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Soil fertility status under smallholder farmers' fields in malawi

Joyce Prisca Njoloma^{1*}, Weldesemayat Gudeta Sileshi^{1,3}, Bruce Geoffrey Sosola¹, Patson Cleopus Nalivata² and Betserai Isaac Nyoka¹

¹World Agroforestry Centre, International Centre for Research in Agroforestry (ICRAF), Chitedze Agricultural Research Station, P. O. Box 30798, Lilongwe 3, Malawi.

²Lilongwe University of Agriculture and Natural Resources (Bunda College), Crop and Soils Department, P. O. Box 219, Lilongwe, Malawi.

³1244 Ibex Hill, Lusaka, Zambia.

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Land degradation continues to contribute to the declining soil fertility especially in the smallholder farms. Thus, soil fertility depletion in the smallholder farms will continue to be the biophysical root cause for reduced food production if farmers do not implement best agricultural practices. It is expected that when farmers understand the current soil fertility status on their farms, they would make informed decisions considering appropriate soil fertility restoration and other conservation technologies. Soil fertility status of selected sites was determined in Northern, Central and Southern regions of Malawi. The overall objective of the study was to document current soil fertility status in smallholder farmers' fields. And that specifically, this study was meant to provide a basis for the promotion of soil fertility restoration interventions in Malawi. A total of 33 participating farmers' fields were selected for soil sampling and from each site soil samples were collected at two depths, 0 to 20 cm and 20 to 50 cm, using an auger. Soil chemical and physical analysis was carried out on all the sampled soils. Statistical analysis on the data was done using Genstat 14.1. The statistical analysis revealed that soils in all the selected sites are slightly acidic with most of the sites having pH <5.5. Another important finding is the low %OM (<2%) in most of the sites especially in Dedza and Mzimba. Soil organic matter (SOM) is important for healthy plant growing as it maintains favourable conditions supporting soil moisture retention, temperature, nutrient, pH, and aeration. The low %OM contributes to the low and moderate levels of N (<0.2%) in most of the sites. Sustainable soil management practices are therefore required to rebuild the soil fertility resource base.

Key words: Soil fertility, soil organic matter, acidic soils, nitrogen-fixing trees.

INTRODUCTION

The sustainable use of soil resource remains a critical determinant of agricultural productivity in Malawi for most

farmers who have traditionally prioritised maize, the staple food over other food and cash crops. However,

*Corresponding author. E-mail: J.Njoloma@cgiar.org. Tel: +265 (0) 1 707 319.

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despite the availability of improved varieties, a number of studies conducted in Malawi and other countries in the sub-Saharan Africa region reported declining levels of crop productivity that pose serious food security concerns for the region (Smale and Jayne 2003; FAO, 2008). Among other factors such as the climate variability, agricultural productivity is being threatened by land degradation resulting in declining soil fertility especially in the smallholder farms. Land degradation is not only negatively impacting on the future of smallholder agriculture in Malawi but also its economic growth prospects for a country whose economy is based on agriculture. It has been estimated that Malawi loses in excess of 30 kg of N and 20 kg of P per hectare per year through erosion on arable land (Henao and Baanante, 1999). Thus, soil fertility depletion in the smallholder farms will continue to be the biophysical root cause of reduced food production if farmers do not implement best agricultural practices (Vlek et al., 2008).

Soil fertility replenishment is one of the corrective measures that should be considered as an investment in natural resource capital (Onyango, 1997). It is therefore important to understand what is meant by soil fertility decline for a farmer to start planning for soil fertility restoration. However, defining soil fertility decline is relatively difficult because most soil chemical properties either change very slowly or have large seasonal fluctuations; in both cases, it requires long-term research commitment to understand the confounding factors that make assessment of soil fertility decline complicated. This calls for some considerable evidence of the overlaps between farmers' and researchers' perceptions of soil fertility decline (Murage et al., 2000). Over the years, researchers have strived to provide a breadth of the understanding of soil physical processes, research developments on soil fertility restoration and other conservation technologies. On the other hand, farmers are expected to have a context specific knowledge required to adapt the developed technologies to local biophysical and socio-economic conditions. Nonetheless soil fertility decline remains a major concern in most parts of the world especially in the developing countries (Acharya et al., 2000). A study was therefore conducted to determine the current soil fertility status levels in some selected maize based growing areas in Malawi to provide an understanding on the soil health status. The specific objective was to establish a scientifically based soil fertility status validation that will influence appropriate decisions on appropriate soil fertility enhancing interventions in the maize based farming systems.

MATERIALS AND METHODS

Soil sample collection sites

A total of 33 sites were selected from three districts in Malawi and these included Mzimba, Dedza and Thyolo. Twelve sites in three Extension Planning Areas (EPAs) were sampled in both Mzimba

(Zombwe, Mpherembe and Emsizini EPAs) and Dedza (Mtakatika, Golomoti and Chafumbwa EPAs) whereas in Thyolo (Matapwata, Dwale and Thyolo Central EPAs) only 9 sites were assessed (Table 1).

Soil sampling and analyses (pp3 -6 re-worked as suggested by reviewers)

Soil sampling was conducted soon after the rainy season in the months between March and April, 2013. The sampling time was planned so in order to take care of sudden pulse-like events of rapidly increasing CO₂-efflux that do occur in soils under seasonally dry climates in response to re-wetting after dry periods (Jarvis et al., 2007; Griffiths and Birch, 1961). A well-mixed composite sample of 500g from three positions (the middle and two other random points) within a 6 m by 6 m plot was obtained. Top soil samples were taken at a depth of 0 to 20 cm and the sub soil samples were collected at a depth of 20 to 50 cm with an auger.

Processed air dried soil samples were analyzed at the Crop and Soils Laboratory, Bunda College Campus of the Lilongwe University of Agriculture and Natural Resources (LUANAR). Sub-soil samples determined through quartering process were analysed for pH, soil organic carbon (SOC), soil organic matter (SOM), total nitrogen (N), extractable phosphorus (P), exchangeable potassium (K) and soil texture. NPK were prioritized on the basis that they are considered as most limiting in the maize production systems. Determination of both the chemical and physical soil properties was carried out following the standard procedures (Mehlich, 1984; Anderson and Ingram, 1993; Wendt, 1996) as described in the subsequent paragraphs:

Soil pH was determined in water (1:2.5 H₂O) (Wendt, 1996). Sieved soil samples each weighing 10g was placed into 50ml centrifuge tubes then 25 ml at room temperature distilled water was added to the tubes and the mixture was then placed in centrifuges, shaken for 5 minutes and pH was determined using a calibrated pH meter.

Total organic carbon was analysed using the Walkley and Black method as described by (Anderson and Ingrams, 1993). The amount of carbon was determined from a standard curve and percent organic carbon (OC) was calculated using the following formula:

$$\% \text{ Organic carbon (OC)} = \frac{M \times 0.39 \times mcf \times (v1 \times v2)}{S} \quad (1)$$

Where: M = molarity of ferrous sulphate solution, V1 = ml of ferrous sulphate solution, V2 = ml of ferrous sulphate solution required for blank, S = weight of air dry sample in grams, Mcf = moisture correcting factor $(100 + \% \text{moisture})/100$, $0.39 = 3 \times 0.001 \times 100\% \times 1.3$ (3 = equivalent weight of carbon) 1.3 = a compensation factor for the incomplete combustion of the organic carbon.

$$\% \text{ Soil organic matter (SOM)} = \% \text{ OC} \times 1.72^* \quad (2)$$

*1.72 is the conversion factor commonly used for converting values of organic carbon to soil organic matter values (Anderson and Ingrams, 1993). Mineralisable Nitrogen was obtained through the following formula:

$$\% \text{ Mineralisable Nitrogen (N)} = \% \text{ OM} \times 0.05 \quad (3)$$

Available phosphorus ($\mu\text{g P/g soil}$) was analysed using Mehlick-3 extractant.

Exchangeable cations were determined after extraction with Mehlich-3 solution and analysis using an atomic absorption

Table 1. Study sites and locations of sampled fields.

District	EPA	Section	Village/Site	South	East
Mzimba (in the Northern region)	Zombwe	Kaluholo	Kenani Shonga	11°18'17.3"	033°54'22.9"
		Ekwendeni	Zinolema Khonje	11°20'59.5"	033°52'06.6"
		Zombwe 2	Bandawe Tembo	11°20'25.2"	033°50'38.5"
		Doroba	Jailosi Mhlanga	11°21'58.1"	033°58'34.7"
	Mpherembe	Kazuni	Tengasalu	11°09'11.3"	033°40'04.1"
		Elunyeni	Kazalawe	11°13'17.5"	033°41'22.7"
		Mpherembe	Chigagu jere	11°17'39.2"	033°36'49.2"
		Ezweleni	Ndindi	11°16'43.6"	033°39'30.5"
	Emsizini	Emtiyani	Chilenga Zamangwe	11°33'19.8"	033°44'25.4"
		Enyezini	Kaigwazanga Mphande	11°27'57.9"	033°51'20.7"
		Emsizini	Saulosi Nkosi	11°25'57.0"	033°50'05.0"
		Emsizini	Mkakangoma	11°27'39.2"	033°48'47.3"
Dedza (in the Central region)	Mtakataka	Nankokwe	Njolo	14°17'43.5"	034°31'30.7"
		Msekeni	Mphonde	14°15'12.5"	034°30'92.2"
		Mua	Kankhande	14°17'09.8"	034°31'15.7"
		Boolera	Asani	14°20'75.9"	034°33'63.5"
	Golomoti	Golomoti Centre	Msamala	14°26'04.3"	034°35'94.5"
		Chikololere	Somanje	14°25'06.3"	034°36'32.0"
		Kabulika	Liwengwa	14°22'67.4"	034°34'73.2"
		Mganja	James	14°24'03.8"	034°49'27.3"
	Chafumbwa	Ching'ombe	Chisani	14°21'25.0"	033°51'13.1"
		Magomero	Mnolo	14°22'76.7"	033°54'62.6"
		Abona	White	14°26'48.7"	033°54'09.7"
		Kadala	Kum'buka	14°25'44.7"	033°54'95.4"
Thyolo (in the Southern region)	Matapwata	Nachipere S.W	Chibwana	16°05'25.3"	035°16'72.6"
		Chingazi	Katundu	15°93'38.6"	035°18'87.7"
		Sharpe	Mtulo	16°01'55.3"	035°19'01.4"
		Makande South	Savala	15°99'06.0"	035°24'88.9"
	Dwale	Muonekera B	Supero	15°95'03.3"	035°09'12.8"
		Chandamale	Mpezo	16°08'03.6"	035°12'01.5"
		Dzimbiri	Mwanaphwa	16°07'83.7"	035°12'18.3"
	Thyolo centre	Nachipere centre site 1	Pemba	16°01'55.3"	035°19'01.4"
		Nachipere centre site 2	Pemba	16°01'55.5"	035°19'01.7"

spectrometer (AAS).

Soil samples each weighing 2.5 g were placed in separate 50 ml centrifuge tubes and then 25 ml of Mehlich 3 extracting solution was added. The tubes were capped and shaken for 5 min and let to stand for 10 min and then centrifuged for 5 min. The samples were then filtered through pure cotton that was previously rinsed with Mehlich 3 solution. Intermediate stock solution standards for K were used to obtain sample filtrates after dilution with lanthanum solution which was then passed through a flame photometer for potassium determination (Anderson and Ingram, 1993). Soil texture was determined using the hydrometer method. In this method the soil particles were dispersed in a 3% sodium hexametaphosphate (calgon) and then agitated. After dispersion, the amounts of each particle group (sand, silt, clay) were determined after the tubes were uncapped and left on racks undisturbed for 30 s. Then solutions from these tubes were poured into corresponding sets of

tubes, leaving the sand that had settled. The second sets of tubes were left to stand for another 30 min to let the silt settle and so on. Volumes of the settled particles then were recorded. This is based on the principle of Stokes law, which states that particles will fall out of suspension at different rates over time, based on particle size, and is used to determine the amount of each particle size present in a soil.

All data collected was statistically analysed using GenStat 14.1 edition. The Analysis of variance procedure (ANOVA) was used to determine treatment effects and their significance levels. For the district comparative analysis a 3*3*9*12 factorial layout (the 3 districts, 3EPAs from the districts, 9 sites from each EPA and 12 sample plots per site) was used. Differences between and within treatments were separated using Least Significant Differences (LSD) tests at $P < 0.05$. Soil texture was analysed with the aid ArcView GIS 3.3 to determine the surface soil texture classification.

Table 2. Comparative soil analysis in the three districts (Dedza, Mzimba and Thyolo) in Malawi.

Soil parameter		Mean per district			LSD (5%)	SE	CV%
		Dedza	Mzimba	Thyolo			
pH	Top	5.14 ^a	5.07 ^a	5.50 ^b	0.12	0.45	8.60
	Sub	5.10 ^b	4.94 ^a	5.44 ^c	0.13	0.47	9.20
% Sand	Top	38.49 ^a	43.99 ^b	40.49 ^a	2.40	9.00	22.10
	Sub	38.38 ^a	42.56 ^b	41.21 ^b	2.50	9.20	22.60
% Silt	Top	18.45 ^b	14.70 ^a	27.95 ^c	1.50	5.40	26.70
	Sub	18.70 ^b	13.40 ^a	28.07 ^c	1.60	5.80	28.90
% Clay	Top	43.06 ^b	41.31 ^b	31.52 ^a	2.90	10.80	27.80
	Sub	42.92 ^b	44.04 ^b	30.67 ^a	3.00	11.20	28.50
% OC	Top	0.67 ^b	0.44 ^a	1.17 ^c	0.15	0.55	72.60
	Sub	0.62 ^b	0.48 ^a	1.25 ^c	0.14	0.52	66.60
% OM	Top	1.38 ^b	0.76 ^a	2.04 ^c	0.25	0.92	66.00
	Sub	1.24 ^b	0.82 ^a	2.19 ^c	0.23	0.85	60.10
% N	Top	0.04 ^b	0.02 ^a	0.06 ^c	0.01	0.03	69.90
	Sub	0.04 ^b	0.02 ^a	0.06 ^c	0.01	0.03	61.30
P(mg/kg)	Top	45.97 ^a	140.65 ^b	40.17 ^a	12.70	47.40	62.70
	Sub	28.55 ^a	129.44 ^b	29.53 ^a	8.90	33.20	53.00
K (mg/kg)	Top	255.50 ^c	24.40 ^a	155.60 ^b	21.70	81.10	55.90
	Sub	197.30 ^c	17.10 ^a	124.10 ^b	17.40	64.80	57.50
BD		1.42 ^a	1.57 ^c	1.50 ^b	0.04	0.14	9.40

Means with different superscripts within a row are significantly different at $P < 0.001$.

RESULTS

A comparative soil assessment of the sites in the 3 districts indicates that the soils in Mzimba are falling into the acidic levels more than the Thyolo sites. Generic soil texture classification shows that Dedza and Mzimba sites are more dominated by clay soils while sites in Thyolo are classified as being clay loam. This follows that the Thyolo soils have significantly higher %OM in relative terms though not reaching optimal levels (Table 2). The site specific soil assessment revealed that there is a lot of variability within and among the sites in the districts as described in the subsequent paragraphs.

Soils from Mzimba district sites (Table 3) show acidic reactions in both the top soil (pH 4.5 to 5.6) and sub soil (pH 4.3 to 5.4). The soil organic carbon varied from 0.2 to 1.5% with relatively higher values in the top soil. The %N for the top soils ranged from 0.007 to 0.042% for the top soil which was relatively lower than in the sub soils. Higher P (81.7 to 200.4 mg kg⁻¹) levels were obtained

from the top soil. There were high variations on the exchangeable K across the sites ranging from 8 mg/kg to 65 mg/kg in the top soil and 4.3 to 56.9 in the sub soils. Soil organic matter (%OM) was also highly variable across the sites ranging from 0.50 to 1.44% in the top soil and relatively higher (0.7 to 2.10%) in the sub soils. Soil clay variations in the two soil depths were also determined.

In Zombwe EPA of Mzimba district, soils have a high proportion of clay ranging from 44.2 to 53.3%, followed by sand (35.3 to 45.1%) and some low proportions of Silt (loam) ranging from 9.4 to 15.0%. These soils have therefore been categorized as Sandy clay to clay. Soils in Mpherembe EPA sites have been categorized as Sandy clay loam with only Ndindi village having clayish soils. In Emsizini EPA the soils are mostly clayish.

Soil for the Dedza district sites (Table 4), shows less variation on the pH levels ranging from 4.6 to 5.5 and 4.6 to 5.8 in the top and sub soils respectively. Soil organic carbon is relatively high (up to 1.4%) in some sites while

Table 3. Soil chemical and physical properties for Mzimba district sites.

Site	pH		% OC		%OM		% N		P(mg/kg)		K (mg/kg)		% Sand		% Clay		%Silt		BD
	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	
Kenani Shonga	5.4	5.4	0.9	0.7	0.50	0.70	0.03	0.04	151.5	149.1	30.5	20.2	40.8	40.3	44.2	47.8	15.0	11.9	1.52
Zinolema Khonje	5.2	5.1	0.8	0.7	1.40	1.07	0.02	0.03	175.4	159.4	24.9	11.7	36.2	35.3	51.0	52.5	12.8	12.2	1.55
Bandawe Tembo	4.6	4.5	1.4	0.9	0.95	1.22	0.04	0.05	102.0	93.5	13.1	7.8	37.5	35.3	49.6	53.3	12.9	11.4	1.67
Jailosi Mhlanga	4.7	4.5	0.5	0.2	0.79	1.15	0.02	0.01	82.4	74.8	8.8	4.3	45.1	42.8	44.4	47.8	10.6	9.4	1.65
Tengasalu	4.6	4.3	0.4	0.2	1.44	1.60	0.01	0.01	99.0	101.8	48.0	21.9	55.6	53.9	31.1	32.2	13.3	13.9	1.59
Kazalawe	5.4	5.3	0.4	0.3	0.50	0.37	0.01	0.02	161.8	156.7	65.0	56.9	52.5	48.1	32.5	37.5	15.0	14.4	1.46
Chigagu jere	4.6	4.5	0.3	0.2	0.43	0.30	0.01	0.01	81.7	79.1	14.2	8.2	45.8	47.2	35.3	42.5	18.9	10.3	1.56
Ndindi	5.0	5.0	1.0	0.7	0.36	0.52	0.03	0.03	143.8	137.1	8.0	4.6	39.2	38.9	44.2	47.8	16.7	13.3	1.56
Chilenga zamangwe	5.3	5.3	0.5	0.4	0.34	0.38	0.02	0.02	130.6	130.6	24.6	13.0	50.0	51.9	33.6	31.4	16.4	16.7	1.60
Kaigwazanga Mphande	5.6	5.3	1.5	0.6	0.13	1.13	0.04	0.03	211.7	167.2	30.2	17.2	41.4	39.7	41.7	43.6	16.9	16.7	1.51
saulosi Nkosi	4.5	4.3	1.4	1.2	1.44	2.10	0.04	0.06	159.2	151.9	11.7	5.5	24.7	19.2	65.3	72.2	10.0	8.6	1.51
Mkakangoma	5.0	4.7	0.2	0.2	0.23	0.43	0.01	0.01	200.4	176.9	24.7	22.0	43.6	38.9	46.4	44.7	10.0	16.4	1.52
Mean	5.0	4.9	0.8	0.5	0.7	0.9	0.02	0.03	141.6	131.5	25.3	16.1	42.7	41.0	43.3	46.1	14.0	12.9	1.6
CV (%)	7.7	8.8	59.8	62.5	68.5	61.6	52.8	62.6	30.8	26.9	67.1	89.7	19.2	22.4	22.3	23.5	20.8	21.6	3.9

traces were recorded in 33% of the sites. Traces of %OM and %N were also determined in the same areas. The P values across the sites were highly variable ranging from 6.8 to 137 mg kg⁻¹ in the top soil and 3.7 to 61.7 mg kg⁻¹ in the sub soil. Overall, almost all the sites have high K values with the lowest mean being 93.7 mg kg⁻¹. These soils in Dedza sites are predominantly clay especially in Chafumbwa and Golomoti ranging from 35.3 to 66.9% in the top soil and 38.1 to 63.9% in the sub soils. In Mtakataka, the clay content ranges from 19.2 to 44.8% in the top soils and almost similar values have been determined in the corresponding sub soils. Soil in Mphonde and Asani villages have high proportions (>55%) of sand in both the top and sub soils.

Sites in Thyolo districts (Table 5) show soil pH levels ranging from 5.3 to 5.8 in the top soil and 5.2 to 5.9 in the sub soil. In both soil depths, soil organic carbon ranges from 0.8 to 1.7%. Soil

organic matter varies from 1.44% to 3.00% in the top soil and the sub soil showed almost same range (1.42 to 3.05%). Nitrogen level in both the top and sub soils is between 0.04 and 0.08%. Lowest levels of P (6.50 and 8.17 mg/kg) were obtained in the sub soil samples from Mwanaphwa and Katundu villages.

Low K values were recorded in Pemba (63.67 mg/kg) and Mtulo (75.92 mg/kg) villages while Supelo village recorded relatively higher K values, in the top (236.92 mg/kg) and 192.92 mg/kg (sub soils). Soil particle distribution in the assessed sites shows relatively high proportions of sand ranging from 36.42 to 44.42% in the top soil and 37.50 to 46.58% across the sites, clay and silt values range between 20 and 40% in both the top and sub soil depths. Bulk density determination showed evidence that the soils are not compacted with Mzimba soils averaging 1.57 g/cm³, Dedza and Thyolo recorded 1.58 and 1.46 g/cm³

respectively.

DISCUSSION

Current status of soil fertility in the study sites in general

This study shows that the current condition of most soils in the districts is of very low soil fertility status. The pH in the three districts varied considerably among sampled sites; values for Thyolo sites are higher than those of Dedza and Mzimba sites. Soil pH falling in the ranges below 5 are regarded as acidic (Brady and Weil, 1996) and not very good for production of most crops including maize. Many crops grow well in soils with pH close to neutral (pH 5.8 to 7.5) though some few crops would do better in a wide range of pH 5.8 to 9.0. In this study, only about 10% of the

Table 4. Soil chemical and physical properties for Dedza district sites.

Site	pH		% OC		%OM		% N		P(mg/kg)		K (mg/kg)		% Sand		% Clay		%Silt		BD
	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	
Njolo	5.3	5.3	1.1	1.4	1.85	2.40	0.054	0.070	108.9	61.7	330.6	269.4	28.0	28.7	44.8	43.1	27.2	28.2	1.24
Mphonde	5.4	5.4	1.8	1.1	3.10	1.91	0.091	0.055	22.9	19.4	358.5	335.1	55.9	57.5	22.3	19.7	21.8	22.8	1.53
Kankhande	5.5	5.8	1.2	1.0	2.08	2.00	0.061	0.050	23.5	20.8	266.4	224.0	23.8	24.9	43.5	41.9	32.7	33.2	1.41
Asani	5.5	5.6	1.1	1.4	1.94	2.00	0.056	0.069	20.6	28.5	324.8	264.2	63.6	62.2	19.2	20.0	17.2	17.8	1.44
Msamala	5.2	5.2	1.2	0.6	2.01	1.00	0.058	0.029	58.6	39.9	270.1	212.1	19.2	21.4	66.9	63.9	13.9	14.7	1.37
Somanje	5.2	5.2	0.7	1.1	1.22	2.00	0.035	0.053	137.3	67.0	327.8	184.9	45.8	44.5	35.3	38.1	18.8	17.4	1.45
Liwengwa	5.1	5.2	Trace	0.5	1.09	1.00	Trace	0.025	8.2	1.7	174.9	107.0	35.3	35.9	45.8	48.2	18.9	15.8	1.50
James	5.2	5.2	0.7	1.3	1.12	2.00	0.033	0.066	80.1	53.6	239.2	216.2	35.3	34.7	43.9	43.8	20.8	21.5	1.38
Chisani	4.8	4.7	Trace	Trace	1.12	1.60	Trace	Trace	7.6	10.6	258.9	212.0	35.3	35.9	47.9	44.9	16.8	19.1	1.44
Mnolo	4.8	4.7	Trace	Trace	Trace	Trace	Trace	Trace	5.9	5.4	200.3	232.0	32.5	33.1	50.7	49.3	16.8	17.7	1.52
White	5.2	4.9	Trace	Trace	Trace	Trace	Trace	Trace	42.6	24.4	128.1	97.2	34.2	30.8	51.1	55.3	14.7	13.9	1.42
Kum'buka	4.6	4.6	Trace	Trace	Trace	Trace	Trace	Trace	6.8	3.7	125.8	93.7	29.2	28.3	54.2	53.1	16.7	18.6	1.38
Mean	5.2	5.2	1.1	1.1	1.7	1.8	0.1	0.1	43.6	28.1	250.5	204.0	36.5	36.5	43.8	43.4	19.7	20.1	1.4
CV (%)	5.5	7.1	33.3	32.6	38.6	27.1	34.7	33.1	100.9	81.0	31.7	36.2	35.1	34.1	30.0	29.9	27.5	28.3	5.5

Table 5. Soil chemical and physical properties for Thyolo district sites.

Site	pH		% OC		%OM		% N		P(mg/kg)		K (mg/kg)		% Sand		% Clay		%Silt		BD
	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	Top	Sub	
Chibwana	5.4	5.3	1.1	1.1	1.89	1.81	0.06	0.05	66.2	53.8	123.8	98.2	44.4	44.6	33.8	34.6	21.7	20.7	1.44
Katundu	5.6	5.5	0.9	1.2	1.60	2.00	0.05	0.06	15.7	8.2	147.7	127.7	40.3	40.8	24.4	23.3	35.3	36.0	1.55
Mtulo	5.3	5.3	0.9	0.8	1.58	1.42	0.05	0.04	55.5	39.3	96.8	75.9	36.4	37.5	41.8	39.3	21.8	23.3	1.54
Savala	5.8	5.9	1.2	1.5	2.10	2.54	0.06	0.07	18.8	14.7	164.0	137.4	40.3	40.8	24.4	23.3	35.3	36.0	1.38
Supelo	5.4	5.3	1.2	1.4	3.00	3.05	0.06	0.07	60.2	39.3	236.9	192.9	44.4	44.6	33.8	34.6	21.7	20.7	1.61
Mpezo	5.4	5.2	0.8	1.0	2.65	2.61	0.04	0.05	28.8	17.7	128.0	82.0	39.5	39.5	38.8	39.3	21.8	21.3	1.45
Mwanaphwa	5.8	5.8	1.7	1.7	2.07	2.32	0.08	0.08	10.5	6.7	225.6	183.4	42.4	46.6	21.8	17.4	35.8	36.0	1.50
Pemba	5.3	5.3	1.2	1.4	1.97	2.28	0.06	0.07	92.4	79.0	74.8	63.7	38.2	37.8	38.8	39.8	23.0	22.4	1.40
Mean	5.5	5.5	1.1	1.3	2.1	2.3	0.1	0.1	47.5	31.0	150.0	120.2	40.7	41.5	32.2	31.5	27.1	27.1	1.5

sampled sites would barely qualify to have adequate pH levels (pH > 5.8) for crop production and the rest fall in the acidic soil range. In very

acidic soils (pH < 5.0), some of the macro and micro nutrient elements including calcium and magnesium, nitrate-nitrogen, phosphorus, boron,

and molybdenum are deficient; whereas aluminum, iron and manganese are abundant, sometimes at levels toxic to some plants (Belachew and Abera,

2010). Thus, soil pH influences the mobility of trace elements in the soil and it is a primary factor for the uptake of most nutrients by plants. Soil pH affects the soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth and yields of most crops decrease where pH is low and increase as pH rises to an optimum level above 5.8 (Karlen et al., 2003).

On the other hand soil bulk density also does play a major role in the nutrient accessibility by the plant roots. Critical value of bulk density for restricting root growth varies with soil type but in general bulk densities greater than 1.6 g/cm^3 tend to restrict root growth (McKenzie et al., 2004). Sandy soils usually have higher bulk densities (1.3 to 1.7 g/cm^3) than fine silts and clays (1.1 to 1.6 g/cm^3) because they have larger, but fewer, pore spaces. In clay soils with good soil structure, there is a greater amount of pore space, and many small pore spaces fit between them. Soils rich in organic matter can have densities of less than 0.5 g/cm^3 . Bulk density increases with compaction at depth and very compact sub soils or strongly indurated horizons may exceed 2.0 g/cm^3 (Cresswell and Hamilton, 2002).

In order to understand the spread of the current soil status in the country, it is clear that while the soils of Malawi have been grouped into 28 classes, they are predominated by three major soil types: (1) The Leptosols, which occur in most hilly areas of the country; (2) The Luvisols, which are the red-yellow soils of the Lilongwe plain and some parts of southern region; (3) The Lixisols, which are the alluvial soils of lacustrine and river-line plains, the Vertisols of the lower shire valley and Phalombe plain and the Mopanosols in the Liwonde and Balaka areas (Dewitte et al., 2013). Other relatively dominant soils include Acrisols, Cambisols and Ferralsols (Sileshi et al., 2010). Studies have shown that most of these soil types are not as productive under poor agricultural management even when inorganic fertilizers are put into use. The high risks associated with inorganic fertilizer on Acrisols and Lixisols could probably be attributed to their inherent infertility (Bationo et al., 2006), low resilience and high sensitivity (Stocking, 2006). Lixisols become depleted quickly under agricultural use, though their physical characteristics are generally better than those of Acrisols (Bationo et al., 2006; Stocking, 2006). Acrisols are acidic, strongly leached, have low base status (Bationo et al., 2006) and they become degraded very quickly when utilized (Stocking, 2006). Even when soil cover is good, Acrisols do not continue to produce reasonable maize yields for more than 4 years (Stocking, 2006). Sileshi et al. (2010) also showed that yield and yield gaps for most of the crops in these soils did not significantly differ. On Cambisols yield risks were generally lower confirming the fact that these soils have high resilience to degradation, and low sensitivity to yield decline (Stocking and Tengberg, 1999). They suffer degradation under persistent mismanagement, while

biological conservation methods can adequately maintain production (Stocking, 2006). This entails that all soil types can be as productive if they receive appropriate management and likewise they are vulnerable to degradation if not properly managed.

What are the implications for soil health and crop productivity based on the current soil status?

Soils with coarse textures may acidify easily compared to clay soils, because they have low organic matter content, a low buffering capacity, a low cation-exchange capacity (poor cation retention), and high rates of water percolation and infiltration (Buresh et al., 1997). However, in this study despite having most sampled soils with relatively high clay proportions, the soil analysis also revealed that %OM is low (<2%) in most of the sites such that the cation exchange buffer effect is limited. Soil organic matter (SOM) is important for healthy plant growing as it maintains favourable conditions supporting soil moisture retention, temperature, nutrient, pH, and aeration. SOM through the organic carbon also provides a steady food source for the decomposing soil biota. Unless the decomposition and loss of organic matter are halted in conventional tillage, the soil fertility will continue to decline and the system is not sustainable (Wolf and Snyder, 2003). From these results, the current soil fertility status is so low such that farming practices that ensure accumulation of organic matter needs to be encouraged in order to ensure improved soil productivity. Organic inputs have an important advantage over inorganic fertilizers with regard to fertility replenishment because they provide a source of C for microbial use. According to Palm (1995), recovery of N by the crop from the leaves of leguminous plants incorporated into the soil is generally lower (10 to 30%) than the recovery from N fertilizers (20 to 50%). Much of the remaining 70 to 90% of the applied organic N are not used by crops or leached and is incorporated into labile pools of soil organic N and C which support microbial growth. Soil microorganisms require C substrate for growth and subsequent release of the N to form soil N capital. Part of the bound N in recalcitrant fractions in the organic materials does also increase soil organic N (Giller et al., 1997; Buresh et al., 1997). Inorganic fertilizers do not contain C sources, and therefore much of the fertilizer N not used by crops is subject to leaching and denitrification losses in the absence of crop residue returns. Pieri (1987) reported that additions of N fertilizer alone did not increase soil C or N stocks in sandy soils but when complemented with organic inputs (crop-residue returns, manures, and composts) they increased soil N and C stocks, except in extremely sandy soils where there are very few clay particles to protect newly formed SOM from decomposition.

With respect to crop productivity, there is no doubt that

inorganic fertilizer gives higher yields than the organic inputs. Sileshi et al. (2010) emphasized that organic inputs from the legumes provide additional ecosystem services that cannot be provided by inorganic fertilizer. In addition, organic inputs from the legumes may have large impact on more sensitive and less resilient soils. Therefore, legume species should be targeted to niches where they can ensure soil cover, improve soil organic matter and maintain productivity. This ensures reduced yield risks, mitigated land degradation and enhances crop yields.

Is the current soil fertility status in Malawi reversible? Can agroforestry trees play a role?

When it comes to consistency on the use of inorganic fertilizer, it has been observed that many farmers switch back and forth between using and not using fertilizer from season to season (Duflo et al., 2008). It has also been reported that farmers are often risk-averse (Simtowe, 2006) as they find it difficult to recover the costs of fertilizer from their produce (Denning et al., 2009). Thus, the availability and use of inorganic fertilizers have also been low amidst growing land-use intensification and expansion of crop cultivation onto marginal soils. As a result, soil fertility has declined and it is widespread, particularly in sub-Saharan Africa (Henao and Baanante, 1999). It has been shown that most smallholder farming households in the sub-Saharan Africa are only able to afford fertilizer application of up to 8 kg/ha which is the lowest application rate to achieve increased yields (Morris et al., 2007) in the already nutrient deprived soils. On the other hand, continued and excessive use of N fertilizers cause problems of acidification and, the over-use of N and P fertilizers cause water pollution in the form of eutrophication among other negative effects on the environment (Brady and Weil, 2008; Olson, 1987). Studies have shown that the presence of nitrogen-fixing trees in a tree-crop farming systems (also commonly known as agroforestry systems) do improve nutrient use efficiency by providing a safety net to recover nutrients leached from the topsoil during intense rainfall and return them to the surface horizons on which crop roots primarily depend, in a manner analogous to the hydraulic lift of water (Sileshi et al., 2014). Furthermore, these tree-based systems enhance soil organic matter through production of good quality leaf biomass that decomposes easily releasing the most limiting nutrient which is nitrogen for subsequent support to crop growth. *Faidherbia albida*, *Gliricidia sepium* and *Tephrosia candida* are among the available tree species that shown significant increases in crop productivity and ensure food security (when integrated into maize cropping systems in rotational fallows or intercrops. Under good field management these nitrogen-fixing trees can be used singly or as a complement to limited inorganic fertilizer input (Akinnesi et al., 2012).

In conclusion, this study clearly shows that the soil fertility indicators include low to medium total nitrogen, available P and exchangeable K across the sites. The nutrient status is mostly affected by the low levels of %OM, associated %OC and pH. The fertility differences across the sites are due to the inherent soil texture properties. These results provide some basic understanding that soil health is varied in the different agro-ecologies such that for improved crop productivity is it paramount to consider site specific soil fertility management. The farmers in these areas must be encouraged to adopt the use of nitrogen-fixing tree-crop intercropping systems among other grain legume intercrops, as one way towards improving the soil organic matter for improved soil and crop productivity; consequently farmers' livelihood and resilience to weather variability is expected to improve over time.

Conflict of Interests

The authors have not declared any conflict of interests.

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