Field experiments were carried out to evaluate the productivity of tef under different tillage practices during 2016–2017 at Alem Tena and Minjar in Central Ethiopia. The experiment was carried out using split-plot design with three replications. The treatments consisted of two tef varieties (Boset and Kora) assigned in the main plot and four tillage practices (conventional tillage, reduced tillage with residue retained, reduced tillage without residue retained and zero tillage) assigned as sub-plots. The results showed that the main effect of tillage practices and variety was significant on grain yield and biomass at Alem Tena. However, at Minjar, only main effect of variety had a significant effect on grain yield. At both locations, the Variety × Tillage interactions were absent; the tef variety, Kora, performed better in yield and than Boset. At Alem Tena, the highest yield (2673 and 2343 kg/ha) and biomass (16,713 and 13,518 kg/ha) were obtained in farmer practice and reduced tillage with residue retained, respectively. Similarly, at Minjar, the highest biomass (9439 kg/ha) was obtained in farmer practice, but was not significantly different from reduced tillage with residue retained and zero tillage. The economic analysis revealed that reduced tillage with residue retained gave highest net benefit and marginal rate of return (MRR) as compared to other practices at both locations. Zero tillage gave lowest net benefit and MRR at both locations. Therefore, reduced tillage with residue retained can be recommended as an alternative tillage practice for resource poor farmers in central Ethiopia without significantly affecting yield.

Subjects: Agriculture & Environmental Sciences; Agriculture and Food; Soil Sciences

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ABOUT THE AUTHOR
Almaz Meseret Gezahegn is an agronomy and crop physiology researcher in Ethiopian Institution of Agricultural Research. Her area of interests is climate smart agriculture such as, conservation agriculture, integrated crop management practices, stress physiology and cropping system.

PUBLIC INTEREST STATEMENT
Tef is cultivated with intensive seed bed preparations with 3–5 passes in semi-arid and 5–8 passes in humid areas of Ethiopia. Due to this, more labor input and longer time is needed to accomplish the plowing activity. Ploughing is done by using the ox-driven local maresha and oxen rental cost is high and unaffordable for most of farmers in Ethiopia even low access during peak time of planting. In order to reverse this devastating situation, there is a need to develop technologies and management schemes that can simultaneously enhance sustainable production and preserve the natural resource base. Thus, conservation tillage, along with some complimentary practices such as soil cover has increased tef yield and reduced cost of production.
1. Introduction
Crop production in Ethiopia is characterized by intensive tillage, low productivity due to land degradation and insufficient use of water resources (Oicha et al., 2010). Smallholder farmers plow their lands by a traditional plough (locally called Maresha), which is pulled by a pair of oxen (Solomon et al., 2006). The ploughing is done 3–5 times depending on crops to be planted, type of the soil, weed conditions and waterlogging (Ketema, 1997).

Tillage have several advantage, such as loosening soil, regulating the circulation of water and air within the soil, increasing the release of nutrient elements from the soil for crop growth, and controlling weeds by burying weed seeds and emerged seedlings (Reicosky and Allmaras, 2003). However, excessive or inappropriate tillage practices has been reported to be the main cause of land degradation in Ethiopia by reducing vegetative cover and water infiltration (Araya et al., 2012). Excessive and repeated tillage when practiced for a long period can alter soil properties and agricultural production (Rashidi & Keshavarzpour, 2007).

Tef is the major staple cereal crops and highly adapted to diverse agro-ecological zones including conditions marginal to the production of most of the other crops (Hailu & Seyfu, 2001). Traditionally, tef field is ploughed 2–5 times depending on the soil type, weed conditions and water logging in semi-arid (Temesgen, Rockstrom, Savenjie, Hoogmoed, & Dawit, 2007) and 5–8 passes in humid areas of the country (Fufa et al., 2001). As a result, more labor input and longer time is needed to accomplish the plowing activity (Oicha et al., 2010). Since the plowing is done by ox-driven local maresha, oxen rental cost is high and unaffordable for most farmers in Ethiopia; availability for hire is even lower during peak time seedbed preparation (Aune, Bussa, Asfaw, & Ayele, 2001).

In order to alleviate the problem, there is a need to develop technologies and management schemes that can simultaneously enhance sustainable production and preserve the natural resource base. Thus, conservation tillage, along with some complimentary practices such as soil cover and crop diversity has emerged as a viable option to ensure sustainable food production and maintain environmental integrity (Corsi, Friedrich, Kassam, Pisante, & de Moraes Sà, 2012). This implies that conservation tillage is a component of conservation agriculture (CA). CA is a crop production system that simultaneously employs three key principles: (i) minimum mechanical soil disturbance, (ii) permanent or semi-permanent plant residue cover on the soil surface, and (iii) diversification of crop species grown in sequences and/or associations (Schier, 2006). According to Conservation Technology Information Center (CTIC) (2002), conservation tillage is any tillage system that leaves at least 30% of the soil surface covered with crop residue after planting to reduce soil erosion by water. The main benefits of CA practices is that it protects the natural resource base for agriculture (e.g. preventing soil erosion and enhance soil biodiversity) thereby contributing to maintenance of long-run agricultural productivity and improved cropping system productivity (Wachira, Kimenju, Okoth, & Kiarie, 2014).

With global discourses on using climate-smart agriculture to alleviate poverty and food insecurity, using CA system for smallholder farmers in Ethiopia is pertinent. Few studies in Ethiopia showed that CA has improved grain and biomass yield of maize and sorghum (Kassie, Zikhali, Manjur, & Edwards, 2009; Mesfine, Abebe, & Al-Tawaha, 2005; Sime, Aune, & Mohammed, 2015), water productivity (Temesgen et al., 2012) and soil organic matter (Nyssen et al., 2011). However, there is a dearth of information about its feasibility on tef production (Habtegebrial, Singh, & Haile, 2007; Tesfahunegn, 2015). Therefore, this study was initiated with the objective of evaluating the effect of conservation tillage on productivity of tef.
2. Materials and methods

2.1. Experimental location and climate
The field experiments were conducted during 2016 and 2017 cropping season at Alem Tena, East Shewa Zone of the Oromia Region and Minjar, North Shewa zone of Amhara Region. Tef is the dominant crop in both locations. Alem Tena is located at a latitude and longitude of 8.30°N 38.95°E with an elevation of 1,611 meters. Total annual rainfall in the year 2016 and 2017 were 867.8 mm and 706.3 mm, respectively (Figures 1 and 2). The average minimum and maximum temperatures 17.64 and 29.9 for 2016 and 12.3 and 28.77 for 2017, respectively. The soil type is Andisol.

Minjar is located at a latitude of 9° 09’ 60.00” N and longitude of 39° 19’ 60.00” E at an 1040 meter a.s.l. Total annual rainfall in the year 2016 and 2017 were approximately 903.4 mm and 702.6 mm, respectively (Figures 3 and 4). The average min and max temperatures 152 and 29.0 for 2016 and 15.9 and 28.4 for 2017, respectively. The soil type is slightly vertisol.

2.2. Experimental design and treatments
The investigation was conducted at farmer’s field using split-plot design with three replications. The treatments were consisted of two different maturity types of tef varieties (Kora, which is late

![Figure 1. Monthly rainfall distribution during 2016 at Alem Tena.](image1)

![Figure 2. Monthly rainfall distribution during 2017 at Alem Tena.](image2)
maturing and Boset, which is early maturing variety) assigned as the main plot and the sub-plots were four tillage practices (Conventional tillage (5 plowings), reduced tillage (2 plowings) with residue retained, reduced tillage without residue retained, zero tillage (post-emergence herbicide recommended for the area)). The subplot size of $5 \times 5 = 25 \text{ m}^2$ was used for all treatments. The spacing between main plots and subplots was 1 m and 0.5 m, respectively.

2.3. Land preparation, planting, field management, and harvesting

The tillage was practiced according to the traditional plowing system of oxen-drawn plow using local implement known as maresha. The first plowing started in mid-April at both locations and years. Dates of all management practices such as planting, tillage for reduced tillage and harvesting time for both locations and years are given in Table 1. For conventional tillage treatment, the farmer practice was applied. Seeds were sown with hand drilling at the rate of 15 (kg/ha) in 20 cm rows spacing. N fertilizer at a recommended rate of 40 kg/ha and 60 kg/ha for Alem Tena and Minjar, respectively, was applied. P fertilizer at a recommended rate of 60 kg/ha was applied for both locations. Urea (46% N) and triple super phosphate (TSP) (46% $P_2O_5$) were used as the source of N and P, respectively. The full dose of P and one-third of N fertilizer were applied at the sowing time. The remaining two-third of N fertilizer was applied at tillering stage as a topdressing. The weed management for the conventional tillage and reduced tillage was done manually. Other
agronomic practices were kept uniform for all treatments. The crop was harvested manually at physiological maturity, when the vegetative parts turned to yellow and samples were taken from a sample quadrat of 2 m × 2 m for each plot.

### 2.4. Data collection and analysis

Plant height was measured from the surface ground to the tip of the panicle at maturity time. Panicle length was measured the node (the first panicle branch started) to the tip of the panicle. Number of tillers per plant was determined by counting the number of additional plants growing from the main stem. The samples for the above parameters were taken from 10 randomly taken plants. Above-ground biomass was determined by taking the total weight of the harvest including the grains from each net plot area. Straw yield was measured by subtracting grain yield per net plot from the total above-ground biomass. Grain yield (kg/ha) was measured after threshing the grains harvested from each net plot. Harvest index was calculated by the ratio of grain yield to above-ground biomass.

To compare the economic feasibilities of conservation and conventional tillages, partial budget analysis and marginal rate of return (MRR) were done as described by CIMMYT (1988). The average yield was adjusted downwards by 10% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. The costs that vary were calculated by adding costs of labor requirement for field operations or oxen ranted for tillage operation was 46.84 USD/ha at one plowing), herbicide (Roundup) cost was 8.36 USD/L. from tef grain at under three conservation tillage techniques and the corresponding traditional tillage system. The mean market price of tef grain (0.90 USD/kg) and straw cost (0.006 USD/kg) were used.

The data were subjected to combined analysis of variance (ANOVA) over years after confirmation of homogeneity of error variance using SAS software program. Separate analyses were conducted for each location because of heterogeneity of error variance. The means were compared by least significant difference (LSD) method at 0.05 probability level.

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### Table 1. Date of management practice

| Date of management practice | Alem Tena       | Minjar       |
|-----------------------------|-----------------|--------------|
|                             | 2016            | 2017         | 2016            | 2017            |
| 1st tillage (for both tillages) | April 15           | April 13           | April 16           | April 17       |
| 2nd tillage (conventional tillage) | May 15          | May 13        | May 16        | May 17         |
| 3rd tillage (conventional tillage) | June 14         | June 13       | June 26       | June 24        |
| 4th tillage (conventional tillage) | June 29         | June 30       | July 10        | July 18        |
| 5th tillage (conventional tillage) | July 6          | July 7        | July 17        | July 18        |
| 2nd tillage (for reduced tillage) | July 6          | July 7        | July 17        | July 18        |
| Planting                     | July 6          | July 7        | July 17        | July 18        |
| Harvesting                   | October 10      | October 9     | November 26    | November 28    |
3. Result and discussion
The main and interaction effect of year, variety and tillage on growth parameters of tef at Alem Tena and Minjar is presented in Table 2. At Alem Tena, the main effect of year, variety and tillage practice were significant ($p < 0.05$) on plant height, and panicle length of tef but not number of tillers. At Minjar, the main effect of year and variety had a significant ($p < 0.05$) effect on plant height and panicle length, but the effect of tillage practices was not a significant on plant height, and panicle length of tef. The interaction effect of variety and tillage was not significant for all measured growth parameters at both locations.

Plant height and panicle length of tef during 2016 were higher than 2017 at both locations. This might be due to the rainfall amount and its distribution was better in 2016 than 2017 cropping seasons. In addition, in 2017 the rainfall was stopped very early (Figures 1–4).

Kora variety gave taller plant and longer panicle length as compared to Boset variety at both locations. The difference of growth parameters between the two tef varieties was due to the variation in their genetic makeup and adaptability to soil and climatic conditions. Shahzad, Wasi-ud-Din, Sahi, Khan, and Ahmad (2007) also reported that height of the wheat crop is mainly controlled by the genetic makeup of a genotype and it can also be affected by the environmental factors. Similarly, Dargo, Mekbib, and Assefa (2016) reported highly significant ($p \leq 0.01$) difference of plant height and panicle length among tef varieties.

Conventional tillage, reduced tillage with residue retained and residue removed gave statistically ($p < 0.05$) similar plant height and panicle length, but gave higher plant height and panicle length

| Treatments | Alem Tena |              | Minjar |              |
|------------|----------|--------------|--------|--------------|
|            | Plant height (cm) | Panicle length (cm) | Plant height (cm) | Panicle length (cm) |
| Year       |          |              |        |              |
| 2016       | 101.79a  | 36.96a       | 88.5a  | 35.41a       |
| 2017       | 69.58b   | 32.42b       | 81.7b  | 30.25b       |
| LSD ($p < 0.05$) | 3.67     | 3.09         | 3.32   | 1.25         |
| Variety (V) |          |              |        |              |
| Kora       | 90.5a    | 36.79a       | 93.92a | 36.00a       |
| Boset      | 80.87b   | 32.58b       | 76.4b  | 29.67b       |
| LSD ($p < 0.05$) | 3.67     | 3.09         | 3.32   | 1.28         |
| Tillage (T) |          |              |        |              |
| Conventional tillage | 88.67a  | 36.17a       | 87.1a  | 33.42a       |
| Reduced tillage (residue retained) | 89.75a  | 35.5a        | 84.0a  | 33.08a       |
| Reduced tillage (residue removed) | 88.33a  | 36.42a       | 86.3a  | 32.83a       |
| Zero tillage + roundup | 76.0b   | 30.67b       | 83.25a | 32.00a       |
| LSD ($p < 0.05$) | 5.1      | 4.37         | ns     | ns           |
| CV (%)     | 7.3      | 15.9         | 6.64   | 6.65         |
| V x T      | ns       | ns           | ns     | ns           |
of tef than zero tillage at Alem Tena. This result is in line with Tesfahunegn (2014b) who reported significant difference of plant height of tef under different tillage practices.

At Alem Tena and Minjar, yield and yield component of tef was significantly ($p < 0.05$) affected by year. Straw, grain and biomass yield in 2016 were higher than in 2017. However, harvest index of tef during 2016 was lower than 2017. The year differences in yield and yield components might be due to the inconsistency of rainfall amount and its distribution in the cropping seasons. In addition, in 2017 the rainfall was stopped very early (Figures 1–4).

Straw yield was significantly ($p < 0.05$) affected by variety and tillage practices at Alem Tena. However, at Minjar, only variety had a significant effect on straw yield of tef. Interaction effect of variety and tillage was not significant at both locations (Table 3).

At both locations, Kora variety gave higher straw yield than Boset variety. This might be due to the variation in their genetic makeup and adaptability to soil and climatic conditions of the two varieties.

The main effect of variety and tillage practices had a significant ($p < 0.05$) effect on grain yield of tef at Alem Tena, but at Minjar, only variety had a significant effect on grain yield of tef. The main effect of tillage and interaction effect of tillage and variety were not significant ($p < 0.05$).

The tef variety Kora performed better in grain yield (2424 kg/ha and 2218 kg/ha) than Boset at Alem Tena and Minjar, respectively. This result is in line with Bekele et al. (2019), who reported that under normal cropping season Kora produces more grain yield than Boset. Similarly, Bogale and

### Table 3. Main effect of variety and tillage practices on yield and yield component of tef at Alem Tena and Minjar during 2016 and 2017 cropping season

| Treatment            | Alem Tena |       | Minjar |       |
|----------------------|-----------|-------|--------|-------|
|                      | SY (kg/ha) | BY (kg/ha) | GY (kg/ha) | HI | BY (kg/ha) | GY (kg/ha) | HI |
| Year                 |           |       |        |       |           |       |
| 2016                 | 11,723a   | 14,445a | 2722a  | 0.19a | 13,542a   | 2611a   | 0.19b |
| 2017                 | 9520b     | 11,042b | 1522b  | 0.16b | 4360b     | 1417b   | 0.33a |
| LSD ($p < 0.05$)     | 375       | 2379   | 384    | 0.04  | 636       | 198     | 0.02  |
| Variety (V)          |           |       |        |       |           |       |
| Kora                 | 11,280a   | 13,704a | 2424a  | 0.21a | 9334a     | 2218a   | 0.24a |
| Boset                | 9963b     | 11,382a | 1819b  | 0.18b | 8567b     | 1810b   | 0.21b |
| LSD ($p < 0.05$)     | 375       | 2379   | 384    | 0.03  | 636       | 198     | 0.02  |
| Tillage (T)          |           |       |        |       |           |       |
| Conventional tillage | 14,040a   | 16,713a | 2673a  | 0.19a | 9439a     | 2059a   | 0.27a |
| Reduced tillage      | 11,175ab  | 13,518ab | 2443a  | 0.18a | 8948ab    | 2096a   | 0.27a |
| (residue retained)   |           |       |        |       |           |       |
| Reduced tillage      | 10,540b   | 12,778b | 2238a  | 0.17a | 8913ab    | 1956a   | 0.26a |
| (residue removed)    |           |       |        |       |           |       |
| Zero tillage         | 6729c     | 7963c  | 1234b  | 0.17a | 8502b     | 1954a   | 0.26a |
| LSD ($p < 0.05$)     | 3206      | 3365   | 544    | ns    | 8502      | ns      | ns    |
| V × T                | ns        | ns     | ns     | ns    | ns        | ns      | ns    |
| CV (%)               | 17.4      | 24.2   | 14.1   | 2     | 16.6      | 12      | 11.6  |

SY = straw yield, BY = biomass yield, GY = grain yield, HI = harvest index.
Wondum (2017) reported that Kora was among the highest yielding cultivars followed Boset (1827 kg/ha) and Dukem (1750 kg/ha).

Regarding tillage practice at Alem Tena, the highest grain yields (2673 and 2443 kg/ha) were obtained in conventional tillage and reduced tillage with residue retained, respectively. This might be due to more water retention of the soil and reducing the risk of soil erosion as residue retained, since Alem Tena is moisture stress area. This result is in agreement with Asmamaw (2014) who reported that conservation tillage had a significant effect on soil fertility improvement, moisture conservation and increased crop yield. Similarly, Aune, Asrat, Teklehaimanot, and Bune (2006) reported that reduced tillage improves the soil system (e.g., soil carbon sequestration, soil nutrients, and soil water holding capacity) and thereby crop productivity after some years as compared to traditional tillage. In contrast, the lowest yield was obtained in Zero tillage. This mainly due to high grass weed infestation as these were not controlled by pre-spray herbicide. In addition, tef seed are very tiny and it requires level and firm seed bed. This finding is in agreement with Tulema, Aune, Johnsen, and Vanlauwe (2008) who reported lower tef yield at zero tillage under Vertisol and Nitisol as compared to minimum and conventional tillage. The result of higher tef yield under conventional tillage as compared to reduced tillage with out residue retained is inline with Tesfahunegn (2014a) who reported that conventional tillage (6 passes) increased tef yield than reduced tillage (4 passes).

Biomass yield of tef was significantly ($p < 0.05$) affected by both variety and tillage at Alem Tena and Minjar. However, the interaction effect of variety and tillage was not significant on biomass of tef. Unlike straw and grain yield Kora varieties performed better biomass yield (13,704 and 9334 kg/ha) at Alem Tena and Minjar, respectively. The result is in agreement with Bogale and Wondum (2017) who reported that Kora variety gave higher biomass than Boset variety.

Conventional tillage gave highest biomass yield of tef (16,713 and 9439 kg/ha) at Alem Tena and Minjar, respectively, but was not statistically ($p < 0.05$) different biomass yield with reduced tillage with residue retained. In contrast, the lowest yield was obtained in Zero tillage. The better biomass yield under reduced tillage with residue retained as compared to reduced tillage with residue removed could be attributed to more water retention of the soil as residue retained provide a better soil moisture conservation, improve infiltration of rainfall and reducing the risk of soil erosion. The result is in agreement with Habtegebrial et al. (2007), who reported higher tef dry matter, yield, and harvest index with four plowings using traditional plow when compared to minimum tillage (1 pass). Rao, Agrawal, and Bishnoi (1986) also reported that conventional tillage gave superior yield of barley (Hordeum vulgare) than reduced tillage without residue retained under semi-arid conditions in India. In contrast of the present result, Debelo (1992) reported that in the presence of proper weed management practices plowing more than once may not be necessary even for tef fields.

Harvest index was significantly ($p < 0.05$) affected by variety. However, harvest index was not significantly affected by the main effect of tillage practices and interaction effect of variety and tillage practices at both locations. Regarding varietal difference of tef, Kora variety gave higher harvest index (0.24) than Boset (0.21). The result is in agreement with Bogale and Wondum (2017) who reported that Kora variety gave harvest index than Boset variety.

### 3.1. Economic analysis

Economic analysis showed that reduced tillage with residue retained gave highest net benefit (1729 $) with acceptable MRR (154) at Alem Tena (Table 4). Conventional tillage gave comparable net benefit with reduced tillage with residual retained, but gave lower MRR (23), which is not acceptable. Although reduced tillage with residue retained could lose some money as residue has cash value and the farmers use the residue as a livestock feed in the study area, the grain yield had enough to compensate the cost of the residue.
Though the statistical analysis showed non-significant difference among tillage practices on yield at Minjar, the economic analysis revealed that reduced tillage with residue retained gave highest net benefits (1469 $) and MRR (948) as compared to other practices (Table 5). This might be due to reduced tillage was minimize cost of labour than conventional tillage. This study also in agreement with Mal, Schmitz, and Hesse (2015) who reported that conservation tillage reduces labor requirement up to 30% as compared to conventional tillage. Toby, Townsends, and Ramsden (2016) reported that there is an average yield reduction of up to 8.5% in reduced tillage compared to conventional tillage, but reduced tillage offers a realistic and attainable sustainable intensification intervention, given the financial and environmental benefits.

### 3.2. Farmer's perceptions

Farmer's perception was assessed at full maturity period of tef. They tend to choose reduced tillage with residue retained and conventional tillage. Many farmers, particularly, men commented that reduced tillage with residue retained is good as the farmers in the area have large farm size and they have got difficulty when ploughed 5 times. Female farmers also preferred reduced tillage because oxen rental and sharecropping are very costly. In the area, it is common for women

### Table 4. Partial budget analysis at Alem Tena

| Treatment                             | GY (kg/ha) | AGY (kg/ha) | GB ($/ha) | TVC ($/ha) | NB ($/ha) | MRR |
|---------------------------------------|------------|-------------|-----------|------------|-----------|-----|
| Zero tillage + roundup                | 1234       | 1111        | 925.8     | 17         | 908.5     |     |
| Reduced tillage (residue removed)     | 2238       | 2014        | 1678.5    | 93         | 1575.8    | 27  |
| Reduced tillage (residue retained)    | 2443       | 2199        | 1832.5    | 103        | 1729.6    | 154 |
| Conventional tillage                  | 2673       | 2406        | 2004.8    | 243        | 1761.8    | 23  |

GY = grain yield, AGY = adjusted grain yield (10% down), GB = gross benefit, TVC = total cost, NB = net benefit, MRR = marginal rate of return.

### Table 5. Partial budget analysis at Minjar

| Treatment                             | GY (kg/ha) | AGY (kg/ha) | GB ($/ha) | TVC ($/ha) | NB ($/ha) | MRR |
|---------------------------------------|------------|-------------|-----------|------------|-----------|-----|
| Zero tillage + roundup                | 1954       | 1759        | 1466      | 17         | 1448      |     |
| Reduced tillage (residue removed)     | 1956       | 1760        | 1467      | 93         | 1374      | D   |
| Reduced tillage (residue retained)    | 2086       | 1877        | 1572      | 103        | 1469      | 948 |
| Conventional tillage                  | 2059       | 1853        | 1544      | 243        | 1301      | D   |

GY = grain yield, AGY = adjusted grain yield (10% down), GB = gross benefit, TVC = total cost, NB = net benefit, MRR = marginal rate of return.
headed household practiced sharecropping and she got only half of the production. In addition, the rain fall in the area stops early and reduced tillage with residue retained keeps the moisture so that it can reduced crop failure due to dry spell during the cropping season. Reduced tillage with residue retained improves overall productivity of the farming system because it allows partly replacing oxen with cows and reduces the soil erosion due to the retained residue.

4. Conclusion
A two-year study showed that tillage practices had a significant effect on growth and yield of tef. The highest grain yield was obtained from conventional tillage and reduced tillage with residue retained at Alem Tena. At Minjar, there was not grain yield difference due to different tillage practices. However, the economic analysis showed that reduced tillage with residue retained gave the highest net benefit and marginal rate of return at both locations. Farmers also preferred reduced tillage with residue retained due to labour saving and moisture conservation technology. Therefore, reduced tillage with residue retained which is conservation tillage can be an alternative tillage practice of tef production in central Ethiopia.

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