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# Evaluation of Modified Implements of Ard on Crop Yield and Property of Soil in Northwest Ethiopia Highlands

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## Abstract

*Ethiopian farmers have been using ard plow to till their land for a long period of time. In the past three decades, some modified implements were delivered to the farmers of northwestern Ethiopia but there is merger information about their effects. The effects of four tillage implements (traditional or Deger, Berken, Aybar side wings and Tenkara kend) were evaluated on crop yield response and soil properties in 2021 and 2022 years at Basoliben and Debre Elias district. During the first plowing, the wider furrow length was recorded from the plots plowed by Aybar and Berken meanwhile slightly deeper furrows were observed from the plots plowed by Tenkara kend and traditional side wings. The highest weed number (41.3m$^{-2}$) was recorded from the plots plowed by Tenkara kend which might be due to the unplowed strip of land exhibiting between two adjacent furrows during plowing. The maximum plant height (95cm), spike length (8.7cm), number of seeds per kernel (42.3) thousand seeds weight (34.4g), grain yield (3.58 t/ha), straw (10.88 t/ha) and biological yield (14.5 t/ha) were recorded from Aybar and followed by Berken. Better residual soil properties in terms of organic matter (1.88%), total N (0.325%), available P (11.89 ppm) and CEC (35 mg/100g) were obtained from Berken and then by Aybar. Besides, the partial budget analysis result revealed that the maximum net benefit of 102,938 ETB (1,888$)/ha was obtained from Aybar and then from Berken (1,774$/ha net profit). Thus, the respective development organizations should focus on the dissemination of Aybar and Berken technologies for sustainable crop production.*

**Keywords**: *Ard plough, Aybar side wings, Berken, Deger, residual soil properties and Tenkara kend*

## 1. Introduction

Soil productivity has been decreasing in most areas of sub-Saharan Africa due to a joint effect of climatic conditions and human activities. Due to the intensive erosion, runoff, crop mining, leaching, the removal of cow dung for fuel and crop residues as animal feeds, poor crop management and continuous cultivation associated with the old traditional tillage practice the organic matter content of soil has been declining from year to year (Tadesse, 2001). The efficiency of soil to provide life support ameliorates declines, especially in developing countries, like Ethiopia where soil management is not given due consideration (Jiru and Wegari, 2022). The subsequent decline in food production, coupled with rapid population growth has an impact on household food security and per capita income. Soil degradation is the major environmental challenge for agricultural production in Ethiopia (Wassie, 2020).

Tillage is the mechanical manipulation of land for crop growing through managing crop residues, killing weeds, and improve soil structure but it has negative impact on soil erosion, organic matter and nutrient cycling (Dheerendra *et al*., 2023). Besides, tillage improves soil porosity and aeration, infiltration rate, water holding capacity of soils and nutrient mineralization from organic material and this enhances the growth of plants (Lipiec and Artur, 2006).

Cultivation of native land can reduce the quality of soil by decreasing topsoil contents of organic carbon, total nitrogen, and phosphorus (Urioste *et al*., 2006). Tillage management, due to its soil mixing effect can alter the distribution of mobile nutrient ($NO_3$ and $SO_4$), soil water and organic matter content and its porosity (Bariot, 2014). Intensive cultivation depletes soil organic matter content and reduce the CEC of the soils but conservation tillage shows lower in nitrification rates ($NO_3$:$NH_4$ ratio), as compared with the conventional tillage (Peeyush *et al*., 2016). Since the frequency of tillage is affected by soil texture and crop type, tillage frequency increases in heavy soil rather than in light textured soil (Babloo *et al*., 2018). Similarly, the field of tef is plowed more frequently than for maize (Melesse *et al*., 2008**)**. The effect of cultivation was much more evident in the larger macro aggregates (>1mm) than the smaller macro aggregate size classes (Yeshanew, 2005).

The various forces of soil compression by agricultural equipment can cause soil particles to become compacted closer together into a smaller volume (Ross and McKenzie, 2010) Soil compaction is a global problem and needs to be tackled worldwide; otherwise, it may continue to remain as one of the underlying causes of yield reduction and environmental degradation (FAO, 2002). Human-induced compaction of agricultural soil resulted due to the usage of heavy weight tillage equipments during cultivation process (Ross and McKenzie, 2010). The bulk density of mechanical farming's soil is higher as compared with the traditional farming's soil due to increment of soil pore space, thus the rate of soil degradation increases as tillage intensity shifts from traditional tillage to mechanized one (Mulugeta, 2004).

Most farmers of Africa (North and East), Europe (South-East), Far East and Latin America are still using various type of *ard* plough (Gebregziabher *et al.,* 2007). Ethiopian farmers have been using an ox-drawn breaking plough, known as *ard* plough for long period of time (Solomon *et al*., 2016). Ethiopian *ard* plough is driven by pair of oxen for plowing and seed sowing purpose (Fig. 1). Most components of *ard* plough are wooden except the plough share and tying unit (Melese, 2000).Typically, *Maresha* penetrates the soil to a shallow depth (less than 20-30 cm) and leave untilled land between two consecutive furrows since the soil is not inverted as the case in moldboard ploughing (Melesse *et al*., 2008; Solomon *et al*., 2016). Hence, the farmers are used to carry the subsequent tillage operations in perpendicular direction to the former tillage (extra cross-tilling)

(Aschalew, 2005, Melesse *et al*., 2008, Solomon *et al.*, 2016).

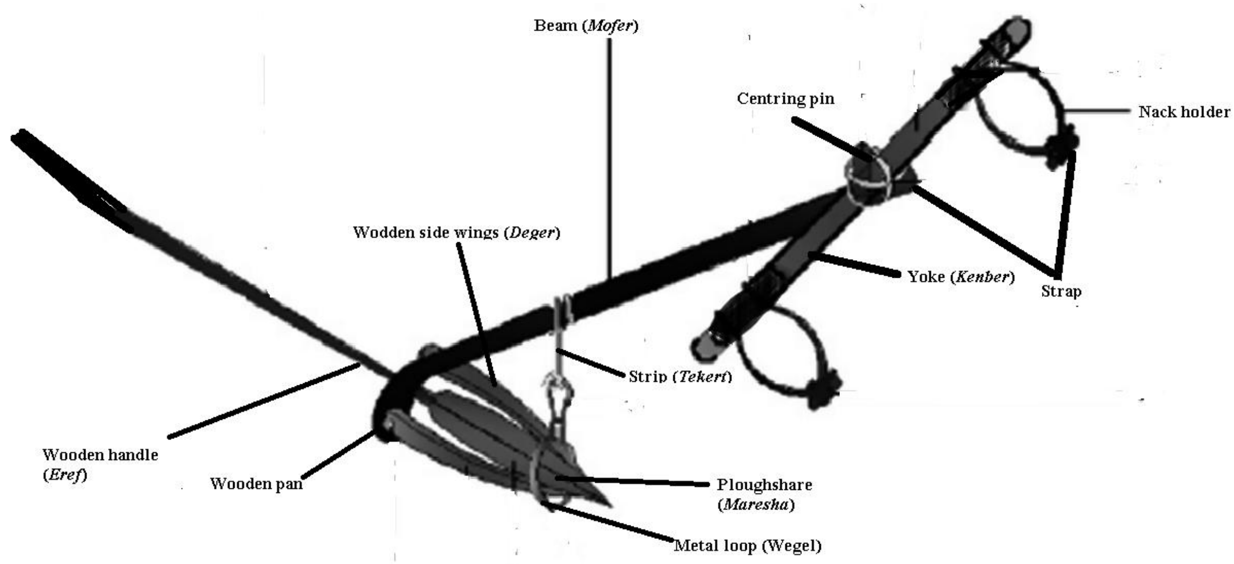


Figure 1. Schematic figure of Ethiopian ard plough or *Maresha*

Source -Gebregziabher *et al*. (2006)

Even though, several modern tillage systems are common in the world but smallholding farmers in the developing countries have not been interested in high cost and energy intensive technologies (FAO, 2003). Most farm implements in the developing countries are not efficient but time consuming, thus the productivity of agriculture is stagnant by usage of these implements (Abebe and Yonas, 2019).

Wheat is the leading cereal crop in acreage production in the world and it ranks first both in acreage and production among the cereal crops of the world (Charles, 2016). The subsistence of one third of the world population is dependent on wheat crop (Shiferaw *et al*., 2013). Wheat is the most important cereal crop in Ethiopia in general and in north western Ethiopia in particular. In terms of production, wheat ranks the fourth after teff, maize and sorghum (CSA, 2018). Despite its importance in Ethiopia, the crop productivity is desperately very low (below 3$tha^{-1}$) compared to its productive potential record of the world (>5 $tha^{-1}$) (CSA, 2016; Birhan *et al*., 2016).) The continuous cultivation by using the traditional plowing implement results in the formation of hard pan as a result crop yield decreases (Angon *et al*., 2024).

The improved tillage practice has great effect on crop productivity and physiochemical properties of soils (Temesgen *et al*., 2009). Similarly, the N uptake of wheat has been high under conservation tillage than conventional tillage (Soon *et al*., 2001). Moreover, tillage practice has great impact on weed infestation. In developed countries of the world weed causes a loss of 10% of the total yield but in the least developed countries weed's yield loss is about 25% (Tamado and Milberg, 2000).

Some attempts have been carried out to modify the farm implements in Ethiopia since 1970s. The major modifications have been done on the traditional ox-drawn *ard* plough to creating various type of surface depressions (Jan *et al*., 2011). The oxen-drawn tool, *Tenkara kend* has been developed to cultivate the subsoil for the areas with subsoil compaction problem. *Tenkara kend* ploughs 6-12 cm deeper than the traditional *Maresha* and it weights about15.5 kg (Aschalew, 2005), even though the dissemination of the modified tools remains limited (Jan *et al*., 2011). *Tenkara kend* implement has been delivered to northwestern Ethiopian highlands farmers since 2003 while *Berken* and *Aybar* side wings have been delivered to the farmers since 2015.

Developing suitable tillage systems and implements leads to maintaining soil resource and increasing food production (Solomon *et al*., 2016). The same authors have disclosed that the design and development works for the improvement of the ard plough has been done since 1939 in Ethiopia, however the limitation of information from the empirical studies about these implements has been hindered the extension service. Thus, this study was designed to determine the effective implement to improve crop yield and soil property of the study area.

## 2. Materials and Methods

### 2.1.Description of the Study Area

The experiment was conducted in two consecutive years (2021 and 2022) on the two wheat producing areas of East Gojjam in Basoliben and Debere Elias districts at Lemechem and Yemezeghn Kebeles, respectively. They are locatedat 305 km and 340 km north-western of Addis Ababa and 281 km and 248 km southwest of Bahir Dar. Geographically, Lemechem is located at $10^{O}14'10''$N and $37^{O}74'63''$ Eon 2211 masl altitude while Yemezeghn at $10^{O}36'86''$ N of latitude and $37^{O}49'07''$ E of longitude with 2190 masl altitude (Fig. 2). Both sites are covered by *Nitisols*.

The locations are characterized by a range of 1270-1400 mm rainfall values and 18-24°C temperature but during the experimental seasons,Yemezeghn had slightly warmer and drier weather condition than Lemechem. However, the agro-ecological condition of both locations is categorized under mid-highland (*Woyina Dega*) and suitable for wheat production.

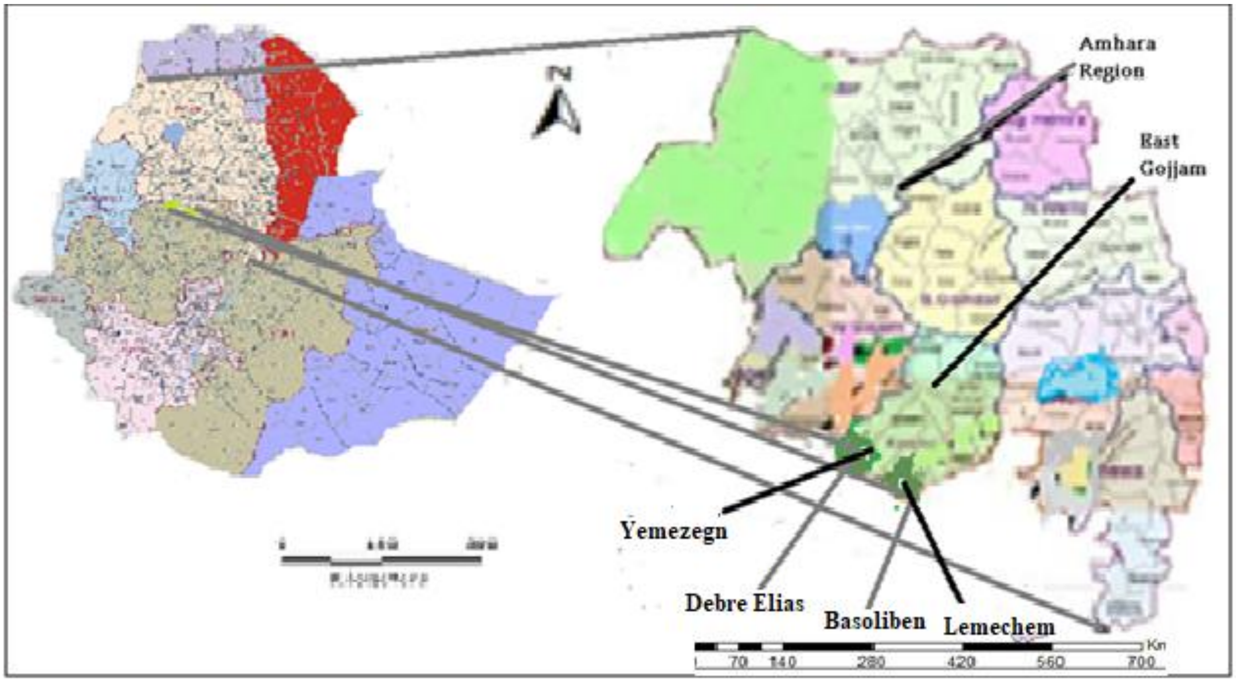


Figure 2. Schematic map of the study locations

## 2.2.Materials Used

Bread wheat Kakaba (Picaflor #1) variety as test crop, NPSB blended fertilizer (100 kg/ha) and urea (200 kg/ha) were applied for the whole plots. The traditional and modified implements (*Deger*, *Berken*, Aybar side wings and *Tenkara kend)* were collected from the local farmers and agricultural offices for experimental treatments. During plowing, *Tenkar kend* required more drought force and slower in speed than other implements sine it is heavier in weight.

The traditional side wings (*Deg*er) are made of wood (Fig. 3a), but *Berken* and Aybar side wings are made up of metal and installed on the traditional *Erfe* without removing ploughshare (*Maresha*) (Fig. 3b and 3c). According to Temesgen *et al*. (2009), Aybar and Berken side wings are easily drawn by oxen as compared to the traditional side wing (*Deger*). Unlike *Berken* and Aybar implements, *Tenkara kend* is installed on traditional side wings (*Deger*) by removing *Maresha* (Fig 3d). *Berken*, the name derived from the capacity of double tilling of root zone at different depths, its sharp edge helps to plow the root zone in shallow depth. Thus, it helps to minimize tillage frequency as compared to the land cultivated by traditional side wings.

**Fig. 3a.** Traditional side wings *(Deger)*

***Fig. 3b.*** During installation and ploughing of Aybar side

**Fig. 3c.** Berken side wing

**Fig. 3d** Uninstalled and intalled Tenkara kend

Source- The images were taken during experimental seasons

## 2.3.Experimental Design and Procedures

In both locations, 850 $m^2$ (17m* 50m) field was separated into three blocks by leaving 2m free space and then each block was separated into four plots by leaving 2m free space, thus the gross size of each plot was 30 $m^2$ (10m in length and 3m in width). The experimental treatments (*Deger*, *Berken*, Aybar side wings and *Tenkara kend*) were laid out in randomized complete block design (RCBD) and three times replication was made in the first season (2021) for evaluating crop yield response in both locations. The plots were plowed by using the predetermined ard's implement at the beginning of small rainfall season (*Belig*) and then plots were cultivated twice within the interval of 20 days before crop planting and crop planting was also carried out by using the same implement.

The second season experiment (2022) was also conducted on the same field and each plot was allowed to receive the previous season's treatment (2021) by following the same procedure on both locations to evaluate the treatment effects on wheat yield and residual soil properties.

The crop was sown by hand drilling at seed rate of 150 kg/ha with 20cm inter-row space. The full dose of NPSB blended fertilizer and the one-third (1/3) dose of urea was applied during crop planting, whereas the two-third (2/3) dose of urea top dressed for the whole plots after 35 days. All recommended cultural practices that were adopted for wheat production were uniformly implemented during the experimental seasons. The net plot size was determined by leaving the outermost two rows and 1m length on both sides to avoid the border effect, thus the net plot area was 17.6 $m^2$ (2.2x8m) for data collection.

## 2.4.Soil Sampling and Analysis

Before starting this experiment (2021) twelve soil samples were collected from each experimental field in X fashion at plowing depth to determine soil properties. The samples were thoroughly mixed and formed a composite sample then air dried ground and sieved through a 2 mm sieve size to determine its selective physiochemical properties of soil (texture, bulk density, soil pH, organic carbon, total nitrogen, available phosphorus and CEC). However, its bulk density and infiltration rate were estimated from the undisturbed soil through using a core sample cylinder and double-ring infiltrometer, respectively. Accordingly, the experimental soil of both locations was categorized in to clay in texture, medium in infiltration rate, strongly acidic, low bulk density, total N, available P and organic carbon but it had high porosity and CEC (Table 1).

Table 1. The experimental soil physicochemical properties at the experimental sites

| Soil property | Unit | Lemechem | Yemezeghn |
|---|---|---|---|
| Texture | | Clay | Clay |
| Sand | % | 17.5 | 13.5 |
| Silt | % | 28 | 32.5 |
| Clay | % | 54.5 | 54 |
| Bulk density | $gcm^{-3}$ | 1.19 | 1.21 |
| Porosity | % | 55.05 | 54.3 |
| Infiltration rate | cm/hr | 0.51 | 0.64 |
| Soil pH | | 5.39 | 5.44 |
| Total N | % | 0.125 | 0.117 |
| Organic carbon | % | 1.00 | 0.88 |
| Organic matter | % | 1.74 | 1.52 |
| Available P | ppm | 9.39 | 9.9 |
| CEC | meq/100g | 31 | 32.5 |

After crop harvest of the second season experiment (2022), six soil samples were collected from each plot net area at plowing depth in zigzag fashion and then thoroughly mixed to form a composite sample to determine the treatment effect on physiochemical properties of soil. Soil texture was determined by the hydrometer method (Day, 1965)while its porosity was estimated through using P = ((1 – (BD/d) × 100) where P = total porosity (%), BD = the bulk density (g/cm3) and its particle density (d) being the whole mineral soil and equivalent to 2.65$gcm^{-3}$.The rate of infiltration was measured by using double-ring infiltrometer with 12 and 24 inches size (Ghildyal and Gupta, 1998). Soil pH was determined from 1:2.5 soils to water ratio solution and using a digital pH meter. Total nitrogen was estimated by Kjeldahl method (Jackson, 1958) while organic carbon using wet digestion (Walkley and Black, 1934). Available phosphorous was extracted by Olsen *et al*. (1954) method and then measured by atomic absorption spectrophotometer. Its CEC was estimated according to Sahlemedhin and Taye (2000) procedures.

### 2.5.Data Collection

#### 2.5.1. Furrow Depth and Width

During the first plowing, the depth and width of the furrows were measured from three points in the net plot size area which were paralleled to the neighborhoods plots then their average value.

#### 2.5.2. Phenological and growth parameters

Days to 50% heading and 90% physiological maturity were determined by counting the number of days from sowing to the time when 50% of the plants start heading and 90% of the plants matured through visual observation. Total numbers of tillers were counted at tillering stage from randomly selected two rows of 0.5m length while plant height was measured from ten randomly selected plants at physical maturity.

#### 2.5.3. Yield and Yield Related Parameters

Spike length and number of kernels were determined from randomly selected ten plants at physical maturity, thousand kernel weight, harvest index, grain, straw and biomass yields. These parameters were measured after crop harvest through using the required methods.

#### 2.5.4. Weed Plants Counts

During the first (primary) weeding, weed survey was done by random sampling from each plot net area by using a quadrate of 1m x1m ($1m^2$) area where parallels with the neighborhood plots for weed count to identify the types and their number.

### 2.6.Economic Analysis

The partial budget analysis for each treatment was equated by using the field variable costs and benefit. The variable costs were the initial cost of farm tools and their operation cost. The field benefits were equated from the actual grain and straw yield and their prices at local market during the crop harvest. The treatments were arranged in an increasing order of variable cost for economically profitable treatments. Marginal rate of return was equated from their net benefit and incurring variable cost by using CIMMYIT (1988) procedure.

The prices of wheat grain and straw in 2021 at both locations were 32 and 0.10 $Birrkg^{-1}$ but during 2022 the price of grain was about 34 $Birrkg^{-1}$. On the other hand, the initial investment cost for the traditional side wings, *Berken*, *Tenkara kend* and Aybar side wings were estimated about 100, 250, 600 and 300 Birr per piece, respectively. The operation cost of the implements was estimated from the time required to accomplish contour plough of the plot during plowing, thus Aybar, *Berken* ,traditional side wings and *Tenkara kend*, in order recorded 800, 900, 1400 and 1700 $Birrha^{-1}$. Plowing by using *Tenkar kend* was harder for drought forces thus it was slower in speed of plowing as compared to using other implements. The overall cost of grain yield packaging and transporting for the local market was estimated about 1.00 $Birrkg^{-1}$

### 2.7. Data Analysis

The collected field and laboratory data were subject to analysis of variance using SAS and JMP software. The significant differences among treatment means were delineated by LSD procedure at 5% significance level.

## 3. Results and Discussion

### 3.1.The Performance of the Implements

The performance of the plough implement was evaluated during the first plowing of each plot through measuring the open V-shape furrow width and depth. The furrow width and depth were significantly affected by the implements. This agrees with Frode’s *et al.* (2002) study that the ploughing quality is identified using the furrow width and depth. Maximum furrow width (33.83cm) was recorded on the plots which were cultivated by Aybar and then followed by *Berken* but the minimum furrow width was obtained on the plots plowed by using *Tenkara kend* and traditional side wings (Table 2). Thus, the plots that were cultivated by *Tenkara kend*, and traditional *Deger* allowed leaving the unplowed strips of land between two consecutive furrows rather than lands cultivated by Aybar and *Berken* side wings. According to Melesse's *et al*. (2008) report, the V-shaped furrows made by *Deger* (traditional side wings) leave untilled land between the successive furrows and farmers used to remove the untilled strip during subsequent tillage.

Table 2.The influence of plowing implements on furrow width and depth (cm).

| Plowing implement | Furrow width | Furrow depth |
|---|---|---|
| Aybar side wings | 33.83[a] | 12.58[C] |
| *Tenkara kend* | 20.08[d] | 19.08[A] |
| *Berken* side wings | 30.0[b] | 16.08[B] |
| Traditional side wings | 24.33[c] | 20.75[A] |
| LSD (5%) | 3.26 | 2. 41 |
| Sd± | 3.94 | 1.99 |

Whereas LSD= Least significance difference, Sd±= Standard deviation. Means with the same letters in a column are insignificant

On the other hand, the maximum furrow depth (20.75cm) was recorded from the plots which cultivated by the traditional side wings and *Tenkara kend* (Table 2). Furrow width has showed significant influence to the location, the wider furrow length (28.8cm) was recorded at Lemechem location than Yemezeghn (25.3cm) since the soil of Lemechem had lower bulk density than Yemezeghn location. However, the furrow depth was insignificantly affected by the experimental location and season. It might be due to the uniformity of soil texture (clay) across both locations. In line with this finding, Dero and Kishorm (2021) and Harrigan and Rotz (1995) revealed that soil texture is the basic characteristic influencing infiltration, moisture, drainage and draft or traction power of farm implements.

### 3.2. Phenological Stages of the Crop

The treatments showed insignificant difference on the crop days to 50% heading and days to 90% maturity. Nevertheless, the delayed matured wheat (115 days) was observed from the traditional side wings (*Deger*) and *Tenkara kend* and then followed by Aybar (113 days).The delayed crop matured crop was observed from traditional side wings and *Tenkara kend* plots. It might be due to the plots were highly infested by weed than the plots plowed by Aybar and *Berken*, since the crop on these plots were exposed to more computation for resources (nutrients, space, light and water) as a result the crop delayed in maturity.

### 3.3.Plant Growth

Plant growth (number of tillers and plant height) was significantly influenced by the treatments. The maximum number of tillers per plant (3.13) and plant height (94.98cm) was obtained from the plots which were plowed by Aybar but the minimum number of tillers per plant (2.17) and plant height (76.77 cm) was from *Tenkara kend* (Fig. 4).

Thus, poor crop growth was observed from the plots which were plowed by using *Tenkara kend* but good crop growth was obtained from the plots plowed by Aybar. In line with this finding Habtamu *et al*. (2022) disclosed that *Berken* tillage was significantly decreased soil penetration resistance up to 40 cm depth, thus maize roots reached 1.5 times deeper as compared to the depth of roots through the conventional tillage treatment.

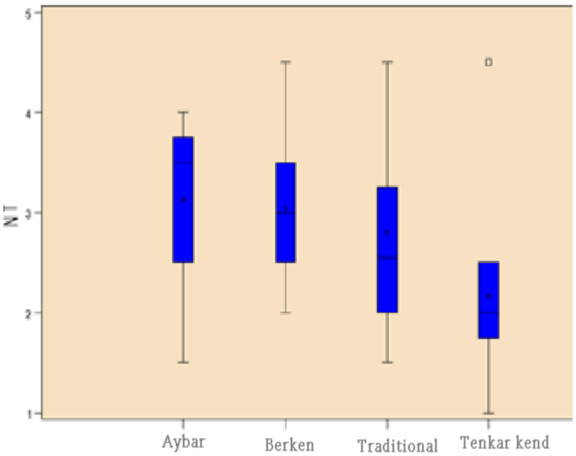


Figure 4A. Effect on number of tillers per plant

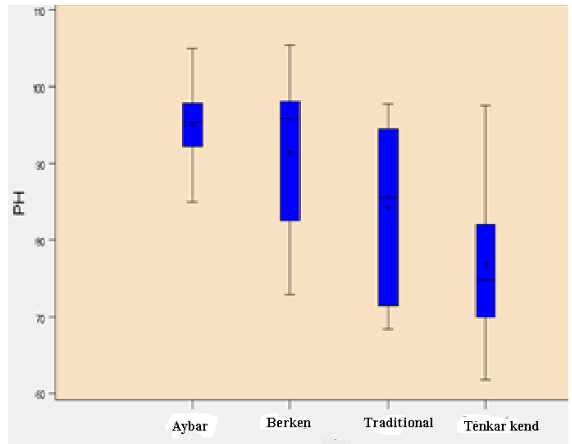


Fig. 4B. Effect plant height (cm**)**

### 3.4.Weed Count

According to the weed type count results indicated that the plots plowed by using *Tenkara kend* and traditional side wings were infested by annual, biennial and perennial grass and broad leave weeds such as *Cyperus spp*, *Avena spp*, *Digitaria abyssinica*, *Loliumtem ulentus*, *Rumex abyssinicus*, *Guizotia scabra*, *Plantago lanceolata*, *Setaria pumila*, *Amaranthus hybridus*, *Xanthium strumarium* , *Snowden iapolystachya* and *Scorpirum uricatus*. However, the plots which were plowed by using *Berken* and Aybar were highly infested by broadleaved weeds only such as *Guizotia scabra*, *Amaranthus hybridus*, *Convolvulus arvensis and Datura stramonium.* In line with this finding Haekansson *et al*. (1998) reported that the deep ploughing substantially reducing the occurrence of perennial weeds.

The number of weeds was highly significant ($p<0.01$) influenced by the implements. The maximum weed number (41.25m$^{-2}$) was recorded from the plots which were plowed by *Tenkarakend*, it might be due to the tool allowed for the occurrence of unplowed strip of land between successive furrows, thus creates the favorable conditions for the rejuvenated weeds. However, the minimum number of weeds was counted from the plots which plowed by Aybar and *Berken* side wings (Fig. 5). The V-shaped furrows created on the plots plowed by *Tenkara kend*, and traditional side wings (*Deger)* leave the unplowed strips in between the adjacent passes, thus the previous grown plants (weeds) rejuvenated on the field. This agrees with the study of Colbach *et al*. (2014) ploughing is found to be beneficial only if the regular tilled layer contains no or few weed seeds. Moreover, Mas and Verdú (2003) noted that the lesser degree of soil disturbance under conservation tillage as compared to the conventional ploughing, thus increase the occurrence of more weeds. Hager (2013) also disclosed that the prior to planting tillage is helpful to control weeds growth and reduce weed density.

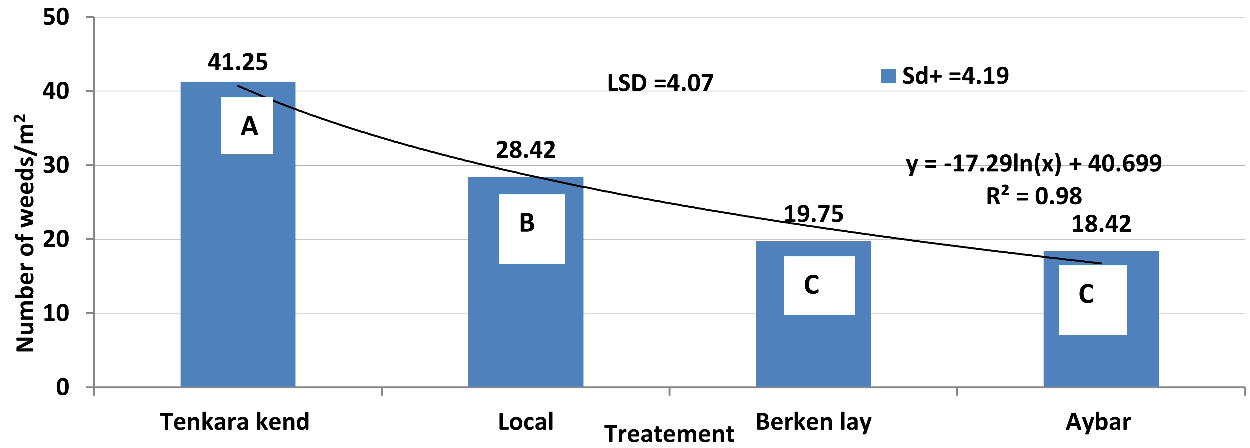


Figure 5. Plowing tools influence on weed number.

The number of weeds was significantly influenced by the experimental location and season, and the more number of weeds were counted in 2022 than in 2021 it might be due to the climatic conditions of 2022 which favoring the growth of weeds. On the other hand, more weed infestation was observed at Yemezeghn location than Lemechem since Yemezeghn is slightly warmer than Lemechem which favors the growth of weeds.

### 3.5.Crop Yield and Yield Components

Crop yield component such as spike length, thousand seeds weight and number of kernels per spike were highly significant ($p<0.01$) to the farm implements. However, the experimental location and season had insignificant influence on these parameters. The maximum spike length (8.7cm), number of kernels (42.3) and seed weight (34.5g) were recorded from crop grown on the plots plowed by Aybar while minimum spike length (6.4cm), number of kernels (26.5) and seed weight (29.6g) were observed from the plots of *Tenkara kend* (Table 3). This shows that tillage type can affect the water consumption of crops (Rongrong *et al.*, 2022).

Plowing through using an improved implement such as Aybar and Berken gave additional crop yield of 20-100% over the yield obtained through using traditional side wings (Melesse, 2000).

Table 3.The plowing implements effect on crop yield though combined analysis result.

| Plowing implement | Length of spike (cm) | Number of kernels/spike | Weight of 1000 seeds (g) |
|---|---|---|---|
| Aybar side wings | $8.7^{a}$ | $42.28^{A}$ | $34.43^{a}$ |
| *Berken* side wings | $8.16^{b}$ | $38.12^{A}$ | $33.18^{a}$ |
| Traditional side wings | $7.7^{b}$ | $37.07^{A}$ | $31.3^{b}$ |

| | | | |
|---|---|---|---|
| *Tenkara kend* | 6.37[c] | 26.5[B] | 29.6[c] |
| LSD (5%) | 0.52 | 5.28 | 1.49 |
| Sd± | 0.62 | 6.38 | 1.79 |

Means with the same letters in a column had insignificance difference.

The harvest index, crop grain, straw and biomass yields were highly significant ($p<0.01$) to the plowing implement. The maximum grain yield of 3.58 t/ha and straw yield of 10.48 t/ha was recorded from the Aybar plots and then followed by *Berken* (Table 4). In line with this finding Habtamu *et al*. (2022) revealed that plowing by using Berken tillage gave more 950 kg/ha (15%) maize grain yield and 6.4t/ha (0.3%) the above ground biomass over the traditional tillage. The number of weeds was highly reduced on the farmland plowed by using Aybar and *Berken* implements rather than on the farmland of tradition (*Deger)* and *Tenkara kend*. The critical period for weed control is also influenced by the weed and crop species, their density, and both soil and environmental conditions during the growing season (Knezevic *et al., 2017).* Similarly, the critical periods of weed competition for wheat ranges from 15 to 45 days after crop sowing (Terefe *et al*., 2016). On the other hand, plowing by using traditional side wings allowed the development of hard crust below the soil surface, thus it reduces water infiltration and root growth. However, *Berken* usage has more effects on disrupting hard crust and control of weeds as a result it improves the root growth. Besides it requires less draft power than traditional implement.

Table 4. Wheat yields as influenced by tillage implements.

| Plowing implement | Grain (kg/ha) | Straw (kg/ha) | Biomass (kg/ha) | Harvest index (%) |
|---|---|---|---|---|
| Aybar side wings | 3578.42[a] | 10879.5[A] | 14457.9[a] | 24.72[A] |
| *Berken* side wings | 3368.08[b] | 10481.1[B] | 13849.2[b] | 24.3[AB] |
| Traditional side wings | 2871.08[c] | 9294.3[C] | 12165.4[c] | 23.61[C] |
| *Tenkara kend* | 2856.75[c] | 9072.3[C] | 11929[c] | 23.98[BC] |
| LSD (5%) | 103.8 | 352.15 | 424.55 | 0.57 |
| Sd± | 125.39 | 425.31 | 512.75 | 0.69 |

Means with the same letters in a column had insignificance difference.

## 3.6.The Physicochemical Properties of Soils

### 3.6.1. Physical Properties of Soils

The field plowed by identical plowing implements for the two consecutive years has shown highly significant ($p<0.01$) difference in the residual physical properties (bulk density and porosity). The maximum bulk density (1.27 $gcm^{-3}$) was obtained from *Tenara kend* and traditional side wings but the lowest bulk density of 1.16 $gcm^{-3}$ observed from *Berken* side wings. In contrary, the highest porosity (55-56%) was observed from the plots plowed by *Berken* and Aybar side wings but the lowest (51 & 51%) from *Tenkara kend* and traditional side wings and this might be due to the value of bulk density. The highest infiltration rate (1.31 cm/hr) was obtained from the plots which were plowed by Aybar while the lower infiltration rate (0.41-0.49 cm/hr) recorded on the traditional and *Tenkara kend* plots (Table 5). The Aybar and Berken plowing implements were increased the infiltration rate, exponentially. The wider furrow observed from Aybar and Berken plots it allowed to minimize the occurrence of unplowed strips of land between the adjacent furrows. It means that the plots were thoroughly cultivated than the plots plowed by traditional side wings and *Tenkara kend*. The plots plowed by Aybar and *Berke* responded higher organic matter and soil porosity, thus it enhanced the infiltration rate. In connection to this, a study by Franzluebbers (2002) showed that a soil with a higher content of organic matter results in better soil aggregation and improved soil structure, increasing the rate of infiltration. In line to this finding, Habtamu *et al*. (2022) disclosed that Berken implement has positive effect on penetration of soil profile and increasing the infiltration rate.

Table 5. The influence of plowing implements on soil physical properties during 2022 season in Basoliben and Debre Elias districts

| Plowing implement | Infiltration rate (cm/hr) | Bulk density ($gcm^{-3}$) | Porosity (%) |
|---|---|---|---|
| Aybar side wings | $1.31^{A}$ | $1.19^{b}$ | $55.22^{A}$ |
| *Berken* | $1.08^{B}$ | $1.16^{b}$ | $56.23^{A}$ |
| Traditional side wings (*Deger*) | $0.41^{C}$ | $1.27^{a}$ | 52.01B |
| *Tenkara kend* | $0.49^{C}$ | $1.27^{a}$ | $51.95^{B}$ |
| LSD (5%) | 0.28 | 0.047 | 2.154 |
| $Sd_{\pm}$ | 0.055 | 0.057 | 1.79 |

Means with the same letters had insignificance difference.

### 3.6.2. Chemical Properties of Soils

Most chemical properties except soil pH and total N were highly significantly (p<0.01) influenced by the plowing implements. The maximum soil pH (5.64) and total N (0.325%) was observed from the plots which plowed by using *Berken* side wings. The highest organic carbon (1.09%), CEC (35 mg/100g) and available P (11.89ppm) was recorded from the plots of *Berken* and then followed by Aybar (Table 6). Thus, the fertility of soil in terms of its organic matter, available P and CEC highly improved by using *Berken* and Aybar implement.

Table 6. Soil chemical properties influenced by plowing implements during 2022 in two locations.

| Plowing implement | Soil pH | Organic carbon (%) | Total N (%) | Available P (ppm) | CEC (mg/100g soil) |
|---|---|---|---|---|---|
| Aybar side wings | 5.46 | $1.003^{ab}$ | 0.123 | $11.45^{ab}$ | $30.5^{AB}$ |
| *Berken* | 5.64 | $1.092^{a}$ | 0.325 | $11.89^{a}$ | $35.33^{A}$ |

| | | | | | |
|---|---|---|---|---|---|
| Traditional side wings | 5.64 | $0.745^{c}$ | 0.114 | $9.275^{c}$ | $25.5^{B}$ |
| *Tenkara kend* | 5.3 | $0.908^{b}$ | 0.111 | $9.752^{bc}$ | $26.33^{B}$ |
| LSD (5%) | 0.25 | 0.157 | 0.288 | 2.093 | 5.543 |
| Sd$_{\pm}$ | 0.041 | 0.13 | 0.057 | 1.07 | 4.60 |

Means with the same letters had insignificance difference.

### 3.7.Economic Analysis

The analysis of partial budget revealed that the maximum net profit of 102,938 ETB (1,888$)/ha was obtained from the plots which were plowed by Aybar and then 96,794 ETB (1,774$)/ha) profit was obtained from *Berken* side wings but the negative net benefit of 1,230 ETB (22.6$)/ha was recorded from *Tenkar kend* below the traditional implement since it had more investment and operational costs than other implements. In contrary, plowing by using Aybar and *Berken* gave additional profit of 20,913 ETB (384$) and 14,770 ETB (271$)/ha over the traditional side wings, respectively this is because the speed of plowing highly increased, as a result it saves the cost of labor. In line to these findings, Habtamu *et al*. (2022) revealed that Berken tillage gave more net benefit of 138 USD/ha as compared to the traditional implement.

## 4. Conclusion

The wider furrow length was opened by Aybar and Berken rather than traditional side wings (*Deger*) and Tenkara kend, thus the traditional and Tenkara kend treatments were allowed to leave unplowed strips of land between successive furrows. However, the deeper furrow was recorded from the traditional side wings and *Tenkara kend* implement. The maturity days of the crop was insignificantly affected by the implement but the growth and yield parameters of the crop was significantly influenced by the treatment. The enhanced growth and improved wheat yield were obtained from Aybar and *Berken* plots. Wheat grain yield on the Aybar and *Berken* plots was increased by 25% (>707 kg/ha) over *Tenkara kend* and traditional side wings plots. Besides, suitable physicochemical properties of soils (rate of infiltration, porosity, pH, available P, organic C, total N and CEC) were obtained from *Berken and Aybar* used plots. Moreover, the partial budget analysis results revealed that the maximum net benefit of 102,938 ETB (1,888$)/ha with acceptable MRR was obtained on the plots of Aybar and followed by *Berken* treatment. Thus, the farmers of northwestern Ethiopian highland are required plow their farm lands by using Aybar or *Berken* side wings. Mechanization farming system has great impact in improving crop productivity and the livelihood of farmers but unaffordable for small-scale farmers because it requires huge initial investment cost. In the long term the governmental and non-governmental organizations should develop a policy on how to establish mechanization farms through private and cooperative system. In short term, the extension service and the respective development organizations should focus on delivering this information and creating suitable conditions for the easy access of Aybar and *Berken* technologies for the farmers to address the sustainable crop development in the area.

**Conflicts of interest**

No conflicts of interest on this work.

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