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Short-term improved fallows of *Tephrosia vogelii* and *Cajanus cajan* enhanced maize productivity and soil chemical properties of a degraded fallow land in Southwestern Ethiopia

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Abstract An improved fallow experiment was established in 2013 to examine the contribution of shrub legume species, *Tephrosia vogelii* and *Cajanus cajan*, in improving the productivity of a degraded tropical soil and crop yields compared with traditional fallow. The study was conducted on five farmers' fields in southwestern Ethiopia laid out in randomized complete block design with farmers as replicates. After 2 years, the amount of aboveground biomass produced was 5–8 t ha^{-1} for *Tephrosia* and 3–5 t ha^{-1} for *Cajanus*. Maize grain yield was 80% higher for *Tephrosia* and 41% for *Cajanus* compared with the traditional fallow. The legume species significantly increased soil pH, organic carbon and total nitrogen levels compared with the natural fallow but there was no significant effect for available phosphorus. The magnitude of fallow benefit from *Tephrosia* in terms of yield advantage and nitrogen availability could be related to its high biomass production capacity compared to *Cajanus*. Fallowing with *Tephrosia* has the potential for improving productivity of degraded tropical soils. Farmers' responses to the improved fallows were in general positive and their preference was *Tephrosia* fallow. Farmers can therefore use *Tephrosia* to enhance soil fertility by increasing N-levels, soil pH and organic matter of the soil. However, phosphate fertilizer is required as basal application to enhance N-fixation by legumes.

Keywords Legume fallows · Maize productivity · Soil degradation · Soil improvement

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Introduction

In Sub Saharan Africa (SSA), about 65% of the land area is classified as degraded and the occurrence of severely degraded soils is very high (Vlek et al. 2008). Soil degradation is a major challenge that threatens the sustainability of cropping systems in south-western Ethiopia. Soil degradation in cropping systems is caused by suboptimal management practices that

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cause the degradation of soil biological, chemical and physical quality, and reduce the capacity of the soil to support production and environmental functions (Zingore et al. 2015). Soil fertility is linked to soil organic matter, which in turn, depends on inputs such as biomass management and outputs such as mineralization, erosion and leaching (Roose and Barthes 2001). The densely populated areas in much of eastern Africa having favorable climate and relatively fertile soils are experiencing the most rapid soil degradation (Smaling et al. 1997; Sanchez 2002). The depletion rate of macronutrients, − 122 kg N ha^{-1}, − 13 kg P ha^{-1} and − 82 kg K ha^{-1}, was estimated to be among the highest in Africa (Stoorvogel et al. 1993; Elias 2017).

Maize (*Zea mays* L.) is one of the most important cereal crops in Ethiopia and the southwestern highlands contain the major maize growing belts. Despite the importance of maize in the region, current average yield levels (3.4 t ha^{-1}) are far too low thus contributing to the food insecurity in the country (Smale et al. 2011). Soil erosion and declining soil fertility (low pH and organic matter, nutrient mining) are among the major causes for the low crop yields (Elias 2017).

The conventional way out of soil nutrient depletion in the past was to periodically fallow the degraded land for one or more seasons to restore its fertility and the use of mineral fertilizers, green manure or combination of organic and inorganic inputs (Sanchez 1999). However, because of population pressure and shrinking of landholding over time the traditional fallows are abandoned (Josephson et al. 2014). In addition, inorganic fertilizers are expensive and many farmers in the region lack financial resources to allocate to external nutrient inputs. Use of local inputs such as farmyard manure, tree and shrub biomass that are easily available at the farm level may be a realistic option to improve soil fertility. However, in the highly degraded and nutrient depleted soils, high amount (10 t or more on dry matter basis) of farmyard manure is needed to match the crop demand for nutrients (Rutunga et al. 1999).

Until recently, farmers in the study area have tried to maintain soil fertility by applying an average rate of 100 kg DAP (Di-ammonium Phosphate: 18% N–46%–P_2O_5) and urea (46% N) per hectare thus supplying 64–20 kg N-P ha^{-1} (Elias 2016). Obviously, the supply of N and P alone over a long period depletes other macro (potassium: K, sulfur: S) and micronutrients (Zinc: Zn, Boron: B, Copper: Cu) and depresses crop yields (Elias 2017). More recently a compound fertilizer (NPS) was introduced to blend with micro-nutrients (Zn, B, Cu) but the purchasing power of the farmers is limited and supply of the new fertilizer blends is limited (Elias 2018).

Short fallow periods using selected fast growing leguminous plant species on small areas can be a very promising method to increase the productivity of smallholder farming systems (Sanchez 1999; Mafongoya et al. 2006; Munthali et al. 2014). Improved fallows with legumes have the potential to enhance soil fertility via biological nitrogen fixation and nutrient cycling and increase overall crop yields, while also providing other benefits such as improved fodder and fuel wood supply (Mafongoya et al. 2006).

Deliberate planting of fast growing legume trees/shrubs for a rapid replenishment of soil fertility, can be seen as a very promising method to increase the productivity of smallholder farming systems (Sanchez 1999; Mafongoya et al. 2006; Munthali et al. 2014). It has been widely applied in densely populated areas of eastern Africa (Kenya in particular) for rehabilitation of degraded lands in the subsistence systems (Sanchez 1999; Jama et al. 2006). Improved fallows using fast growing leguminous nitrogen-fixing shrubs and trees substantially improved crop yields compared with traditional fallows (Snapp et al. 1998). In many parts of eastern Africa, fodder trees and shrubs (*Tephrosia vogelii*, *Cajanus cajan*, *Gliricidia sepium, Calliandra calothyrsus* and *Leucaena trichandra* are incorporated in the farming systems as viable source of biomass, fodder and nutrients (Jama et al. 2006; Ikerra et al. 2001). *T. vogelii* and *C. cajan* are native to the tropical foothills of the Himalayas in India and are cultivated and naturalized throughout Southeast Asia (Gichuru 1991; Fagerström et al. 2002). Agroforestry technologies that may contribute to productivity, profitability and sustainability of farming systems such as improved fallows have not been widely disseminated in Ethiopia. Some of the challenges include lack of knowledge on agroforestry systems that are knowledge intensive and lack of seed supply system as many tree species do not seed very quickly after planting (Jama et al. 2006).

In this study, therefore, we tried to validate the applicability and beneficial effects on soil fertility and maize yields on degraded agricultural lands that have been left unproductive for years in the humid southwestern Ethiopia. The aim of this study was therefore to examine the effect of nitrogen-fixing legume shrub species on maize productivity and soil fertility in the tropical humid agro-ecosystem of southwest Ethiopia.

Materials and methods

Description of study sites

The improved fallow experiment was established at Bedele, Limu-seka and Omo-Nada districts of south western Ethiopia (Fig. 1) on five farmers' fields having altitudes ranging from 1700 to 2000 m a.s.l. Degraded fallow lands that have been left unproductive for years were selected to establish the improved fallow experiment. Farmers in the study areas were selected based on their willingness to give the land free of charge and to handle and manage the field trials as per the advice of researchers.

The study sites are generally located in the mid altitude zones of south-western Ethiopia characterized by crop/coffee-livestock mixed farming system with high potential for maize production (CASCAPE 2014). Tepid humid to sub-humid climate regimes characterizes the agroecology of the area (MoARD 2005). Landholding in the area is very small ranging from 0.1 to 2 ha with an average of 1.2 ha per household while the average family size of a household is 6.5 per household (CASCAPE 2014).The study areas are further characterized by typical smallholders and subsistence rain fed-based crop-livestock mixed agricultural activity. The predominant food crop is maize but crops such as wheat, teff, barley, maize, sorghum and common beans are also widely grown. Maize-maize continuous mono-cropping is the

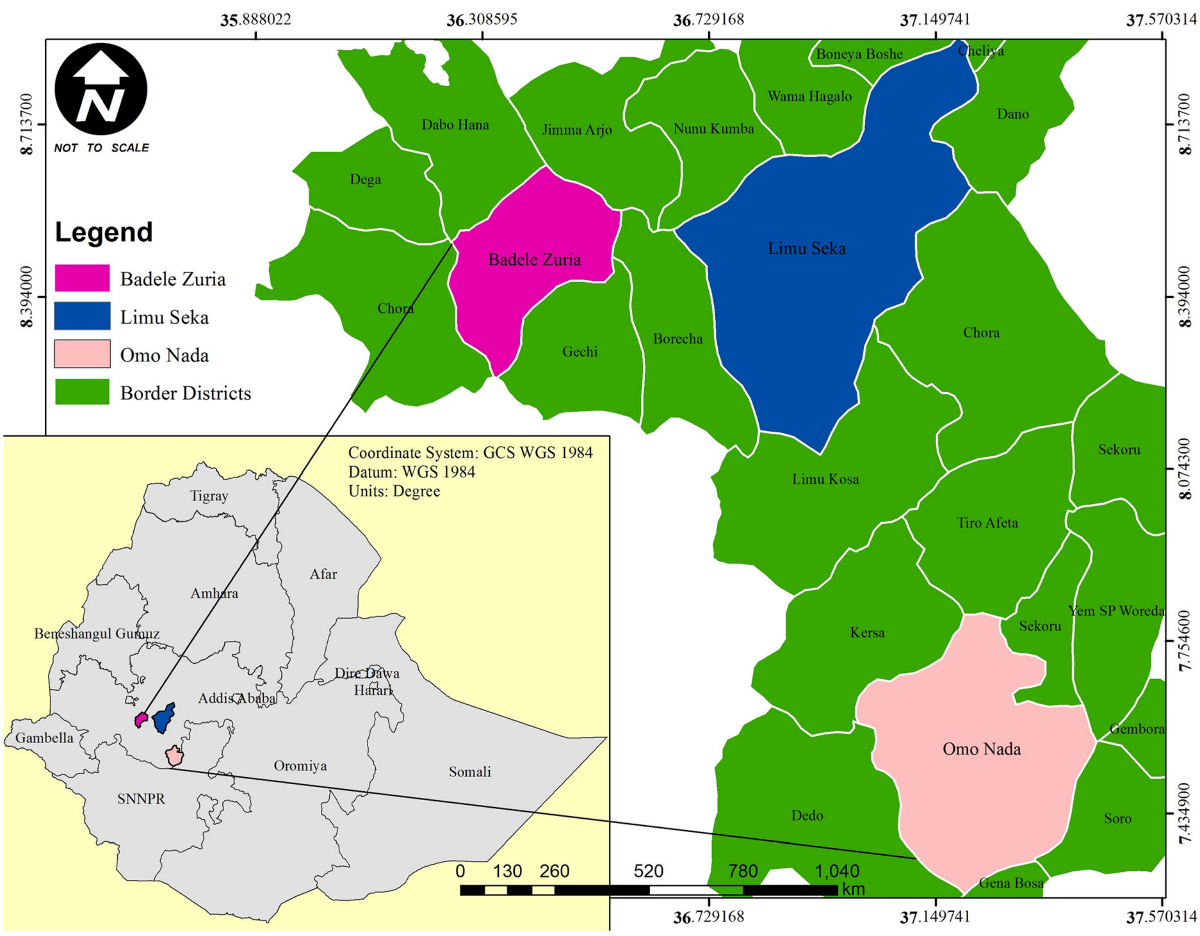

Fig. 1 Map of the study area showing the sites in southwestern Ethiopia

dominant cropping system while livestock production is also an integral part of the system. Land degradation due to soil erosion and loss of soil fertility is widespread in the study area.

Twenty years (1998–2017) weather information (data from the national meteorology agency, Jimma meteorology station) revealed that the study areas have a uni-modal rainfall pattern with mean annual rainfall of 1762 mm. The rainy season extends from April to October and maximum rain is received in the months of June, July, August and September with the mean monthly rainfall exceeding 300 mm. The mean minimum and maximum air temperatures are 26.0 and, 13.0 °C, respectively (Fig. 2) while the average annual temperature varies from 18.7 to 19.4 °C. The soils of the study sites are classified as Nitisols based on the World Reference Base for Soil Resources World Reference Base (WRB) system (WRB 2006).

Establishment of fallow species

Legume shrub-fallows, *T. vogelii* (Roxb.; Fabaceae) and *C. cajan* (L. Mill Fabaceae), and natural fallow (NF, as a control) were assessed for their effects on maize yield (variety BH-661) and selected soil physical and chemical properties of a degraded agricultural land. These species were chosen because of their high biomass yield, dense vegetative cover, deep root system and nitrogen fixation ability (Kadiata et al. 1996; Fagerström et al. 2002).

Each of the legume shrub species were planted in 10 m × 10 m plots at a spacing of 0.25 m between plants and 0.5 m between rows in May 2013. The shrub species were established by direct manual seeding. The plots were separated by 2 m wide as a buffer between treatments. The same plot of land was used as NF. The fallow period lasted for a period of 2 years (from 15 May, 2013 to 5 June, 2015) NF plots were left undisturbed until the end of the fallow period and tilled only during land preparation for maize. No fertilizer or soil amendment was provided to the fallow species or the maize crop. The experimental design used was a randomized complete block design with farms as replicates.

At the end of the fallow, the legume species were harvested, their leaves and twigs chopped, weighed and incorporated manually into the soil 3 months before sowing maize. The maize was sown on 05 June, 2015 at a spacing of 0.75 m between rows and 0.25 m between plants. No inorganic fertilizer or soil amendment was provided to the maize crop. Weeding was done manually whenever needed.

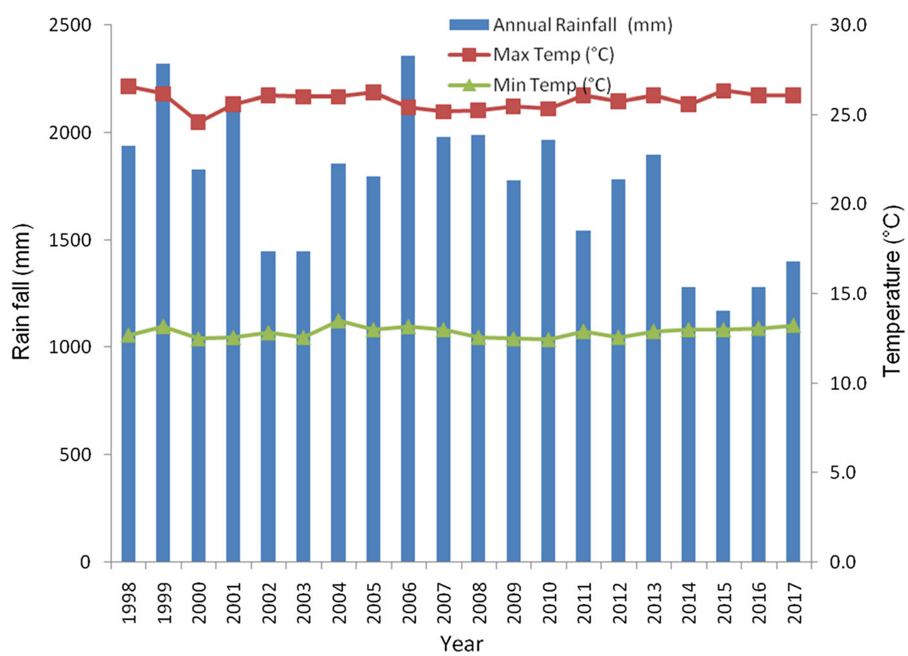

Fig. 2 Long term (1998–2017) annual rainfall (mm) and maximum and minimum temperature (°C) of Bedele District, Southwest Ethiopia (Data obtained from National Meteorological Agency, Jimma Meteorological Station)

Soil sampling and analysis

In order to characterize the pre-treatment soil physical and chemical properties, composite topsoil (0–20 cm) samples from five sampling points per farm were collected from each of the study farm fields in 2013. The samples were air-dried, crushed using mortar and pestle and passed through a 2 mm square-mesh sieve. Analyses were made at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) soil laboratory for soil texture (by the Boycouos hydrometric method (van Reeuwijk 2002), soil pH (in 1:2.5 (weight/volume) soil to water dilution ratio (van Reeuwijk 2002), organic carbon (OC) by the wet digestion method (Walkley and Black 1934), total nitrogen using the Kjeldahl method (He et al. 1990), available phosphorus by using Bray II (Bray and Kurtz 1945), cation exchange capacity (CEC) and exchangeable cations (Ca, Mg, K and Na) were analyzed by the ammonium acetate method at pH 7 (Chapman and Pratt 1965). The soil was clay loam, low in organic matter (1.2 $\pm$ 0.2%) and pH (5.2). The other pre-treatment soil chemical properties are shown in Table 3. After 2 years of fallowing and maize cropping, the changes in soil chemical properties under each of the fallow species were determined following similar analytical procedures.

Data collection and statistical analysis

Maize grain and biomass yield were recorded in each harvest season by harvesting a net area of 80.75 m^2 at grain maturity per plot. The grain and stover weights were recorded after sun drying to a constant weight. Selected soil chemical properties were analysed from each plot after maize harvest in 2015 and 2016. The data were then subjected to analysis of variance (ANOVA) following the GLM procedure of SAS version 9.0 (SAS Institute Inc 2002). Treatment means over the five farms were compared using the LSD at $p < 0.05$ level of significance.

Farmers' perceptions towards improved fallow

Farmers' views towards the species for recovery of degraded fallow lands were captured using a check list. Five experimenting farmers were selected for the interview and discussions. Farmers were asked to list criteria to characterize a good maize stand and yield. The researchers also provided the farmers during the interview with guiding question to supplement to the questions in the check list (Kuntashula and Mafongoya 2005; Mekoya et al. 2008).

Accordingly, all the listed criteria were organized into uniformity of germination, greenness of maize leaves, thickness of maize plant, cob size, total grain yield, grain quality and soil improvement. Each criterion was given a weighed percentage value which all together account for 100%. Pair wise ranking was made to arrive at the point of interest in the order of importance. In order to quantify the selected criteria, farmers were asked to rate each treatment as 1 (low), 2 (medium) and 3 (high).

Results

Biomass production of the legume species

There was significant difference ($p < 0.01$) in fresh, green biomass production between *T. vogelii* and *C. cajan* across sites while the variations in biomass production among farmers was not significant ($p > 0.05$) (Table 1). *T. vogelii* produced twofold aboveground biomass compared to that of *C. cajan*. *T. vogelii* aboveground biomass yield ranges between 5 and 8 t ha^{-1} while *C. cajan* produced between 3 and 5 t ha^{-1}. The biomass from the natural fallow was negligible.

Maize grain and biomass yield

The total grain and stover yield of maize averaged over five farms are shown in Fig. 3 and Table 2, respectively. Grain and stover yield differ significantly ($p < 0.01$) between the improved fallow legume species. The legume species also significantly ($p < 0.05$) differ from the control. Grain and stover yield of maize grown on *T. vogelii* plots was 80 and 63% higher than that obtained from the control plot and 27 and 26% higher compared to *C. cajan* plot. Similarly, 41 and 28% higher maize grain and stover yield were obtained from *C. cajan* compared to the control plot. Farm to farm variability of maize grain yield was also assessed averaged over the improved fallows in the present study. Grain yield tended to be greater for farm 1 compared with the other farms (Fig. 4).

Table 1 Total aboveground foliar biomass production (t ha^{-1}) of the legume fallows species (*Tephrosia vogelii and Cajanus cajan*) and the natural fallow (NF) after 2 years in Southwestern Ethiopia

Fallow type	Farm 1 t ha^{-1}	Farm 2	Farm 3	Farm 4	Farm 5	Average (± SE)
Tephrosia vogelii	8.1	7.1	5.2	6.2	5.9	6.5 ± 0.5
Cajanus cajan	5.1	4.2	4.0	4.2	3.4	4.2 ± 0.2
NF	*Nd	Nd	Nd	Nd	Nd	–
p value (fallow type)	0.002					
p value (farms)	0.072					

*Nd = biomass not determined as it was so negligible

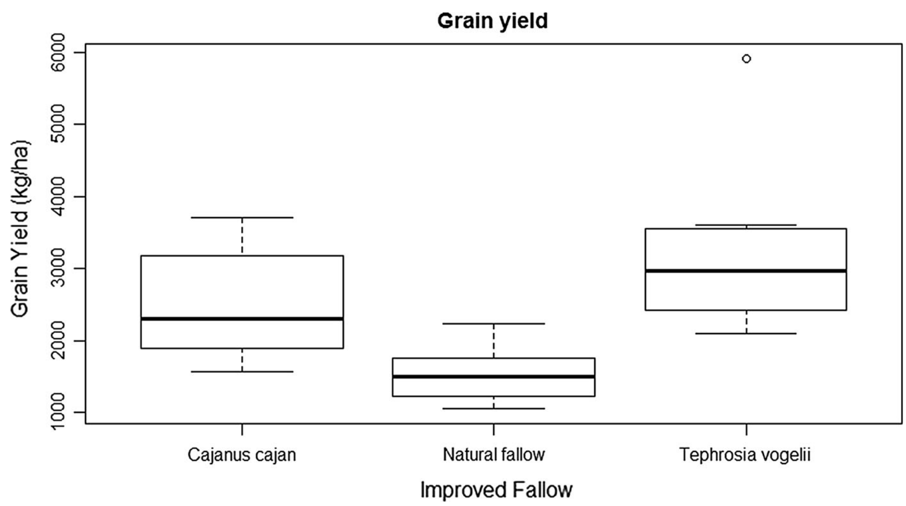

Fig. 3 Effect of improved fallows on maize grain yield (kg ha^{-1}) in a degraded fallow land in southwestern Ethiopia

Table 2 Maize stover yield following a short-term improved fallows of legumes in southwestern Ethiopia

Fallow	Stover yield (kg ha^{-1})	% increase over natural fallow
Tephrosia vogelii	6153.5 ± 560.1a	62.8
Cajanus cajan	4849.4 ± 367.0b	28.3
Natural fallow	3778.4 ± 375.2c	
CV (%)	19.4	
p value	< 0.0001	

Soil chemical properties

Table 3 shows the changes in soil chemical properties after 2 years of improved fallow period. After 2 years of fallowing and maize cropping, soil pH increased significantly regardless of the legume species when compared with the initial soil pH (5.2 ± 1.1) which was categorized as strongly acidic. In *T. vogelii* fallows, the pH was raised to 6.3 while, in *C. cajan*, it increased to 6.0 constituting about 22% and 15% increase from the initial pH status, respectively. Soil pH change due to the natural fallow was negligible.

Soil OC varied between 0.5 and 3.4% (Table 3). Organic carbon was enhanced by threefold in *T. vogelii* and by twofold in *C. cajan* plots than in the natural fallow which was not as such different from the initial SOC. The observed SOC content of the natural fallow can be rated as very low (< 1.7%) and low (2–4%) for that of *T. vogelii* and *C. cajan* plots based

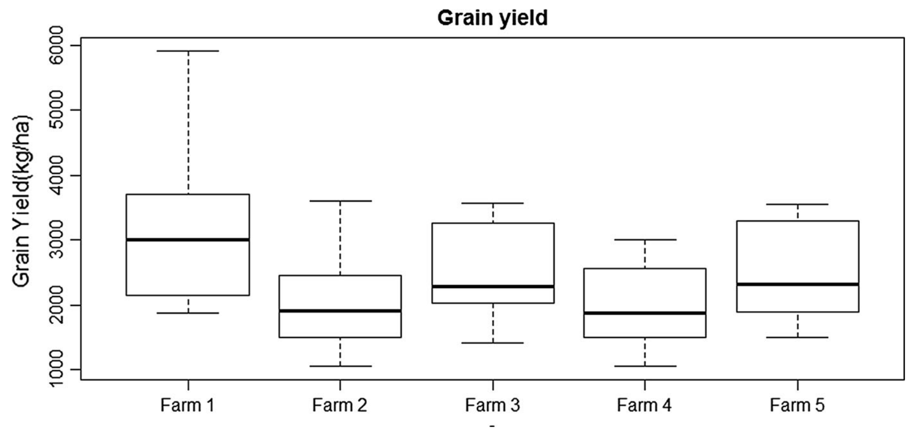

Fig. 4 Farm to farm variablity in maize grain yield (kg ha^{-1}) in a degraded fallow land in southwestern Ethiopia

Table 3 Effect of legume fallow species on selected topsoil chemical properties (mean ± SE) of degraded acid soils after 2 years of fallow period in southwestern Ethiopia

Soil properties	Pre-treatment value (2013)	*Tephrosia vogelii*		*Cajanus cajan*		Natural fallow	
		2015	2016	2015	2016	2015	2016
$pH_{(H2O)}$	5.2 ± 1.1	6.7 ± 0.3	6.4 ± 0.2	6.3 ± 0.2	5.9 ± 0.3	5.8 ± 0.2	5.4 ± 0.2
OC (%)	1.2 ± 0.2	3.4 ± 0.2	2.9 ± 0.2	2.3 ± 0.2	1.9 ± 0.3	1.5 ± 0.3	0.46 ± 0.2
TN (%)	0.1 ± 0.0	0.4 ± 0.03	0.4 ± 0.04	0.2 ± 0.02	0.3 ± 0.04	0.1 ± 0.03	0.06 ± 0.03
AP (mg/kg)	1.3 ± 0.4	2.75 ± 0.6	6.9 ± 0.57	1.7 ± 0.1	4.3 ± 0.4	0.6 ± 0.2	2.62 ± 0.8
CEC (cmol(+)/kg)	11.9 ± 1.8	36.2 ± 0.9	32.12 ± 2.12	25.8 ± 1.2	25.0 ± 0.8	21.7 ± 0.5	20.14 ± 0.4
Exch. K (cmol (+)/kg l)	0.11 ± 0.1	0.3 ± 0.03	0.6 ± 0.1	0.2 ± 0.03	0.4 ± 0.1	0.1 ± 0.0	0.19 ± 0.03
Exch. Ca (cmol (+)/kg)	9.2 ± 1.4	25.8 ± 1.2	25.1 ± 1.7	21.7 ± 0.6	19.5 ± 0.6	20.3 ± 1.0	15.70 ± 0.3
Exch. Mg(cmol (+)/kg l)	1.2 ± 0.2	3. 7 ± 0.2	3.3 ± 0.2	2.9 ± 0.1	2.6 ± 0.1	2.8 ± 0.2	2.09 ± 0.04
Exch. Na (cmol (+)/kg)	0.1 ± 0.0	0.1 ± 0.02	0.5 ± 0.05	0.1 ± 0.0	0.3 ± 0.03	0.1 ± 0.01	0.21 ± 0.1

on the ratings of soil test values interpretation by EthioSIS (2014).

Total N content also followed the trend of soil OC and varied between 0.1% and 0.4%. Total nitrogen increased with the improved fallows compared to the initial nitrogen status (0.1%) which was rated as low. Soil total N was higher in plots under *T. vogelii* (0.4%) than *C. cajan* plots (0.3%). The natural fallow had no effect in improving nitrogen status. The observed total N contents due to the improved fallows can be rated as optimum (0.15–0.3%) as per the rating of EthioSIS (2014).

The soil available P content was found to be highly variable among the fallow plots (Table 3). It varied from 0.6 after the first year of the natural fallow to 6.8 mg kg^{-1} after the second year of *Tephrosia* fallows. However, the status of P before and after maize growing were found to be deficient in plant available P based on the critical level suggested by EthioSIS (2014). Only plots with *T. vogelii* had available P of slightly above the critical value of 5 mg kg^{-1}. P under *C. cajan* and the natural fallow was below the critical value.

The low P condition could be associated with the clay loam textured soils of the study area which might be attributed to P fixation. Low external application rates of P containing fertilizers, continuous crop uptake, losses due to erosion and fixation by acidic soils in the maize-growing fields might be linked to the inadequate P levels recorded in the studied soils. Therefore, since P was not enhanced by the legume fallows the use of inorganic/organic P fertilizer sources could be needed along with the fallows to sustain maize yields.

In general, there existed variability of exchangeable bases (Table 3). All the exchangeable cations, except for exchangeable Na, increased in their concentrations compared to the values observed before the improved fallow. Exchangeable Ca was dominant and can be rated as high (10–20) in the exchangeable site followed by Mg^{2+}, K^{+} and Na^{+}. The concentrations of calcium and magnesium were threefold higher in the plots under *T. vogelii* and twofold under *C. cajan* and natural fallow compared with the initial status. Similarly, values for CEC were threefold higher in plots fallowed by *T. vogelii* and twofold for *C. cajan* and natural fallow plots.

The exchangeable K values were substantially enhanced by the improved fallows. The degraded sites had an initial exchangeable K value (0.1 ± 0.1 cmolc kg^{-1}) which was below the critical value for K (0.15 cmolc kg^{-1}) indicating that K was probably one of the limiting nutrients in the study areas. The values of K between 0.6 ± 0.11 under *T. vogelii* plots and 0.4 ± 0.09 under *C. cajan* would likely indicate that K will not be yield limiting. The results in the present study highlighted that K could become limiting at many locations but improved fallows could play an important role in alleviating potential K problems.

Farmers' preferences

The assessment of farmers' evaluation and selection criteria for the legume fallows at the end of the fallow period indicated that there is a strong interest to improved fallows. The Farmers' responses to the improved fallows were in general positive. Grain yield response, cob size and soil fertility improvement after the fallows were the major criteria reported by the farmers. From among the improved fallows, *T. vogelii* (97%) was ranked first followed by *C. cajan* (67%) (Table 4).

Discussion

Generally, leguminous plant species for reclamation of degraded fallow lands have advantages in improving the degraded land and enhancing of crop productivity if the appropriate species is duly selected. A species suitable for an improved fallow should have the capacity to yield higher levels of the limiting nutrients and accumulate more biomass than the natural fallow (Gichuru 1991). In the present study, both *T. vogelii* and *C. cajan* plots had substantial amounts of above-ground biomass at the end of the fallow period. But we observed that large portion of *C. cajan* biomass was composed of woody material whereas *Tephrosia* had substantial amounts of leafy material. Mafongoya and Jiri (2016) demonstrated that the fallow benefit of legumes was related to the biomass production.

Maize grain yield generally ranged between 2064 kg and 3866 kg ha^{-1} on degraded soils of the study area. *T. vogelii* and *C. cajan* grown in a degraded fallow land for 2 years resulted in improved stover and grain yield of maize compared with the natural fallow. A comparison of the effects of planting legume shrub species in degraded fallow lands along with natural fallow demonstrated that *T. vogelii* had a significantly positive impact on the succeeding maize productivity in terms of grain and total biomass compared with the effects of *C. cajan*, which however had significantly positive effect compared with the natural fallow. The effect of *Tephrosia* was particularly pronounced with respect to nitrogen which is a major limiting nutrient in degraded soils. *Tephrosia* has therefore showed the potential for improving soil productivity through nitrogen fixation. The improved maize grain and stover yield in *Tephrosia* plots could therefore be associated with increased nitrogen supply. The present results agree with Gichuru (1991) and Ikerra et al. (2001) who showed that maize productivity and soil fertility were enhanced through improved legume fallows.

This study demonstrated that selection of improved fallows for short-term fertility enhancement of degraded lands can improve maize yield in the succeeding years of the fallow period. However,

Table 4 Farmers' preference selection criteria for legume fallows in southwestern Ethiopia. The values in the table show the percentages of each preferred criterion that the farmers gave to select the fallow species

Preference criteria*	Fallow types		
	Tephrosia vogelii	*Cajanus cajan*	NF (control)
Total grain yield (25)	24	20	8
Soil improvement (20)	20	18	7
Cob size (17)	16	11	5
Grain quality (14)	13	10	5
Speed of germination (10)	10	7	3
Greenness of maize leaves (vegetative color) (8)	8	7	1
Thickness of maize plant (6)	6	4	1
Total score (%)	97	67	30
Rank	1st	2nd	3rd

*Numbers in parenthesis indicate the weighted percentage of the criteria

nutrient content and composition of the legume biomass to be incorporated into the soil is an important factor in determining later crop improvement and sustainability of yields (Ikerra et al. 2001; Hall et al. 2005). Planting of N-fixing shrub legumes is also shown to have implications for soil fertility improvement in the present study.

The soil chemical properties of the degraded soil in the present study were also improved substantially due to the legume fallows. Soil organic carbon increased considerably with *T. vogelii* fallows relative to *C. cajan* and the control. This could be attributed to the high biomass production potential of *T. vogelii* which upon decomposition could result in high organic carbon in the soil. The results are in agreement with findings of Munthali et al. (2014) who reported that use of *Tephrosia spp* improved soil fertility. The increase in total N in the soil under *Tephrosia* plots could be related to the total biomass yield of the species at the end of the fallow as well as the high N content of *Tephrosia* leaves and twigs (Mafongoya and Jiri 2016).

The increase in available P due to the improved fallow species was not considerable to support crop growth. Available P was generally below the critical level which suggests that P could become a problem when N and K deficiencies are overcome by the improved fallows. Hence, further studies with other P mobilizing fallow species would contribute to increasing P availability.

Farmers' decisions to adopt a given practice may require suitable bio-physical and socioeconomic environments in addition to adequate knowledge, awareness and favorable attitudes (Mekoya et al. 2008). Tesfaye (2003) studied adoption of soil and water conservation practices in Ethiopian highlands and reported that farmers' knowledge on and their attitudes to soil and water conservation practices have an essential but limited role in determining technology adoption. This may as well demonstrate in the present study that improved fallow system practices could be affected by factors other than interest and awareness.

Conclusions

The present study suggests that through incorporation of *T. vogelii* and *C. cajan* fallow biomass, resource-poor farmers can increase maize grain yield by up to 80%. The significant differences in the maize yield between the NF (control) and the legume fallows indicates that introduction of legume species into degraded lands would be a viable option to reduce the rate of soil nutrient depletion, probably due to nutrient cycling by the deep root system and N fixation capacity of the legumes. In conclusion, both *T. vogelii* and *C. cajan* improved fallows can increase soil fertility and improve maize yield in degraded lands. Compared to *C. cajan, Tephrosia* has a potential to improve soil chemical properties of degraded lands through its high foliar biomass. Improvements in plant available P by the legume fallows was not, however, considerable. Additional introduction and screening of other P mobilizing fallow species is suggested. Further research may also be necessary to determine the nutritional composition of maize grain grown after improved fallows.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

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