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# Restoration of grazing land to increase biomass production and improve soil properties in the Blue Nile basin: effects of infiltration trenches and *Chloris Gayana* reseeding

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**Research Paper**

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## Abstract

Degradation of crop and grazing lands is a pervasive problem that negatively impacts agricultural productivity and livelihoods of crop-livestock farmers in the Blue Nile basin of Ethiopia. Area enclosure together with a cut and carry livestock feeding system is often advocated as an approach for the regeneration of degraded grazing lands. This paper reports the results of a two-year farmer participatory study conducted to assess the effects of infiltration trenches (ITs) and *Chloris gayana* Kunth (Rhodes grass; cultivar Masaba; tetraploid; C4 grass species) reseeding on restoration of degraded grazing lands. A split plot design was used with IT as the main plot and *C. gayana* reseeding as a sub-plot on 28 private grazing plots under enclosure. The results showed that IT alone increased soil moisture content and prolonged the growing period. IT and *C. gayana* reseeding together significantly ($P \leq 0.05$) increased herbage dry matter yield and improved soil chemical properties. The highest mean herbage dry matter yield (21 Mg ha$^{-1}$ per cut) was recorded for plots treated with IT and reseeded with *C. gayana*. The higher herbage dry matter yield was attributed to increased soil moisture and the resultant prolonged growing period induced by the trenches coupled with the ability of *C. gayana* to effectively utilize the retained water. The results suggest that an integrated land management approach involving enclosure, in-situ water conservation and *C. gayana* reseeding can rapidly increase biomass productivity on degraded grazing lands while also enhancing soil quality with concomitant livelihood benefits for farmers.

## Introduction

Land degradation (LD) poses a conspicuous impediment to agricultural production and livelihoods in the semi-arid and humid lowlands of western Ethiopia (Erkossa *et al*., 2009; IFDC, 2012). Cultivation of crops including maize (*Zea mays*), sorghum (*Sorghum bicolor*), finger millets (*Eleusine coracana*) and rearing constitute the dominant means of livelihood for the majority of the population in the area (Duressa *et al*., 2014). Open grazing constitutes the main livestock feeding system for the majority (72%) of farmers. Both the crop and grazing lands are degrading at an increasing rate, due to natural and anthropogenic factors (Tireza *et al*., 2013; Assemu and Shigdaf, 2014).

Until the early 1970s, the lowlands in western Ethiopia were thinly inhabited grasslands or woodlands due to high *malaria* infestation and incidence of animal diseases including *trypanosomosis* (Teferra, 2010). However, private and government commercial farms were introduced to the areas during the second half of the 20th century, which attracted settlers from the nearby highlands and from other drought affected areas of the country (Teferra, 2010). The areas were perceived as a 'promised land' that resettlements continued unabated. The resettlement involved merely moving subsistent farmers from severely degraded highlands to the fragile lowlands with no guidance on appropriate use and management of the 'new' land. The settlers continued the same type of farming practices that led to the LD that necessitated their departure from their place of origin (Feleke, 2003).

Studies show crop productivity in the area is declining as a result of LD (Tireza *et al*., 2013; Duressa *et al*., 2014; Wudneh *et al*., 2014). A recent study in Diga district revealed maize grain yield reduction equivalent to financial loss estimated at USD 220 and 150 ha$^{-1}$, respectively due to nitrogen and phosphorus loss by water erosion (Erkossa *et al*., 2015). Shifting land use from cropping to grazing in response to severe degradation is a common practice in the area (Assemu and Shigdaf, 2014). However, uncontrolled grazing with a high stocking rate further aggravates the problem.



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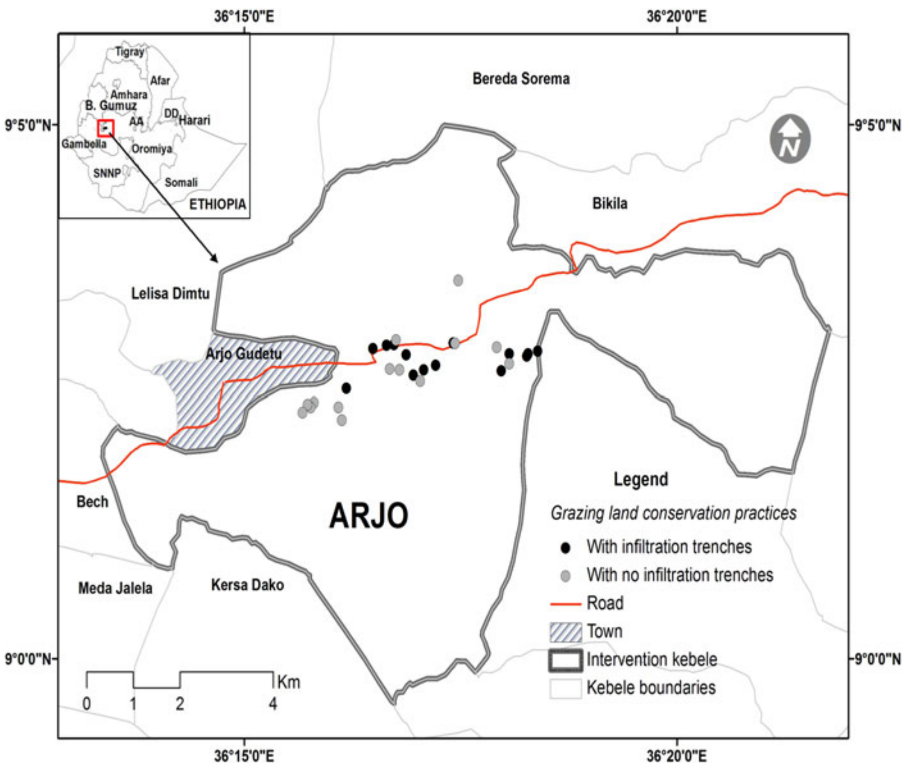


**Fig. 1.** Location of the sampling sites in Arjo peasant association of West Wollega.

Area enclosures which keep people and livestock away from the degraded lands for up to 15 years, have been widely used to allow natural regeneration of such lands in Ethiopia (Mekuria and Yami, 2013; Alemayehu, 2016). However, the long period it takes for the natural recovery process is a disincentive to the farmers. The process of restoration can be enhanced through manipulation of the soil surface and improvement of vegetation cover. Enhancing infiltration and availability of water and nutrients and introduction of suitable plant species can accelerate the process of restoration and increase productivity (Kinyua *et al*., 2009; Opiyo *et al*., 2011). An integrated application of physical and biological soil and water conservation practices can reduce surface runoff, improve soil quality, increase water availability and uptake capacity of plants (Tireza *et al*., 2013; Rumpel *et al*., 2015; Schmidt and Zemadim, 2015).

An infiltration trench (IT), which is an excavated depression perpendicular to the land slope prevents soil erosion by trapping and storing sediments and run-off and promotes infiltration (Vishwanath, 2016). A study in Malaysia showed IT reduced run-off from 86.1 to 7.8 mm $h^{-1}$ (Singh *et al*., 2006). The choice of suitable grass that is easy to establish, able to thrive in degraded areas, grow fast and able to withstand cutting and grazing is equally important. *Chloris gayana*, which is native to Africa and widely grown throughout the tropical and subtropical world as a naturalized species (Ahmed *et al*., 2014), was selected for this study, because of its ability to spread fast to cover the ground, tolerance to drought, light frost and its suitability for growing in association with many tropical legumes (Osman *et al*., 2013).

The aim of this paper is to test the hypothesis that supplementing area enclosure with a combination of soil and water conservation measures and a highly productive grass will accelerate the rejuvenation of degraded grazing lands. For this purpose, we evaluated the effects of combining ITs and reseeding of *C. gayana* on soil physical and chemical properties and herbage dry matter productivity in the lowlands of western Ethiopia.

## Materials and method

### *Description of the study area*

The study was conducted over two growing seasons (2014–2015) at Arjo Rural *Kebele* Administration (KA). Kebele is the smallest administrative unit in rural Ethiopia located in the lowlands of Diga district of East Wollega Zone, Oromia Regional State. The district lies between 09° 00′N and 09° 10′N latitude and 36° 10′E and 36° 30′E longitude and is located about 346 km to the west of Addis Ababa, near Didessa River, one of the major tributaries of the Blue Nile River (Fig. 1). The KA was purposively selected as it represents the vast severely degraded lowland areas abandoned to communal grazing. Owing to overgrazing and termite infestation, the grazing lands in the area are either invaded with unpalatable and weedy species or devoid of any vegetative cover, exposing the soil to erosion and lowering livestock feed availability (Duressa *et al*., 2014).

With a total area of 59,550 ha, the district is endowed with varied topographic features with elevations ranging from 1100–2300 m asl and corresponding climatic variations. Broadly, the agro-ecology of the district can be categorized into the mid-altitude zone (49%) and the lowland zone (51%) (Tolera *et al*., 2014). The KA lies within the lowland with a unimodal rainfall pattern ranging from 1200–2000 mm per year and temperature ranging from 18–32°C. As estimated using the FAO local climate estimator (FAO, 2005), the potential evapotranspiration in the area exceeds the precipitation for over 6 months in a year (Fig. 2). However, because of the high intensity rainfall, steep slopes and poor water infiltration into the soil, a major portion of the rain is lost as runoff.

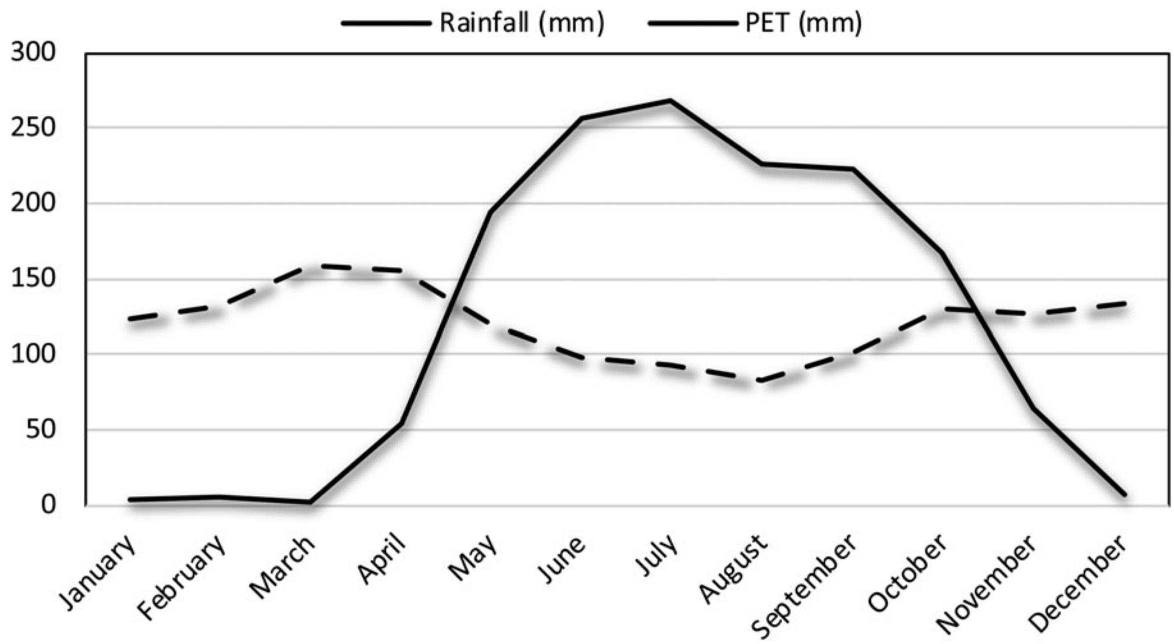


**Fig. 2.** Long term average rainfall and potential evapotranspiration as estimated using FAO NewLcoClim (FAO 2005).

Acrisols and Alisols are the dominant soils. Acrisols are strongly weathered acid soils with low base saturation at some depth making them susceptible to erosion and undesirable chemical characteristics such as acidity (IUSS Working Group WRB, 2015). Alisols also have a low base saturation at certain depths and high-activity clays. Toxic levels of Al within the rooting depth and poor natural soil fertility are some of their major constraints (FAO, 2014*a*). According to Ogunwole *et al.* (2014) the average soil organic carbon content of the site was low (0.27%). In terms of texture, the soils are generally clayey (66% clay) which limit their infiltration capacity.

### *Selection of farmers, treatments and experimental design*

The experiment involved two factors at two levels each, laid out in a split plot design with 14 replications, each farmer representing a replicate (Fig. 3). Water conservation using IT and control was considered as the main plot factor while grass management, reseeding of *C. gayana* and keeping the native pasture, was considered as the subplot factor. The participating farmers and the farm plots were selected involving the innovation platform that was composed of farmers, representatives of public sector agencies (responsible for land, agriculture and the environment), non-governmental organizations, government extension agents and researchers, established through an earlier project to guide research and development in the area (Lema *et al.*, 2015). Accordingly, 28 farmers (21 men and 7 women) were randomly selected out of those who were willing to allocate 0.125 ha of their grazing lands with an average steepness of about 12% for the field experiment in 2014. Initially, all 28 farmers enclosed their trial plots to prevent livestock interference throughout the study period. Half of them have implemented IT while the rest have not (Fig. 3). All the participating farmers have re-seeded half of their trial plots with untreated seed of *C. gayana* obtained from the district office of agriculture and left the other half for growth of native pasture dominated by *Cynodon dactylon* (L.) Pers., a local species which is a stoloniferous perennial grass mostly with rhizomes. When enclosed for an extended period, the *Cynodon dactylon* dominated native grasslands in the area tend to evolve into *Hyparrhenia rufa* (Nees) Stapf dominated grasslands (Lulseged and Alemu, 1984) although smaller annual legumes such as local clover species (mainly *Trifolium decorum* Chiov.) are common in the area mainly during the wet seasons of the year. While 16 of the participating farmers (eight from each group) have maintained the enclosure in 2015, the rest have not done it properly and as a result they were excluded from the trials in the second year.

The farmers supported by the development agents have prepared the IT before the beginning of the rain in 2014. The ITs were laid out across the slope (following contour) with 0.6 m depth and 0.6 m width and an average length of 25 m at an average spacing of 11 m. To avoid concentration of runoff to part of the field, the ITs were tied at 3 m intervals, which otherwise may result in overflowing of water and erosion. Depending on the dimension of the plots, and the slope which affects the spacing, five to six ITs were constructed in each plot. The *C. gayana* plots were oxen plowed two to three times prior to seeding in order to suppress the weeds and create fresh soil surface for the seeds. The *C. gayana* was sown in June 2014 at a seeding rate of 4 kg $ha^{-1}$, without any seed treatment. Both *C. gayana* and the native grass plots were weeded as often as necessary.

### *Soil sampling and analysis*

In June 2014, immediately before the treatments were implemented, composite surface (0–30 cm) soil samples consisting of 10 sub-samples were taken using a zigzag pattern to form a 1 kg sample from each plot. In addition, immediately after the grass was cut in November 2014 and after the 3rd cut in December 2015, composite soil samples (0–30 cm) with five subsamples were collected from the treated (diagonally at equidistant from subsequent trenches) and control plots alike and immediately transported to laboratory and stored in refrigerator until analyzed.

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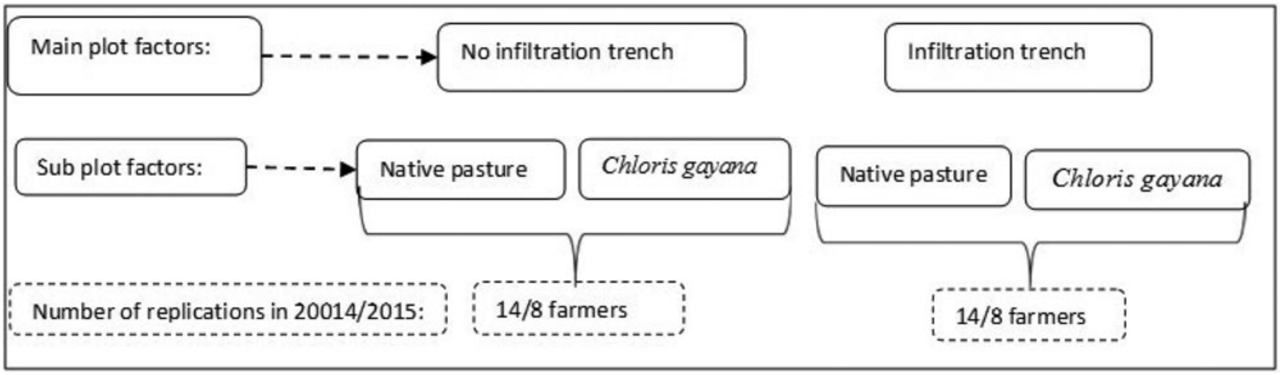


**Fig. 3.** Schematic diagram showing treatment factors and number of plots (participating farmers) in 2014 and 2015, respectively.

The samples were analyzed in a private soil laboratory (Horticoop) for selected chemical properties such as pH, organic carbon ($C_{org}$), available phosphorus, total nitrogen ($N_t$), available nitrogen (nitrate N and ammonium N) and available sulfur.

Soil pH was determined at a 1 : 2 soil : water suspension ratio using a pH meter (Mylavarapu, 2009). Soil $C_{org}$ was determined by the dichromate oxidation method (Walkley and Black, 1934). Total soil nitrogen was analyzed by the Kjeldahl digestion and distillation method (Jackson, 1958). Mineral nitrogen ($NH_4^+$ and $NO^{3-}$) was determined using a spectrophotometer (Estefan *et al.*, 2013). Available phosphorous was extracted according to the Bray II method (Bray and Kurtz, 1945) and measured using a spectrophotometer, while available sulfur was determined using a turbid metric method (Kowalenko, 1985). Also, gravimetric soil moisture at 0–30 cm and 30–60 cm depth was determined at about 15 days and 10 days intervals during the rainy season and after the cessation of the main rain, respectively.

### Agronomic data collection

Agronomic data including grass population density (number $m^{-2}$), fresh and dry herbage yields were determined using 0.25 m × 0.25 m and 1 m × 1 m quadrants, respectively. The quadrants were placed randomly at three spots per plot. During the first year, the population of the herbage grass species in the quadrants was counted in late August and the average density was recorded, and the same process was repeated at the same time the following year. When *C. gayana* was ready for harvest (50% flowering stage), three quadrant samples from random spots were mowed at the ground level using a sickle and weighed using a calibrated spring balance. The three samples were thoroughly mixed and about one kg of sample was taken to the laboratory. In the laboratory, 20 g fresh sample was measured using a top-loading sensitive balance and oven dried at 65°C for 48 h to determine the moisture content and this was used to calculate the total dry matter yield per hectare. This was done once in 2014 (October) and repeated three times in 2015 (in July, September and November).

### Data analysis

The agronomic data was analyzed using a general linear model procedure of the Statistical Analysis System (SAS, 2008). In those cases where the treatment effects were significant, the mean comparison was performed using least significance differences (LSD) at 5% level of probability. In addition, a paired *t* test was conducted to test the changes in characteristics of the soils sampled before the implementation of the treatments (2014) and a corresponding sample taken after the last harvest of the grass in 2015.

## Results

### Soil moisture content

As shown in Figures 4 and 5, the use of IT has considerably affected soil moisture content. However, the difference in moisture content between *C. gayana* and native grass was negligible. ITs increased soil moisture content as compared to the control at both depths and throughout the growing period. The moisture content of the surface layer (0–30 cm) (Fig. 4) exceeded that of the field capacity for about 8 and 7 weeks under the IT and the untreated plots, respectively. Yet, the grasses did not show any sign of poor aeration, indicating that both the native and improved grass species have tolerated the waterlogged conditions. The soil moisture content of the surface layer under the IT ranged from 130 to 191 mm where the lowest and highest values were recorded during the dry and rainy seasons, respectively (Fig. 4).

### Grass population density and dry matter yield

The effect of the IT treatment on the edible grass stand density was significant ($P \leq 0.05$) for the 2015 season but not in 2014 (Table 1). However, the interaction effect of the treatments was not significant ($P \leq 0.05$). Temporally, the herbage grass population density was higher (numerically) in 2014 than in 2015 (Table 1). In 2014, overall mean edible grass stand density was significantly higher in *C. gayana* plots (33%) compared to those under native grass stand, showing the apparent benefit of reseeding in improving stand population and the consequent improvement of above ground herbage off-take (3.3 Mg $ha^{-1}$; see yield values presented in Table 2). However, in 2015 season the population of grassy vegetation generally decreased regardless of the treatments, and the values were lower for plots under IT and *C. gayana* seeded ones.

In 2014, the use of IT did not affect herbage dry matter yield but reseeding did, the latter giving the highest yield amounting to 3.3 Mg $ha^{-1}$ (Table 2). However, in 2015 all treatments significantly ($P \leq 0.05$) affected the dry matter yield of all the three cuts. The use of IT increased dry matter yield by 28, 44 and 23% during the first, second and third cuts as compared to the corresponding yield levels obtained from plots without IT, with an overall increase of 32% during the year. The corresponding increase due to *C. gayana* reseeding was 21, 42 and 31% during

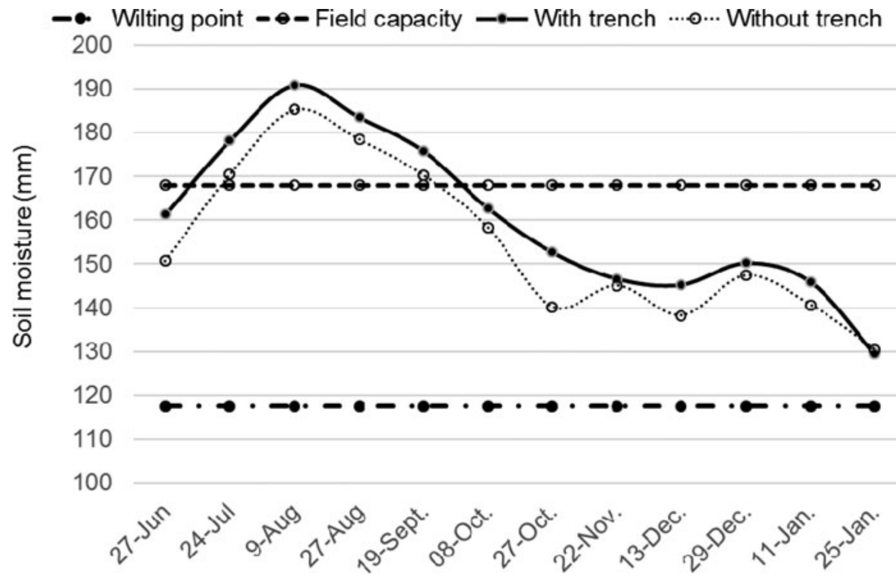


**Fig. 4.** Average soil moisture content of a degraded grazing land at 0–30 cm depth at Diga under two water conservation options in 2014.

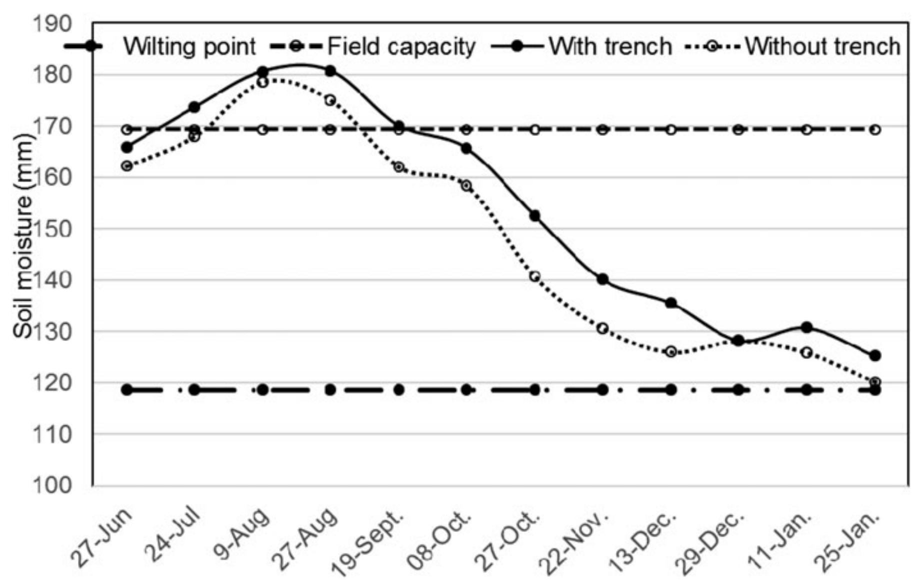


**Fig. 5.** Average soil moisture content of a degraded grazing land at 30–60 cm depth at Diga under two water conservation options in 2014.

the first, second and third cut in 2015 while the overall increase was 32% as compared to the native grass.

### *Soil chemical properties*

Neither the main nor the interaction of the treatments have significantly affected the soil chemical properties. Table 3 shows the initial soil chemical characteristics (2014) and the characteristics determined after the last harvest of the grass in 2015. The $C_{org}$, $NH_4$-N, $NO_3$ and available sulfur content of the soil significantly increased ($P \leq 0.001$) as compared to their respective initial conditions, irrespective of the treatments, possibly in response to the area closure, which is common to all the plots.

## Discussion

### *Soil moisture content*

Regardless of the sampling depth, the soil moisture content of both the treated and control plots followed the same pattern, approaching the maximum by mid-August, which shows a slight lag as compared to that of the rain (Fig. 2) which hit its maximum in July, and continually decreasing during the rest of the growing period. However, the plots treated with IT consistently held higher moisture than the control plots. Apparently, the recession limb of the soil moisture, regardless of the treatments was steeper than that of the rainfall (Figs. 4 and 5). This concurs with Niu *et al.* (2015) who observed a persistent decrease in soil moisture after hitting its seasonal peak despite continued heavier rainfall in northeast China. This may partly be related to the possible increase in evapotranspiration (Fig. 2) driven by the increase in temperature and sunshine hours towards the end of the rainy season and the consequent faster vegetative growth. The time lag between rainfall and soil moisture peak can be partly attributed to a slow infiltration rate because of the fine soil texture (66% clay), surface sealing and compaction and a possible delay in lateral movement of water from IT where the runoff is retained in the trenches from where it eventually infiltrated. The observed higher soil moisture content under IT than the control plot throughout the growing period corroborates the earlier reports where soil and water conservation structures were reported to

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**Table 1.** ITs and *C. gayana* reseeding effect on grass stand density at Diga during 2014 and 2015

| | Population per m$^2$ | |
|---|---|---|
| Practices | Year 2014 | Year 2015 |
| Soil and water conservation | | |
| ITs | 148.8 | 107.6$^b$ |
| Without ITs | 160.7 | 119.2$^a$ |
| LSD (5%) | ns | 6.0 |
| CV (%) | 12.4 | 14.3 |
| Grass management | | |
| *C. gayana* over-sown | 176.5$^a$ | 104.4$^b$ |
| Native grass | 132.9$^b$ | 122.4$^a$ |
| LSD (5%) | 22.9 | 5.6 |
| CV (%) | 26.9 | 6.4 |

ns, not significantly different; LSD, least significant difference, CV, coefficient of variation, ns, not significant.
Means in the same columns followed by different letters vary significantly at 95% confidence limit.

**Table 2.** Effects of ITs and grass types on fresh and dry matter of *C. gayana* and Native grasses at Diga

| | Dry matter yield (Mg ha$^{-1}$) | | | |
|---|---|---|---|---|
| | 2014 | 2015 | | |
| | Soil and water conservation practices | | | |
| Treatment | 1st cut | 1st cut | 2nd cut | 3rd cut |
| With ITs | 2.8 | 17.7$^a$ | 20.7$^a$ | 17.9$^a$ |
| Without ITs | 3.0 | 13.8$^b$ | 14.4$^b$ | 14.6$^b$ |
| LSD (0.05) | ns | 0.78 | 0.33 | 0.39 |
| CV (%) | 20.7 | 5.49 | 3.38 | 2.54 |
| | Grass management practices | | | |
| *C. gayana* | 3.3$^a$ | 17.2$^a$ | 20.6$^a$ | 18.4$^a$ |
| Native grass | 2.4$^b$ | 14.2$^b$ | 14.5$^b$ | 14.1$^b$ |
| LSD (0.05) | 0.32 | 0.66 | 0.51 | 0.31 |
| CV (%) | 20.7 | 4.57 | 4.10 | 4.42 |

LSD, least significant difference; CV, coefficient of variation; ns, not significant.
Means within the same column for the same factor followed by different letters are significantly different at the 95% confidence level.

reduce the loss of water, soil and valuable nutrients (Erkossa *et al.*, 2015).

### Grass population density and dry matter yield

The lower grassy vegetation count under IT treated plots can partly be explained by the possible improvement in soil moisture status which further affects the inter- and intra-species competitive ability of giant grass species such as *C. gayana* against native or other smaller species (Fugita *et al.*, 2009). Reporting specifically on species richness data, several authors showed that under protected conditions, species richness declines with a parallel improvement in the resource gradient (Goldberg and Miller, 1990; Rebele, 2000; Rajaniemi, 2003).

Only one harvest was possible in 2014 while three harvests were taken in 2015. The total herbage dry matter yield obtained in the second year was up to 20 times higher than that of the first year and this concurs with other reports which indicated that the highest dry matter yield of *C. gayana* is achieved during the second year (Cook *et al.*, 2005; FAO, 2014*b*). The increased number of cuts achieved in the second year can be attributed to the prolonged growing period as growth of the stand that was established in the preceding year was assisted by the first showers at the onset of the second season. In addition, the growing season was extended as a result of the increased infiltration of water in the case of the plots with ITs.

Although the dry matter yield recorded under the current study for *C. gayana* was on the high side, it falls within the range reported elsewhere (35–60 Mg ha$^{-1}$; InfonetBiovision – Animal husbandry and welfare-fodder production: http://www.infonet-biovision.org/AnimalHealth/Fodder-production). Studies suggest that total herbage dry matter yield of *C. gayana* depends on the frequency of cutting. Bebawi *et al.* (1992) observed the highest dry matter yield of 45.6 Mg ha$^{-1}$ per year at an 8-week cutting frequency.

In 2015, although the interaction effect between the treatments was not significant, the highest total dry matter yield was obtained with reseeding of *C. gayana* on plots with IT as opposed to the lowest that was obtained from native grass grown without ITs. The increase in dry matter yield due to reseeding treatment on plots with IT as compared to the lowest was nearly 40%. This may be related to the increased soil moisture availability for a longer duration because of the enhanced water infiltration induced by the IT, the fast growing nature of the *C. gayana* with the C4 type of photosynthesis that effectively utilized the conserved soil moisture to rapidly accumulate relatively high amounts of biomass (Rumpel *et al.*, 2015) and the impeded termite damage due to water seepage into the termite tunnels and their underground networks.

### Soil chemical properties

Irrespective of the treatments, the sample taken after the last harvest in 2015 has shown a significant increase, in soil $C_{org}$, $N_t$, ammonium nitrogen ($NH_4$-N) and available sulfur as compared to their initial conditions. The increase in $N_t$ and available S content is related to the higher $C_{org}$ (Tiejun *et al.*, 2007; Alexandra *et al.*, 2013), which is in part, attributed to the reduced soil erosion, increased below and above ground biomass production induced by the area enclosure and the grass grown. This corroborates Mussa *et al.* (2016) who reported increased organic carbon and total nitrogen due to area enclosure in grazing land. The higher S content as compared to the initial conditions, irrespective of the treatments may be related to the recent introduction of S containing compound fertilizer (NPS) which has replaced the commonly used diammonium phosphate (IFDC, 2015). It is believed that the S applied to crop land has been transported and deposited in the plots. This shows a faster restoration as compared to the findings of previous studies in Ethiopia, where 5–10 years enclosure increased soil organic matter (by 1.1%), total nitrogen (by 0.1%) and available phosphorous (by 1.8 mg kg$^{-1}$) when compared with communal grazing lands (Mekuria *et al.*, 2007). A study conducted in Baringo County in Kenya also showed a significant increase in $C_{org}$ and $N_t$ due to enclosure

**Table 3.** ITs and *C. gayana* reseeding effects on selected soil chemical properties as compared to the initial condition (2014) and after the last harvest (2015)

| | Soil and water conservation practices | | | |
|---|---|---|---|---|
| | ITs | | Without ITs | |
| Soil parameter | Initial | After last harvest in 2015 | Initial | After last harvest in 2015 |
| pH | 5.7 ± 0.7 | 5.5 ± 0.5 | 5.7 ± 0.5 | 5.6 ± 0.6 |
| $C_{org}$ (%) | 2.1 ± 0.3 | 3.8 ± 1.1*** | 2.0 ± 0.2 | 3.9 ± 1.2*** |
| $N_t$ (%) | 0.20 ± 0.0 | 0.3 ± 0.0*** | 0.2 ± 0.0 | 0.3 ± 0.0*** |
| $NH_4$-N (mg $kg^{-1}$) | 2.3 ± 1.0 | 0.7 ± 0.8*** | 2.1 ± 1.1 | 0.5 ± 0.5*** |
| $NO_3$-N (mg $kg^{-1}$) | 86.8 ± 33.4 | 77.2 ± 38.0 | 117.2 ± 103.8 | 71.3 ± 23.5* |
| Available phosphorus (mg $kg^{-1}$) | 12.7 ± 5.8 | 13.2 ± 4.3 | 13.2 ± 5.8 | 12.7 ± 3.9 |
| Available sulfur (mg $kg^{-1}$) | 2.9 ± 0.6 | 11.5 ± 3.6*** | 2.9 ± 0.6 | 14.7 ± 5.8*** |
| | Grazing land management practices | | | |
| | *C. gayana* | | Native grass | |
| | Initial | After last harvest in 2015 | Initial | After last harvest in 2015 |
| pH | 5.7 ± 0.6 | 5.5 ± 0.5 | 5.7 ± 0.6 | 5.5 ± 0.6 |
| $C_{org}$ (%) | 2.0 ± 0.3 | 3.8 ± 1.2*** | 2.0 ± 0.3 | 3.9 ± 1.0*** |
| $N_t$ (%) | 0.2 ± 0.0 | 0.3 ± 0.0*** | 0.2 ± 0.0 | 0.3 ± 0.0*** |
| $NH_4$-N (mg $kg^{-1}$) | 2.2 ± 1.1 | 0.7 ± 0.9*** | 2.2 ± 1.1 | 0.6 ± 0.5*** |
| $NO_3$-N (mg $kg^{-1}$) | 102.0 ± 78.7 | 74.4 ± 34.6 | 102.0 ± 78.7 | 74.4 ± 28.6 |
| Available phosphorus (mg $kg^{-1}$) | 12.9 ± 5.8 | 12.8 ± 3.6 | 12.9 ± 5.8 | 13.2 ± 4.6 |
| Available sulfur (mg $kg^{-1}$) | 2.9 ± 0.6 | 13.2 ± 5.7*** | 2.9 ± 0.6 | 13.0 ± 4.4*** |

(Mureithi *et al*., 2014). In the study reported here, the increase in soil $C_{org}$ content under enclosure was further boosted by the IT, which might be related to the increased above ground biomass and corresponding increase in below ground biomass growth and root enhanced activities due to increased moisture availability (Peres *et al*., 2013; Rumpel *et al*., 2015). However, $C_{org}$ content of the soil is still low (Landon, 2014). The $N_t$ and available S also followed the same trend. Therefore, preventing the area from livestock grazing allowed good ground cover that reduced surface runoff, increased above ground biomass production, and increased organic matter input.

Although some have reservation regarding the cut and curry feeding system instead of grazing, most of the farmers who participated in the field trial have appreciated the benefits due to the use of IT and *C. gayana* reseeding. Most of the participants have fed the grass to their livestock, sold the extra feed as hay to the urban dairy farmers and the *C. gayana* seeds to neighboring farmers. Some have suggested that the income per unit area was more than what they could obtain, even from crop lands with better quality. Others were overwhelmed by the effect of IT on termites, in which they suggested that the runoff in the IT has tracked the termites through their underground networks. Consequently, the area under *C. gayana* is expanding throughout the district, with or without IT.

## Conclusion

This study revealed that the use of ITs consistently increased water availability during the growing period, confirming the findings of the previous studies, and contributed to increased herbage dry matter yield per cut. Further, reinforcing this physical intervention with agronomic practices such as reseeding the land with an improved grass species (e.g. *C. gayana*) that can effectively utilize the retained water to produce above ground fodder and below ground biomass led to significantly higher herbage dry matter yield, with economic and ecological advantages. The availability of higher quantity and quality fodder will enhance livestock productivity which, in turn, will contribute to improved household nutrition and farm income.

It appears that the soil quality parameters require a longer time to be significantly affected by the treatments. However, there was a relative increase in soil organic carbon with a corresponding increase in total nitrogen and sulfur over time. The effect is apparent, especially due to the combined effect of IT and reseeding of *C. gayana*, which indicates the potential of the treatments in improving soil quality in the long run. This suggests that an integrated approach that combines area enclosure, soil and water conservation and reseeding with improved grass species can lead to increased fodder output fairly quickly to provide food and livelihood support to farmers.

The approach advocated here will be particularly relevant for the vast area of degraded rangelands in the humid and semi-arid lowlands of Western Ethiopia and, with appropriate adaptation to similar agro-ecologies in tropical Africa and other continents. However, additional studies on cutting frequencies, conservation or processing of the grasses for hay, the long-term biophysical, economic, social and environmental impacts and cost effectiveness of the interventions should be studied and packed. In addition, studies on the integration of legumes and organic fertilizer resources should be thought of to make the interventions more sustainable.

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