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Research Article

Effects of Conservation Agriculture and Conventional Tillage on the Soil Physicochemical Properties and Household Income in Southern Ethiopia

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In Ethiopia, soil degradation has been ongoing for centuries and caused the population to be food insecured. To cope with the challenges of soil fertility loss and related stress, various indigenous reclamation practices have been developed and implemented by local smallholder farmers. However, the contributions of indigenous soil management in augmenting soil quality and crop productivity were not well studied. This study selected two neighboring districts, Derashe and Arba Minch Zuriya, with different indigenous soil management practices. The Derashe people as an adaptation strategy designed indigenous soil management, locally known as Targa-na-Potayta with zero tillage, and mixed/rotational cropping. However, in the neighboring Arba Minch Zuriya district, smallholder farmers use conventional tillage using animal power. Representative soil samples were collected from selected four adjacent kebeles of the two districts. Eight farm plots per kebele were selected and a total of 32 composite samples were collected following a zigzag pattern to the depth of 30 cm. Bulk density (BD), field capacity (FC), permanent wilting point (PWP), particle size, soil textural classes, power of hydrogen (pH), cation exchange capacity (CEC), available potassium (Av. K), available phosphorous (Av. P), total nitrogen (TN), exchangeable bases (Na, Mg, Ca, and K), and soil organic carbon (OC) were analyzed. To assess crop production and income, a total of 392 household heads were interviewed using a structured questionnaire. The collected data were analyzed using an independent sample *t*-test. The results showed, soils under indigenous management, clay content was $53.74 \pm 2.68\%$, FC $47.8 \pm 1.09\%$, AWHC $15.2 \pm 0.37\%$, pH 8.02 ± 0.07, SOC $1.8 \pm 0.02\%$, and sum of cations 68.2 ± 1.66 meq/100 g. The values in the tested parameters were statistically significant ($P < 0.05$) and favor good soil management practice as compared to conventional tillage. Using the three consecutive cultivation seasons, CA and CT groups' mean production from pooled annual crops was 81.28 and 51.03Q ha-1, respectively. CA and CT groups' mean gross income from annual crops was 98,250.15 ETB ($2751.78) ha-1 and 71,099.48 ETB ($1993.4) ha-1, respectively. Considering the pooled three consecutive cultivation seasons, CA and CT groups' income from annual + perennial crops was 93,405.29 ETB ($2870.69) ha-1 and 280,721.73 ETB ($8325.17) ha-1, respectively. CA and CT groups' per annum income from annual + perennial crops was 49,672.86 ETB ($1444.82) ha-1 and 157,980.60 ETB ($4595.13) ha-1, respectively. To sustainably maximize the productivity of the land, conventional tillage practicing smallholder farmers need to integrate the indigenous soil management approach—Targa-na-Potayta. Besides, the benefits of Targa-na-Potayta as sustainable agricultural land management practice need to be scaled out with policy support.

1. Introduction

The Ethiopian population is increasing and projected to reach 133.5 million in 2032 and then 171.8 million in 2050 [1]. Agriculture is the mainstay of the Ethiopian economy and the main employment sector for about 80% of the country's population [2]. The sector is dominated by smallholder farming and 95% of the land is cultivated by smallholders to generate the key share of total production for the main crops [3]. From the total tilled land, 90% is plowed using backward technology and produced main crops (e.g., cereals, pulses, oilseeds, vegetables, root crops, fruits, and cash crops) [4]. However, smallholder farms are facing various constraints that hamper crop productivity including soil erosions, poor soil fertility, erratic and variable rainfall, and flooding [5, 6]. These problems are further exacerbated by the rapid population growth rate and high dependence on inappropriate and excessive soil management of conventional tillage (CT).

CT includes postharvest removal or burning of crop residues and intensive soil disturbances using tillage [7]. This causes a structural degradation of the soil and results in the formation of crusts and compaction, leading to a serious loss in important soil physicochemical properties that we are facing today [8, 9]. Besides, the practice often uses a high amount of artificial fertilizers to enhance the productive potentials of the degraded land [10]. This activity reasons environmental pollution and affects ecosystem functioning [11]. Therefore, appropriate soil management is urgently needed to resolve the constraints and to increase crop production without altering its potential for future generations.

Conservation agriculture (CA) was initiated as a solution to the problems associated with CT and is based on the following three key principles: disturb the soil as little as possible; keep the soil covered as much as possible (no burning and grazing in the field); mix and rotate the crops (i.e., leguminous cover crops) [9, 12]. Numerous studies [9, 13, 14] have recommended CA as a soil management approach to increase yields, soil moisture, soil fertility, and carbon sequestration, and reduce soil erosion, land degradation, and production costs (e.g., labor and inputs). Overall, CA comprises a package of crop production technologies that can achieve sustainable agriculture production and improve smallholder farmers' livelihood [9].

For thousands of years, Ethiopian farmers have been implemented CT using traditional farm equipment called "Maresha," which is commonly drafted by oxen [5, 15]. Owing to the incomplete and V-shaped plowing pattern by "Maresha," farmers have to often do repeated tillage. CT may have several short-term advantages, such as loosening soil, regulating the circulation of water and air within the soil, increasing the release of nutrient elements, and controlling weeds by burying weed seeds and emerging seedlings [16–20]. Despite all these, the V-shaped furrows result in higher relative surface area exposure leading to an increased surface runoff, lower water availability to crops due to high evapotranspiration, a rapid loss of soil organic matter due to prompt decompositions, and a high potential for soil degradation [21–25]. Therefore, it is important to find solutions that help to improve and manage the land for sustainable crop production.

To manage the farmland from soil degradation and soil moisture stress and to increase soil fertility, mainly in moisture shortage (arid and semiarid) parts of Ethiopia, smallholder farmers initiate and practice CA. These comprise manuring, minimum/zero tillage, and inter and mixed cropping [26–29]. These technologies were then promoted/scaled out through Sasakawa Global 2000 using Extension Management Training Plot (EMTP), as a technology transfer approach, to reach as many smallholder farmers in different parts of Ethiopia [27]. However, yet the wide application of CA with mulching is challenging as farmers prefer to use crop residue as fodder and as a source of biomass energy because it gives them an immediate benefit. In addition, smallholders accepted that there is no yield difference between CT and CA practices [27] since little is known about the comparative benefits of various soil management and its contribution to yield and household economy.

In this study, we hypothesized that CA in contrast to CT helps to (1) increase the soil quality by improving the soil physical and chemical properties, (2) increase annual crops mean production and gross income, and (3) enhance the net income from the annual crops. However, since CT practicing smallholder farmers get high monthly income from banana fruit marketing, they could obtain high pooled (annual- + perennial crops) income as compared to CA.

The objective of this study was, therefore, to examine and compare the soil physicochemical properties and household income under CA and CT soil management in the selected neighboring plots of southern Ethiopia. Derashe and Arba Minch Zuriya districts were selected since they are adjacent to similar agroecologies and different soil management approaches. The Derashe people dominantly cultivate *Moringa stenopetala* + maize/teff/sorghum using the three principles of CA. In the adjacent plots of Arba Minch Zuriya, smallholders intensively grow banana fruit + maize/teff using CT. To enhance banana fruit production, they use chemical fertilizers and have accessible small-scale irrigation. Thus, using five physical and six chemical soil quality indicating variables, the soil under two tillage approaches were examined and compared. Besides the average production, gross and net income of both annual and perennial plants were identified and compared.

2. Methodology

2.1. Description of the Study Sites. The study was carried out in Arba Minch Zuriya and Derashe districts in the southwestern region of Ethiopia (Figure 1). Arba Minch Zuriya is one of the 14 districts in the Gamo Zone and consists of 18 kebeles. It is about 505 km south of Addis Ababa, the capital city of Ethiopia. The district lies within the coordinates from 37023'51.37" Eastern longitude and 5055'16.24" Northern latitude. Its elevation ranges from 1250 to 2600 m. a.s.l. [30]. In the last 10 years, the district receives the total annual rainfall of 892 mm, with maximum and minimum temperatures of 30.4 and 15.6°C, respectively [31]. Among the total kebeles, the study was employed in two neighboring kebeles, namely Zeyis Eligo and Zeyis Wezeqa.

Derashe district is 525 km away from Addis Ababa and geographically located between 5035'25" Northern latitude and 37012'41.00" Eastern longitude [32]. The elevation ranges from 1250 to 2300 m. a.s.l. [30]. The area receives a total annual rainfall of 952.1 mm, about 261.2 mm in the long rainy season (June-September) and about 413.8 mm in the short rainy season (March-May) [33]. Most parts of the southern region are considered to be short rainy season

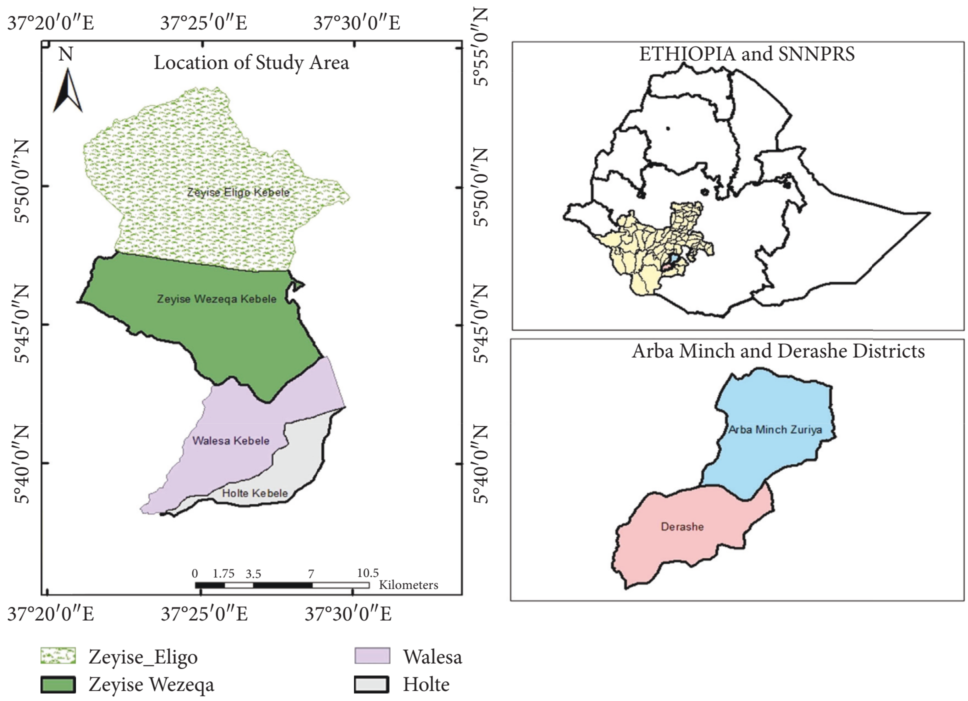

Figure 1: Map of Arba Minch Zuriya district, Derashe district, Zeyis Eligo, Zeyis Wezequa, and Holte and Walessa kebeles.

(Belg) growing areas in which rainfall reaches its peak during April/May and daytime temperature reaches its peak during that these months. Belg growing season is also characterized by erratic rainfall nature (in amount, distribution, onset, and cessation). From the total of 19 kebeles, Walessa and Holte kebeles were purposively selected based on an intensive land management culture and their adjacency to the selected kebeles of Arba Minch Zuriya district.

Agriculture is the mainstay of the community in selected kebeles. The major types of crops grown in Holte and Walessa kebeles are maize, sorghum, teff, and haricot beans in integration with *Moringa stenopetala* trees in an agro-silviculture system. The local communities of Derashe are the hardest working people in Ethiopia as all the household members devote their time spending their days in the field ensuring the success of their crops [34]. Given their commitment to the harsh environment, they may be regarded as among the best managers of the arid ecosystem. In Zeyis Eligo and Zeyis Wezequa kebeles, maize, teff, sweet potato, haricot beans, cassava, and vegetables mixed with mango and banana fruit trees are mainly practiced as fruit tree-based agroforestry system.

2.1.1. Characterization of the Agroecology, Land Use, and Land Management in the Study Areas. Most parts of the Derashe area are located in the semiarid area [35]. The mountainous topography makes the area susceptible to flooding, soil erosion, and soil fertility loss and caused the people to be food insecured triggered by low productivity and agricultural production [35]. As a coping strategy, the elderly people developed an indigenous CA, locally known as Targa-na-Potayta. It represents a mulch arrangement technique where maize and sorghum residues are mulched in the field in a rectangular shape roughly, 60 cm × 80 cm with the continuing patterns [34]. It is organized in such a way that the longer parallels are known as "Targa" and the shorter transverse residue stem making the rectangular partition called "Potayta," one long Targa-na-Potayta can use 0.17 ha of land and is known as Apha. They separate each Apha using a ditch/trench, and a total of six Apha can be found in 1 hectare of land. When water ponded on the surface of one Potayta following high rainfall, they open the rectangular crop residue and pass it to the next Potayta, and if one Apha (consisting of one long structure of Targa-na-Potayta) is ponded then they pass it to the trench/ditch that connects the next Apha (Figures 2 and 3).

The rectangular crop residues in the "Targa-na-Potayta" fashion help to crop in a row, conserve moisture, serve as a mulch material, regularly decompose and release plant nutrients, improve soil fertility, and reduce soil erosion. During the cropping season, seeds are put into drilled soil using a wooden or metal rode (locally known as "Totale") to each partition with zero tillage. Indigenous soil management helps even to produce crops sometimes three times a year. Century long-formed soil management approach still is the farm management culture and sustainable production strategy for smallholder farmers in the Derashe area.

Derashe people are known for their continuous engagement in farm management such as managing their land using Targa-na-Potayta, sowing using zero tillage, and incessant hand weeding even in the times of dry seasons. To reduce the daily traveling time from home to farm, during the times of major agricultural activities, they make a tiny thatched roof hut inside their farm and may stay there for a month without a back home (Figure 4).

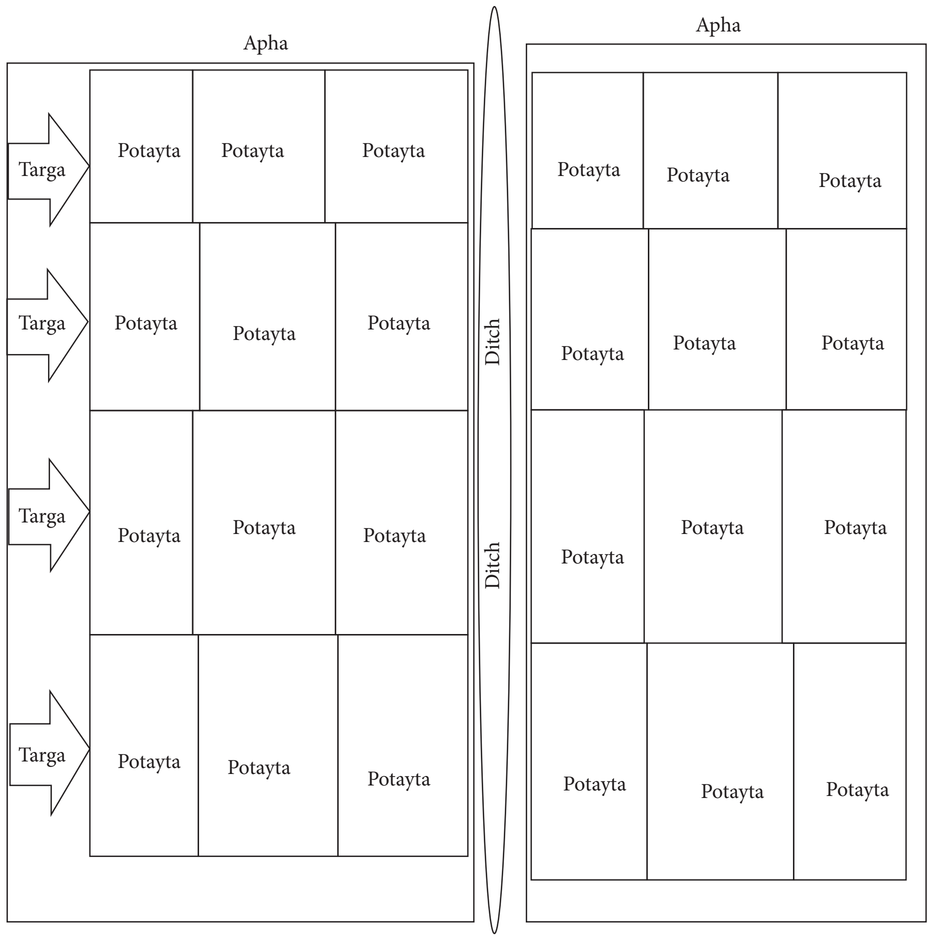

Figure 2: Schematic representation of Apha constituting Targa-na-Potayta, an indigenous mulching technique in Derashe district.

Figure 3: Parkland Agroforestry with Targa-na-Potayta (indigenous conservation agriculture in Derashe district, picture by the author).

Figure 4: A tiny thatched roof made by the Derashe people to manage their farmland staying in the field.

The selected neighboring kebeles smallholders' plot in Arba Minch Zuriya is also located in the semiarid area and known for the dense intercrop of banana + maize/teff using intensive tillage and application of chemical fertilizers. According to Fanos [36], banana production in the area dates back to the early 1980s, where the then Arba Minch state farm had about 62 hectares of land covered by the Dwarf Cavendish banana variety. During that time, the smallholder farmers' lands were covered by maize, cotton, and sweet potato, which led to a lack of productivity, making smallholders to be food insecured. The area is blessed with an all-year flowing river and spring water and smallholders mainly use small-scale irrigation to produce banana fruit. As the selected study plots in Derashe and Arba Minch Zuriya

Table 1: Characterizing the agroecology, land management, and land uses of Derashe and Arba Minch Zuriya districts.

Characteristics	Derashe	Arba Minch Zuriya
Major crops	Maize, teff, sorghum, pulses [37]	Maize, fruits, root crops, teff, pulses [37]
Elevations (m. a.s.l.)	1250–2300 [30]	1250–2600 [30]
Average annual rainfall (mm)	952.1 [33]	892 [31]
Temperature (°C)	15.1–27.5 [37]	16–37 [38]
Land management	Conservation agriculture [35]	Conventional tillage
Agroecology		Highland, 13.79%; mid-altitude, 51.72; low-land, 34.49% [38]

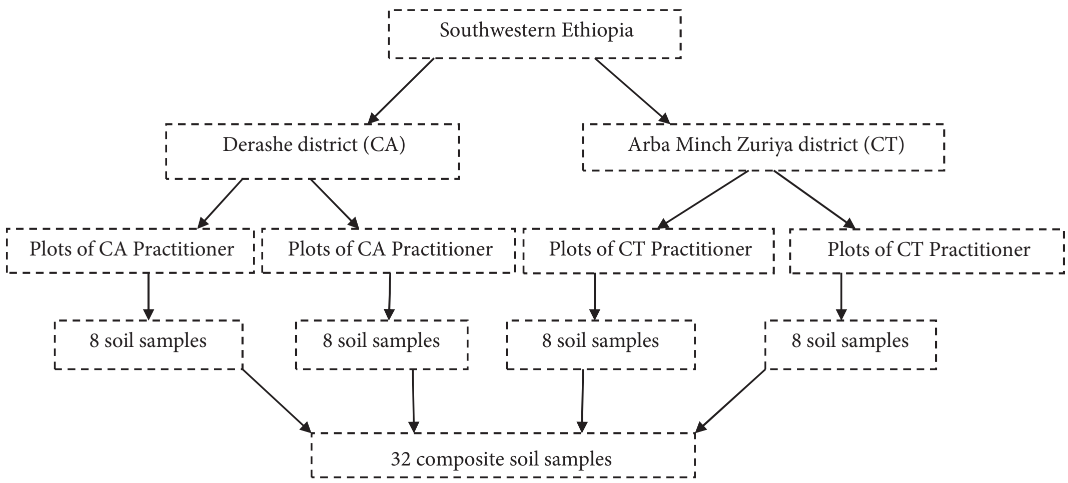

Figure 5: Representation of soil sample collection in the selected four study kebeles of Derashe and Arba Minch Zuriya districts.

are adjacent, they have alike agroecology and cultivate similar annual crops (Table 1). However, the area's soil management culture is pretty different.

2.1.2. Conservation Agriculture (CA) and Conventional Tillage (CT). In this study, CA refers to soil management, where mulch is applied following Targa-na-Potayta fashion, with zero tillage, rotation, and/or mixed leguminous crop. In contrast, smallholders engage in conventional tillage (CT) when they use ox-drawn plows for plowing the whole land during land preparation and for covering seed when planting, without intentional applications of mulch, and they do not rotate and/mix other leguminous crops.

2.2. Farm Plot Sampling. Arba Minch Zuriya is naturally blessed with plenty of all-year flowing rivers and spring water. This helps smallholders to devotedly grow water-demanding banana trees using small-scale irrigation. At the early stages of banana plantations, farmers intercrop cereals for household consumption and marketing. When bananas develop three or four suckers per hill and full canopy, farmers make the shift to mono-banana cultivation. Access to irrigation water and the regular market are considered as pulling factors to shift the farming system. Importantly, to increase soil productivity and fruit production, chemical fertilizer (mainly phosphorous and nitrogen combined diammonium phosphate (DAP)) was applied in large quantities. In this study, plots where banana + maize-based agroforestry were practiced were purposively selected. In the Derashe area, smallholders commonly practice *M. stenopetala* + maize/sorghum/teff-based agroforestry, thus plots were randomly selected from the sampled study populations.

2.2.1. Soil Sample Preparation and Analysis. From the selected four neighboring study kebeles, eight composite soil samples and a total of 32 soil samples were collected using a zigzag approach (Figures 5 and 6), a design best recommended for field sampling [39], and the soil test results from the sample are used to represent the entire sampling area [40].

Using Zigzag shape, 16 soil subsamples to the depth of 30 cm from farm plots count as one composite was collected, representing the topsoil using a soil auger. Each star represents points where soil subsamples collected from one plot (Figure 6). We selected eight farmers' plot of land in each selected four study kebeles, Therefore, a total of 32 soil samples were collected from 32 farmers' plot.

Soil samples were collected before planting and/or at fertilization. Before and after the collection of the soil samples, rocks and debris were extracted by hand, because these often cannot be distinguished empirically from soil organic matter or litter [41].

For bulk density determination, undisturbed core samples were taken carefully from the soil profile between 0 and 30 cm at intervals of 5 cm. The core sampling was made using cylinders of 5 cm diameter and 5 cm high. Then the collected sample was oven-dried at 105°C for 24 h. Apart from the bulk density samples, the rest of the samples were air-dried in a room with good ventilation. After a week, the

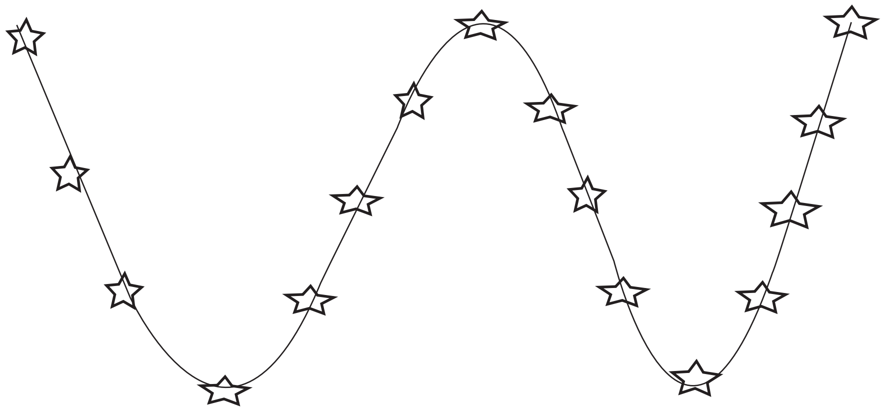

Figure 6: Methods of soil subsample collection following a zigzag shape.

dried soil was ground and passed through a 2-mm sieve and made ready for further laboratory analysis.

2.2.2. Soil Laboratory Analysis. The soil physical and chemical analysis was carried out at Arba Minch University, College of Agriculture Soil Laboratory, and Ethiopian Construction Design and Supervision Works Corporation Laboratory.

(1) Analysis of Physical Properties. Soil particle size distribution was determined following Bouyoucos hydrometer method [42]. Calgon (sodium hexametaphosphate + sodium carbonate anhydrous) was dissolved in a liter of distilled water. The prepared soil was added to another jar, stirred, and allowed to soak for 16 hours. Soil was mixed with calgon solution and well-stirred using a dispersing machine. With tight hand holding and pressing on the stopper, vigorously shake back and forth and place on the table for time record. After 40 seconds, the hydrometer was slowly inserted into the cylinder to note the reading, and the suspension temperature was also recorded. The suspension was shaken again and placed on the table to settle without disturbance. After 2 hrs, the hydrometer reading and the temperature of the suspension were recorded. Using the procedure given in the observation sheet, the sand, silt, and clay percentages were calculated.

The soil textural classes were determined using the soil textural triangle from USDA-NRCS online. BD was calculated by the core method [43] based on oven-dried mass of a known volume of soil as follows:

$$\mathrm{BD}\left(g/cm^{3}\right) = \frac{W}{\pi * r^{2} * L}, \qquad (1)$$

where r is the internal radius of a soil core sampler, L is the length of soil core and w is the total weight (g) of oven-dried soil; the soil sample was oven-dried at 105°C for 24 h.

Field capacity (FC) and PWP of the soil were measured at 1/3 and 15 bars soil water potential, respectively, using the pressure plate apparatus. The available water holding capacity (AWHC) is the difference between the soil moisture held at FC and PWP [44].

$$\mathrm{AWHC} = \mathrm{FC} - \mathrm{PWP}. \qquad (2)$$

(2) Analysis of chemical properties. The pH of the soils was measured in water suspension in a 1 : 2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode [45]. To determine soil carbon content, Walkley and Black [46] cited in [47] used a wet digestion method. The percent of soil OM was obtained by multiplying percent SOC by a factor of 1.724 following the assumptions that OM is composed of 58% carbon [48]. Total N was analyzed using the Kjeldahl digestion, distillation, and titration method as described [45] by oxidizing the OM in concentrated sulfuric acid solution (0.1 N H_2SO_4). Available soil P was analyzed according to the standard procedure of Olsen et al. [49] extraction method.

Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K, and Na) were determined after extracting the soil samples by ammonium acetate (1 N NH_4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were analyzed using atomic absorption spectrophotometer, while Na and K were analyzed by a flame photometer [45]. Cation exchange capacity was thereafter estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution [45]. Percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the base-forming cations (Ca, Mg, Na, and K) by the CEC of the soil and multiplying by 100.

2.3. Sampling Study Population for Production and Income Contribution Study. The study populations were all the households in each study kebeles that implement banana + maize in Arba Minch Zuriya *and Moringa stenopetala* + maize/teff/sorghum in the Derashe districts. The total household head in the selected four kebeles was 7502. Therefore, for the large populations, Cochran [50] developed an equation to yield a representative sample for proportions.

$$\mathrm{no} = \frac{Z^{2} \times p \times q}{e^{2}}. \qquad (3)$$

This is valid where n0 is the sample size, Z^2 is the abscissa of the normal curve that cuts off an area α at the tails ($1-\alpha$) equals the desired confidence level), e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, and q is $1-p$.

$$Z = 1.96; P = 0.5; e = 0.05. \quad (4)$$

Thus, total sample sizes (n) of 392 or 98 respondents per study kebeles were selected. In the two study districts, sampled household heads' selection process was relatively different. In the Derashe district, respondents were randomly selected using random tables. However, in the Arba Minch Zuriya district, respondents were purposively selected since the majority of smallholders converted their main farmland to a sole banana plantation. To compare production and income from annual crops with the neighboring farmers, practitioners of banana + Maize/teff were considered solely.

2.3.1. Methods of Data Collection. This study was based on a cross-sectional and longitudinal dataset. Annual and perennial plants' postharvest productions and income in the two consecutive production seasons were collected following the farmers' recall method and the last season was collected using both farmers' estimation and crop harvest methods. Postharvest estimations for annual crops are commonly made at the farmer's house or at the site where the harvest is stored for the enumerator to cross-check the estimates with the available storage capacity. In all studied kebeles, harvested crops in the previous cultivation seasons were either sold or consumed and a few quintals were left, but for the last season, harvested products were checked in the field.

To support the recall methods, during the last data collection seasons, annual crops were harvested from the purposively selected 508 (20 Arba Minch and 30 Derashe districts) farmers' fields that the crops were ready for harvest. From each selected plots, crops were harvested from five subsamples forming 2 m × 2 m quadrants. Then the harvested crop was mixed and the yield converted to quintals per hectare. Furthermore, to get total banana fruit production from a single tree, 20 banana farm plots were randomly selected and 10 m × 10 m quadrants were purposively formed. The larger quadrants were selected because most farmers' plant banana seedlings were within 3 m × 3 m spacing. The bunch of fruits in all subsamples were mixed, measured, and converted to quintal per hectare. However, since the production potential of *Moringa stenopetala* for leaf biomass was different in each month of the year, farmers' estimation methods were used solely to estimate the leaf biomass production and income.

$$\text{Crop yield} = \frac{\text{Amount of harvested products}}{\text{Crop harvested area}}. \quad (5)$$

To obtain the gross income from the CA and CT practices, crop production in quintal ha^{-1} and the market price for specific marketing seasons were assessed from the local markets. In addition, to calculate the net income, all variable costs were identified using a structured interview, key informant interview, and local market assessment. Gross income was considered as annual + perennial crop production/yield multiplied by the market price of each crop. To make the comparison uniform, production was converted to hectare. Costs include all incurred expenses for specific crop productions, that is land preparation, seeds and seedlings, fertilizer, sowing/planting, digging, watering, cleaning, weeding, harvesting, and transportation to market after harvest. The net income was computed for each CA and CT practice as follows:

$$\text{Net income} = Y \times P - TVC, \quad (6)$$

where Y is annual and perennial crops' yield (quintal ha-1), P is the selling price of products in the nearby local market, and TVC is the total variable cost/s incurred to produce annual + perennial crops with CA and CT practices. Collected production and income data for 18 months (three cultivating seasons) were converted to US dollars (USD) using the mean exchange rate of each month.

2.3.2. Market Survey. The market price method was used to estimate the value of goods that are bought and sold in the local market. For this study, respondents were asked about the prevailing market prices of goods traded in the local marketplace, such as the price of crops, banana fruit, and *M. stenopetala* leaves. Therefore, their answer was checked from the closest market where the study kebele residents commonly used. Local market assessment helps to determine the accurate income of households. After products from land were collected and brought to market, the market survey was conducted in March 2021.

2.3.3. Statistical Analysis. The contributions of each land management on the mean values of soil physicochemical properties, that is BD, FC, PWP, particle size, soil textural classes, power of Hydrogen (pH), CEC, available potassium (Av. K), available phosphorous (Av. P), total nitrogen (TN), exchangeable bases (Na, Mg, Ca, and K), and soil organic carbon (SOC) were compared using an independent sample *t*-test at 0.05 level of significance. A linear regression model was used to observe the effects of predictor variables, that is CEC, pH, and the sum of exchangeable cations, a linear regression model was used. In addition, to compare production, mean gross, and net income from both annual and perennial plants, descriptive and inferential statistics were employed. The collected data were analyzed using Statistical Package for Social Sciences (SPSS) version 26.

3. Results and Discussion

3.1. Effects of CA and CT on the Soil Physical Properties

3.1.1. Soil Particle Size and Field Capacity. The amount of clay was significantly higher ($P < 0.05$) in the CA. The findings agreed with Ngwira et al. [51], Thierfelder et al. [52], and Teravest et al. [53], as they found that the three principles of CA contributed significantly to improving soil

Table 2: Mean (±SE) effects of CA and CT land management on the sand, silt, and clay (%) distribution in Arba Minch Zuriya and Derashe districts.

Land management type	Particle size (mean (±SE))		
	Clay	Silt	Sand
CT	45.79 ± 2.19^a	45.01 ± 1.41	9.2 ± 1.35
CA	53.74 ± 2.68^b	40.01 ± 2.07	6.25 ± 0.86
t-value	0.029	0.056	0.076

Means with the different letters across column are significantly different ($P < 0.05$) to land management. *Note.* CA, conservation agriculture; CT, conventional tillage.

Table 3: *T*-test on the effects of CA and CT on the soil field capacity (%), permanent wilting point (%), and available water holding capacity (%) in Arba Minch and Derashe districts.

Land management type	Water holding		
	FC	PWP	AWHC
CA	47.8 ± 1.09^a	32.5 ± 0.85	15.2 ± 0.37^a
CT	42.9 ± 1.21^b	32.2 ± 1.19	10.6 ± 0.09^b
P-value	0.02	0.87	0.001

Means with the different letters across column are significantly different ($P < 0.018$) to land management. *Note.* CA, conservation agriculture; CT, conventional tillage.

properties including soil moisture retention. In both land managements, the soil contained less sand fraction (Table 2).

Soil texture is an inherent soil property; however, management practices may contribute indirectly to the changes in particle size distribution. In the selected plots of CA practitioners, farmers manage their land leaving the residues of maize and sorghum on the farmland, locally known as Targa-na-Potayta. Therefore, the differences in particle size distribution among the two land managements can be attributed to the impact of farming practices and management.

The soil serves as a reservoir, which holds water that may be withdrawn by plants. The amount of water retained by the reservoir at the upper or full end is FC [54]. In this study, the FC value was significantly different ($P < 0.05$) among the two land managements (Table 3). The conservation of soil water may support the no-till crop through short drought periods without severe moisture stresses developing in the plants.

The PWP or the water content at which plants start to wilt during daytime was higher in CA (32.5 bar) as compared to CT (32.2 bar). Additionally, the AWHC was also higher in CA (15.2%) than in CT (10.6%) (Table 3). The result agrees with the findings of Yimam et al. [55]; in the subhumid Ethiopian highlands where the water holding capacity of the CA was higher than CT in the drip-irrigated field. The study identified that CA with a drip irrigation system was found efficient for agricultural water management than the CT system.

Silt clay and clay soil were the dominant soil textural classes in the study sites. The dominant textural classes were clay in CA and silt clay in CT. Moreover, FC, PWP, and AWHC were compared against the soil textural classes and FC, and AWHC was the highest in clay soil, and the PWP was the highest in silt clay soil. Soil textural classes and lithology in Brazil revealed that in the surface horizons, FC

Table 4: *T*-test on the effects of CA and CT on the soil bulk density in Arba Minch and Derashe districts.

Land management type	Bulk density (BD)	*P*-value
CA	1.07 ± 0.025	0.39
CT	1.03 ± 0.033	

Table 5: *T*-test mean comparison on the effects of CA and CT on the soil chemical properties in the selected kebeles of Arba Minch Zuriya and Derashe districts.

Parameters	CA	CT	*P*-value
pH	8.02 ± 0.07^a	7.69 ± 0.06^b	0.01
SOC	1.8 ± 0.02^a	1.6 ± 0.05^b	0.001
SOM	3.09 ± 0.03^a	2.75 ± 0.08^b	0.001
Av. P	47.35 ± 1.62^a	90.53 ± 7.6^b	0.001
TN	0.04 ± 0.003	0.06 ± 0.004	0.07

Means with the different letters across column are significantly different ($P < 0.05$) to land management.

was greater in the clay and loamy soils, intermediate in the sandy loam soils, and lowest in the sandy class [56]. The increase in FC and PWP in soils with higher clay and silt contents was also observed in the Rio Grande do Sul, RS [57], the USA [58], and France [59].

3.1.2. Bulk Densities. Soil bulk density (BD) was not significantly different ($P < 0.05$) among the two land managements (Table 4). According to Reynolds et al. [60], a BD in a range of 1.4 to 1.6 g/cm^3 was found to be severely restricting root growth. In both study districts, with different land management approaches, the BD was lower than the above-explained ranges and indicated the presence of favorable soil bulk density for plant growth. The decrease in BD values in CA will be obtained after a long-term CA practice due to residue retention [61].

The decrease in BD values in CA will be obtained after a long-term CA practice due to residue retention [61]. Besides, in Derashe area, the practicing CA started hundred plus years ago.

3.2. Effects of CA and CT on Soil Chemical Properties

3.2.1. Soil pH, Organic Matter (SOM), Available Phosphorous (Av. P), and Total Nitrogen (TN). The slightly higher (8.02) soil pH-H_2O values were recorded in CA compared to CT (Table 5). The soil pH-H_2O value was significantly affected by a land management ($P \leq 0.01$). The higher value of pH under the CA could be related to cations released from decomposing mulch material. Thus, farmers try to restore annually received minimal rainwater using "Targa-na-Potayta." Annually received low precipitation cause little leaching of base cations, associated with carbonates and bicarbonates found naturally in soils and irrigation water, resulting in a relatively high degree of base saturation and pH values greater than 7 [62].

SOM is considered as the indicator of soil quality because of its contribution in influencing soil biological,

Table 6: *T*-test mean comparison on the effects of CA and CT on the soil the exchangeable bases (meq/100 gm of soil) and PBS (meq/100 gm of soil) in the selected kebeles of Arba Minch Zuriya and Derashe districts.

Parameters	CA Mean (±SE)	CT Mean (±SE)	*P*-value
Na^+	1.05 ± 0.1	0.96 ± 0.05	0.47
K^+	0.94 ± 0.04^a	1.46 ± 0.23^b	0.03
Ca^{2+}	44.69 ± 3.52^a	34.95 ± 1.63^b	0.01
Mg^{2+}	15.97 ± 2.86	14.27 ± 0.32	0.56
Sum of cations	68.21 ± 1.66^a	60.67 ± 1.52^b	0.002
CEC	68.2 ± 1.66^a	60.67 ± 1.52^b	0.002
Percent base saturation (PBS)	113.4 ± 23.2	85.15 ± 1.8	0.24

Means with the different letters across row are significantly different ($P \leq 0.01$) to land management.

chemical, and physical properties and crop yields [63]. In this study, SOM was higher in CA as compared to CT due to the heavy inputs obtained from the crop residues. The difference between the two land management was statistically significant ($P < 0.01$) (Table 5). The finding was in line with Araya et al. [64] who reported higher SOM in permanent raised bed compared to plots under the CT in vertisols of Tigray in northern Ethiopia. Baudron et al. [65] reported the importance of mulching to improve the soil quality, as the amount of topsoil was twice the plots with residue retention, compared to those with no retention of residues. Veloso et al. [66, 67] reported improved and build-up SOM and the physical, chemical, and biological characteristics in the CA system. However, the finding was against Liu et al. [68] who reported slow rates of organic matter decomposition in CA as compared to CT, because tillage enhanced short-term CO_2 evolution and microbial biomass turnover and accelerated organic C oxidation to CO_2. In this study, soil organic matter is high in the CA due to continued and sustained input of the crop residue as mulch material and never used as livestock feed or burned as it is the case in other land management.

The Av. P value was significantly affected by a land management ($P \leq 0.01$). Av. P and TN were higher in CT as compared to CA (Table 5). The higher Av. P in the CT as compared to CA could be due to an abundant application of DAP fertilizer to increase the soil fertility and banana fruit production. It was quite evident that the applications of fertilizer alter soil properties, such as P and N. Among them, chemical fertilizer significantly enhances Av. P content since soil possesses strong adsorption for phosphorus, which can be released by chemical fertilizer [71].

3.2.2. Cation Exchange Capacity (CEC) and Percent Base Saturation (PBS). The potential of the soil to attract, retain, and hold exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, etc.) is governed by the CEC of any soil. The CEC of CA was higher as compared to CT, and the values were significantly different ($P \leq 0.01$) (Table 6). In both land management, the CEC value was generally high according to Landon's [70] classification.

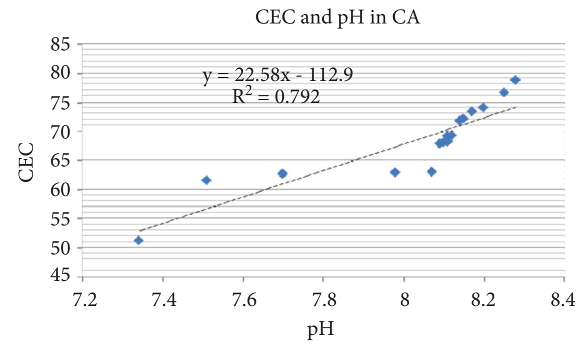

Figure 7: The effect of CA on the positive relationship between soil pH and CEC in the selected kebeles of Derashe district.

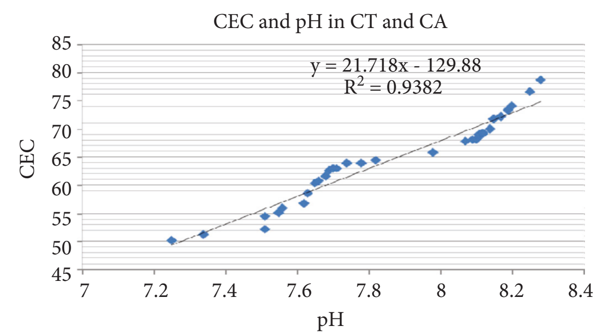

Figure 8: The effect of CA and CT on the positive relationship between soil pH and CEC in the selected kebeles of Derashe and Arba Mich Zuriya districts.

Concentrations of exchangeable cations were generally in the order of $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ in CA and $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ in CT. Ca^{2+} is more strongly absorbed than Na because it is divalent and has the smallest hydrated radius. The value of Ca^{2+} and K^+ were significantly higher in CA as compared to CT (Table 6). The value of K^+ in the CT was significantly higher ($P < 0.01$) as compared to CA. Many research results indicated that weathering and generally harvesting all parts of the crop for different purposes affect the distribution of K in the soil systems and enhance its depletion (e.g., [71, 72]. In the CT (banana-based AF) since the fruit is perennial and densely planted, the impact of sunlight on the soil is less. Besides, the unconditional fall of the banana leaves during the fruit collection and pruning may help to enhance the available K^+.

There is a positive relationship between pH and the CEC content of the soil (Figures 7 and 8). Foth [73] revealed the positive correlation between soil pH and CEC.

3.3. CA and CT Practitioners' Mean Production, Gross, and Net Income from Annual + Perennial Crops. In the study areas, agricultural activities are the main source of income. Among the total sampled households, 89% of CA and 66% of CT practitioners rely on crop cultivation; and 28% of CT practitioners rely on banana + maize-based agroforestry. The mean gross income from annual crop productions in three consecutive cultivation seasons (18 months) for CA

Table 7: Pooled three cultivation seasons' mean crops gross income (ETB10 ha^{-1}) of CA and CT practitioners from annual crops in Derashe and Arba Minch Zuriya districts.

Practitioners	Mean	Std. dev	Std. error
CA	98.250.15 ($2,751.78)[a]	7.2753.3	5.483.99
CT	71.099.48($1993.4)[b]	5.6281.11	4.115.68
t-test	3.99***		

Source: Household survey data. Mean values with different superscript letters across columns are statistically different ($P < 0.01$).

Table 8: Mean gross income (ETB ha^{-1}) in three consecutive cultivation seasons of CA practitioners from annual crops + *M. stenopetala* leaves and CT practitioners from annual crops + banana fruit in Derashe and Arba Minch Zuriya districts.

Land use	Mean	Std. dev	Std. error
CA	93.405.29 ($2.870.69)[a]	7.8311.9	5.593.65
CT	280.721.73 ($8.325.17)[b]	13.629.76	9.735.05
t-value	−16.68***		

*** Significant at 1% probability level. Mean values with different superscript letters across columns are statistically different ($P < 0.01$).

practicing groups were higher as compared to CT (Table 7). The increase in gross returns for CA practitioners could be the all-in-one use of the three pillars of CA with intensive farm management. Smallholder farmers of the Derashe area use a novel mulching technique known as Targa-na-Potayta. The organic inputs from the recycling of crop residues are the main source of nutrients for subsequent crop growth, and the soil nutrient removal (mining) is only through the grain harvest [34]. A study was conducted in Central Malawi to identify the benefits of CA on maize yield. The study finding showed maize yields in CA (3.98–4.43 Mg ha^{-1}) were significantly higher ($P < 0.018$) than CT (1.84 Mg ha^{-1}) [74]. Besides, Thierfelder et al. [75] revealed, in South Africa, maize yields under no-till with mulch retention were marginally better than under CT in a regional study on long-term trials.

T-test was employed to compare CT practitioners' income from the whole produced crops + banana fruit and CA practitioners' income from annual crops + *M. stenopetala* leaves. Accordingly, the mean gross income of CT practicing groups was significantly higher than CA in three consecutive production seasons-1. An independent sample *t*-test showed a significant annual income difference among the two practitioners $P < 0.001$ (two-tailed *t*-test) (Table 8). The overstated income difference among the two groups was due to monthly banana fruit production potential coupled with an accessible and structured marketing system.

Using the three consecutive cultivating seasons' production and income data, CA practitioners obtained 4333.87ETB ($118.91) ha^{-1} from sole *M. stenopetala* leaves and CT practitioners obtained 213,733.82ETB ($6331.77) ha^{-1} from sole banana fruit marketing. The Derashe people depend only on the short and erratic natured rainfall and apply an indigenous adaptation strategy to produce crops. Their regular and dedicative effort changed the productive potential of the barren land and able to produce crops for household consumption and marketing.

Table 9: CA and CT practitioners' annual mean net income (ETB ha-1) from annual crops + *M. stenopetala* leaves and annual crops + banana fruit in Derashe and Arba Minch Zuriya districts.

Tillage type	Annual crops		Annual + perennial	
	Mean	Sta. dev	Mean	Sta. dev
CA	46.783.61	48.018.6	49.672.86	48.127.83
CT	34.441.76	35.936.54	157.980.60	87.959.6
T-test	2.81***		−15.12***	

*** Significant at 1% probability level.

From the total gross production and income, the share of banana fruit was 76.14% and *M. stenopetala* leaves contributed 4.64% for the total household income in Arba Minch Zuriya and Derashe districts, respectively.

To identify annual net income from perennial and annual crops, the collected data for the three consecutive cultivating seasons (18 months) were converted to annual basis. The annual net income from annual crops were higher for CA practicing groups and net income from annual + perennial crops was higher for the CT practicing groups (Table 9).

Mean values with different superscript letters across columns are statistically different ($P < 0.01$). Net income from banana fruit was 123,539.21 ETB ha^{-1} and has a share of 78.2% and *M. stenopetala* leaves contribute 5.81% for the total household income.

4. Conclusions

The Derashe area known with the problem of soil erosion and moisture stress, and to relieve the challenge, hundred plus years ago, they innovated CA with an indigenous mulching technique, locally known as Targa-na-Potayta. This technology helped to relieve the problem and change their livelihood from being dependent on the government food support to potential producers. However, the neighboring Arba Minch Zuriya district smallholder farmers still depend on the conventional tillage. Therefore, using the two lands management approaches, this study tried to analyze and compare the effect of CA and CT, for the soil physical and chemical properties through collecting representative soil samples from the four kebeles, and assess CA and CT practicing groups' production and income from annual + perennial crops.

Five soil physical and seven soil chemical properties indicating variables were used to test the soil quality under the two land managements. The results showed the soil physical and chemical property under CA land management was promising as compared to CT. These were due to the use of the three principle of CA, that is cropping rotation, crop mixture with legumes, and mulch application using Targa-na-Potayta technique. Besides, they use zero tillage to reduce the soil disturbance and soil moisture evaporation. Legume incorporation helps to fix the atmospheric nitrogen, release in the soil high-quality organic matter, facilitate soil nutrients' circulation, and water retention. Based on these multiple functions, legume crops have high potential for conservation agriculture, being functional as growing crop. Crop rotation also helps to increase the soil nutrients, limits the prevalence of pest and disease, and improves the soil structure. Crop residue application on the other hand helps to increase the soil moisture and soil nutrients that returned back from added crop residues.

Annual + perennial crop production and income was also determined and compared. In the Derashe area, smallholder farmers dominantly practice maize/sorghum/teff + *Moringa stenopetala* tree. In Arba Minch Zuriya district, it is common to look maize/teff + banana fruit tree cultivation. However, an accessible small-scale irrigation and nationwide structured marketing attracted smallholder farmers to dominantly cultivate sole banana fruit tree by removing the integrated annual crops. The production and income from annual crops of CA practicing groups were higher as compared to CT. This was due to the favorable physicochemical soil quality in CA practicing smallholder farmers' plot. However, the pool gross and net income from annual + perennial crops were higher for CT practicing households. The main reason for this was the available favorable environment for banana fruit production, that is accessible marketing and irrigation. Therefore, to sustainably maximize the productivity of the soil, neighboring Arba Minch Zuriya smallholder farmers need to integrate the indigenous land management approach Targa-na-Potayta of the Derashe people, and to make the Derashe people beneficial, appropriate bodies need to establish small-scale irrigation in the area. Besides, the benefits of Targa-na-Potayta as sustainable agricultural soil management practice need to be scaled out with policy support.

Data Availability

All the data are available with Lemlem Tajebe Lejissa (lemlemtajebe@gmail.com).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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