating a consistent increase. However, in 2023-A, the growth was less consistent, with a decline at 30 DAP before recovering

slightly by 45 DAP. This method had the second-highest values at the initial stages but didn't maintain the lead as consistently as minimum tillage. Medium Tillage, showed steady performance in both seasons. In season 2022-B, the diameter increased from 1.64 cm at 15 DAP to 2.92 cm at 45 DAP, making it one of the better performers. The results in 2023-A were similar, with the diameter reaching 2.94 cm by 45 DAP, indicating consistent effectiveness throughout the growing period. Minimum Tillage, Demonstrated the best overall performance across all stages and both seasons. In season 2022-B, the broccoli diameter increased from 1.94 cm at 15 DAP to 3.19 cm at 45 DAP, the highest among all treatments. In season 2023-A, this method again led to the largest diameters, with the value reaching 3.59 cm at 45 DAP, further reinforcing the effectiveness of minimum tillage. Zero Tillage, Recorded the lowest broccoli diameters overall. In season 2022-B, the diameter was relatively low at 15 DAP (1.36 cm) and ended at 2.68 cm by 45 DAP. In season 2023-A, the diameter started at 1.4 cm and reached 2.98 cm at 45 DAP, which, while better than in 2022-B, was still lower than the results from other tillage methods. During Season 2022-B, the general mean (GM) values indicate that broccoli diameters increased steadily with time, with minimum tillage showing the best results.

Table 3. ***Response of various depths of tillage on broccoli diameter (cm) in seasons 2022-B and 2023-A***

	Season 2022-B			**Season 2023-A**		
Treatments	**15 DAP**	**30 DAP**	**45DAP**	**15DAP**	**30DAP**	**45DAP**
Conventional method	1.52^{c}	1.9^{e}	2.81^{ab}	1.75^{abc}	2.23^{bc}	2.43e
Maximum tillage	1.81^{a}	2.09^{cd}	2.97^{a}	1.8^{a}	1.86^{e}	2.59^{de}
Medium tillage	1.64^{bc}	2.23^{bcd}	2.92^{a}	1.63^{c}	2.13^{cd}	2.94^{c}
Minimum tillage	1.94^{a}	2.73^{a}	3.19^{a}	1.93^{a}	2.73^{a}	3.59^{a}
Zero tillage	1.36^{d}	2.08^{d}	2.68^{ac}	1.4^{d}	1.96^{de}	2.98^{bc}
General Mean(GM)	**1.65**	**2.2**	**2.91**	**1.7**	**2.18**	**2.9**
CV (%)	0.054	0.07	0.063	0.052	0.067	0.063
LSD (5%)	0.14	0.24	0.28	0.14	0.22	0.28

Means followed by the same letter(s) in a column are not significantly different by LSD at a 5% level of significance, CV=Coefficient of variation, LSD=Least Significant Differences.

The CV (Coefficient of Variation) values indicate moderate variability across the treatments, particularly at 30 and 45 DAP, but the differences between treatments are statistically significant (as shown by the LSD values). During Season 2023-A, the trend is similar to that of 2022-B, with diameters generally increasing over time. Minimum tillage continued to outperform other methods, with the highest general mean and the lowest variability (as reflected by the CV and LSD values). The LSD values at the 5% significance level indicate significant differences in broccoli diameter across the different treatments. These values suggest that the differences observed, especially between minimum tillage and zero tillage, are statistically significant, confirming the robustness of the results. Minimum Tillage consistently results in the largest broccoli diameters, suggesting that this method provides the most favorable conditions for the growth of broccoli in terms of diameter. This superiority is evident across both seasons and all stages of growth. Medium and Maximum Tillage also result in relatively large diameters, especially at later stages, but they do not match the performance of minimum tillage. Conventional Method provides moderate results but does not perform as well as the more intensive tillage methods. Zero Tillage is the least effective, leading to smaller diameters overall, which could impact the marketability and yield of the crop. These findings reinforce the importance of selecting the appropriate tillage depth to optimize broccoli growth, particularly in terms of diameter, with minimum tillage emerging as the most effective practice. Jokela and Nair (2016) studied effect of tillage on broccoli stem diameter in 2014 and 2015 and it was shown that in 2014 conventional tillage performed better than no tillage and strip tillage, while in 2015 the performance was not significantly different among the treatments. Agricultural practices were reported to influence on plant development (Al-jaf *et al.*, Darley *et al.*, 2019; Pankaj *et al.*,2019). Increase in stem diameter depends on type of a tillage and agricultural season.

Broccoli yield parameters as influenced by conservation agriculture practices

Broccoli head diameter

There was a significant difference in head dimeter of broccoli for different treatments in both seasons at $P<0.05$ as presented in the Table 4 during the 2022-B and 2023-A seasons. Conventional Method, the head diameter was relatively moderate, with values of 11.17 cm in season 2022-B and slightly lower at 11.00 cm in season 2023-A. This method showed consistency across both seasons but was outperformed by other methods, particularly minimum tillage. Maximum Tillage (20 cm) produced

smaller head diameters compared to most other tillage methods. The diameter was 10.18 cm in season 2022-B and slightly lower at 10.10 cm in season 2023-A. These values suggest that deeper tillage may not be as effective in promoting larger head diameters in broccoli. Medium Tillage (10 cm), **s**howed better results than maximum and conventional tillage. The head diameter was 11.56 cm in season 2022-B and increased slightly to 11.60 cm in season 2023-A. Medium tillage appears to offer a good balance, resulting in consistently larger head diameters than deeper tillage methods. Minimum Tillage (5 cm), **c**onsistently produced the largest head diameters across both seasons. In season 2022-B, the head diameter was 14.66 cm, and it increased to 15.70 cm in season 2023-A. This method clearly outperforms all others, suggesting that shallower tillage depths (5 cm) are highly beneficial for maximizing the head size of broccoli. Zero Tillage (0 cm) resulted in the smallest head diameters, with 8.51 cm in season 2022-B and slightly lower at 8.30 cm in season 2023-A. The lack of tillage appears to significantly limit the development of the broccoli head, making it the least effective method. During Season 2022-B, the general mean head diameter (GM) was 11.21 cm. The results indicate variability across treatments, with minimum tillage producing a significantly larger head diameter than the other methods.

Table 4. ***Head diameter of broccoli in cm per treatment***

Treatments	**Size of Head Diameter Season 2022-B**	**Size of Head Diameter Season 2023-A**
Conventional method	11.17^{cd}	11.00^{cde}
Maximum tillage (20 cm)	10.18^{de}	10.10^{de}
Medium tillage (10 cm)	11.56^{bcd}	11.60^{bcd}
Minimum tillage (5 cm)	14.66^{a}	15.70^{a}
Zero tillage (0 cm)	8.51^{e}	8.30^{e}
General Mean(GM)	**11.21**	**11.30**
CV(%)	0.18	0.2
LSD (5%)	3.03	3.1

Means followed by the same letter(s) in a column are not significantly different by LSD at a 5% level of significance, CV=Coefficient of variation, LSD=Least Significant Differences.

The CV (Coefficient of Variation) is 18%, suggesting moderate variability in head size across the different treatments. During Season 2023-A, the general mean head diameter was slightly higher at 11.30 cm, showing an overall improvement in head size. The trend is consistent with the 2022-B season, with minimum tillage again leading to the largest head diameters. The CV of 20% indicates slightly higher variability compared to 2022-B, but the pattern of results remains similar. The LSD values at the 5% significance level (3.03 cm for 2022-B and 3.1 cm for 2023-A) indicate that there are significant differences between treatments. The differences in head diameter, particularly between minimum tillage and other methods, are statistically significant, underscoring the effectiveness of minimum tillage. Minimum Tillage (5 cm) is the most effective method for increasing the head diameter of broccoli. The consistent and significantly larger head sizes in both seasons highlight the advantages of this shallower tillage depth. Medium Tillage (10 cm) also provides relatively large head diameters, making it a good alternative if slightly deeper tillage is required for other agronomic reasons. Conventional and Maximum Tillage methods result in moderate head diameters but are not as effective as minimum tillage. Zero Tillage (0 cm) consistently produces the smallest head diameters, indicating that tillage is essential for promoting larger head development in broccoli. These results suggest that for maximizing the head diameter of broccoli, a minimum tillage approach (5 cm) should be preferred. The consistent findings across two different growing seasons further support this recommendation. It was reported that broccoli reaches maturity at head diameter varying between 7.62 to 15.24 cm of head diameter (Sawant, 2024) which is aligned with the results of this study. Effect of farming practices on the broccoli head development was also reported by other authors (Al-jaf *et al*., 2018**;** Darley *et al.* 2019; Pankaj et al.,2019). The increase in diameter of broccoli depends on type of tillage and agricultural season.

Broccoli weights per plant as influenced by conservation agriculture practices

The weights of broccoli from different treatments were evaluated. There was a significant difference in all treatments for both seasons at $P < 0.05$ as shown in Table 5 across different tillage treatments during the 2022-B and 2023-A seasons. Conventional Method, in season 2022-B, the head weight was 219.10 grams, which decreased to 173.40 grams in season 2023-A. The reduction in head weight from 2022-B to 2023-A suggests that the conventional method may be less reliable in ensuring consistent high yields across different seasons. Maximum Tillage (20 cm) produced one of the lowest head weights among

the treatments. The head weight was 218.70 grams in season 2022-B, dropping further to 152.70 grams in season 2023-A. This decrease indicates that maximum tillage might be less effective in promoting optimal head weight in broccoli. Medium Tillage (10 cm), **s**howed an improvement in head weight compared to conventional and maximum tillage methods. In season 2022-B, the head weight was 230.50 grams, which increased to 219.50 grams in season 2023-A. While there was a slight decline in season 2023-A, this method still performed better than conventional and maximum tillage, indicating its relative effectiveness. Minimum Tillage (5 cm), Demonstrated the highest head weights across both seasons, making it the most effective tillage method for this parameter. In season 2022-B, the head weight was 414.80 grams, and it further increased to 469.80 grams in season 2023-A. The substantial increase in head weight between the two seasons suggests that minimum tillage provides optimal conditions for broccoli growth, leading to significantly higher yields. Zero Tillage (0 cm) produced the lowest head weights among all treatments. The head weight was 216.30 grams in season 2022-B, which decreased to 159.30 grams in season 2023-A. The consistently low head weights suggest that zero tillage is ineffective for promoting high broccoli yields. During Season 2022-B**,** the general mean head weight (GM) was 259.89 grams, with significant variability across treatments. Minimum tillage stood out with a much higher head weight than the other methods, indicating its superiority. During Season 2023-A, the general mean head weight decreased slightly to 234.95 grams. The overall trend was similar to that of 2022-B, with minimum tillage again producing the highest head weights. The reduction in the general mean may indicate slightly less favorable growing conditions in this season, but the relative effectiveness of each tillage method remained consistent.

Table 5. ***Comparative Response of different tillage on the head weight in gram per plant in Seasons 2022-B and Season 2023-A.***

Treatments	Head Weight(gr) per plant Season 2022-B	Head Weight(gr) per plant Season 2023-A
Conventional method	219.10^{cde}	173.40^{cde}
Maximum tillage (20 cm)	218.70^{de}	152.70^{e}
Medium tillage (10 cm)	230.50^{bcde}	219.50^{b}
Minimum tillage (5 cm)	414.80^{a}	469.80^{a}
Zero tillage (0 cm)	216.30^{e}	159.30^{de}
General Mean(GM)	**259.89**	**234.95**
CV (%)	0.112	0.123
LSD (5%)	44.68	44.68

Means followed by the same letter(s) in a column are not significantly different by LSD at a 5% level of significance, CV=Coefficient of variation, LSD=Least Significant Differences.

The LSD value at the 5% significance level (44.68 grams) suggests that the differences in head weight across treatments are statistically significant. This means that the observed differences, particularly between minimum tillage and the other methods, are not due to random chance but are likely due to the effectiveness of the tillage practices. Minimum Tillage (5 cm) is clearly the most effective method for increasing the head weight of broccoli. The significant and consistent increase in head weight across both seasons underscores the benefits of this shallow tillage depth. Medium Tillage (10 cm) offers a moderate alternative, with head weights that are higher than those from conventional and maximum tillage but still fall short of the results from minimum tillage. Conventional and Maximum Tillage (20 cm) methods result in lower head weights, indicating that these methods may not be optimal for maximizing broccoli yield. Zero Tillage (0 cm) consistently produces the lowest head weights, highlighting the importance of some degree of tillage for promoting better crop yields. These findings suggest that for maximizing the head weight of broccoli, minimum tillage (5 cm) is the most effective approach. The results from both seasons strongly support the adoption of this tillage method for achieving higher yields. Sawant (2024) reported that a good quality broccoli should have a head weight of 250-300 g. It was further reported that conventional

tillage, no tillage and strip tillage did not influence dry matter of broccoli grown in 2014 and 2015 (Jokela and Nair, 2016). Schellenberg *et al*. (2009) reported no significant difference of broccoli grown in spring and fall under conventional tillage and no tillage. The weight of broccoli head weight varies with agronomic practices and weather conditions.

Broccoli head yield per hectare (t/ha) as influenced by conservation agriculture practices

Yield of broccoli was evaluated in both seasons and all treatments. There was a significant difference in all treatments for both seasons at $P<0.05$ as presented in Table 5 during the 2022-B and 2023-A growing seasons. Minimum Tillage (5 cm) consistently produced the highest yields in both seasons. In season 2022-B, the yield was 27.67 t/ha, which increased to 31.32 t/ha in season 2023-A. This method significantly outperforms all other treatments, demonstrating that a shallow tillage depth of 5 cm is highly effective for maximizing broccoli yield. Medium Tillage (10 cm) **y**ielded moderately well, but significantly less than minimum tillage. In season 2022-B, the yield was 15.37 t/ha, slightly decreasing to 14.63 t/ha in season 2023-A. While this method is more effective than conventional, maximum, and zero tillage, it produces roughly half the yield of minimum tillage. Conventional Method produced lower yields compared to minimum and medium tillage. The yield decreased from 14.61 t/ha in season 2022-B to 11.56 t/ha in season 2023-A, indicating a decline in productivity over time. This method does not seem to support high yields as effectively as the other methods. Maximum Tillage (20 cm) also resulted in relatively low yields. In season 2022-B, the yield was 14.58 t/ha, dropping further to 10.18 t/ha in season 2023-A. The deeper tillage depth of 20 cm appears to be less effective, possibly due to excessive soil disturbance or other factors negatively affecting plant growth. Zero Tillage (0 cm) produced the lowest yields among all treatments. The yield was 14.42 t/ha in season 2022-B, which further decreased to 10.62 t/ha in season 2023-A. The consistently low yields suggest that not tilling the soil is detrimental to broccoli production, likely due to poor soil aeration and other unfavorable conditions. During Season 2022-B, the general mean yield was 17.33 t/ha, with significant variability across treatments. Minimum tillage far exceeded the mean, reinforcing its effectiveness in enhancing yield. During Season 2023-A the general mean yield decreased slightly to 15.66 t/ha, indicating overall lower productivity in this season. Despite the decrease, minimum tillage still produced a much higher yield compared to other methods, highlighting its consistency and reliability.

Table 6. ***Comparative yield (t/ha) in season 2022-B and season 2023-A***

Treatments	Yield (t/ha) season 2022-B	Yield (t/ha) season 2023-A
Minimum tillage (5 cm)	27.67[a]	31.32[a]
Medium tillage (10 cm)	15.37[b]	14.63[b]
Conventional method	14.61[b]	11.56[c]
Maximum tillage (20 cm)	14.58[b]	10.18[c]
Zero tillage (0 cm)	14.42[b]	10.62[c]
General Mean(kg/ha)	17.33	15.66
CV (%)	1.139	1.038
LSD	1.67	2.83

Means followed by the same letter(s) in a column are not significantly different by LSD at a 5% level of significance, CV=Coefficient of variation, LSD=Least Significant Differences.

The yield of minimum tillage was compared with other methods. The yield from minimum tillage was nearly double or more than double the yields from other methods. This significant difference indicates that shallow tillage at 5 cm provides the most favorable conditions for broccoli growth, likely due to better soil structure, moisture retention, and nutrient availability. Medium Tillage (10 cm) and Conventional Methods, both methods result in moderate yields, with medium tillage slightly outperforming the conventional method. These methods may be suitable in situations where minimum tillage is not feasible, but they still lag considerably behind in terms of yield. Maximum Tillage (20 cm) and Zero Tillage (0 cm), these methods are the least effective, particularly in season 2023-A, where their yields dropped significantly. Maximum tillage may cause excessive soil disruption, while zero tillage likely leads to poor soil conditions for plant growth. Minimum Tillage (5 cm) is clearly the superior tillage method for maximizing broccoli yield, producing significantly higher yields in both seasons. Its effectiveness suggests that it should be the preferred tillage practice for broccoli cultivation. Medium Tillage (10 cm), while less effective than minimum tillage, still provides a moderate yield, making it a viable alternative under certain conditions. Conventional Method, Maximum Tillage (20 cm), and Zero Tillage (0 cm) result in significantly lower yields, with zero tillage being the least effective. These methods may not be optimal for achieving high broccoli yields and could lead to reduced productivity. The consistent results across both seasons emphasize

the importance of selecting the appropriate tillage method, with minimum tillage emerging as the best practice for maximizing broccoli yield. The average yield for broccoli varies from 19-24 t/ha (Swant, 2024). According to Wikifarmer (2023), a good yield of broccoli would be 20 tons per hectare and the weight of each plant depends on the variety and growing conditions. This aligns with the yield of minimum tillage while other treatments were significantly lower. Schellenberg *et al*. (2009) reported no significant difference among broccoli grown under convention tillage and no tillage. Broccoli growth and yield is affected by agricultural practices and seasons.

Yield increment of broccoli

Yield increment was assessed compared to conventional tillage and zero tillage. When conventional tillage was taken as standard, the highest increment was observed for minimum tillage with 89.3 and 170.9% for season 2022B and season 2023 A respectively. Zero tillage and maximum tillage had negative increment in both seasons as depicted in Figure 1. Furthermore, when zero tillage was taken as reference, the highest increment recorded was for minimum tillage at 91.8% and 195.0% for seasons 2022B and 2023 A in that order. The lowest increment was for maximum tillage at 1.1% and 1.3% for conventional tillage in season 2022B, while negative increment of -4.1% was observed for maximum tillage in season 2023 A followed by conventional tillage at 8.9% in season 2023 A as shown in Figure 2. A study conducted on cabbages revealed that increasing tillage to 30cm depth increased plant biomass at 23 to 33% in the period of 29 to 44DAP respectively comparing to tillage of 10 cm depth (Mochizuki *et al.*, 2007). It was reported that conventional tillage increases broccoli yield 31% and 46% better than strip tillage and no tillage respectively (Jokela and Nair,2016). It was also reported that increase in tillage depth from 10 to 30 cm led to the increase of cabbage by 22% while yield at 30 cm depth was similar to convention tillage (Mochizuki *et al.*, 2007). Yield increment of broccoli depends on type of tillage and growing season. The findings of higher yield in minimum tillage compared to the rest were on the fact that by disturbing the soil less, minimum tillage helps to retain soil moisture more effectively than conventional tillage. The presence of surface residues in minimum tillage acts as a mulch, reducing evaporation and maintaining higher moisture levels in the soil, which is crucial for crop growth, especially in areas with limited rainfall or during dry spells. The reduced disturbance in minimum tillage systems allows for more efficient nutrient cycling. Soil microorganisms, which play a key role in decomposing organic matter and releasing nutrients, thrive in the stable

environment created by minimum tillage. In fact, Minimum tillage creates a more favorable environment for broccoli growth by enhancing soil structure, moisture retention, and fertility while reducing erosion and maintaining a healthy soil ecosystem. These factors combine to improve plant health, root development, and ultimately, yield. In contrast, conventional tillage can lead to soil degradation over time, reducing the long-term productivity and sustainability of the cropping system.

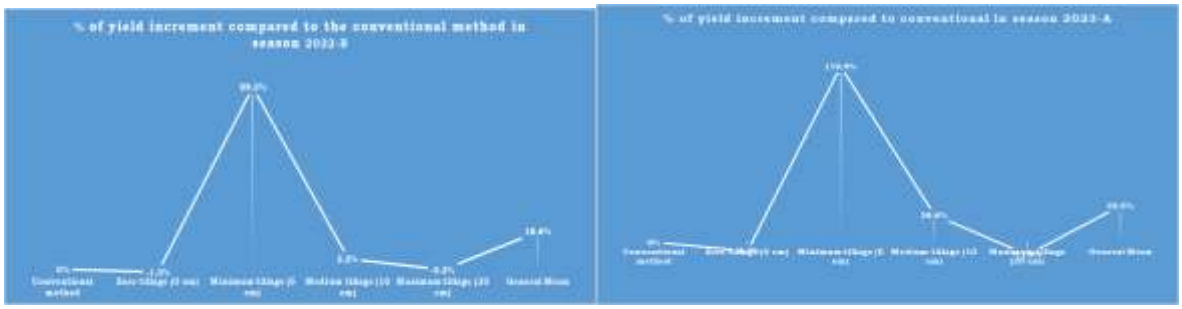

Figure1. Yield increment compared to conventional method

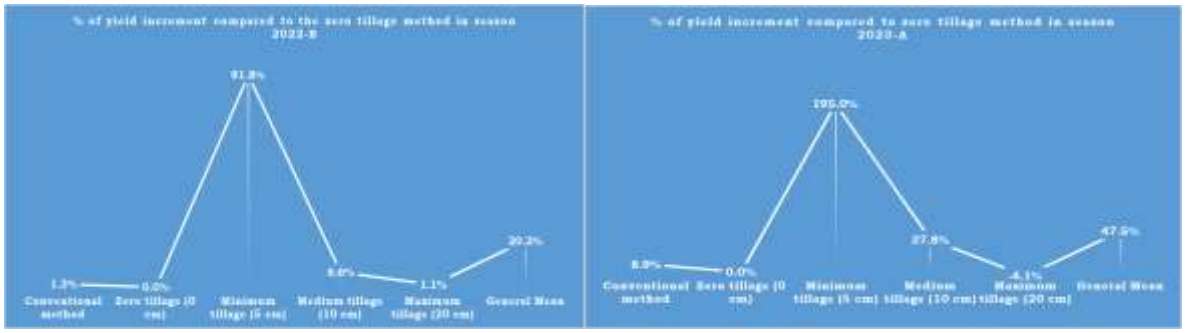

Figure 2. Yield increment compared to zero tillage

Conclusion

Crop respond differently to various types of tillage in different seasons. The minimum tillage and medium tillage influenced significantly the broccoli vigor comparing to other treatments for the crops planted in different seasons of 2022B and 2023A. This vigor was one of the factors contributing to the Broccoli yield. The more the plant vigor, the more it resulted in the broccoli head yield increase as well as the profit. Therefore, minimum tillage can be recommendation in production of broccoli which increases both yield and environmental conservation.

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laboratories and farmers for providing experimental fields.

Conflict of Interest

The authors confirm that this manuscript has no conflict of interest.

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