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Improvement of maize yield and soil fertility by 2-years compost application in Malawi's northern districts

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Fertilizer use in Malawi is limited due to the relatively high fertilizer price, improvement of fertilizer efficiency is therefore necessary to enhance both maize yield and soil fertility. 2-years compost application was conducted to evaluate its effectiveness in improving soil fertility and enhancing maize yields. Compost application was shown to be effective even at the early stage of application in improving soil fertility and consequently enhancing maize yields. Before compost application, soil fertility was quite poor reflected in a low maize yield (0 to 1.5 t/ha), however compost application made 2 to 4 times larger maize yields. Despite the sufficient amount of N (92 kgN/ha), single application of chemical fertilizer adversely affected maize yield coupled with the poor initial growths. Soil moisture content became 4 times larger with compost application with a shift from 5 to 20%. Moreover, CEC was improved from 10.2 meq/100mg to 13.7 meq/100mg by compost application, resulting in an increase of nutrient retention capacity. Soil C % decreased in 2.5 years if no compost was applied, but soil C % increased by compost application. As such compost application can be effective to maintain soil C % for enhancement of soil fertility. Nitrogen use efficiency (NUE) was greatly improved 2 to 5 times larger when chemical fertilizer (46 kgN) was applied mixed with compost while a single chemical fertilizer application (92 kgN) represented lower NUE than mixed application.

Keywords: compost, maize yield, soil fertility, CEC, soil C, nitrogen use efficiency

INTRODUCTION

Soil fertility and land productivity have been declining and becoming a significant problem in the sub-Saharan African countries including Malawi. This problem is now explicitly perceived as major constraint by farmers (Budelman and Defoer, 2000; Tully et al., 2015). Malawi government started the Farm Input Subsidy Program (FISP) in 2005 which was a large scale, national program aimed at enhancing household food security. However, fertilizer prices rose dramatically in 2007 and 2008 (Yara, 2008), doubling the cost of the FISP and leading to a

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projected budget shortfall of almost US$80 million. This rise in fertilizer prices is caused by the vulnerability of Malawi to international market, which is exacerbated by being landlocked (Denning et al., 2009) illustrated by the fact that a metric ton of urea which cost about U.S. $90 FOB (free on board) in Europe, arrive in Malawi at 8 times higher price of $770 (Sanchez, 2002). Given the high cost of fertilizer, efficient use of N fertilizer is of both agroeconomic and environmental importance.

According to the study conducted by IFA (1992), 50% of total arable land for maize was fertilized with the amount of 26 kg/ha in Malawi. This figure is rather low considering that the average value of fertilizer rate between 1994 and 1996 was 136 kg/ha in the world, and 55 kg/ha in Africa (FAO, 2006). Besides a low application rate of fertilizer, many Malawian farmers find fertilizer use to be of limited profitability or even negative effect (Ricker-Gilbert and Jayne, 2011; Kamanga et al., 2014). A profitability of fertilizer use is a constraint to its use on maize so that fertilizer efficiency, especially N use efficiency shall be improved.

The improvement of soil fertility status through the use of organic matter applications has been demonstrated by a number of researchers in Malawi (Sakala, 2003; Mustafa-Msukwa et al, 2011; Thierfelder et al. 2015). Compost application shall be a promising measure for enhancing soil fertility as a part of organic matter based technologies (Kumwenda et al., 1997; Scotti et al. 2015; Solomon and Jafer 2015). Since soils in Malawi are inherently poor in organic matter, nutrient retention capacity is low, and a leaching rate is high. An increase of the N-use efficiency by compost application is therefore quite necessary to decrease leaching loss.

Sustainable land management promotion (SLMP) project started in November, 2011 by the collaboration between Malawi and Japanese Governments with the objective of “Enforcement of technology to increase soil fertility” through compost application. Towards this, this study was carried out to evaluate its effectiveness of compost application both to improve soil fertility and to enhance maize growths in two crop seasons at 2013/14 and 2014/15.

MATERIALS AND METHODS

Experiment locations

The 2 years maize growing study was conducted to evaluate effects of compost application in the four stations, Lunyangwa (LNG), Banga (BNG), Mkondezi (MKD) and Ntchenachena (NTC) of the Department of Agricultural Research Services (DARS) in the northern Malawi (Figure 1). Average rainfall in the cropping season between October and May during 2002 to 2013 was 1,008 mm in LNG, 1,219 mm in BNG, 1,439 mm in MKD and 1,346 mm in NTC. Variety SC637 was cultivated for the maize growing test in both cropping seasons of 2013/14 and 2014/15. Split-plot having 3 x 3.5 m was designed with three replications. In order to avoid the border effects, two middle rows of each split-plot were harvested and weighted fresh maize grain *in situ* was converted to dry yield (t/ha) after drying.

Compost preparation

Different methods were adopted for compost making as shown in Figure 2. Windrow was made by placing the mixture of raw materials in a long narrow piled called wind-row while Changu was made by piling in a circle forming a conical shape. Application rates of composts were calculated based on N content which aims to determine the analysis. N content was adjusted to 92 kgN/ha which is the Malawian recommendation level described in the Guide to Agricultural Production (Ministry of Agriculture; MOA 1991). 46 kgN at basal and the remaining 46 kgN was applied at top dressing (Table 1). In a single chemical fertilizer application, two different application rates, recommended rate (RCF) (92 kgN/ha) and conventional rate (CCF) (46 kgN/ha) were applied by NPK at basal and urea at top dressing.

Soil analysis

Soil analysis was carried out to determine both current soil fertility level and effects of compost application on soil fertility. For the analysis, the analytical laboratory was established for the first time in the northern region of Malawi in SLMP. Moisture content was measured from samples collected with a 100 cc stainless steel cylinder. Sand content was measured by the nylon mesh method (Moritsuka et al. 2015). pH, Na and EC were measured after shaking soil samples for 1 h at a soil-to-water ratio of 1:5. K, NO_3, Na were measured by the Ion meters (HORIBA LAQUA twin, the model B-731 for K, B-741 for NO_3 and B-722 for Na). Available P was determined using the spectrophotometer (BELLSTONE WSP-UV800A) with the extraction solution by Mehlich III (Mehlich, 1984). Total C and N contents were determined by the Walkley-Black method (Walkley and Black, 1934) and by micro Kjeldahl method (AOAC 1995), respectively. Cation exchange capacity (CEC), calcium and magnesium were measured by Kjeldahl Ammonia Distillation method and by Complexometric Determination (Niina, 1960). For the results of maize yields and soil analysis, statistical analysis was conducted using the software JMP 8.0.2 version for Windows (SAS Inc., 2009). Tukey-kramer HSD test was performed for F-test at a significance level either at 0.1 or 0.5. N efficiency has been defined in different terms and at different scales by various researchers, but the concept of N efficiency is very useful for implementing a wise fertilizer use. The study adopted the definition used in Zimbabwe (Vanlauwe et al., 2011) in which an increase of grain yield per unit of fertilizer N applied over the unfertilized production is defined as Nitrogen Use Efficiency (NUE).

RESULTS, DISCUSSION AND CONCLUSION

Maize yield

Table 2 and Table 3 showed the yield results (dry grain weight) from the maize growing test at the four stations in 2014 and 2015. In 2-years experiment, higher average yields in the compost application were recorded in BNG, NTC while the lowest yield was recorded in MKD. Effects of compost application didn’t vary a lot between two methods and among the three environments. Yields in mixture were notably high, and which were higher than chemical fertilizer application (RCF, CCF) except for LNG 2014 (Table 2).

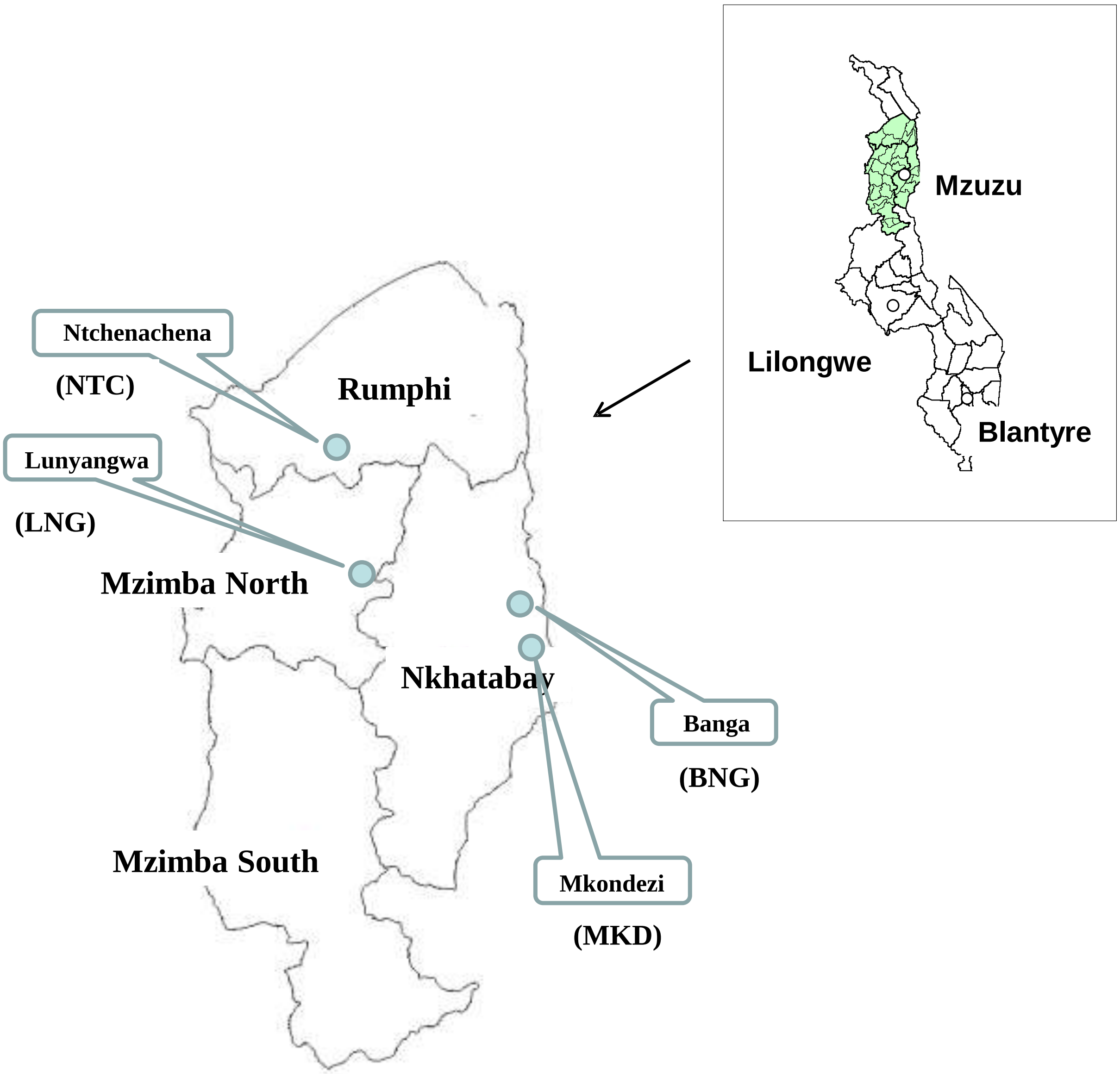

Figure 1. Locations of the four research stations where this study was conducted.

The yields in no treatment plot can be considered as the current soil fertility which is not influenced by any treatments, and which increased in the order of MKD (0.00 t/ha) < LNG (0.82 t/ha) < BNG (0.95 t/ha) < NTC (1.51 t/ha). These figures are low considering that average maize yield (t/ha) in 2008 to 2010 was 5.15 for world and 1.81 for Sub-Sharan Africa (FAOSTAT, 2013). No yield was recorded in MKD showing the current soil fertility is extremely low. Maize yields of other stations were almost as same as national average yield which was 1.3 metric tons per hectare (t/ha) during the 20 years from 1998 to 2007 (FAO, 2008).

Comparing to the existing soil fertility, compost application produced higher yields and their effects were as high as those of chemical fertilizer. RCF was the second lowest yield despite having the same N content as compost application. RCF was two times higher in N application rates than CCF, but yields of RCF were inferior than those of CCF. This fact indicates that N amount was not a determinant factor for maize yield in the studied soils. Moreover, the current soil fertility (No treatment) was almost the same in LNG and BNG but effects of compost application on maize yields were significantly higher in BNG, showing that there is a certain condition to activate effects of compost application.

Yields in 2015 increased from 2014 in most of stations except for MKD. In 2014, compost application produced high yields as chemical fertilizer in BNG, NTC and even superior yields in LNG, MKD. RCF showed a quite low

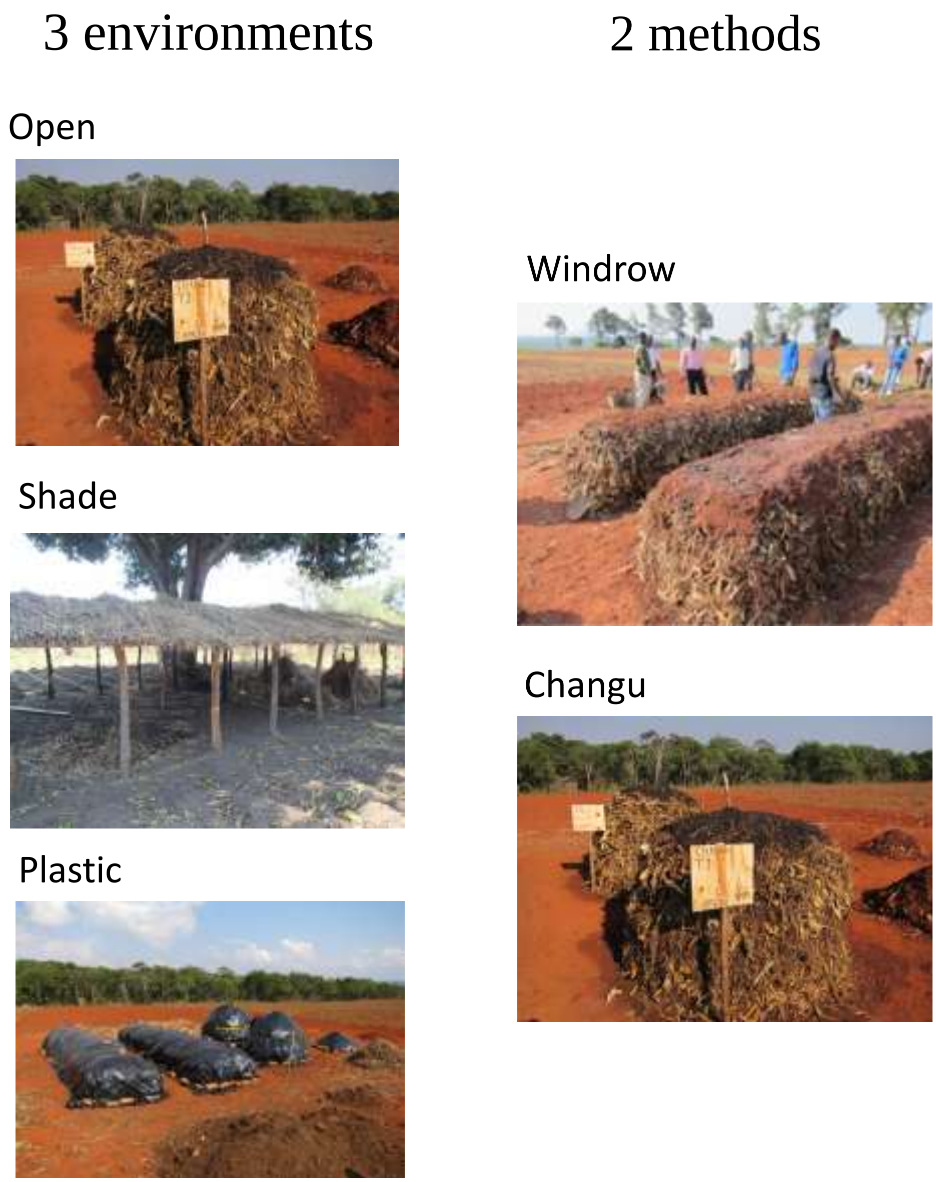

Figure 2. Three different environments and two methods examined in this study.

yield and survival rate in LNG while the mixture plot produced the highest yield (Figure 3). Growth difference among treatments became relevant 4 weeks after germination in MKD (Figure 4) as shown by poor crop developments in CCF, RCF in contrast to compost (Changu and Windrow) and Mixture.

Two years comparison showed different tendency regarding compost application effects (Figure 5). A significant decline of yield together with quite low survival rate was observed in RCF at LNG while both yield and survival rate were highest in Mixture. Rainfall in 10 to 15 days between male flowering and silk emergence is considered to be most important for maize growths since it influences effective growth and grain formation (Araus et al., 2012). Rainfall during this period in 2014 was 101 mm but only 61 mm in 2015 in MKD. Lesser amount of rainfall was attributable to the decline of maize yield from 2014 to 2015. NTC also showed highest yield in mixture which was 4 times higher than no-treatment (Control).

Changes of soil properties in two years

Soil chemical properties

Soil chemical properties determined before and after 2 seasons of compost application, were compared. Soils were weakly acidic to acidic before compost application

Table 1. Application and rates of compost and inorganic fertilizer and its application.

Treatment Category and Symbol		Results of Analysis				Application Rate	
		Total Nitrogen (%)	Available P (ppm)	Available K (mg/l)	Moisture (%)	Basal (kg/plot)	Top Dressing (kg/plot)
Compost	CO + L	1.13	6.28	270	33.4	6.4	6.4
	– L	0.74	3.45	400	33.4	9.8	9.8
	CS + L	1.13	3.58	270	25.6	5.7	5.7
	– L	0.78	4.94	340	25.6	8.3	8.3
	CP + L	1.12	4.73	380	26.9	5.9	5.9
	– L	1.12	9.45	340	26.9	5.9	5.9
	WO + L	1.10	4.64	370	33.4	6.6	6.6
	– L	0.89	2.12	460	33.4	8.1	8.1
	WS + L	1.11	3.79	480	25.6	5.8	5.8
	– L	0.76	3.03	220	25.6	8.5	8.5
	WP + L	1.13	4.49	210	26.9	5.8	5.8
	– L	1.00	3.58	360	26.9	6.6	6.6
Chemical fertilizer		(%)	(%)	(%)			
RCF	NPK 23-21-0	23	21	0		0.11	
	Urea	46	0	0		0.05	0.11
CCF	NPK 23-21-0	23	21	0		0.21	
	Urea	46	0	0			0.11
Mixture	Compost	1.32			19.8	4.6	
	Urea	46					0.11
No treatment	No composts and no chemical fertilizers						

CO = Changu Open, CS = Changu Shade, CP = Changu Plastic, WO = Windrow Open, WS = Windrow Shade, WP = Windrow Plastic, +L = With Legume Biomass, –L = without Legume Biomass; RCF = Recommended Chemical Fertilizer (92 kgN/ha); CCF = Conventional Chemical Fertilizer (46 kgN/ha); Mixture = Chemical Fertilizer (Urea) 50% + Compost 50%.

Table 2. Average yield (t/ha) between different composting methods and environments by stations (2014).

Composting methods and Environments		LNG	BNG	MKD	NTC
Methods	Changu	1.46[a]	3.29[ab]	0.67[a]	3.24[a]
	Windrow	1.26[a]	3.53[ab]	0.36[a]	2.35[a]
Environment	Open	1.55	3.49	0.52	2.04
	Shade	1.47	3.69	0.39	3.28
	Plastic	1.07	3.03	0.63	3.07
Legume	With legume	1.36	3.63	0.21	3.29
	Without legume	1.36	3.14	0.82	2.31
Chemical fertilizer	RCF	0.98[a]	2.29[ab]	0.09[a]	2.92[a]
	CCF	2.03[a]	3.21[ab]	0.57[a]	2.54[a]
Mixture		1.63[a]	5.48[a]	1.70[a]	5.77[a]
No treatment		0.82[a]	0.95[b]	0.00[a]	1.51[a]
	P value	0.34	0.02	0.57	0.24

Different letters mean statistically significant at 5% level.

and pH was the lowest in LNG (Table 4). Compost application increased soil pH in most of the stations except for BNG. A most significant change of pH was observed in LNG, with the change from 4.93 to 6.36.

Table 3. Average yield (t/ha) between different composting methods and environments by stations (2015).

Composting methods and Environments		LNG	BNG	MKD	NTC
Methods	Changu	2.78[ab]	6.28[a]	0.46[a]	5.24[b]
	Windrow	2.04[abc]	5.63[a]	0.35[a]	5.08[b]
Environment	Open	2.41	5.52	0.26	4.73
	Shade	2.27	5.33	0.44	5.69
	Plastic	2.55	5.51	0.45	5.06
Legume	With legume	2.49	6.08	0.36	5.27
	Without legume	2.33	5.70	0.46	5.05
Chemical fertilizer	RCF	0.11[c]	6.44[a]	0.03[a]	4.00[bc]
	CCF	1.84[abc]	5.81[a]	0.07[a]	3.72[bc]
Mixture		3.45[a]	6.75[a]	0.77[a]	8.03[a]
No treatment		0.86[bc]	2.65[a]	0.08[a]	1.75[c]
	P value	< 0.001	0.33	0.20	< 0.001

Different letters mean statistically significant at 5% level.

Figure 3. Growths conditions of the trials, mixture (left) and in RCF plot (right) in LNG, 2015.

Acidity amelioration by compost application would be more effective if soils are quite acidic and not coarse texture.

pH also significantly changed by chemical fertilizer application (CCF and RCF), and by mixed application of compost and chemical fertilizer. Since pH in no treatment plot showed no significant difference in two years, pH increase in chemical fertilizer plots would be due to the fact that one H^+ ion is absorbed by the plant (or OH^- excreted) at the uptake of nitrate.

Good quality topsoil should have EC within the range of 100 to 1500 µS/cm (Bardgett, 2005). EC before and even after compost application were mostly less than 100 µS/cm showing soil fertility level was low. Low soil fertility also was reflected in low content of NO_3, K and P. Since changes of EC in two years were only significant in BNG, soil fertility improvement was not sufficient by 2-yrs compost application.

Soil C % is the key of soil fertility and all stations showed C % was less than 1.0 % (Table 4). In 2.5 years from December , 2012 to May, 2015 soil C % decreased significantly in no treatment and CCF while no significant change was recorded in Changu and significant increase was recorded in Windrow (Table 5). 15 ton/ha of compost was applied in this study however this amount was not enough to increase soil C in Changu and Mixture, but was only able to maintain current soil C level. Since soil C level was quite low in the study area, further study to

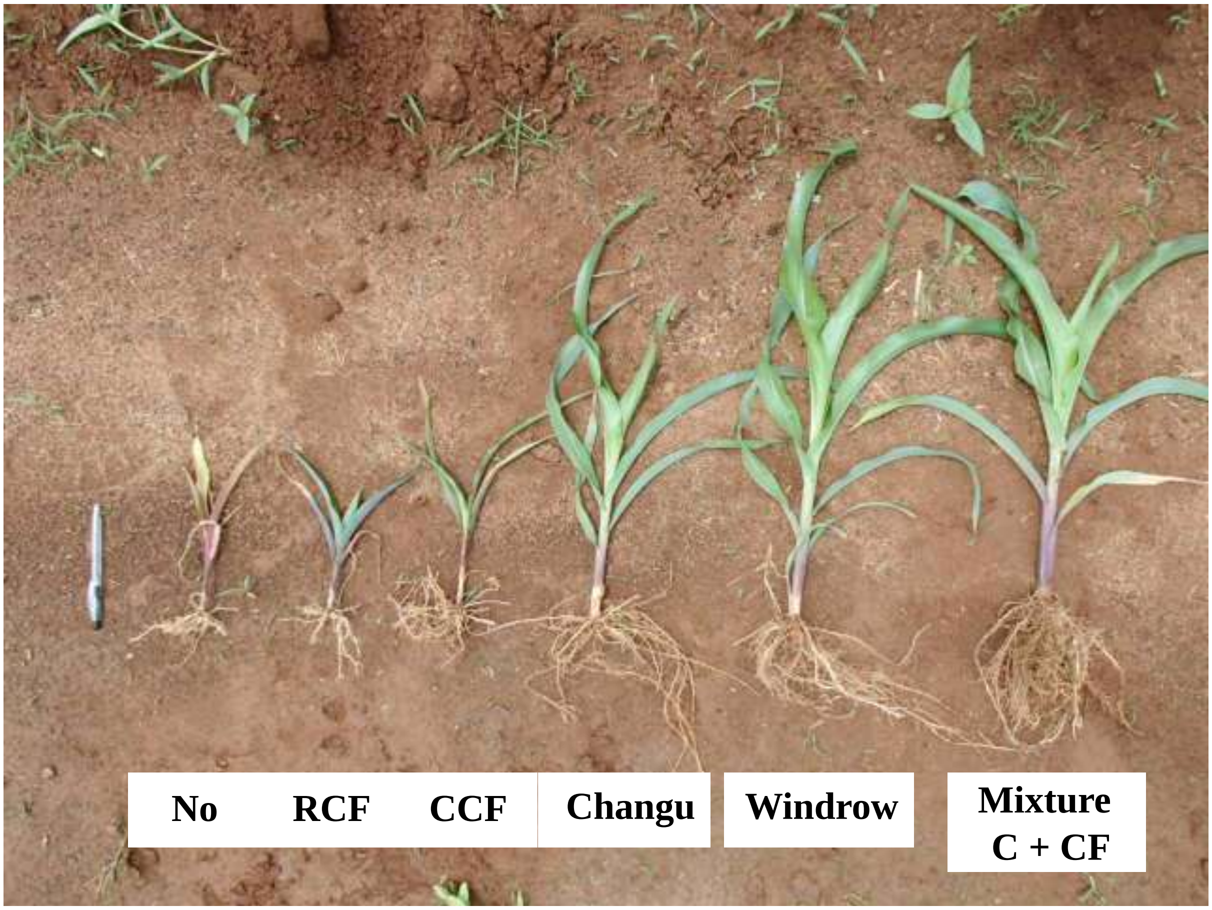

Figure 4. Growths conditions at the different treatments 4 weeks after germination in MKD (No: no treatment, RCF; recommended chemical fertilizer, CCF: conventional chemical fertilizer, C + CF: mixture of compost and chemical fertilizer).

increase current C % by compost application will be necessary in terms of application amount and compost quality.

Soil physical properties

Soil moisture content

Keeping a good range of soil moisture content is important for agriculture practice. When a moisture content is low, microbial activity is hampered and then important N source as microbial biomass cannot be expected. Compost can be counter-measure against drought. US compost council (2008) has stated that the frequency and intensity of irrigation may be reduced by compost because of its drought resistance and efficient water use. Water holding capacity can be increased even in sandy soils with the addition of compost. As most of project site soils are sandy, effect of compost application would be highly expected.

Soil moisture content changed after compost application in MKD and BNG (Figure 6). At MKD, soil water contents before compost application were around 5%, but it increased over 20 % which is almost 4 times higher. Likewise, 10% increase in Changu and Windrow, and 15 % in Bokasi at BNG. As over 20% of moisture content was reported as an appropriate maize growth (Quaye et al., 2009), an increased soil water content by compost application in this study could have attributed to an increased in maize yield.

Improvement of CEC

Sandy soils such as this study soils are subject to a significant nutrient leaching unless proper measure is not provided. Compost application will help to refrain the soil from leaching because negatively charged compost attracts positively charged bases such as Mg^{++}, Ca^{++} and K^{+}. Also, compost indirectly reserve N in soils.

Microorganisms digest organic matter (composts) and

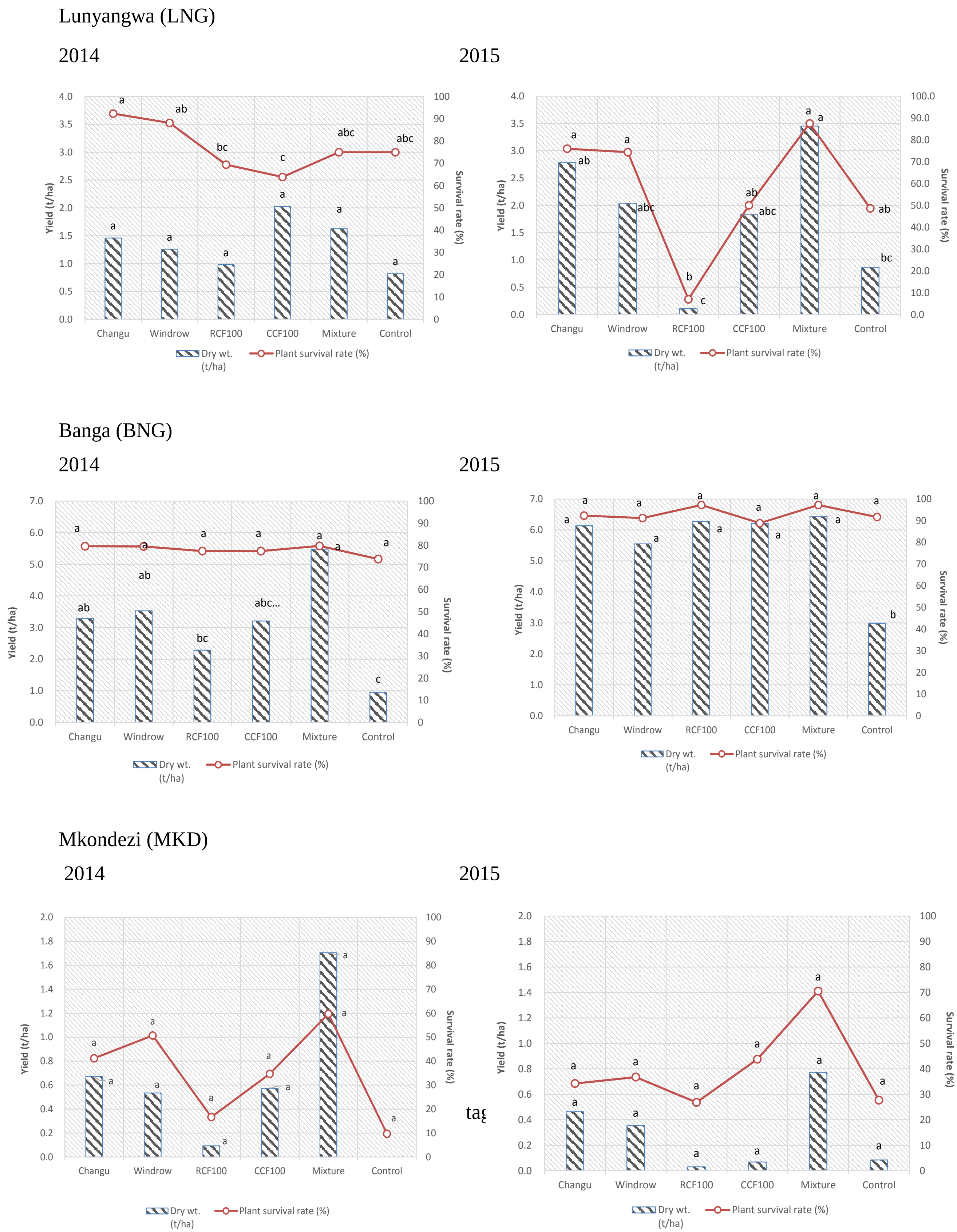

Figure 5. Maize yields and survival rates in the growing tests at the four stations in 2014 and 2015. Different letters among the treatments indicate the significance at the 5% level.

Table 4. Soil analysis results in three times (n = 23 in 2012 Dec, n = 16 in 2015 May)

Station	Collection time	Sand content (%)	pH	EC (μS/cm)	NO_3 (mg/l)	P (μg/g)	C (%)	N (%)	K (mg/l)
LNG	2012 Dec	54.5	4.93^a	54.1^a	34.5^a	-	0.39^a	0.10^a	4.2^a
	2015 May		6.36^b	57.8^a	28.8^a	2.89	0.33^a	0.18^a	37.6^b
BNG	2012 Dec	73.8	5.72^a	20.3^a	314.6^a	0.94^a	0.39^a	0.17^a	12.1^a
	2015 May		5.63^a	152.8^b	24.1^b	5.03^b	0.42^a	0.22^a	24.3^a
MKD	2012 Dec	71.4	5.69^a	44.1^a	51.9^a	1.37^a	0.63^a	0.12^a	43.2^a
	2015 May		6.26^b	39.3^a	19.3^a	1.76^a	0.17^b	0.15^a	25.3^a
NTC	2012 Dec	70.3	5.22^a	28.3^a	97.7^a	3.59^a	0.52^a	0.13^a	56.9^a
	2015 May		6.25^b	51.9^b	17.9^b	1.50^b	0.20^b	0.12^a	31.2^b

Table 5. Changes of soil C % before and after compost application (n = 55 in all treatments, n = 17 in Changu, n = 14 in Windrow, n = 4 in Mixture, n = 6 in CCF, n = 4 in No treatment).

Collection time	All treatments	Changu	Windrow	CCF	Mixture	No treatment
2012 Dec	0.48a	0.43^a	0.34^b	0.42^a	0.52^a	0.43^a
2015 May	0.28a	0.43^a	0.63^b	0.21^b	0.47^a	0.12^b

Different letters mean statistically significant at 5% level.

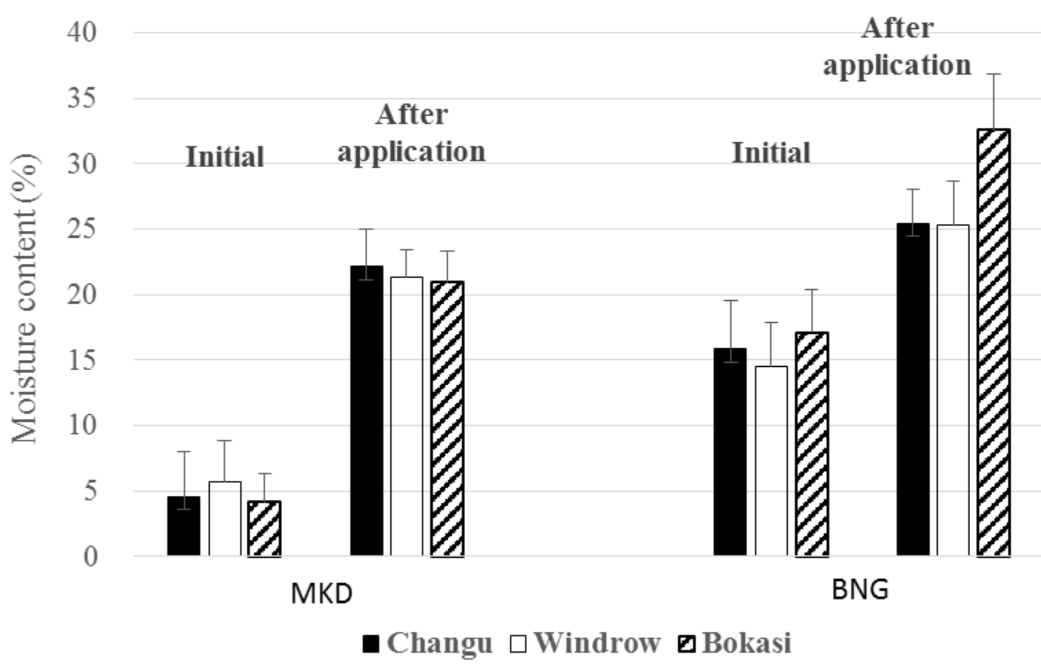

Figure 6. Changes of soil moisture content after compost application at MKD and BNG.

entrain into its body which becomes N reservoir. Cation exchange capacity (CEC) is an important soil property influencing soil structure stability, nutrient availability, soil pH and the soil's reaction to fertilizers and other ameliorants (Hazelton and Murphy, 2007). CEC is greatly determined by organic matter and clay content, but both

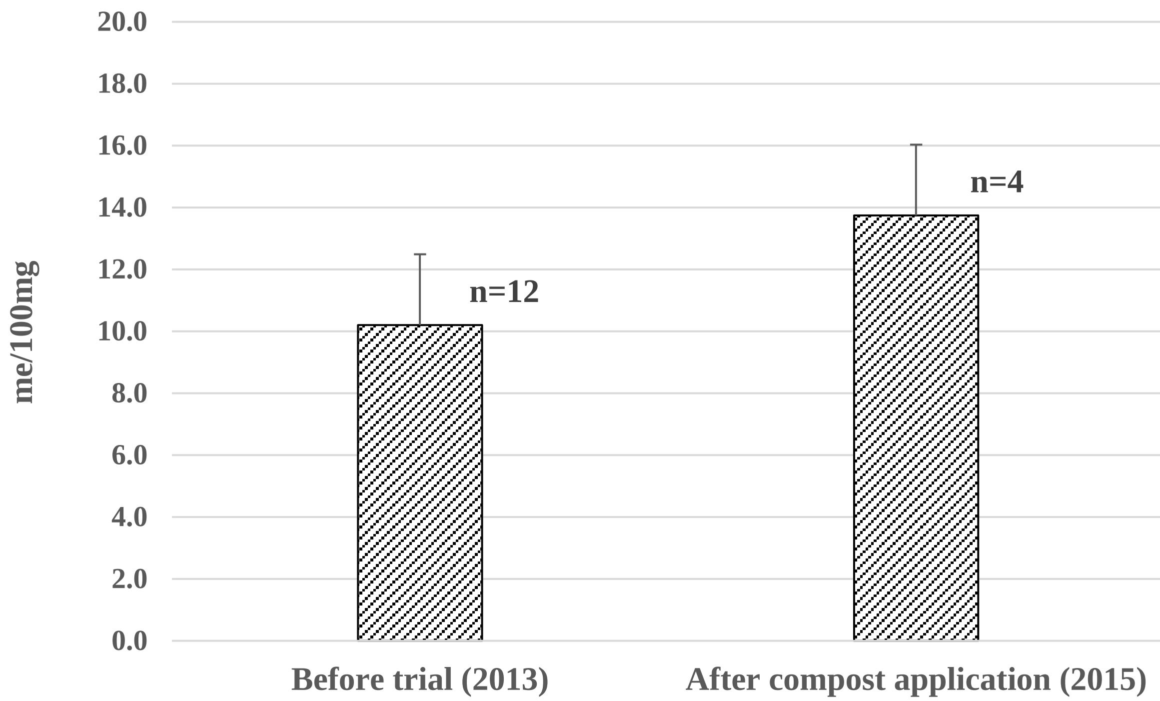

Figure 7. CEC before compost trial and after compost application in LNG.

Table 6. Base saturation of each station soil.

	BS (%)	Ca (%)	Mg (%)	K (%)
LNG	71.6	42.0	28.8	0.7
MKD	116.7	68.4	47.8	0.5
BNG	89.1	59.0	29.6	0.5
NTC	84.3	57.1	26.6	0.6

are quite low in the studied soils. Before starting compost trial, the mean CEC in LNG was 10.2 meq/100mg but it increased to 13.7 meq/100mg after compost application since compost had higher CEC values (Figure 7). Retention of nutrients in the topsoil can be promoted by an increased CEC stimulated by compost application.

Base saturation

Measured values of CEC (=13), base elements (K, Mg, Ca) and base saturation (BS) were calculated for each stations assuming that bulk density is 1.2, and thickness of soil is 10 cm (JICA SLMP Expert work report, March 2013, unpublished). Consequently, 71.6±22.1 meq/100g for LNG, 116.7±55.2 meq/100g for MKD, 89.1±23.3 meq/100g for BNG, and 84.3±22.1 meq/100g for NTC were obtained (Table 6). BS values ranged between 80 and 100, which were within the optimal range.

Optimal Ca saturation is between 60 and 80% but LNG showed only 42%. Moreover, K % was quite low at all stations considering that optimal range is over 2. The mean K value in LNG was 4.5 mg/100g. Since the required K value is 12.2 mg/100g, 7.7 mg/100g which is approximately 77 kg/ha are required. Mean K value of prepared composts was 55.8 mg/100g, and then 67 kg/ha which will be provided if 12 ton/ha of compost is applied in the application rate of Changu in SLMP.

Nitrogen use efficiency (NUE)

Leaching loss was reported as much as 53.6% of applied N inorganic fertilizer in Dedza, Malawi (Snapp et al. 2001), which is close to the values shown on sandy soils in Zimbabwe (Hagmann, 1994; Vogel et al., 1994). Nitrogen use efficiency (NUE) was estimated for the full rate and the half rate of chemical fertilizer compared with the conventional fertilizer rate. NUE was 44 in the conventional rate at Dedza, and ranged between -0.2 and 35 in 92 kgN application rates (Table 7). Even lower N rate (46 kgN) produced higher NUE than those of high rate (92 kgN).

This results is consistent with the finding of Whitbread et al. (2013) that NUE decreases with increasing in N rate and the highest NUE with moderate levels of N fertilizer rates (15 to 30 kgN/ha). NUE was much higher at mixture trials indicating that compost application is effective in

Table 7. Nitrogen balance and N use efficiency (NUE) in Dedza and SLMP project (Upper row; conventional 92 kgN, lower row; compost mixed 46 kgN).

	LNG 2014/15	BNG 2014/15	MKD 2014/15	NTC 2014/15	Dedza (Snapp et al. 2001)
Fertilizer rate (kg N ha^{-1})	92 46	92 46	92 46	92 46	69
Maize yield (kg N ha^{-1})	1.836 3.453	6.214 6.443	72 812	3.716 8.035	3.033
Removal N by harvest (kg N ha^{-1})	32 59	105 108	3.1 15	63 135	52
N leached (kg N ha^{-1})	-	-	-	-	37
NUE (kg maize/kg N applied)	10.6 56.3	35 75	-0.2 15	21.4 136.6	44

increasing NUE.

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Conflict of interests

The authors have not declared any conflict of interests.

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