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# Physiographic characteristics of agricultural lands and farmers' soil fertility management practices in Wolaita zone, Southern Ethiopia

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## Abstract

**Background:** Understanding the landscape features of agricultural lands and soil management practices is pertinent to verify the potential and limitations of the soil resources; and devise relevant land management strategies. However, information is lacking in Wolaita, Southern Ethiopia. Thus, this study aimed at investigating the physiographic characteristics of agricultural lands, farmers' soil fertility management practices and their influences on soil fertility and crop productivity was conducted. The survey involved 789 randomly sampled agricultural lands. Soil sample as well as data on slope, topography, land use, crop rotation, fallowing, cropping intensity, crop residue management, fertilizer use and farmers' estimated crop yield were collected and evaluated.

**Results:** The result indicated that agriculture has been practiced under diverse slope positions (1–58%). This significantly influenced most of soil physico-chemical properties in which an increase in soil bulk density, and decrease in available phosphorous, exchangeable calcium, extractable boron, copper, iron and zinc with an increase in slope positions were recorded. Furthermore, continuous cultivation without any fallow periods and complete crop residue removal (96%) were common practices. Fertilizer use was not sufficient. The average use ( $\text{kg ha}^{-1}$ ) was 30 and 9 for diammonium phosphate (DAP) and urea, respectively, and about 89% of study area received manure below  $1.5 \text{ t ha}^{-1}$ . All these limitations made farmers to experience lower crop yield than the national average estimates.

**Conclusion:** Based on the result, it is possible to conclude that the following soil management interventions such as soil conservation, application of sufficient organic and inorganic fertilizers are recommended to restore the soil fertility and improve crop productivity.

**Keywords:** Fertilizer, Slope, Soil management, Soil properties, Yield

## Background

Ethiopia is one of the fastest growing non-oil economy countries in Africa. The country is heavily reliant on agriculture as a main source of employment, income and food security for a vast majority of its population (IFDC 2012). Agriculture generates 40% of gross domestic products (GDP) (UNDP 2014), and accounts for 85 and 90% of total employment and exports, respectively (IFDC 2012).

Agricultural activities in the country have been taking place under widely varying dynamic contexts such as physiography, agro-ecology, climate and soil conditions. The success in the sector is then strongly influenced by topographic settings, degree of human interferences and underlying biophysical features (Chamberlin and Emily 2011; Diwediga et al. 2015).

In Ethiopia, pressure on landscape stability is extremely high where there is a sharp increase in population density (Thiemann et al. 2005; Haile and Boke 2011). This has been causing intensive land utilization and forest clearing for cultivation even in areas that are not practical

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for agriculture (e.g., steep hill slopes or marginal land) (Simane 2003; Thiemann et al. 2005). Particularly, farmers on densely populated parts of the country produce everything from the soil and very little remains to re-invest in soil fertility replenishment for the following year (IFPRI 2010). All these farming practices brought disturbances to the ecosystems particularly on soils by disrupting the stable natural biogeochemical processes of nutrient cycle, causing rapid nutrient depletion (Yengoh 2012) and attributing to changes on the landscape characteristics (Alemu 2015; Gebreselassie et al. 2015).

It is reported that variation in the physiography of agricultural lands has an enormous influence on soil properties and plant production (Damene 2012; Dessalegn et al. 2014). This is supported by a research in Wollo, Ethiopia that revealed an increasing trend of soil pH and exchangeable bases with a decrease in slope (Damene 2012). Another study in northwestern Ethiopia by Gebreselassie et al. (2015) also indicated that mean values of total nitrogen (TN), organic matter (OM) and cation exchange capacity (CEC) were higher on lower than upper slope land position. Furthermore, significant variations in soil organic carbon (SOC), total N, exchangeable cations, CEC and percentage base saturation (PBS) were reported on varied altitudinal ranges of Bale Mountains, Ethiopia (Yimer and Abdulkadir 2011).

Other studies also showed that the involvement of farmers in different soil management practices and land use types put impact on soil fertility and productivity (Karlton et al. 2013a; Moges et al. 2013; Yitbarek et al. 2013; Gebreselassie et al. 2015). For instance, the report from wheat growing highlands of southeast Ethiopia indicated very low return of crop residue, lack of crop rotation, low rate of mineral fertilizer application and absence of long term fallowing (Belachew and Abera 2010). The finding by Moges et al. (2013) also indicated lower SOC content in cultivated lands compared to grazing or protected forest areas which was attributed by continuous cultivation, absence of fallowing and erosion. Limited maintenance of soil chemical and physical health is very likely to result poor aggregate stability, decline of soil OM, nutrient related plant stresses and stagnation of crop yields (Gajic et al. 2006; Damene 2012; Yengoh 2012) and exacerbates soil degradation. Conversely, studies by Yimer and Abdulkadir (2011), Tematio et al. (2011), Oriola and Bamidele (2012) documented an improvement in soil aggregates, SOC, TN, exchangeable cations and CEC due to fallowing. Besides, Gebreselassie et al. (2015) reported the positive impacts of soil bund construction and manure application for restoring soil fertility and productivity. Generally, it is noticed that the soil quality is associated with biophysical setting and anthropogenic factors. This calls the need for having adequate

information to intervene and solve soil degradation problem.

Wolaita, located in Southern Nations, Nationalities and Peoples' Regional State (SNNPRS) of Ethiopia is densely populated zone (385 km<sup>-2</sup>) (CSA 2010) where the livelihood of farmers relies heavily on agriculture, even though, farm lands are small in size. About 57% of households in the zone possess less than 0.25 ha of land (WZFEDD 2012). This situation is forcing most farmers to practice an intensive farming including hilly slopes and marginal lands (Pound and Jonfa 2005). Hence, before going to site specific soil management intervention, information concerning landscape features of agricultural fields and farmers' soil management practices is very pertinent. This is practically helpful to verify the limitations and devise land management strategies. Nevertheless, very little information is currently available in the study area. The objective of this research was, therefore, to study the physiographic characteristics of agricultural lands, farmers' soil fertility management practices and their influences on soil fertility and crop productivity in Southern Ethiopia.

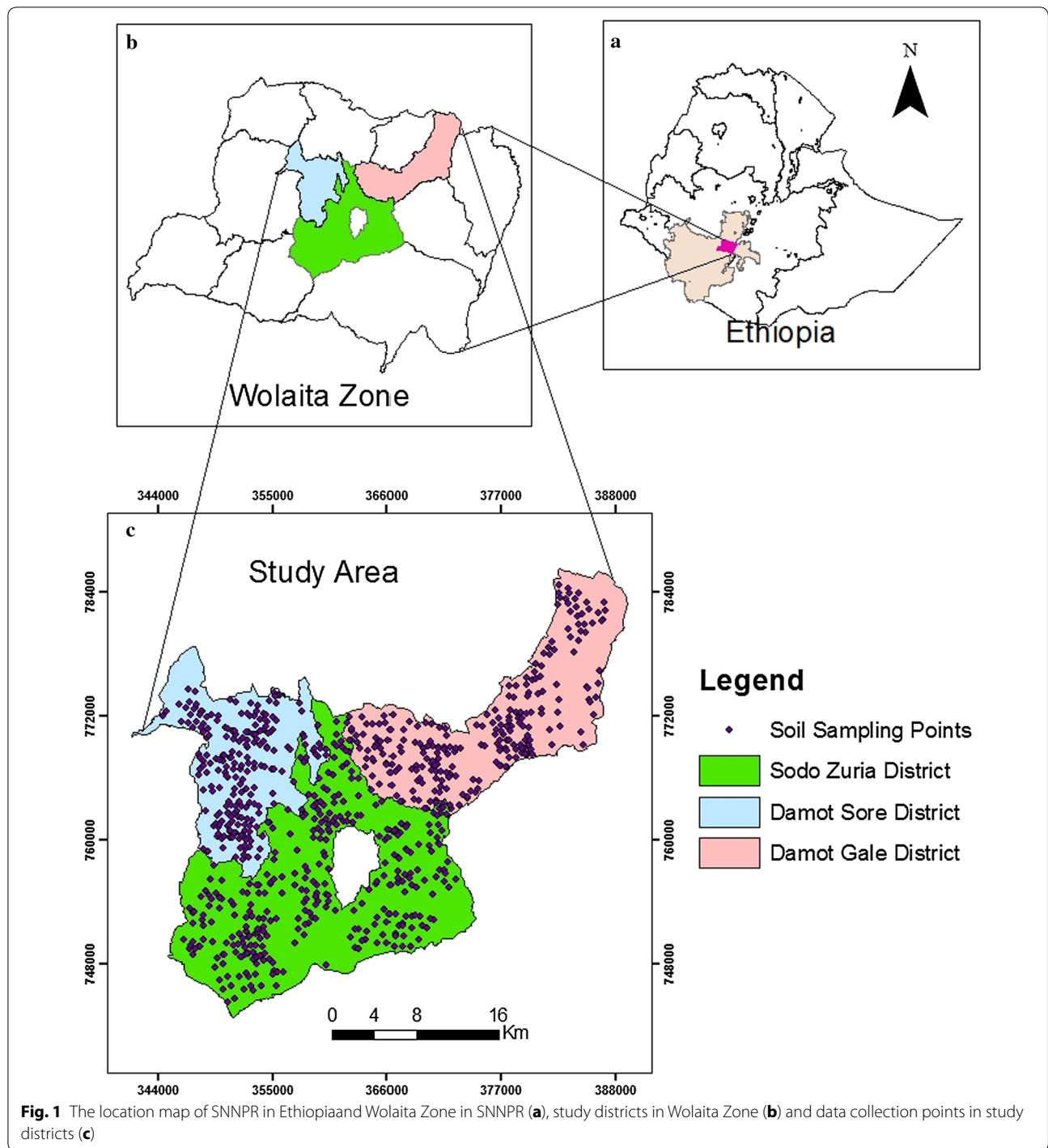
## Methods

### Study area

The study was conducted in Damot Gale, Damot Sore and Sodo Zuria districts, Wolaita zone, SNNPRS, Ethiopia (Fig. 1) during 2013. The sites are situated between 037°35'30"–037°58'36"E and 06°57'20"–07°04'31"N with altitudinal range of 1473–2873 m above sea level (masl) (Fig. 2). A total of 82 *kebeles* (peasant associations) (i.e. 31 from Damot Gale, 18 from Damot Sore and 33 from SodoZuria district) covering a total of 84,000 hectare (ha) were covered by the study. The 10 years (2003–2013) mean annual precipitation of the study area was 1355 mm. The area has a bimodal rainfall pattern (Fig. 3), where about 31 and 39% fall during autumn (March–May) and summer (June–August) seasons, respectively. The remaining 30% falls between September and February. The mean monthly temperature for the decade (2003–2013) ranges from 17.7 to 21.7 °C with an average of 19.7 °C (NMA 2013).

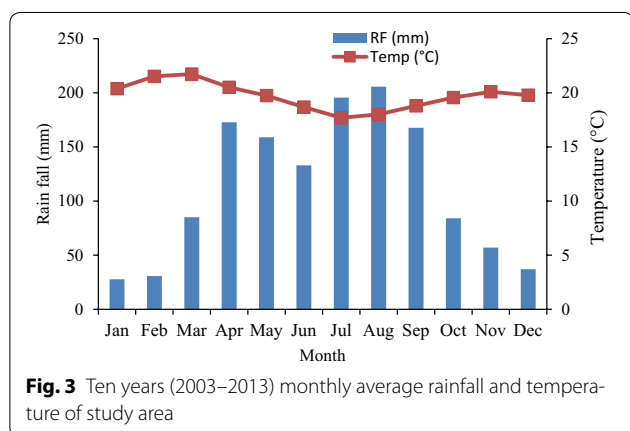
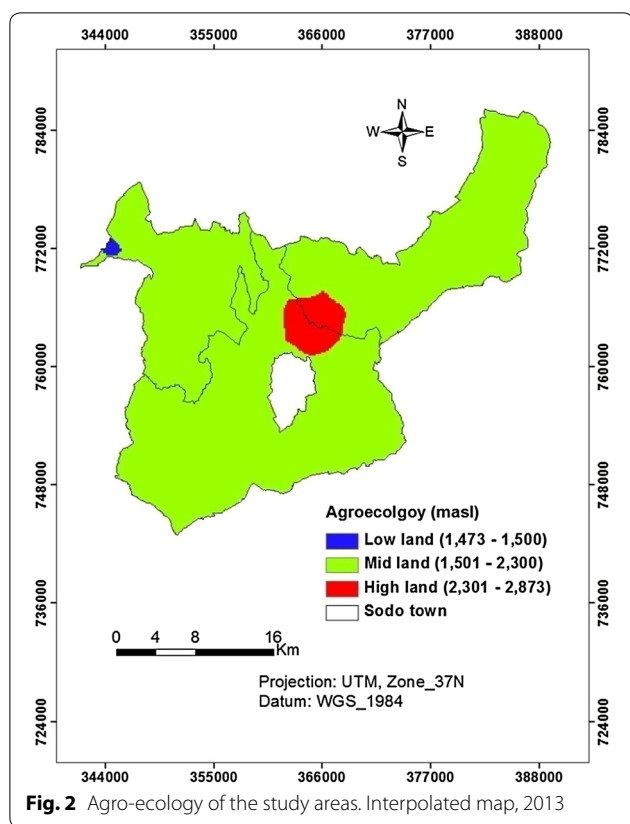
As per agro-ecological zone classification of Ethiopia, the area is predominantly characterized by mid highland (1500–2300 masl) agro-ecology. Besides, small portion of highlands (2300–2873 masl) in Damot Gale and Sodo Zuria districts; and very small pocket areas of the lowland areas (1473–1500 masl) in Damot Sore districts were identified (Fig. 2). Spatially out of the total study area, about 0.003, 96 and 3.7% are found under lowland, mid highland and highland agro-ecologies, respectively.

Eutric Nitisols associated with Humic Nitisols, which are dark reddish brown with deep profiles, are the most



prevalent soil types in Wolaita zone (Tesfaye 2003). Agriculture in the study area is predominantly small-scale mixed subsistence farming. The farming system is mainly based on continuous cultivation without any fallow periods. The major crops grown in the study area include tef (*Eragrostis tef*), maize (*Zea mays*), bread wheat (*Triticum*

*aestivum*), haricot bean (*Phaseolus vulgaris*), field pea (*Pisum sativum*), potato (*Solanum tuberosum*), sweet potato (*Ipomea batatas*), taro (*Colocasia esculenta*), enset (*Enset eventricosum*) and coffee (*Coffea arabica*). Besides, the vegetation is dominated by eucalyptus trees (*Camauldulensis* spp.). In addition, remnants of indigenous tree



species such as croton (*Croton macrostachyus*), cordia (*Cordia africana*), *Erythrina* spp., podocarpus (*Podocarpus falcatus*) and Juniperus (*Juniperus procera*) are also present.

**Data collection**

Geographical information system (GIS) was employed to randomly assign a total of 789 data collection points representing all land uses. The samples were randomly

distributed at an average distance of 512 m. During the survey work, the pre-defined sample locations were visited in the field and recorded using the geographical positioning system receiver (model Garmin GPSMAP 60Cx). To describe each data collection point, a short structured questionnaire was used to record the following variables: topography, dominant land use types, crop type grown, crop rotation practices, fallowing, cropping intensity, crop residue management, fertilizer use (types and rates), and farmers’ estimated crop yield level. Data collection was undertaken from April to August of 2013.

Slope was measured using a clinometer. The existing land use and crop types were recorded. Farmers owning the fields were interviewed for fertilizer use and list of the preceding crops grown during the previous cropping season. The types and rates of fertilizers used were also recorded for the existing crops which were sown during sampling period. Additionally, cultivated area and fertilizer (types and amount) distributed per year of in the study districts were collected from secondary sources.

**Soil sampling and analysis**

Disturbed and undisturbed soil samples were taken from the field using augur and core sampler, respectively. In order to form 1 kg composite sample, 10–15 sub-samples from each field were collected. The sampling depth was 20 cm for tef, haricot bean, wheat and maize while it extends up to 50 cm for perennial crops such as *enset* and coffee growing fields. From the composite sample, 1 kg of soil was taken with a labeled soil sample bag.

After soil processing (drying, grinding and sieving), soil physicochemical properties like texture, bulk density (BD), pH, soil organic carbon (OC), macro and micronutrient contents and cation exchange capacity (CEC) were analyzed. Particle size distribution (PSD) was analyzed by laser diffraction method using laser scattering particle size distribution analyzer (Horiba- Partica LA-950V2) (Stefano et al. 2010). Soil BD was determined using the core method (Anderson and Ingram 1993). Soil pH (1:2 soil: water suspension) was measured with a glass electrode (model CP-501) (Mylavarapu 2009). Available P, available S, exchangeable basic cations (Ca, Mg and K) and extractable micronutrients (Fe, Mn, Zn, Cu and B) were determined using Mehlich-III multi-nutrient extraction method (Mehlich 1984). The concentration of elements in the supernatant was measured using inductively coupled plasma (ICP) spectrometer. Mid-infrared diffused reflectance spectral analysis was also used to determine the amount of soil OC, total N and CEC. The available soil Mn content was determined using manganese activity index (MnAI) (Karlun et al. 2013b). Particle size distribution, pH, OC, TN and CEC were analyzed at the National Soil Testing Center (NSTC), Addis Ababa,

Ethiopia while Ca, Mg, K, B, Cu, Fe, Mn and Zn were analyzed in Altic B.V., Dronten, The Netherlands.

**Data analysis**

Descriptive statistics was employed for data analysis. Frequency, mean ± standard deviation, range and percentage were computed for different variables. In addition, Pearson and Spearman correlations, Chi square, t and F tests were also computed. Data analysis was carried out using Microsoft excel and statistical package for social sciences (SPSS) software version 20. Additionally, maps showing spatial variability and area coverage of slopes and fertilizer application were produced using GIS software (Arc Map version 10) with spatial analyst function.

**Results and discussion**

**Farming topography and their effects on soil properties**

*Farming topography*

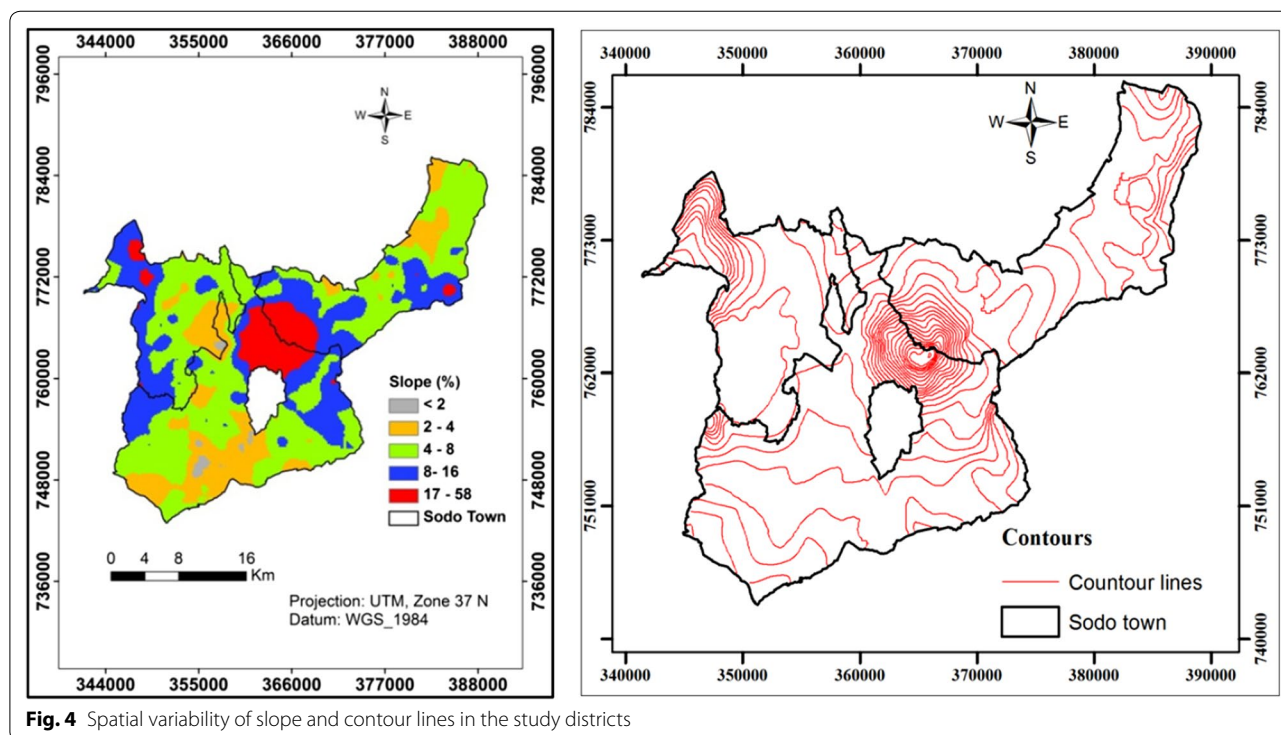
The study area is characterized by marked topographic variations in which agriculture is practiced under flat to very hilly sloping topographic lands. The result showed that, out of the sampled agricultural fields (n = 789), about 20% were found to lie on flat lands (slope < 4%), 49% on gentle slope (4–8%), 20% on strong slope (8–16%), and 11% on hilly topographic lands (slope > 16%). Considering districts, about 36% of sampled agricultural fields in Damot Gale, 31% in Damot Sore and 30% in Sodo Zuria districts were situated on strong to hilly sloping topographic lands. Spatially, from

the total agricultural lands, about 17.6% is lying on flat topographic lands, whereas 48, 26.1 and 8.3% is occupied by gentle slope land, strongly sloping land and hilly topographic land forms, respectively (Fig. 4).

During field survey, farmers in Damot Gale, Damot Sore and Sodo Zuria districts were observed cultivating lands having a slope of 58, 31 and 58%, respectively. In general, about 34% of agricultural activities in the study area were practiced on strong to hilly topographic lands which are marginally suitable and not suitable for cultivation. Thus, this practice is a major concern that needs a special attention. Land encroachment to extremely steep areas in study area could be linked to rapidly growing population (CSA 2010) and shortage of land (Pound and Jonfa 2005; WZFEDD 2012; Karlton et al. 2013a; Abate 2014). In relation to this, the study by Gebregziabher et al. (2013) and Gedamu (2008) in northern Ethiopia also documented steep slope cultivation due to scarcity of cultivable land.

**Effect of farming topography on selected soil physical properties**

Soil physico-chemical properties showed considerable variation along farming topographies (Table 1). Soil particle size distribution was significantly (p < 0.001) influenced by the landscape position. The trend of distribution for sand was in the following order: lower slope (<4%) >middle slope (4–8%) >upper slope (>16%). Meanwhile, the trend on silt was not steady; however,



**Table 1 Mean soil properties, fertilizer use and crop yield as influenced by topographic position in three districts of Wolaita Zone, Southern Ethiopia**

Parameter	Physiographic category/slope (%)					F	Sig
	<2	2–4	4–8	8–16	>16		
	F	AF	GS	SS	HS		
Physical property							
Sand (%)	15.98	15.77	14.07	11.69	11.73	13.84	0.000
Silt (%)	41.93	44.01	31.89	28.10	31.02	15.07	0.000
Clay (%)	42.09	40.22	54.04	60.21	57.25	16.17	0.000
Textural class							
	Silty Clay	Silty Clay	Clay	Clay	Clay		
BD (gm cm <sup>-3</sup> )	1.12	1.05	1.17	1.20	1.24	13.1	0.000
Chemical property							
pH <sub>H2O</sub>	6.15	6.07	6.11	6.08	6.08	0.51	0.731
OC (%)	2.06	2.0	2.04	1.99	1.8	1.33	0.256
TN (%)	0.13	0.13	0.14	0.15	0.15	1.02	0.400
P (mg kg <sup>-1</sup> )	15.25	13.32	9.92	11.03	4.74	2.49	0.042
S (mg kg <sup>-1</sup> )	10.54	11.88	10.73	11.15	10.98	1.42	0.225
Ca (Cmol c kg <sup>-1</sup> )	8.84	8.34	7.87	7.99	7.3	2.28	0.060
K (Cmol c kg <sup>-1</sup> )	1.33	1.15	1.33	1.3	1.03	3.17	0.013
Mg (Cmol c kg <sup>-1</sup> )	1.85	1.77	1.92	2.18	2.18	3.43	0.009
TEB (Cmol c kg <sup>-1</sup> )	12.83	12.11	11.89	12.19	11.34	1.16	0.328
B (mg kg <sup>-1</sup> )	0.61	0.52	0.56	0.53	0.46	2.01	0.091
Cu (mg kg <sup>-1</sup> )	0.65	0.52	0.58	0.54	0.31	12.17	0.000
Fe (mg kg <sup>-1</sup> )	142.3	182.9	122.3	118.9	120.2	22.37	0.000
Mn (mg kg <sup>-1</sup> )	133.6	109.9	153.9	150.4	121.4	13.90	0.000
MnAl (mg kg <sup>-1</sup> )	509.3	421.8	586.1	573.2	464.6	14.42	0.000
Zn (mg kg <sup>-1</sup> )	10.7	9.4	9.1	7.8	6.4	5.48	0.000
Fertilizer use							
DAP (Kg/ha)	35	32	35	33	31	0.31	0.90
Urea (Kg/ha)	9.8	2.9	7.6	5.2	6.4	1.31	0.27
FYM (t/ha)	1.0	1.5	0.9	0.6	0.4	2.31	0.06
Crop yield							
Maize (W/O) (t/ha)	0.6	0.6	0.6	0.5	0.2	1.84	0.12
Maize (with) (t/ha)	2.3	2.2	2.1	2.0	1.3	1.83	0.12
Haricot bean (W/O) (t/ha)	0.4	0.4	0.4	0.3	0.3	2.01	0.09
Haricot bean (With) (t/ha)	1.2	1.2	1.2	1.0	1.1	2.90	0.02
Sweet potato (W/O) (t/ha)	3.9	5.0	4.7	5.0	3.0	0.28	0.89
Sweet potato (With) (t/ha)	9.7	10.3	11.1	12.7	6.0	1.12	0.36

W/O without fertilizer application; With with fertilizer application; F flat; AF almost flat; GS gentle slope; SS strong slope; HS hilly slope

the amount seems higher on lower slope compared to upper slope position. According to Lawal et al. (2014), the movement of sand and silt particles down the slope is accelerated by run-off water, wind and gravity. Similar to silt, the trend on clay was not stable; however, the proportion was higher on upper slope than lower slope position.

Soil textural class in the study area varied along topographic positions (Table 1). The soil texture of lower slope position is silty clay whereas the texture is clay for other

slope categories (Table 1). The prevalence of clay texture in upper slopes might be linked to the recent cultivation history. Conversely, the deposition of soil particles at lower slope positions may attribute to silty clay textural class. As stated by Taichi (2012) and Lawal et al. (2014), topography has an influence on pattern of soil distribution over landscape. In view of that, surface erosion and depositional processes that are influenced by topography might have been responsible for the differences observed in textural classes (Lawal et al. 2014).

Data regarding soil bulk density (BD) indicated that it was significantly influenced by landscape position. The mean BD value ranges from 1.05 to 1.24 g cm<sup>3</sup>. Except 2–4% slope category, the BD value showed an increasing trend with the slope (Table 1). The probable reason could be the difference in soil texture and organic matter content. The result is in line with the work of previous researchers (Lawal et al. 2014 and Gebreselassie et al. 2015) who reported an increased BD value with the slope.

#### Effect of farming positions on soil chemical properties

As indicated in Table 1, soil pH, organic carbon (OC), total nitrogen, available S, exchangeable Ca, extractable B and total exchangeable bases (TEB) did not show significant differences among landscape positions. However, the variation was significant for available P, exchangeable (K and Mg) and extractable soil micronutrients (Cu, Fe Mn, and Zn).

Available P across farming positions varied from 4.7 to 15.3 mg kg<sup>-1</sup>, whereas exchangeable K and Mg (Cmol (+) kg<sup>-1</sup>) ranged between 1.03 and 1.33 and 1.77–2.18, respectively. The content of Cu, Fe Mn, and Zn (mg kg<sup>-1</sup>) varied from 0.3–0.65, 119–183, 110–154 and 6.4–10.7, respectively (Table 1). In most of the cases the concentration trend along slope categories was not steady. However, it was noticeable that hilly lands (>16%) showed the least amount of available P, K, Cu, Fe and Zn compared to lower landscape position (<4%). This may be linked with loss from hilly slope through runoff water and accumulation at the bottom slope position. Steep slopes are ecologically fragile areas and farming on these areas usually resulted in soil and nutrient losses (FAO 1998; Damene 2012; Erkossa et al. 2015). In relation to this, the work of other researchers also confirmed the decrease in nutrient contents in upper than lower slope position which they presumed to be due to soil erosion (Khan et al. 2007; Damene 2012; Khan et al. 2013; Gebreselassie et al. 2015).

Besides this, fertilizer application by smallholder farmers showed a non-significant difference with respect to topographic position, yet the decrease in manure application from flat to hilly position was observed (Table 1). Similar to fertilizer application, variation in landscape position did not significantly influence most of crop yields (Table 1). However, hilly lands (>16%) revealed lower yield than other slope position. This is supported with significant ( $p < 0.05$ ) and negative correlation in the absence and presence of fertilizer application in their order (e.g., maize ( $r = -0.17$  and  $-0.29$ ), haricot bean ( $r = -0.13$  and  $-0.15$ ) (Additional file 3). Irrespective of landscape positions, the soils of the study area were qualified as very low (<2%) to low (2–4%) in OC and low TN (<0.2%) based on the rating of Landon (2014). As per the ratings used in Ethiopia (EthioSIS 2014), samples

were very low in available P (<15 mg kg<sup>-1</sup>), low in S (10–20 mg kg<sup>-1</sup>), low in B (0.5–0.8 mg kg<sup>-1</sup>), and very low (<0.5 mg kg<sup>-1</sup>) to low (0.5–0.9 mg kg<sup>-1</sup>) in Cu. The limitation in soil management and associated nutrient losses may attribute to the lower and insignificant yield differences (Gajic et al. 2006; Damene 2012; Yengoh 2012).

#### Land use and soil fertility management practices

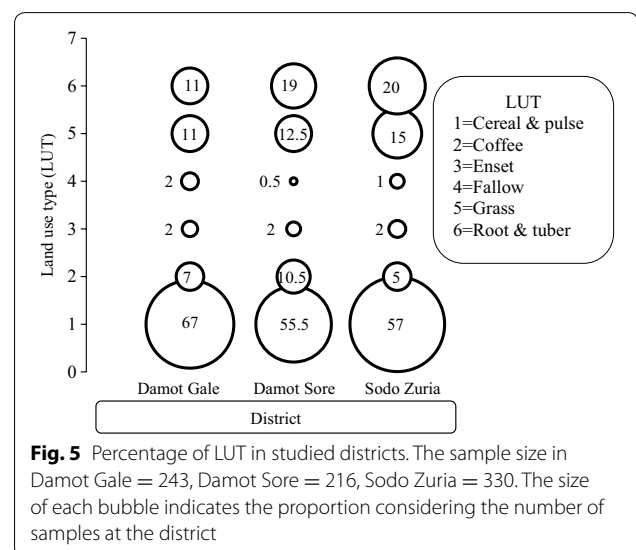
##### Land use types

The results on land use types (LUT) indicated that rain fed agricultural activities are prevalent in the study area (Fig. 5). About 60% of the sampled areas were used for cereal and pulse crops production followed by root and tuber crops, grass land, coffee plantation, enset plantation and fallow lands in that order. Furthermore, a culture of keeping small patchy grass fields for livestock “*Maatta Gadya*” (i.e., grassland) has been observed. Grass lands from sampled agricultural fields had considerable share (13%) indicating that livestock as an integral component of livelihoods. This is supported by the report of previous researchers in Wolaita area (Elias and Scoones 1999 and Alemayehu et al. 2001). In the study area, different LUTs were observed at different topographic positions. Cereals, pulses, coffee, enset and root crop land uses were dominant under gentle slope topographic positions. However, the grass lands were reasonably distributed from flat to hilly topographic features.

##### Soil fertility management practices

##### Fallowing

Fallowing is among soil management practices considered to replenish soil fertility. However, it was rarely practiced in the study area. In this finding, about 2.5% (Damot Gale), 0.5% (Damot Sore), 1.2% (Sodo Zuria) and



overall 1.4% of sampled agricultural fields were fallowed (Additional file 2). Meanwhile, fallowing significantly varied along topographical categories ( $\chi^2 = 32.6, p < 0.001$ ) (Table 2). Among the few farmers who practiced fallowing, larger proportion (64%) of fallowed lands were located on hilly topographic positions. This indicates the extent of soil fertility problems on hilly areas which is associated with intense runoff (Buyinza and Nabalegwa 2011). This compels farmers to employ fallowing on steep slopes.

As noticed from the discussion, farmers in the study area practiced fallowing not deliberately for restoring soil fertility; rather it was due to very low return from it (i.e., when the cultivable land has reached the point of no return in crop yield). The small size of farmland in the study area (WZFEDD 2012) is one of the main motivations for limited fallowing. Reports in different parts of Ethiopia also documented the limited practice of fallowing due to small landholdings (Pound and Jonfa 2005; Abera and Belachew 2011; Tekeste et al. 2015). Continuous cultivation without fallowing the land could affect soil quality and productivity (Yimer and Abdulkadir 2011; Tematio et al. 2011; Oriola and Bamidele 2012).

**Table 2 Farmers’ soil management practices at different topographical categories on sampled agricultural fields of three districts, in Southern region, Ethiopia. Survey result, 2013**

Soil fertility management practices	Total users $\chi^2$	Topographical category $\chi^2$
Fallowing (N = 789)		
Yes	3.5 <sup>NS</sup>	32.6 <sup>***</sup>
No		
Crop intensity (N = 674)	20.5 <sup>***</sup>	14.7 <sup>NS</sup>
One		
Two		
Rotation (N = 674)		
No	5.3 <sup>NS</sup>	4.7 <sup>NS</sup>
Yes		
Residue management (N = 789)		
Clear	2.9 <sup>NS</sup>	5.4 <sup>NS</sup>
Retain		
Inorganic fertilizer (N = 674)		
Yes	0.13 <sup>NS</sup>	1.3 <sup>NS</sup>
No		
Organic fertilizer (N = 674)		
Yes	11.4 <sup>**</sup>	10.0 <sup>NS</sup>
No		

“N” indicates the number of sampled lands used to compute the proportions

NS not significant

\*\* 0.05, \*\*\* 0.01

**Continuous cropping/cropping intensity/**

Continuous cropping refers to growing a number of crops in the same field during one agriculture year. The practice revealed significant differences ( $\chi^2 = 20.5, p < 0.01$ ) among sampled fields; however, it was not influenced by topographical categories (Table 2). From cultivated fields in each district, 62% (Damot Gale), 51% (Damot Sore) and 61% (Sodo Zuria) had grown two successive crops in a year in the same field (Additional file 2). The field observation by Amede et al. (2001) also indicated that farmers in Gununo, southern Ethiopia were growing up to six different crops in mixtures reasoning their small farm size. This would lead to over exploitation of the land through nutrient mining and nutrient depletion (Hartemink 2006). Despite having small land size, farmers in the study area opined that not only soil related problems (i.e., poor soil fertility and water logging particularly on flat topographic position) but also socio-economic factors (e.g., lack of oxen and/or capital to purchase input) were reasons hindering continuous cropping.

The status of the soil is the primary factor to support high crop intensity in which the soil need to be fertile, well drained and responsive to applied fertilizer (URL1 2014). Exposure of the field to intensive cropping through double, relay or inter-cropping implies that the demand on soil for plant nutrients is becoming more in the growing year. In this regard, soil fertility of the sampled fields is assumed not to have been managed properly using adequate fertilizer application, fallowing and residue maintenance. Therefore, cropping intensity might lead to heavy nutrient removal unless complemented by proper soil management practices.

**Crop rotation**

Crop rotation is considered as one of the soil management practices that increase soil workability and nutrient recovery. In the present study, a Chi square statistics showed insignificant differences among rotation practices and topographical categories (Table 2). Overall, crop rotation was practiced on 66, 57, 58 and 61% of sampled cultivated fields of Damot Gale, Damot Sore, Sodo Zuria and total districts, respectively (Additional file 2). Cereals are often rotated with legumes and root crops. Haricot bean is a major legume crop used in the rotation cycle. The rotation in the present study is implemented in the following patterns: (maize → haricot bean → teff); (root crops → haricot bean → teff or cereals with root crops). According to local farmers, rotation is implemented to: replenish soil fertility, control pests, make use residual fertilization and receive yield advantage on succeeding crop.

Experimentally, the positive effects of rotation from the added N from legumes, improvement of soil biological



and physical properties, solubilizing occluded P and calcium (Ca) bound P using legume root exudates were documented (Bationo et al. 2012). In addition, the authors have also mentioned the advantages of crop rotation on soil conservation, soil OM restoration and pest and disease control. Furthermore, the practice of crop rotation to maintain the positive effects of fertilizers for better growth and yield of crops was also reported (Amede et al. 2001; Karlun et al. 2013a).

### Crop residue management

Crop residues in almost all of the surveyed fields have been removed for varied purposes (feed, fuel and construction material). Return of crop residue into the soil among the users and topographical categories did not show significant differences (Table 2). Crop residues were removed from 98, 94 and 96% of sampled agricultural fields in Damot Gale, Damot Sore and Sodo Zuria districts, respectively (Additional file 1). Crops such as haricot bean, field pea, sweet potato and potato were harvested by complete uprooting. In the case of maize, teff, wheat and sorghum, harvesting has been done by mowing close to the soil surface and then the farm was again subjected to grazing. Besides, uprooting of roots (e.g., maize and sorghum) for fuel purposes was observed. During the survey, it was also noticed that the leaves of coffee trees were collected in a piecemeal fashion to make locally made coffee “*Haita tukya*” and also leaves are serving as source of income.

Incorporating plant residues into the soil is an alternative soil management option particularly it is important where farmers have limited economic potential to purchase synthetic fertilizers (Yengoh 2012). However, the result in the present study indicated that very little amount remained in the field to replenish the soil. This implies a negative impact on the building up of soil OM and plant nutrient restoration processes, as residues are important for recycling of plant nutrients into the soil system (Gajic et al. 2006; Buyinza and Nabalegwa 2011). The low soil OC and nutrient content of the soils in the study area (Table 1) also confirms this speculation.

In annual crops, considerable portion of total nutrient uptake is found in straw and vine compared to grain and tuber, respectively (Hartemink 2006). The finding of this author in Papua New Guinea indicated that more than 75% of nutrient uptake was found in the above ground part (sweet potato vines). Another study also indicated that 51, 68 and 46% of N, P and K uptake in maize residue, respectively (Surendran et al. 2010). This implies that crop residues are stores for nutrients that upon decomposing would release plant nutrients for the subsequent crops. However, the small return of crop residues into crop fields including the study area is common problem

in Ethiopia (Amede et al. 2001; Abera and Belachew 2011; Belete 2014; Mekonnen 2014). This calls for looking options that could restore and maintain the soil chemical and physical health.

### Fertilizer use and application rates

As indicated in Table 2, the analysis result of inorganic fertilizer application showed a non-significant difference among the users and topographical categories. However, the result regarding organic fertilizer revealed a significant difference among the users ( $\chi^2 = 11.4$ ,  $p < 0.01$ ) but not among topographical categories. From sampled cultivated fields, only 58 and 25% were managed with inorganic and organic fertilizer types, respectively (Additional file 2). Di-ammonium phosphate (DAP) [18-46-0], urea [46-0-0] and farm yard manure (FYM) were fertilizer sources used in the study area. Inorganic fertilizer is well known in the area, as the WADU (Wolaita Agricultural Development Unit) project promoted the use of DAP extensively in the 1970s (Alemayehu et al. 2001). In the present study, relatively higher application rate of DAP than urea was observed. Farmers pointed the following reasons for using more DAP than urea fertilizer: belief that DAP can satisfy the crop nutrient demand, fear of additional cost incurred for urea fertilizer; fear of risks from urea application (e.g., crop lodging; and promoting excessive vegetative growth and its susceptibility during erratic rainy season).

The use of DAP fertilizer in the study area ranges from 0 to 200 kg ha<sup>-1</sup>. The maximum was observed in one irrigated field; otherwise the range for remaining fields was not above 100 kg ha<sup>-1</sup>. On cultivated fields, the use of DAP varied from 16 to 200 kg ha<sup>-1</sup> with a mean rate of 59 ± 19 kg ha<sup>-1</sup> (Table 3). The application rate of urea fertilizer (kg ha<sup>-1</sup>) ranged between 0 and 100, with mean rate of 7 ± 18. On cultivated fields, the use of urea varied from 18 to 100 with a mean rate of 47.7 ± 17 kg ha<sup>-1</sup>. Data regarding FYM (t ha<sup>-1</sup>) indicated that the range varied from 0 to 10 with a mean rate of 0.82 ± 1.8; whereas cultivated fields received FYM from 0.5 to 10 with mean rate of 3.3 ± 2.1 t ha<sup>-1</sup> (Table 3). Furthermore, from the spatial analysis (Fig. 6) it was noted that 36, 61 and 3% of study area received DAP fertilizer at rate of 5–25, 26–50 and 51–75 kg ha<sup>-1</sup>, respectively; whereas about 97% of study area received urea at a rate below 25 kg ha<sup>-1</sup>. In addition, 89% of study area received FYM at a rate below 1.5 t ha<sup>-1</sup> and 9% received at 1.6–3 t ha<sup>-1</sup>.

Time framed inorganic fertilizer application rates (2009–2013) were also computed from the ratio of distributed fertilizer and cultivated areas (Table 4). The average use of DAP ranged from 27 to 35 kg ha<sup>-1</sup> and that of urea varied from 7 to 13 kg ha<sup>-1</sup>. The amount is almost comparable with the survey findings presented in

**Table 3 Average application rate of fertilizers on total cultivated and fertilized cultivated fields of three districts, in Southern region, Ethiopia during 2013. Survey result, 2013**

District	DAP (kg ha <sup>-1</sup> )		Urea (kg ha <sup>-1</sup> )		FYM (t ha <sup>-1</sup> )	
	Cultivated field	Fertilized field	Cultivated field	Fertilized field	Cultivated field	Fertilized field
Damot Gale	33 ± 30	56 ± 15	7 ± 17	42.4 ± 13	0.98 ± 2.0	4.2 ± 2.2
Damot Sore	36 ± 33	62 ± 16	4 ± 14	52.5 ± 15	0.99 ± 2.0	3.0 ± 2.2
Sodo Zuria	34 ± 33	58 ± 22	9 ± 21	50.3 ± 18	0.57 ± 1.4	2.9 ± 1.6
F test	0.4 <sup>NS</sup>	3.3*	4.9**	3.2*	4.0*	5.8**
Grand total	34 ± 32	59 ± 19	7 ± 18	47.7 ± 17	0.82 ± 1.8	3.3 ± 2.1

Cultivated = fields managed with + without fertilizer. Fertilized fields = fields managed with fertilizer

NS non significant difference

\*,\*\*, Significant at p < 0.05, 0.01, respectively

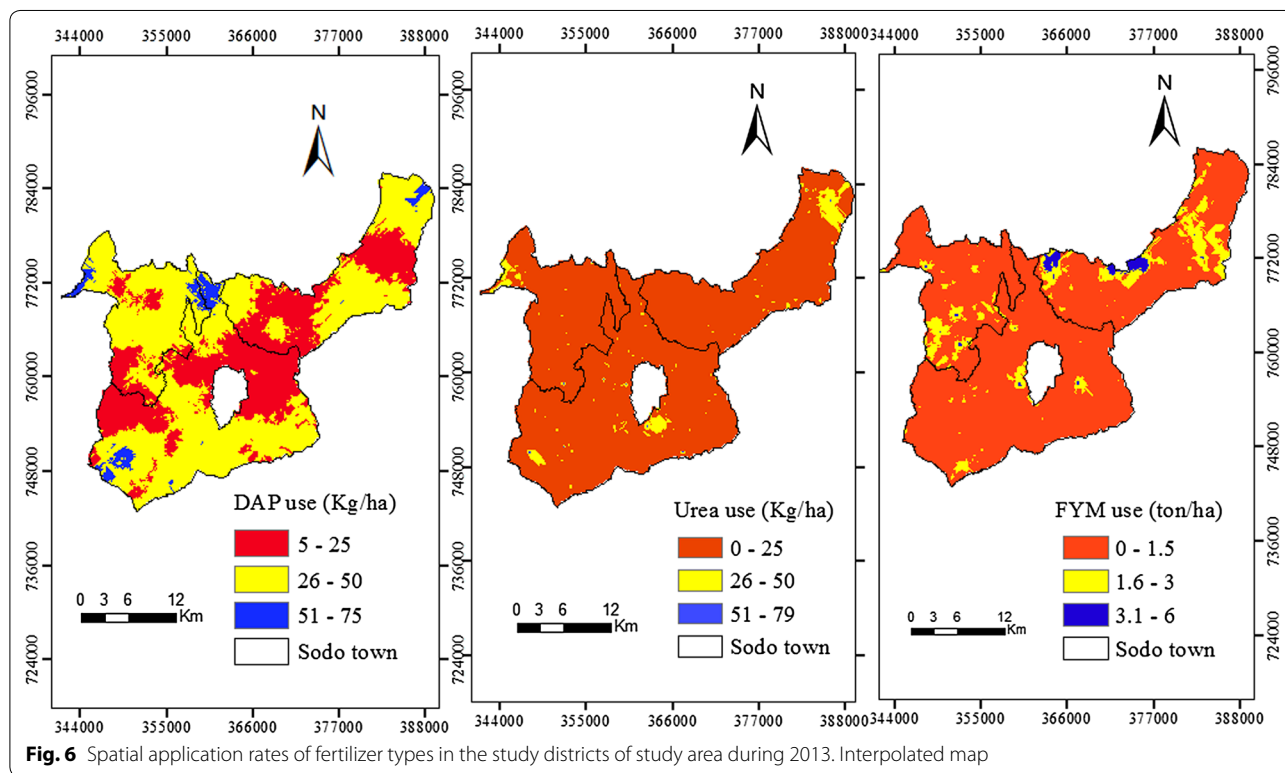


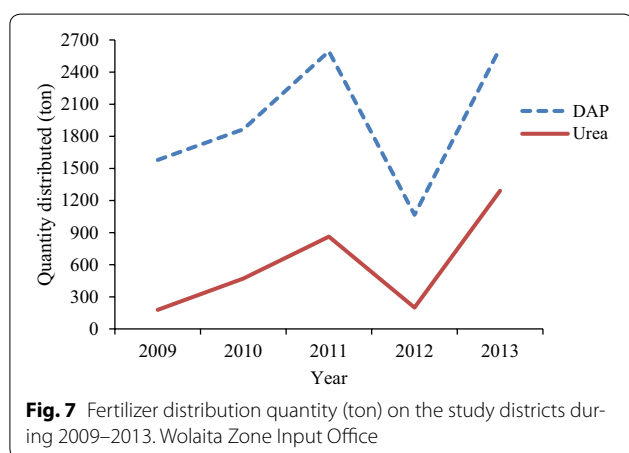
Table 3. Meanwhile, the absence of credit and low ability of farmers to purchase fertilizers with cash in hand system caused low use of fertilizer in 2012 (Table 4; Fig. 7). The low ability of smallholder farmers and increasing price had been reported as a cause for no to lower application rates of inorganic fertilizer in Ethiopia (Karlton et al. 2013a) and Cameron (Yengoh 2012).

In general, the amount of inorganic fertilizer used on cultivated fields of the study area seems higher than the reports of World Bank (2012) and Sommer et al. (2013) that indicated 23.8 and 13–16 kg ha<sup>-1</sup> on arable lands of

Ethiopia, respectively. However, the rate was far lower than blanket recommendation (i.e., 100 kg ha<sup>-1</sup> of each DAP and urea fertilizer) used in Ethiopia (Admasu 2009; Laekemariam and Gidago 2013; Sime and Aune 2014). High fertilizer costs, credit availability, lack of timely delivery, uncertainty of climatic condition and fear of addiction of their farm lands to applied fertilizers were among major reasons attributed to lower mineral fertilizer application rates in the study area. Regarding FYM, the amount used in the study area was very small compared to FYM recommendation at 12–18 t ha<sup>-1</sup> (Bekele

**Table 4 Fertilizer application rates ( $\text{kg ha}^{-1}$ ) in three districts in Southern region, Ethiopia (2009–2013) calculated from Wolaita Zone agricultural and input office data**

Year	Fertilizer application rate ( $\text{kg ha}^{-1}$ )							
	Damot Gale		Damot Sore		Sodo Zuria		Average	
	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea
2009	26.2	3.4	16.2	2.5	21.4	1.4	21.9	2.5
2010	29.5	10.8	22.6	4.5	24.8	3.6	26.0	6.6
2011	46.0	17.3	50.2	15.2	34.0	10.5	42.5	14.1
2012	13.7	3.1	21.4	4.1	16.6	2.5	16.5	3.1
2013	32.1	13.6	63.0	37.6	36.4	16.1	40.9	20.1
Average	30.0	10.0	35.0	13.0	27.0	7.0	30.0	9.0



1993); and integrated use of compost with inorganic fertilizer at  $5 \text{ t ha}^{-1}$  (Laekemariam and Gidago 2013). This implies that the lower application rate of chemical fertilizers have not been compensated with FYM or integrated use of organic and inorganic fertilizers. This might be associated with scarcity, difficulty of transportation to distant fields and priority to home stead area crops (e.g., *enset*). Previous studies in Wolaita also indicated strong linkage between manure and garden areas (*enset*, coffee and taro fields) (Elias and Scoones 1999; Data and Scoones 2003).

#### Fertilizer type uses and application rates on crop types

In the study area fertilizer application rate showed significant differences ( $p < 0.001$ ) among the crop types (Table 5). It is generally noted that fertilizer use and rate were found to be crop specific. This is confirmed by a significant ( $p < 0.001$ ) and negative ( $r = -0.42$ ) relationship between inorganic and organic fertilizer application. The use of inorganic fertilizer was higher for cereals (maize, teff, wheat) and haricot bean compared to perennial crops. Conversely, fields growing taro, *enset* and coffee received higher amount of FYM than cereal and pulse crops.

The probable reason for using higher inorganic fertilizer rates for maize, teff, wheat, potato and haricot bean might be related to the soil fertility status of cultivated field (i.e., usually poor due to continuous cultivation), noticeable yield differences in the absence and presence of fertilizer, crop relevance as source food and demand in the market. Farmers also indicated that the reasonable yield obtained from root crops made them to grow in the absence of fertilizers by giving priority for cereals. Earlier studies in Wolaita also reported crop specific fertilizer management approach in which farmers use more of the organic fertilizer to *enset*, and larger application of inorganic fertilizer to the out-field crops (Elias and Scoones 1999; Alemayehu et al. 2001). In addition, the use of more fertilizer for maize, teff and wheat in Ethiopia was reported (FAO 2002; Admasu 2009). Besides, relatively large share of fertilizer for maize in Africa due to its response to fertilizer and higher market demands has been shown (Morris et al. 2007).

As shown on Table 5, the mean application rate of DAP ( $\text{kg ha}^{-1}$ ) was highest for teff ( $61.3 \pm 20.3$ ) followed by wheat ( $57.5 \pm 24.3$ ), maize ( $46.7 \pm 30.1$ ), potato ( $52.7 \pm 24.5$ ) and haricot bean ( $45.5 \pm 25.8$ ). The mean application rate of urea fertilizer was very small ranging from nil to  $24 \text{ kg ha}^{-1}$ . It was also found that sorghum in the area was sown without any type of fertilizers. The use of FYM ( $\text{t ha}^{-1}$ ) was highest on *enset* ( $3.8 \pm 2.3$ ) followed by coffee ( $3.5 \pm 2.7$ ), taro ( $2.4 \pm 2.1$ ) and sweet potato ( $1.1 \pm 2.0$ ) (Table 5). The use of small and non-balanced nutrient application would lead to depletion of other nutrients as uptake without replenishment occurs in the soil (Abebe 1998; Romheld and Kirkby 2010; MoA and ATA 2012), and consequently results reduction of crop yield.

#### Farmers' estimate of crop productivity based on fertilizer use

Crop yield in the study area revealed significant differences due to fertilizer application (Table 6). The correlation analysis between yield and fertilizer use also

**Table 5 Fertilizer type uses and application rates of crops grown in the study districts of Wolaita Zone, South Ethiopia during 2013. Survey result, 2013**

Crop	Sample size	% fields receiving			Average fertilizer rate		
		DAP	Urea	FYM	DAP (kg ha <sup>-1</sup> )	Urea (kg ha <sup>-1</sup> )	FYM (t ha <sup>-1</sup> )
Maize	213	76	35	17	46.7 ± 30.1	17.5 ± 25.9	0.5 ± 1.3
Teff	20	95	45	0	61.3 ± 20.3	18.0 ± 21.5	0.0 ± 0.0
Wheat	14	93	57	0	57.5 ± 24.3	24.1 ± 23.7	0.0 ± 0.0
Sorghum	10	0	0	0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Haricot bean	188	82	1	4	45.5 ± 25.8	0.4 ± 4.1	0.1 ± 0.4
Field Pea	21	10	5	10	5.2 ± 16.6	0.9 ± 3.9	0.2 ± 0.8
Potato	29	90	7	10	52.7 ± 24.5	2.6 ± 10.2	0.3 ± 1.0
Sweet potato	36	3	3	33	1.7 ± 10.0	0.9 ± 5.3	1.1 ± 2.0
Taro	46	4	2	78	3.0 ± 14.6	1.0 ± 7.1	2.4 ± 2.1
Cassava	12	25	8	8	13.3 ± 25.7	2.5 ± 8.7	0.1 ± 0.2
Enset	15	0	0	100	0.0 ± 0.0	0.0 ± 0.0	3.8 ± 2.3
Coffee	55	0	0	91	0.0 ± 0.0	0.0 ± 0.0	3.5 ± 2.7
F test		–	–	–	45***	16.3***	40.2***

\*\*\* Significant at  $p < 0.001$ **Table 6 Farmers' estimated mean yields on sampled cultivated fields in the absence and presence of fertilizer in the three districts, Southern region, Ethiopia during 2013. Survey result, 2013**

Major crop	Fertilizer application	Mean yield (t ha <sup>-1</sup> )				F test
		Damot Gale	Damot Sore	Sodo Zuria	Overall Mean ± SD	
Maize (195)	No	0.76 ± 0.3	0.52 ± 0.2	0.26 ± 0.16	0.55 ± 0.31	63.9***
	Yes	2.54 ± 0.9	1.95 ± 0.64	1.54 ± 0.50	2.08 ± 0.81	27.2***
	t test	***	***	***	***	
Teff (105)	No	0.17 ± 0.09	0.16 ± 0.09	0.08 ± 0.11	0.15 ± 0.10	7.4***
	Yes	0.73 ± 0.23	0.69 ± 0.15	0.65 ± 0.19	0.70 ± 0.19	1.3NS
	t test	***	***	***	***	
Wheat (62)	No	0.50 ± 0.3	0.46 ± 0.25	0.18 ± 0.16	0.45 ± 0.28	3.4*
	Yes	1.9 ± 0.65	1.93 ± 0.84	1.05 ± 0.48	1.81 ± 0.74	3.9*
	t test	***	***	**	***	
Haricot bean (244)	No	0.37 ± 0.14	0.35 ± 0.13	0.22 ± 0.13	0.34 ± 0.14	19.6***
	Yes	1.14 ± 0.32	1.21 ± 0.33	0.88 ± 0.15	1.12 ± 0.32	16.2***
	t test	***	***	***	***	
Potato (42)	No	2.56 ± 0.87	1.89 ± 1.09	0.47 ± 0.42	2.14 ± 1.09	7.4**
	Yes	7.30 ± 2.32	7.63 ± 3.80	2.67 ± 0.61	7.11 ± 3.16	3.7*
	t test	***	***	**	***	
Sweet potato (46)	No	4.11 ± 1.68	4.59 ± 2.34	5.52 ± 2.55	4.69 ± 2.28	0.9NS
	Yes	9.88 ± 3.04	11.13 ± 3.76	12.23 ± 4.12	11.13 ± 3.71	0.8NS
	t test	***	***	***	***	
Taro (58)	No	4.43 ± 1.96	5.89 ± 2.43	8.20 ± 6.34	5.73 ± 2.96	3.4*
	Yes	13.41 ± 7.09	13.03 ± 3.28	15.20 ± 3.35	13.33 ± 4.68	0.5NS
	t test	***	***	*	***	
Coffee (37)	Yes (FYM)	0.56 ± 0.16	0.42 ± 0.10	0.49 ± 0.25	4.9 ± 1.5	4.3*

Numbers in parenthesis indicates number of samples

NS not significant

\*, \*\*, \*\*\* Significant at  $p < 0.05, 0.01, 0.001$

strengthens this observation. The result showed a significant ( $p < 0.001$ ) and strong correlation for maize ( $r = 0.73$ ), teff ( $r = 0.41$ ), wheat ( $r = 0.80$ ), potato ( $r = 0.71$ ), sweet potato ( $r = 0.52$ ) and taro ( $r = 0.74$ ) yields (Additional file 3). Accordingly, the yield of maize ( $\text{t ha}^{-1}$ ) from fertilized fields was found to be  $2.1 \pm 0.8$  followed by wheat ( $1.8 \pm 0.74$ ), whereas haricot bean gave  $1.1 \pm 0.32 \text{ t ha}^{-1}$ . The yield of root crops ( $\text{t ha}^{-1}$ ) such as potato, sweet potato and taro using fertilizer were  $7.1 \pm 3.2$ ,  $11.1 \pm 3.7$ ,  $13.3 \pm 4.7$ , respectively (Table 6). This indicated that there is yield increment potential in the study area, if proper management strategies are implemented.

Nevertheless, farmers in the study area are experiencing lower yield than the national average productivity ( $\text{t ha}^{-1}$ ) (CSA 2013) such as maize (3.06), teff (1.4), wheat (2.11), haricot bean (1.26), sweet potato (28.46), potato (11.52) and Taro (27.04). Scarcity of arable lands, intensive exploitation of crop fields at diversified slope ranges, abandoned fallowing, very poor crop residue maintenance, low nutrient status and inadequate compensation of plant nutrients into the soil system could explain the lower crop yields in study area. Hence proper practices leading to soil fertility enhancement are mandatory to generate better yields.

## Conclusions

Agricultural lands in the study area are characterized by different landforms, highly varied slope gradients, diverse altitudinal ranges and almost similar agro ecology. Farmers in the area have been practicing agricultural activities to the extent of steep slope topographic positions which are prone to quick degradation. These areas are very susceptible to the deterioration in soil physico-chemical properties. Consequently, a significant variation in soil particle distribution, soil texture, bulk density, available P, exchangeable Ca, and extractable soil micronutrients (B, Cu, Fe and Zn) were found along topographic positions.

Farmers' soil fertility management practices were insufficient to replenish soil nutrients. Where this cannot take place, nutrient deficiencies are very likely to occur. In relation to this, low level of OC, TN, available P, available S, B and Cu was recorded. This implies that yield in the area would be constrained due to limiting nutrients. This could justify why farmers in Wolaita are experiencing lower yield than the national average and on station (potential) yield. Meanwhile, a potential for possible yield increment in the study area due to applied soil management practices was recorded. Therefore, integrating the following activities such as appropriate soil conservation measures, inclusion of restorative crops in cropping systems, use of locally available organic materials, use of bio-fertilizers and use of balanced fertilization

are recommended to combat soil fertility problems and exploring the potential crop productivity.

## Additional files

**Additional file 1.** Topography and slope category of sampled agricultural fields in the study area.

**Additional file 2.** Farmers' soil management practices (%) on sampled agricultural fields of Damot Gale, Damot Sore and Sodo Zuria districts, in Southern region, Ethiopia.

**Additional file 3.** Correlation between fertilizer use, slope and crop yield.

## Authors' contributions

FL collected, analyzed and interpreted the data, which was part of his Doctoral thesis of Soil Science at Haramaya University, Ethiopia. KK, TM, EK and HG helped to draft the manuscript as well as approved the final manuscript. All authors read and approved the final manuscript.

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## Competing interests

The authors declare that they have no competing interests.

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