Quantifying effects of selected soil fertility management techniques on water use efficiency in the Central Highlands of kenya

ABSTRACT

Declining rainfall distribution and variability lead to low soil moisture amounts and high evapotranspiration rates reducing water use efficiency that negatively affects crop productivity. Various soil fertility management techniques have been put in place to improve soil fertility status but there is little attempt to asses there effects on water use efficiency and grain yields. The overall objective of the study was to quantify the effects of soil fertility management techniques on water use efficiency in the Central Highlands of Kenya. The experiment was laid out in a randomized complete block design with fourteen treatments replicated four times. Treatments were sole mineral fertilizer (Rf), crop residues + mineral fertilizer (RMf), crop residues + mineral fertilizer + animal manure (RMfM), crop residue + Tithonia diversifolia + animal manure (RTiM), crop residue + Tihonia diversifolia + rock phosphate (RTiP). Data on yield and water use efficiency was analysed using statistical analysis systems software version 9.2 at *P*=0.05. We observed significant (*P*<.0001) effect of the treatment on biomass water use efficiency during the short rains 2017, however, there was no significant effect of the treatments on grain water use efficiency because of the frequent dry spells that occurred during the study period. Soil fertility management techniques had a significant effect on grain yield at *P*<.0001 during the study period. Yields increased significantly (P<0001) under Rf, RMf, RMfM RTiM and RTiP by 90, 110, 120, and 176%, respectively. Water use efficiency also increased significantly under Rf, RMf, RMfM RTiM and RTiP by 200, 140, 180, 129, and 176%, respectively compared to the control. From the study the combination of organic inputs and mineral fertilizers enhanced water use efficiency and yield hence provides a preferred practise for improved water use efficiency and yield increase.

Keywords: water use efficiency, soil fertility management, rain-fed agriculture

1. INTRODUCTION

Agricultural productivity is declining worldwide due to decreased rainfall amounts (1). In Sub-Saharan Africa (SSA) agricultural productivity has declined steadily, posing a challenge to food security (2).this is mainly because over 80% of Sub-Saharan Africa depend mainly on rain-fed agriculture(3). In the central highlands of Kenya, smallholder farmers continue facing a decline in agricultural productivity(4) due to decline in soil fertility as well as reduced rainfall coupled with frequent dry spells that occur during the most critical crop growth stages (5). For these reasons soil fertility management (SFM) practices like mulching, use of mineral fertilizers, cereal-legume intercrop and animal manure have been put in place. They have shown remarkable increase in yields however, the focus has been mainly on improving the soil quality status (4) hence their effect on water use efficiency is limited hence the need to quantify the effects of this practices on water use efficiency.

Despite the fact that rainfall is not sufficient and the quantity is decreasing over time, most smallholder farmers in the central highlands of Kenya depend on rainfall for agricultural production (6). This is evident from the prolonged periods of droughts and dry spells observed in the central highlands of Kenya by various researchers such as (7,8). Additionally, poor soil fertility management practices that focus on conservation water and soil moisture are less practised by the farmers (4). Smallholder farmers in the central highlands of Kenya practise rigorous and continuous land cultivation leading to soil deterioration. Crop residue incorporation is less practised due to competition from other uses such as animal feeds and to some extent they are burnt after harvesting (4). The application of mineral fertilizes is limited due to unaffordability. The low soil fertility inputs application coupled with continuous and rigorous ploughing leads to reduced water use efficiency and low soil nutrient replenishment hence low yields (4). Therefore, to alleviate the water scarcity issues proper soil water conservation measures need to be practised to full capacity to adapt to seasonal rainfall variability.

For instance the use of crop residue and mineral fertilizers increases the soil organic matter enhancing soil fertility and increasing yields (9). Crop residue adds nutrients to the soil upon decomposition indirectly in contrary to the mineral fertilizer which directly adds nutrients to the soil and taken up by the crop (10). The synergetic effect of the combinations results to increased yields(11). Additionally, animal manure improves soil organic matter (SOM) enhancing soil moisture and retention and nutrient availability leading to increased yields despite their implications the adoption of this practices is quite low and also they face competition from other uses. For example, crop residues are widely used as animal feeds and animal manure for house building (4).

Water use efficiency is defined as the aboveground biomass production per unit area per unit evapotranspiration (12). Water use efficiency can be expressed based on vegetative growth or reproductive (grain) growth (13). It is as a result of many factors including crop type, water availability, agronomic and economic factors. Soil management practices have an impact on water use efficiency through the change in energy and plant photosynthetic efficiency (14) .they affect water and nutrient status within the soil and their impact on plant response in terms of increased plant growth and yield which offers an opportunity to improve water use efficiency (15). The use of mulch has proved to increase soil moisture content in various studies (16), (17), (8). Qi et al.,(18) also reported an increase in soil water content reducing evaporation rates under the mulching strategy. Mulching also reduces the impact of raindrops, thereby maintaining soil aggregation and reducing soil loss (16). Mulching ensures water availability for crops uptake (19). The use of legume-maize intercrop has shown increased agricultural productivity (20), this is as a result of nitrogen (N) fixed in the soil by the legume crop. Contrary, it can lead to decreased yields as well as soil moisture due to the competition of resources (20). Tillage practices such conventional tillage which entails soil inversion breaks down soil aggregates increasing soil porosity (12) leading to increased infiltration. Minimum tillage, on the other hand, leads to reduced soil disturbance enhanced soil moisture storage under long term conditions (21).

The combined effect of increasing water use efficiency and the addition of nutrients by organic mulch contributes to enhancing soil quality hences increase in productivity(22). Mineral fertiliser, especially the nitrogen phosphorous and potassium NPK, leads to proper root development, increasing the ability to tap water from the soil. Proper understanding of the effects of these technologies on water use efficiency will help increase agricultural productivity.

Use of organic inputs, mineral fertilisers and animal manure enhance soil fertility replenishment, which could enhance water use efficiency. *Tithonia diversifolia* (a herbaceous flowering plant whose green bimomass has been recognised as an effective source of nutrients for soils) increases soil organic matter due to its high rate of decomposition. The increased organic matter enhances the ability of soil to hold water, thereby increasing soil moisture. The SFM practices maintain soil aggregate stability increasing the water holding capacity of the soil apart from increasing the soil organic matter and nutrient cycling (23). Additionally, they provide soil surface cover reducing evaporation losses and surface runoff (24). Proper decisions concerning the appropriate practice to adopt as well their accrued benefits should be made. The choice should not solely be based on the short term benefits but sustainability as well (25). Therefore, the study sought to quantify the effects of selected technologies on water use efficiency.

2. MATERIAL AND METHODS

2.1 Study area

The study was implemented at Kangutu Primary school (00°98′ S, 37° 08′ E) in Meru south sub-county in Tharaka Nithi County (Figure 1). Meru sub-County is located in the upper midland zone two (UM2) which is a predominantly coffee growing zone and upper midland zone three (UM3) agro-ecological zones which is the marginal coffee zone. The sub-County lies at an altitude of 1500 m above sea level and has an annual mean temperature of 20°C. It receives a total annual rainfall of 1200 to 1400 mm (26) that is highly variable both spatially and temporally (7)* The rainfall is bimodal with long rains starting from March to mid -June and short rains from mid-October to December hence two cropping season annually. The area is predominantly a maize growing zone. The soil type of the study area is *humic nitisols*, characteristically deep and weathered soil with moderate to high inherent fertility. More details about the soil chemical and physical properties are shown in (Table 1 and 2).

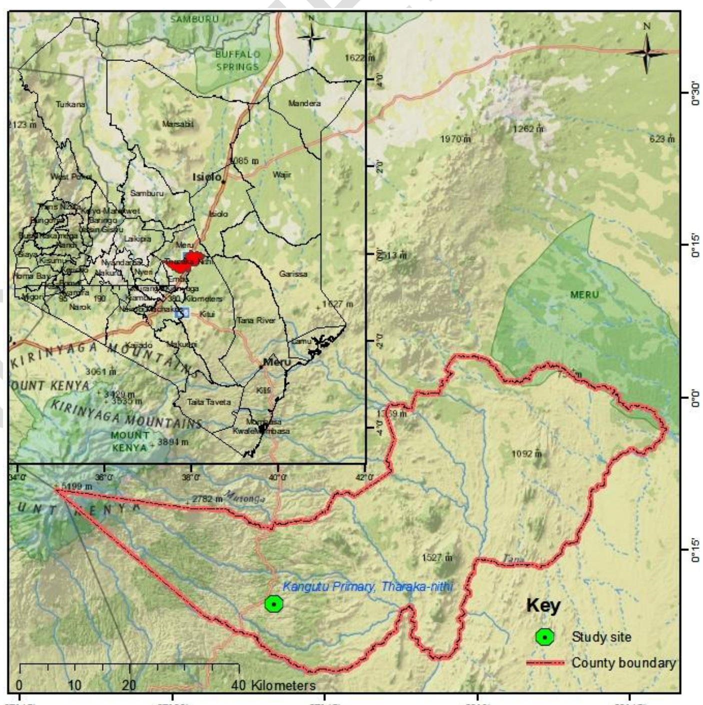

Figure 1 Map of the study area.

2.2 Experimental design

The field experiment was laid out in a randomised complete block design (RCBD) Tillage and soil inputs were used as combined treatments (Table 1). The treatment combination resulted in fourteen treatments replicated four times. In minimum tillage land preparation was done using a machete at 10 cm depth while in conventional tillage land was prepared by hand hoeing to 15 cm depth. The animal manure was acquired from the local farms, mixed and dried under a shade for two months before application. Crop residue (Maize stover), *Tithonia diversifolia* and animal manure were incorporated into the soil to a depth of 15 cm during land preparation (two weeks to the onset of the season) throughout the experimental period in the CT system (25). Under minimum tillage (MT) system, the maize stover was surface applied while *Tithonia diversifolia* and animal manure incorporated into the soil to a depth of 10 cm in the planting holes (25). Nitrogen was split applied at the rate of 30 kg/ha during planting and 30 kg/ha at knee height. Phosphorus was applied as Triple Super Phosphate (TSP) during planting at the rate of 90 kg/ha (Table 3)(11). The experiment was carried out for two season short rains of 2016 (SR16) and short rains of 2017 (SR17).

Table 1 soil physical and chemical properties at the beginning of the study period

Treatment	**Chemical Properties**					**Physical properties**			
						Bulk density	**texture**		
	pH	**OC**	**K**	**Mg**	**N**		**sand**	**silt**	**clay**
CtC	4.75	1.23	0.44	1.17	0.14	1.00	13.50	15.50	71.00
CtMf	4.75	1.23	0.44	1.17	0.14	0.91	14.00	15.50	70.50
CtRMf	4.75	1.23	0.44	1.17	0.14	0.98	15.00	14.00	71.00
CtRMfM	4.75	1.23	0.44	1.17	0.14	0.95	12.50	16.00	71.50
CtRML	4.75	1.23	0.44	1.17	0.14	0.96	18.50	9.50	66.00
CtRTiM	4.75	1.23	0.44	1.17	0.14	0.92	14.50	17.00	69.50
CtRTiP	4.75	1.23	0.44	1.17	0.14	0.94	14.50	15.50	70.00
MtC	4.75	1.23	0.44	1.17	0.14	0.99	14.00	17.00	69.00
MtMf	4.75	1.23	0.44	1.17	0.14	1.05	13.00	17.00	69.50
MtRMf	4.75	1.23	0.44	1.17	0.14	0.96	11.50	17.50	71.00
MtRMfM	4.75	1.23	0.44	1.17	0.14	0.97	13.50	16.50	70.00
MtRML	4.75	1.23	0.44	1.17	0.14	0.94	13.50	15.50	71.00
MtRTiM	4.75	1.23	0.44	1.17	0.14	0.93	13.50	16.00	70.50
MtRTiP	4.75	1.23	0.44	1.17	0.14	0.99	12.50	16.50	71.00

Table 2 chemical soil properties at the end of the study period

Trt	**pH**	**OC**	**N**	**K**	**Mg**	**Ca**
C	4.96	1.63	0.16	0.27	1.58	2.25
CtMf	4.54	1.75	0.17	0.26	1.40	2.20
CtRMf	4.84	2.13	0.17	0.28	1.44	2.50
CtRMfM	4.91	1.79	0.18	0.37	1.63	3.50
CtRML	5.20	1.79	0.17	0.45	1.56	3.90
CtRTiM	5.19	1.92	0.18	0.64	1.58	5.33
CtRTiP	5.12	1.91	0.18	0.55	1.49	3.05
Mt	4.83	1.78	0.17	0.30	1.42	2.30
MtMf	4.49	1.74	0.16	0.21	1.45	2.40
MtRMf	4.60	1.73	0.16	0.29	1.48	2.75
MtRMfM	4.96	1.73	0.17	0.49	1.57	4.15
MtRML	5.35	1.94	0.17	0.66	1.60	4.48

MtRTiM	5.41	1.90	0.18	0.85	1.70	4.58
MtRTiP	5.21	2.00	0.19	0.46	1.61	5.30

Table 3 Treatment combinations as implemented in the study area.

Treatment (a combination of tillage and soil organic inputs)	Abbreviations
Control	C
Conventional tillage + mineral fertilizer	CtMf
Conventional tillage + crop residue + Mineral fertilizer	CtRMf
Conventional tillage + crop residues + Mineral fertilizer + Animal manure	CtRMfM
Conventional tillage + crop *Tithonia diversifolia* + phosphate rock (Mijingu	CtRTiP
Conventional tillage + crop residue + Animal manure + Legume intercrop (Dolichos lablab)	CtRML
Conventional tillage +crop residue + *Tithonia diversifolia* +Animal manure	CtRTiM
Minimum tillage	Mt
Minimum tillage + mineral fertilizer	MtMf
Minimum tillage + crop residue +Mineral fertilizer	MtRMf
Minimum tillage + crop residue + mineral fertilizer + Animal manure	MtRMfM
Minimum tillage+ crop residue+ *Tithonia diversifolia*+ Phosphate rock (Mijingu)	MtRTiP
Minimum tillage + crop residue + Animal manure + Legume intercrop (Dolichos lablab)	MtRML
Minimum tillage + crop residues + *Tithonia diversifolia* + Animal manure	MtRTiM

2.3 Grain and stover data

Maize was harvested at maturity by omitting the guard rows, the first and the last maize plants in each row to reduce trans-boundary effects. The fresh weight was determined immediately after detaching the cobs from the stover. Later the cobs were sundried and hand shelled after which the weight was determined. Stover weight was determined at harvest and samples taken weighed and further dried under shade until constant weight. The ultimate weight of the dry stover grain was used to correct for moisture content of the stover weight and derivation of the per hectare stover and grain yield**.**

2.4 Rainfall and moisture data

Rainfall was recorded daily using a manual rain gauge installed at the site around 20 m from the experiment plots. For soil moisture PVC access tubes were installed at the middle of each plot and soil moisture measured weekly at a depth of 0-80. This was done at a regular interval of 10 cm using Diviner2000™ Version 1.5 190 capacitance sensor (Sentek Sensor Technologies, Stepney, South Australia). During the long rains 2017 moisture was not determined because the probe was damaged.

2.5 Data analysis

Data was subjected to analysis of variance (ANOVA) in Statistical analysis systems 9.3 software (27). Where there was stastitical mean difference, the mean separation between treatments was done using Duncan multiple range test at p=0.05.

3. RESULTS AND DISCUSSION

3.1 Rainfall distribution

Varying rainfall amounts and distribution was observed. The cumulative rainfall received during the short rains 2016 and 2017 was 381 and 571 mm, respectively. (Table 4) there were period of dry spells ranging between 10-21 days at the beginning of the SR16 and a meteorological drought of 31 days at the end of the season (Figure 1). During the SR17 dry spells of 17,15 and 27 days were experienced.

Table 4 Rainfall characteristics for the short rains 2016 and 2017.

	SR16	SR17
Onset	15th October	15th October
Cessation	31st January	31st January
Cumulative rainfall	385mm	571mm
5-10 days	3	1
11-15 days	1	2
More than 15 days	1	2
Total dry spells	5	5

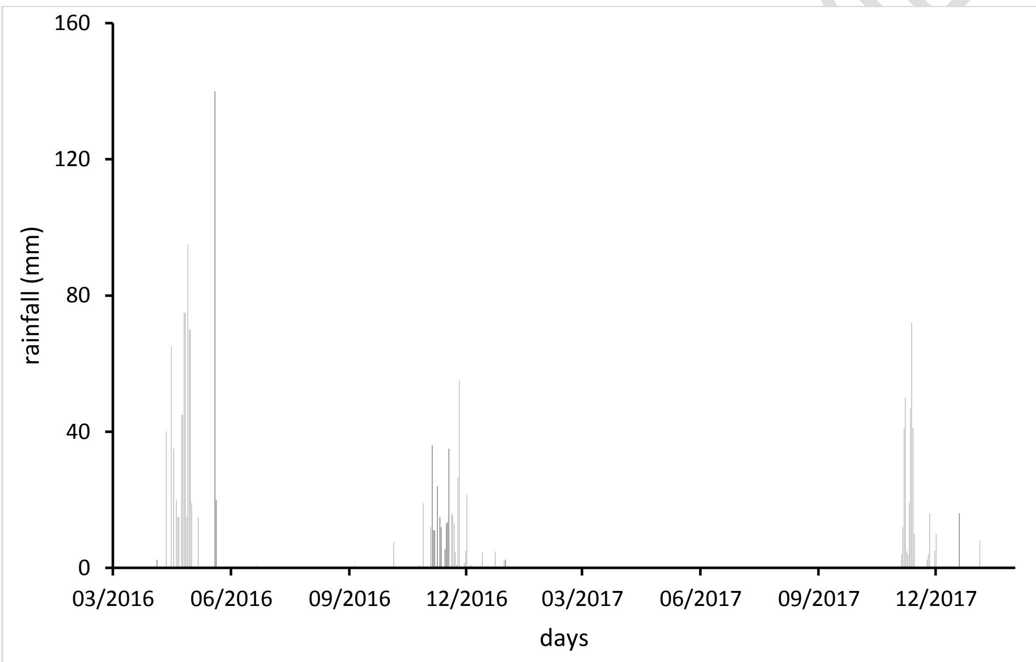

Figure 2 rainfall distribution during short rains 2016 and 2017

The study site received little rainfall due to variations in the rainfall patterns as observed by (28). We observed frequent dry spells especially during the early stages of the crop growth and at the vegetative stages where water is essential. This concurred with the findings of (11) who reported the frequency of dry spells during the critical stages of crop water requirements. A meteorological drought was also experienced in both season ascribing to the lack of rainfall for more than 15 days. The findings tally with the findings of (29). From our findings rainfall was insufficient especially during the critical crop growth stages with the frequent dry spell affecting crop productivity (7).

3.2 Yield

The treatments significantly affected the grain yields (P<0001) during the two seasons and stover yield during the SR17 (Table 3). Treatments containing mineral fertilizer and crop residue and animal manure had significantly (Table 3) higher yields compared to the control. Treatments comprising crop residue and mineral fertiliser (CtRF) had an increase in yields by 110% SR16 compared to the control. The use of mineral fertiliser, crop residue and animal manure (CtRMfM) led to an increase in yields by 120% compared to the control and MtRMfM 120 during the short rains SR16. This was also the case during the SR17, (Mf) increased the yield by 90% compared to the control. Treatment containing mineral fertiliser, animal manure and crop residue (CtRMfM) gave higher yield by 130% compared to the control. (MtRMf) and (MtRMfM) increased yield by 120% and 90%, respectively compared to the control. CtRMf had the highest increase in stover yields at 164% compared to the control during the SR16. This was different during the SR17 where MtRMf had the highest increase in yields at 188% compared to the control.

Table 5 grain yields at Meru south during the SR16 and SR17

Treatment	Grain mg/ha		Grain mg/ha	
	SR16	SR17	SR16	SR17
C	0.1^{e}	0.1^{e}	3.31^{ab}	1.54^{ef}
CtMf	0.7^{bcd}	0.9^{abc}	5.34^{a}	5.95^{ab}
CtRMf	1.1^{ab}	1.1^{ab}	5.43^{a}	5.66^{ab}
CtRMfM	1.2^{a}	1.3^{a}	4.91^{ab}	5.24^{ab}
CtRML	0.1^{e}	0.1^{e}	1.59^{b}	1.67^{ef}
CtRTiM	0.7^{bcd}	0.4^{de}	3.42^{ab}	4.44^{bc}
CtRTiP	0.6^{ed}	0.5^{cde}	4.9^{ab}	3.15^{de}
MtC	0.1^{e}	0.1^{de}	3.07^{ab}	1.49^{f}
MtMf	0.7^{bcd}	0.7^{cde}	5.07^{ab}	6.25^{a}
MtRMf	1.2^{ab}	1.2^{ab}	4.66^{ab}	5.35^{ab}
MtRMfM	0.9^{abcd}	0.9^{abcd}	4.46^{ab}	4.64^{abc}
MtRML	0.1^{e}	0.1^{e}	2.84^{ab}	2.5^{def}
MtRTiM	0.4^{cd}	0.4^{de}	3.155^{ab}	3.39^{cd}
MtRTiP	0.4^{de}	0.4^{de}	3.29ab	1.67^{ef}
P	<.0001	<.0001	0.05	<.0001

Means with the same letter(s) within the same column are not significantly different at P=0.05.

Generally, treatments comprising (CtRMf and (CtRMfM) had a significant increase in yield. This could be ascribed to the combined effect of animal manure, mineral fertiliser and crop residue in replenishing the soil through the addition of nutrients. Animal manure increases soil organic matter and amends soil improving soil fertility status as reported by (The resultant is the availability of nutrients for plant uptake and growth, leading to increased yields. Nevertheless, other studies (30,31) argue that organic manure mineralises over time and hence should be applied for sustainable yield increase.

Increased yields in treatments comprising crop residues under conventional could be attributed to the increased soil organic matter content. Our findings concur with (32)who reported an increase in grain yields through mulching. Similarly, a study done in the central highland of Kenya (26) reported mulching as one of the best practises of increasing yields with proper tillage. Conventional tillage leads to faster integration of organic inputs increasing the soil organic matter and improved yield as deduced from our study. The findings collaborate with (8) who reported increased yield stability under convention tillage. The low yields observed under minimum tillage are in line with a study carried out in the central rift valley (33) who reported similar results relating to the slow organic matter integration in minimum tillage. However, we observed an increase in stover yield (MtMf) attributing to the reduced soil disturbance and leaching of nutrients. Our observations are in line with a study conducted in Machakos (34). Animal manure effect on increased yield relates to the addition of nutrients to the soil, enhancing soil fertility and improved yields. Our findings are similar to (32), who reported an increase in yields with the application of animal manure.

Treatments containing mineral fertilisers and crop residues showed an increase in yield. This was ascribed to the synchronisation of nutrients. In the same context (14) reported that application of inorganic fertilisers and crop residues substantially increased maize yields by 75%. Also, previous studies carried out in Henan province (13) reported a 6% yield increase with the use of mineral and organic inputs.

We observed a decrease in yields under RML compared to the control. Although various studies have shown an increase in yields through intercropping (3, 35).This was attributed to the utilisation of the limited resources by the legume and the cereal. Additionally, the differences in the growth cycle and root proliferation contributes to the utilisation of the resources. This tallies with the findings of (22) who attributed it to the competition of water and nutrients between the legume and maize.

Tithonia diversifolia on the other hand led to an increase in yield. It improves the soil organic matter content which augments the soil structure and aggregate stability improving the soil properties to hold water (27). The use of a legume intercrop led to a decrease in yields due to the competition of the limited resources by 51% and 1% under conventional and minimum tillage respectively. This is because of competition of the limited resources. A study conducted in Malawi also reported the same findings (21). This was contrary to other findings where yield increased by the use of legume intercrop (36, 3).

3.3 Water use efficiency

We observed an increase in water use efficiency for grain during the short rains 2016 for the treatment containing crop residue animal manure and mineral fertilizers (CtMf, CtRfM and CtRMF) at 200, 180 and 140%, respectively compared to the control (Table 4). The RTiM and RTiP treatment significantly increased by 129 and 176%, respectively under conventional tillage. a significant increase yields under MtRf, MtRMf, MtRMfM, MtRTiM and MtRTiP treatments was observed by 160,180,162,123 and 106%, respectively compared to the control. During the short rains 2017, MtRf, MtRMf, MtRMfM treatments significant increased yield by 87, 68 and 232% respectively compared to the control. Water use efficiency for biomass increased significantly under Rf, RMf, RMfM, RTiM and RTiP at 201,160,163,122 and 149%, respectively compared to the control during the short rains 2016. There was no significant increase under legume intercrop (RML) treatment for biomass and grain water use efficiency during the two seasons. However, we observed a significant (P<.0001) effect of the treatment on biomass water use efficiency at during the SR2017 (Table 4).

Table 6 water use efficiency for stover and grain yields during SR2016 and SR2017

Treatment	WUEs^{s}	WUEg^{g}	WUEg^{g}	WUEs^{s}
C	13.99^{ab}	2.04^{a}	0.00^{b}	5.98^{d}
CtMf	28.18^{a}	4.24^{a}	0.87^{ab}	20.19^{a}
CtRMf	22.34^{ab}	2.86^{a}	0.68^{ab}	21.58^{a}
CtRMfM	22.87^{ab}	3.76^{a}	2.32^{a}	20.26^{a}
CtRML	6.86^{b}	0.5^{a}	0.00^{b}	5.86^{d}
CtRTiM	17.049^{ab}	3.11^{a}	0.91^{ab}	17.01^{abc}
CtRTiP	20.87^{ab}	3.59^{a}	0.23^{ab}	11.12^{cd}
MtC	14.05^{ab}	2.66^{a}	0.00^{b}	5.031^{d}
MtMf	21.66^{ab}	3.27^{a}	1.25^{ab}	22.84^{d}
MtRMf	19.71^{ab}	3.67^{a}	0.93^{ab}	18.54^{ab}
MtRMfM	20.87^{ab}	3.3^{a}	1.60^{ab}	18.34^{ab}
MtRML	13.89^{ab}	2.09^{a}	0.042^{b}	8.29^{d}
MtRTiM	14.28^{ab}	2.51^{a}	0.74^{ab}	11.73^{bcd}
MtRTiP	18.27^{ab}	2.17^{a}	0.19^{b}	11.12^{d}
P	0.13	0.46	0.900	<.0001

^{S}*water use efficiency for stover;* ^{g}*water use efficiency for grain; Means with the same letter(s) within the same column are not significantly different at P=0.05.*

In our study, Rf, RMf RMfM treatments gave the highest significant increase in water use efficiency for both stover and grain yields compared to the control. This could be attributed to the increases in soil organic matter from crop residue and animal manure as well as enhanced water holding capacity by mineral fertilisers. In India, (37) reported that mineral fertilisers add nutrients to the soil, thereby improving the soil quality and root development for water uptake. Similarly (38) observed an increase in water use efficiency with the use of mineral fertilisers.

The increased water use efficiency under combined use of mineral fertiliser (RMf) is influenced by first, both the nutrients are available in insufficient quantity. Secondly, their positive interaction and lastly both are required for long term soil fertility replenishment (4). Crop residues lead to soil organic matter accumulation upon decomposition, which in turn contributes to the soil aggregate stability and quality, thereby increasing the water holding capacity. Also, crop residues applied as mulch reduce evaporation from the soil, maintaining a maximum soil cover, thereby conserving soil moisture (27). Other studies have also reported that mulch reduces surface runoff and overland flow, increasing the infiltration rate hence high water storage (39,40). Mineral fertilizer enhances soil aggregate stability, thereby improving the water holding capacity as observed by(41). Also, they provide the energy required for water uptake by the roots (42).
Animal manure binds the soil particles increasing the water holding capacity as observed from our study. This concurs with a study carried out by (30) who observed an increase in water use efficiency and yields with the application of animal manure also animal manure adds nutrient to the soil improving the soil quality status (43). This enhances the capacity of the soil to slow runoff and increase the infiltration rate as observed by(44) in western Kenya.

4. CONCLUSION

From the study treatments comprising mineral fertilizers crop residue and animal manure significantly increased yields and water use efficiency followed by *Tithonia diversifolia* and rock phosphate. Rainfall was poorly distributed during the study period, and this was a hindrance for crop nutrient uptake. This attests to the low yields we observed during the study period as well as low water use efficiency. Organic inputs increase the soil organic matter and ph increasing the availability of nutrients for uptake by crops leading to the increased yields; also organic input applied as mulch conserves soil moisture reducing evaporation losses as well as infiltration rate increasing the water use efficiency. Mineral fertilisers, on the other hand, releases nutrients are directly leading to increased uptake by crops. However, the increased rate of nutrient release leads to the decrease in soil organic matter. The steady release of nutrients by the organic inputs improves the soil quality gradually through the additive effect improving soil quality and water use efficiency. Hence the combination of organic inputs and mineral fertilisers should be adopted for sustainable yields and water use efficiency. Therefore, soil fertility management practices adoption should be based on maximising yield and water use efficiency.

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