Tropical and Subtropical Agroecosystems
E-ISSN: 1870-0462
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Universidad Autónoma de Yucatán
México

Karuku, G.N.; Gachene, C.K.K.; Karanja, N.; Cornelis, W.; Verplacke, H.
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Tropical and Subtropical Agroecosystems, vol. 17, núm. 3, 2014, pp. 509-523
Universidad Autónoma de Yucatán
Mérida, Yucatán, México

Tropical and Subtropical Agroecosystems, 17 (2014): 509 -523

EFFECT OF DIFFERENT COVER CROP RESIDUE MANAGEMENT PRACTICES ON SOIL MOISTURE CONTENT UNDER A TOMATO CROP (*Lycopersicon esculentum*)

[EFECTO DE PRÁCTICAS DE MANEJO DE RESIDUOS DE DIFERENTES CULTIVOS DE COBERTURA SOBRE EL CONTENIDO DE HUMEDAD DEL SUELO EN UN CULTIVO DE TOMATE (*Lycopersicon esculentum*)]

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SUMMARY

Water relations are among the most important physical phenomena that affect the use of soils for agricultural, ecological, environmental, and engineering purposes. In sub-Saharan African, water is most critical in limiting crop production and yields especially in the Arid and Sub-arid regions. The soil water storage, available water content and soil water balance under various cover crop residue management practices in a Nitisol were evaluated in a field experiment at the Kabete Field Station, University of Nairobi. The effects of surface mulching, above and below ground biomass and roots only incorporated of velvet bean (*Mucuna pruriens*), Tanzanian sunhemp (*Crotalaria ochroleuca*) and purple vetch (*Vicia benghalensis*) cover crops, fertilizer and non fertilized plots on soil water balance were studied. The experimental design was a split plot and tomato (*Lycopersicon esculentum*) was the test crop. Since water content was close to field capacity, the drainage component at 100 cm soil depth was negligible and evapotranspiration was therefore derived from the change in soil moisture storage and precipitation. Residue management showed that above and below ground biomass incorporated optimized the partitioning of the water balance components, increasing moisture storage, leading to increased tomato yields and water use efficiency (WUE). Furthermore, vetch above and below ground biomass incorporated significantly improved the quantity and frequency of deep percolation. Soil fertilization (F) and non fertilization (NF) caused the most unfavourable partitioning of water balance, leading to the lowest yield and WUE. Tomato yields ranged from 4.1 in NF to 7.4 Mg ha^{-1} in vetch treated plots. Vetch above and belowground biomass incorporated had significant ($p \leq 0.1$) yields of 11.4 Mg ha^{-1} compared to all other residue management systems. Vetch residue treatment had the highest WUE (22.7 kg mm^{-1} ha^{-1}) followed by mucuna treated plots (20.7 kg mm^{-1} ha^{-1}) and both were significantly different ($p \leq 0.05$) compared to the others irrespective of residue management practices.

Key words: Water balance components; Management practices; Yields and Water Use Efficiency.

RESUMEN

El efecto del agua es uno de los fenómenos físicos más importantes para propósitos de la agricultura, ecología, ambiente e ingeniería. En el África Sub-Sahariana, el agua es un factor crítico que limita la producción y rendimiento de cultivos, especialmente en áreas áridas y sub áridas. Se evaluó el almacenamiento de agua del suelo, agua disponible y balance hídrico con varias prácticas de manejo de cultivo de cobertura en un suelo Nitisol en un experimento de campo realizado en la estación experimental de Kabete, Universidad de Nairobi. Se estudiaron los efectos sobre el balance hídrico de la cobertura superficial, biomasa área y subterránea y raíces incorporadas de los cultivos de cobertura *Mucuna pruriens*, *Crotalaria ochroleuca* y *Vicia benghalensis* y parcelas fertilizadas y no fertilizadas como control. Se empleó un diseño experimental de parcelas divididas y el tomate (*Lycopersicon esculentum*) fue el cultivo modelo. Debido a que el contenido de agua del suelo estaba cerca de su capacidad de campo, el valor del drenaje a 100 cm de profundidad fue mínimo y la evapotranspiración fue obtenida a partir del cambio en la humedad del suelo y la precipitación. El manejo de los residuos mostró que la biomasa área y subterránea incorporada optimizaron la partición de los componentes del balance hídrico, incrementando la humedad acumulada, mejorando la producción de tomate y uso eficiente del agua. Más aun, la biomasa aérea y subterránea de *V. benghalensis* mejró significativamente la cantidad y frecuencia de la percolación profunda. Los suelos fertilizados y no fertilizados tuvieron la partición del balance de agua menos favorable y obtuvieron menor rendimiento y eficiencia de uso de agua. La producción de tomate fluctuó de 4.1 en suelos no fertilizados a 7.4 Mg/ha en las parcelas de vicia. La biomasa aérea y subterránea de vicia fue significativamente mejor (11.4 Mg/ha) comparado contra todos los tratamientos. El manejo del residuo de vicia resultó en la mayor eficiencia de uso del agua (22. 7 kg mm^{-1} ha^{-1}) seguido por las parcelas de mucuna (20.7 kg mm^{-1} ha^{-1}) que fueron significativamente mejores comparados con los tratamientos restantes.

Palabras clave: Balance hídrico; prácticas de manejo; producción; uso eficiente del agua.

INTRODUCTION

The improvement of agricultural crop yields requires, among other things that water be harnessed and the soil adequately exploited (Van Den Abeele, 2004). Contribution of legume cover crops to soil moisture conservation and crop production have been shown to improve smallholder land productivity. However, this depends, primarily on legume biomass production and chemical composition of residues, which in turn controls decomposition and nutrient release.

Though cover crops are usually grown to control soil erosion and for improvement of soil tilth (Mannering, *et al.* 2007; Birte *et al.,* 2008).**)**, other important benefits include the enhancement of soil structure, soil fertility (Lu *et al*. 2000) and preservation of environmental quality (Yadev *et al*., 2000; Prasad *et al.*, 2002). All these benefits are not associated with a specific cover crop; however many of them can occur simultaneously (Luna, 1998). Dense cover crop stands growing in the field, physically slows down the velocity of rainfall before it comes into contact with the soil surface, preventing soil splashing and erosive surface runoff (Birte *et al.* 2008). Additionally, the vast cover crop root networks help anchor the soil in place and increase soil porosity and water intake, creating suitable habitat networks for soil macro fauna (Tomlin *et al*. 1995). Cover crops or green manure are grown and incorporated (by tillage) into the soil before reaching full maturity, and are intended to improve soil moisture, soil fertility and quality. Studies carried out in the central highlands and in western areas of Kenya have shown sunhemp (*Crotalaria ochroleuca*); velvet bean (*Mucuna pruriens)* and purple vetch (*Vicia benghalensis*) enhance moisture retention in the soil (Gachene *et al.* 2000). This formed the basis of the selection of the three cover crops in this study.

The aim of this study was therefore, to determine the effect of cover crop residue management practices on soil moisture under a tomato crop (*Lycopersicon esculentum*) in a Nitisol and how the results can be used to increase crop production and yields in ASAL regions.

MATERIALS AND METHOD

Study area

The study was carried out at Kabete Campus Field Station, University of Nairobi. The Field Station farm lies at $1°15^{l}$ S and 36° 44^{l} E and is at an altitude of 1940 m a.s.l. The site is representative, in terms of soils and climate, of large areas of the Central Kenya highlands. The geology of the area is composed of the Nairobi Trachyte of the Tertiary age. The soils are well-drained, very deep (> 30 m), dark red to dark reddish brown, friable clay (Gachene, 1989). The soil is classified as humic Nitisol (FAO, 1990, WRB, 2006). There is no surface sealing or crusting and clay increases with depth (Gachene, 1999). The groundwater is more than 30 m deep and runoff was negligible in the research plots. Slope gradient is relatively flat. According to the Kenya Soil Survey agro climatic zonation methodology (Sombroek *et al*., 1982), the climate of the study area is characterized as semi-humid. The ratio of annual average rainfall to annual potential evaporation, r/Eo is 58%. The site experiences a bimodal rainfall distribution with long rains in mid March – May and the short rains in mid October – December. The mean annual rainfall is 1006 mm. The land is cultivated for horticultural crops such as kales (*Brassica oleracea*), tomatoes (*Lycopersicon esculentum*), cabbage (*Brassica oleracea*), carrots, (*Daucus carota*), onions (*Allium fistulosum*), fruit trees such as avocadoes (*Persea americana*) and coffee (*Coffea arabica)* as cash crops.

Experimental design and layout

The experimental design was a split plot. The main plots consisted of the residue management practices of surface mulch, above and below ground biomass and roots only incorporated. The subplots consisted of three cover crop treatments and the fertilized and non fertilized plots. The main blocks measured 15 m x 15 m separated by a 1 m path while the main plots were 15 m x 5 m. The subplots were 5 m x 3 m and were 0.5 m apart. Cover crops were first planted after the long rains on 4^{th} of July 2001 and allowed to grow up to end of September of the same year. Plots requiring mulch and those for fertilized (F) and non fertilized (NF) treatments were left bare until the commencement of experiment after termination of cover crops.

Data collection

The cover crop tested were velvet bean (*Mucuna pruriens*) (M), purple vetch (*Vicia benghalensis*) (V) and Tanzanian sunhemp (*Crotalaria ochroleuca*) (S). Cover crop biomass were harvested and applied to the respective plots as (a) surface mulch in plots not previously planted with cover crops. (b) below and aboveground biomass incorporated in the soil for plots previously under cover crops and (c) roots only incorporated in soil for plots previously under cover crops. Surface mulch for each of the cover crops was applied at the rate of 5 Mg DM ha^{-1}. Biomass for surface mulch was harvested from plots left with roots only. Both below and aboveground biomass was incorporated in the 30 cm soil depth. Plots with or without chemical fertilizers were taken as the control. Tomato seedlings were planted in all the plots and fertilizer rate was applied at 78 kg ha^{-1} for tomato seedlings. Spacing was 90 cm x 90 cm for tomato and 30 cm x 60 cm for velvet bean of which one seed was planted in each hole giving a population density of 55,555 velvet bean plants ha^{-1}. Seeds were broadcasted on weight basis at the rate of 34.17 and 19.0 grams per subplot (3 m x 5 m) for purple vetch and Tanzanian sunhemp, respectively (LRNP, 2006).

All agronomic practices such as weeding, pest and disease control were carried out according to the prevailing local conditions. Weeding was initially done two weeks after transplanting and thereafter any weeds growing in the field were uprooted. Spraying with Dithane M45 (2.5 kg ha^{-1}) was done early in the season. Thereafter, the plants were closely monitored for any disease or pest incidences. The Standardized Precipitation Index (SPI) for the study area was calculated to indicate whether 2001 and 2002 were normal rainfall years. The SPI is a tool which was developed primarily for defining and monitoring draught and allows analyst to determine the rarity of a draught at a given time (temporal resolution) of interest for any rainfall station with historic data. It can also be used to determine periods of anomalously wet events but bear in mind that it is not a draught prediction tool.

Determination of soil water balance parameters

The water balance was determined using the equation:

$$\Delta S = P + I - R - ET - D$$

where, ΔS is change in soil water-storage, P is precipitation, I is irrigation, R is runoff, ET evapotranspiration and D drainage (percolation) out of the root zone (D is positive) or upward capillary flow into the root zone (negative value of D).

Rainfall, wind speed, sunshine hours, Tmax and Tmin and RH were recorded at the meteorological station. Soil water storage was determined by gravimetric method (Hillel, 2004). Measurements of volumetric water content, at different depths of 15, 30, 45, 60, 75, 90, 105 and 120 cm, were done biweekly and the water content profiles were plotted and used to quantify soil moisture storage between the soil surface and 100 cm depth for each time, t using the trapeze rule (Jin *et al.,* 2007). As the observed water contents during the study were rather low and lower than or close to field capacity, the drainage component at 100 cm depth was negligible. Since no irrigation was applied, the soil water balance equation was simplified as:

$$\Delta S = P - ET$$

Thus enabling the determination of ET from ΔS and P as runoff (R) was negligible.

Determination of water use efficiency (WUE**)**

WUE was computed as the dry matter yield per unit of water evapotranspired by the tomato crop following Cooper *et al.* (1988) method.

$$WUE\left(kg\,ha^{-1}\,mm^{-1}\right) = \frac{Yield\ \left(kg\ ha^{-1}\right)}{ET\ (mm)}$$

where, WUE is water use efficiency in (kg ha^{-1} mm^{-1}), ET is amount of evapotranspiration by crop (mm)

Statistical analysis

Analyses of variance were performed on the measured parameters using Genstat discovery edition 3. The LSD was used to compare the means of treatments and their interactions. The statistical significance referred to $\alpha = 0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Monthly climatic data during tomato development stages

Climatic data during the tomato development stages are shown in Table 1 while Figure 1 shows the relationship between rainfall and potential evapotranspiration (ETo) during the study period. Most rainfall was recorded when tomato crop was being harvested. The ratio P/ETo < 1 observed throughout the development stages indicated absence of humid periods hence profile soil moisture recharge was not possible. The P/ETo ratio observed, ranging from 0.1 at vegetative to 0.8 at maturity stages, indicated that the soil dried in the early stages of tomato development where the atmospheric demand exceeded water additions. The very low P/ETo ratio of less than 0.2 in the vegetative and reproductive stages further suggested that the crop's water requirements were not met early in the cropping cycle. This confirms work done by Meerkerk and Van Wesemael (2008) who demonstrated that climate directly affects soil water availability especially in situations where soil moisture conservation measures were not in place.

The observed temperature range of 12.6 - 26.7 °C for both night and day is within the requirements for optimal tomato yields of 16 - 27 °C and 10 - 20 °C day and night temperature ranges, respectively (Peralta and Spooner, 2007) indicating that temperature was not limiting tomato growth in the study area. The sunshine hours, wind speed and RH were generally ideal for tomato production. Low values of rainfall, ETo, and insolation ratio (n/N) were observed at initiation stage and this reflects the short duration of this stage. The small number of sunshine hours may impact negatively on crops at initiation stage as they require more sunshine for proper establishment. Start of tomato growing season was possible at initiation as ½ ETo was equal to precipitation (Figure 1). As this stage progressed, there were few rainfall events, and the soil dried probably due to less ground cover and thus allowing for direct moisture evaporation from the soil surface.

The Standardized Precipitation Index (SPI) for the study area was 0.59 and 0.29 for the 2001 and 2002 respectively, indicating near normal rainfall years. However, this was the short rainy season where the rainfall frequency and amounts were expected to be low leading to poor crop performance. The ½ ETo values were 5 and 2 times higher than precipitation during vegetative and reproductive stages, respectively, indicating a possibility that the tomato crop was not receiving its transpiration water requirements. Wind speed at vegetative stage was slightly higher at 2 ms^{-1} compared to the other three stages where it was 1.5 ms^{-1} on average. This suggested a high evaporation and transpiration water loss due to turbulence.

Precipitation was low considering this stage lasted 30 days. Low rainfall observations were noted at the reproductive stage (40 days) and this could have been the precursor of the low yields observed later in the season. Patanè and Cosentino (2010) and Nurrudrin and Madramootoo, (2001) observed reduced fruit size and yield as a result of soil water deficit during tomato fruit ripening and development. The correlation between evapotranspiration (ET) and crop yield is normally high and reduction in ET due to insufficient soil moisture means reductions in yield can be expected as tomato is highly-sensitive to water stress, especially during the fruiting stage (Obreza *et al*., 2010).

At maturity, precipitation was expected to reduce so that tomato fruits can have a drier period to mature as they require a relatively cool, dry climate for high yield and premium quality (Van der Vossen *et al.,* 2004). However, this was not the case in this study and it had an effect on the quality and quantity of tomato through fruit drops as was experienced at times during the experiment.

Table 1. Climatic data during the tomato growing period

Development stages	P mm	ETo mm	ETo/2 mm	P/ETo mm	WS ms^{-1}	n/N (hrs)	Tmax °C	Tmin °C	Tmean °C
Initiation	27.5	70.5	35.2	0.4	1.5	0.6	22.4	13.9	18.1
Vegetative	14.8	148.2	74.1	0.1	2.0	0.7	23.0	13.9	18.5
Reproductive	49.6	235.0	117.5	0.2	1.5	0.8	26.7	12.6	19.7
Maturity	146.6	184.9	92.4	0.8	1.4	0.7	24.6	14.4	19.5

P; precipitation, ETo; potential evapotranspiration, n/N; insolation ratio, WS; wind speed at 2 m above ground, T; temperature

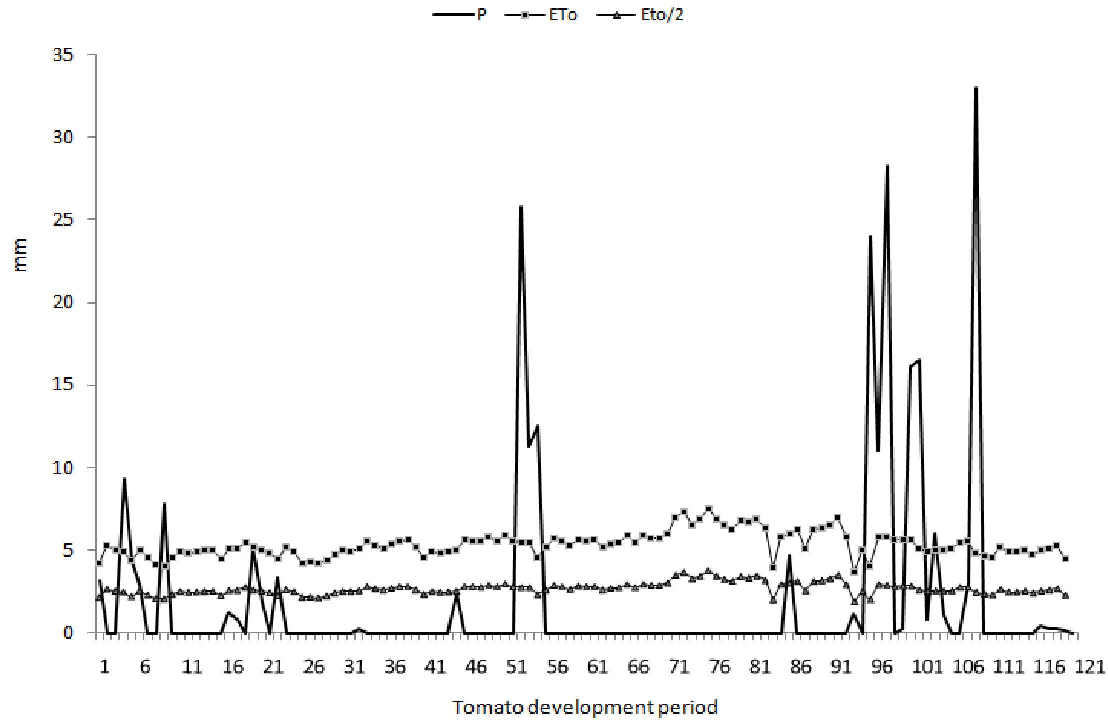

Figure 1. Rainfall, P, ETo and ½ ETo during the tomato development stages

Effect of cover crop residue material on soil water storage

Initial cumulative soil water storage before transplanting tomatoes seedlings is shown in Table 2. The data indicated that plots treated with vetch cover crop irrespective of residue management practices stored significantly higher ($p \leq 0.001$) moisture (449.7 mm) prior to transplanting of tomatoes compared to other legume cover crops. Velvet bean treated plots followed with 410.3 mm of water and this was significantly higher ($p \leq 0.05$) than sun hemp (337.8 mm), fertilized (F), (375.5 mm) and non-fertilized (NF), (371.0 mm) treated plots, irrespective of residue management. Crop residues left as mulch have been shown to help both natural precipitation and irrigation water to infiltrate in the soil where it can be utilized by plants. The crop residue left as mulch also limits evaporation and conserve water for plant growth. It has also been reported that residue removal adversely affects agronomic production by altering the dynamics of soil water and temperature regimes (Humberto and Lal, 2009; Joyce *et al*.; Bunch, 2010). Above and below ground biomass incorporated had highest soil water storage (402.2 mm) and this was significantly higher than surface mulch (396.2 mm) and roots only incorporated (392.2 mm) plots irrespective of the type of cover crop.

Cover crops residues influence soil water content as a result of reduced surface evaporation due to the mulching effect, increased infiltration and retention of precipitation unlike the fertilized and NF plots. However in this study, some of the surface mulch was eaten by termites while others were blown away by the wind and thus reducing its effect on evaporation process. This could have been the reason for the high cumulative soil water storage under below and aboveground biomass observed in this study. Use of crop residues, either incorporated in the soil or placed on the soil as surface mulch help to maintain adequate infiltration rates (FAO, 2000; Shaxson and Barber, 2003), prevent soil surface crusting, improve soil aggregation (NCRS, 2010), improve the water transport system and retention (Dahiya *et al.,* 2003) in the soil.

Table 3 shows cumulative soil moisture storage at the beginning of tomato vegetative development stage. Across residue treatments, vetch residue treated plots had higher moisture storage (340.41 mm) and was significantly ($p \leq 0.05$) higher compared to all other cover crops residues. Velvet bean and sunhemp residue treated plots had 322.18 and 318.28 mm of water stored and were significantly higher ($p \leq 0.05$) compared to non cover crops plots (F and NF). Above and below ground biomass had significantly higher ($p \leq 0.05$) soil water content stored irrespective of the type of cover crop. No significant difference was observed between F and NF.

Table 2. Cumulative soil water storage (mm) before transplanting tomatoes in the 0-105 cm soil depth

Management/ Treatment	Velvet bean	Vetch	Sunhemp	Fertilizer	Non-fertilized	mean
Surface mulch	409.7a(13.4)	449.0a(13.4)	377.1a(13.4)	374.9a(13.4)	370.3a(13.4)	396.2a(2.2)
Above and below ground biomass	415.2a(13.4)	454.9a(13.4)	383.3a(13.4)	380.8a(13.4)	376.5a(13.4)	402.2b(2.2)
Roots only incorporated	405.9a(13.4)	445.1a(13.4)	372.8a(13.4)	370.7a(13.4)	366.3a(13.4)	392.2a(2.2)
Mean	410.3b(8.6)	449.7cb(8.6)	377.8ab(8.6)	375.5ab(8.6)	371.0a b(8.6)	396.8

An l.s.d. of 14.9 is used when comparing means with same levels of management. Mean figures followed by same letter along the rows or down the columns are not significantly different at p = 0.05

Table 3. Cumulative soil water storage (mm) at beginning of vegetative stage in the 0-105 cm depth

Management/ Treatment	Velvet bean	Vetch	Sunhemp	Fertilizer	Non-fertilized	mean
Surface mulch	321.57(9.9)	339.80(9.9)	317.84(9.9)	308.03(9.9)	306.01(9.9)	318.65a(2.1)
Above and below ground biomass	327.38(9.9)	345.61(9.9)	322.70(9.9)	313.29(9.9)	311.65(9.9)	324.13b(2.1)
Roots only incorporated	317.58(9.9)	335.81(9.9)	314.25(9.9)	304.33(9.9)	303.19(9.9)	315.03a(2.1)
Mean	322.18b(6.3)	340.41c(6.3)	318.26b(6.3)	308.55a(6.3)	306.95a(6.3)	319.27

An l.s.d. of 11.0 is used to compare means at same management level. Mean figures followed by same letter either in a row or column are not significantly different at p = 0.05

Retention of soil moisture by mulches has been shown to significantly increase available water, total porosity and soil moisture retention at low suctions (Mulumba and Lal, 2008). Research elsewhere has shown that use of surface mulch can result in storing more precipitation water in soil by reducing runoff, increasing infiltration and decreasing evaporation (Ji and Unger, 2001). However loss of some mulch due to wind and consumption by termites may have contributed to the observed results where above and belowground biomass stored more moisture than surface mulch.

Table 4 shows cumulative soil moisture storage at the 0-100 cm soil depth during the tomato development stage. Vetch residue treated plots had significantly ($P \leq 0.05$) higher soil water storage compared to all other treatments irrespective of crop residue management. Among management practices, above and below ground biomass incorporated in the soil stored more water in the 0-100 cm soil depth, and was significantly higher ($P \leq 0.05$) compared to the other two residue management practices. Surface mulch and roots only were not significantly different from each other. This could be a reflection of the moisture storage content observed under different residue management on the onset of the experiment. Among the residue management, above and below ground biomass incorporated had highest storage at the onset of the experiment (402.2 mm) compared to surface mulch (396.2 mm) and roots only (392.2 mm). This could be an indication of the high biomass material returned to the soil through both roots and crop residues as they decomposition and contribute to the organic matter pool in the soil that eventually lead to high water retention.

Figure 2 show precipitation, P, cumulative soil water storage and critical soil water storage (Scr) during tomato development stages (initiation, vegetative, reproductive and maturity). Critical water storage (SCR), the storage below which crops experience water stress for the

0-100 cm depth was calculated at 300 mm, when considering a critical matric potential for tomato of –80 kPa (Taylor and Aschroft, 1972). Cumulative soil water storage and soil moisture content followed rainfall events (Figure 2). Vetch residue treated plots showed the highest response to rainfall followed by mucuna plots for the first 36 days, after which, sunhemp plots surpassed mucuna at vegetative stage. Cumulative soil water storage followed rainfall events and was highest with above and below ground biomass followed by surface mulch and this could have been due to better infiltration due to higher organic matter additions (Figure 3). During the vegetative and reproductive stages of tomato growth, cumulative soil moisture storage was below SCr, meaning that the potential for optimal yields was reduced.

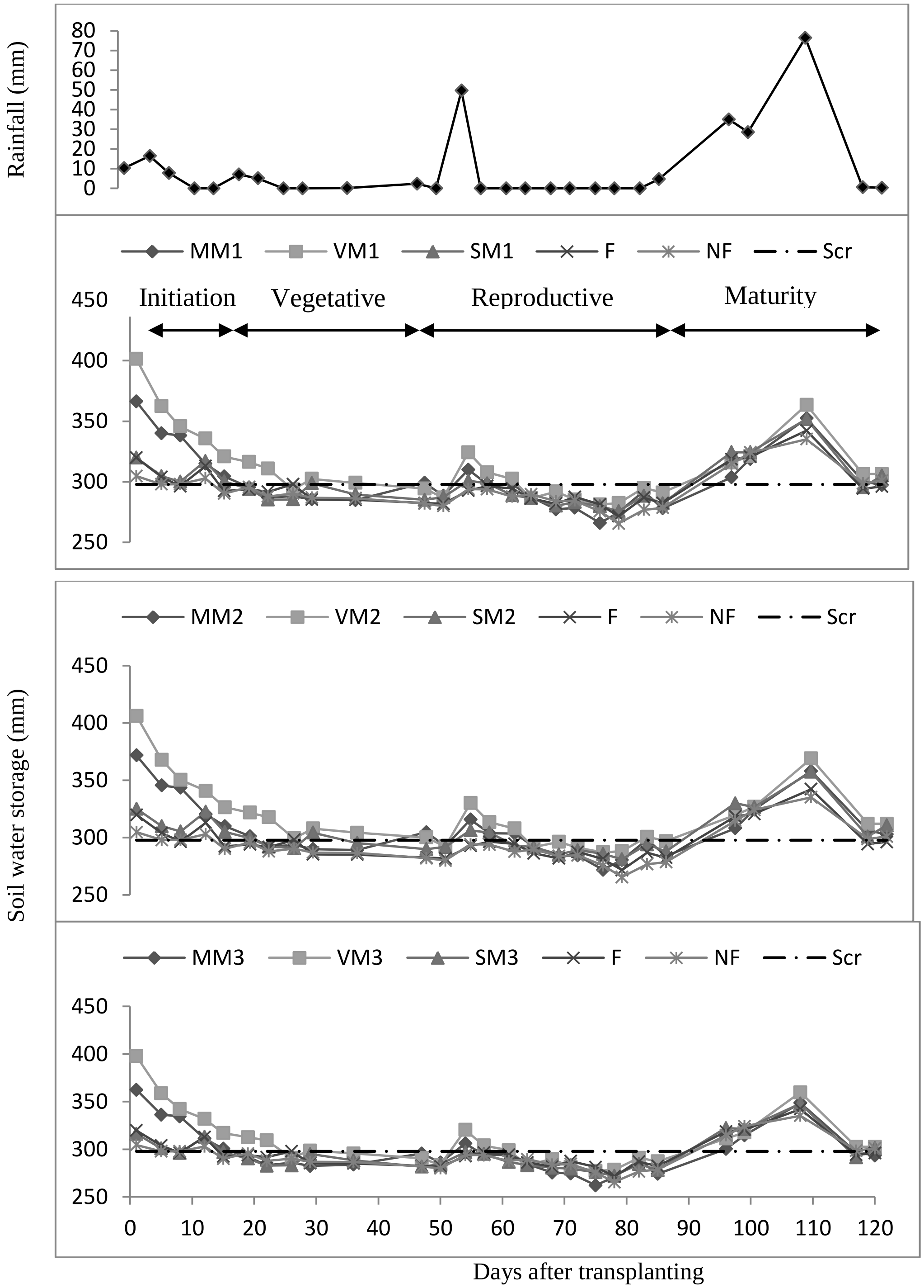

Figure 2. Soil moisture storage during tomato development stages in the 0-100 cm soil depth

Where, V, vetch; M Velvet bean ; S, sunhemp, M1, surface mulch, M2, below and aboveground incorporated; M3, roots only incorporated; Scr, critical soil water storage

Table 4. Soil moisture storage (mm) in the 0-100 cm depth

Management/ Treatment	Velvet bean	Vetch	Sunhemp	Fertilizers	Non-fertilizers	mean
Surface mulch	317.86a(4.0)	331.56a(4.0)	314.15a(4.0)	311.24a(4.0)	309.05a(4.0)	316.77b(1.4)
Above and below ground biomass	323.35a(4.0)	337.21a(4.0)	319.62a(4.0)	316.86a(4.0)	314.47a(4.0)	322.23c(1.4)
Roots only incorporated	314.40a(4.0)	327.92a(4.0)	310.83a(4.0)	307.91a(4.0)	305.98a(4.0)	313.41a(1.4)
Mean	318.54c(2.5)	332.23d(2.5)	314.15b(2.5)	311.24ab(2.5)	309.84a(2.5)	317.49

Mean figures followed by same letter either in a row or column in each respective case are not significantly different at p = 0.05

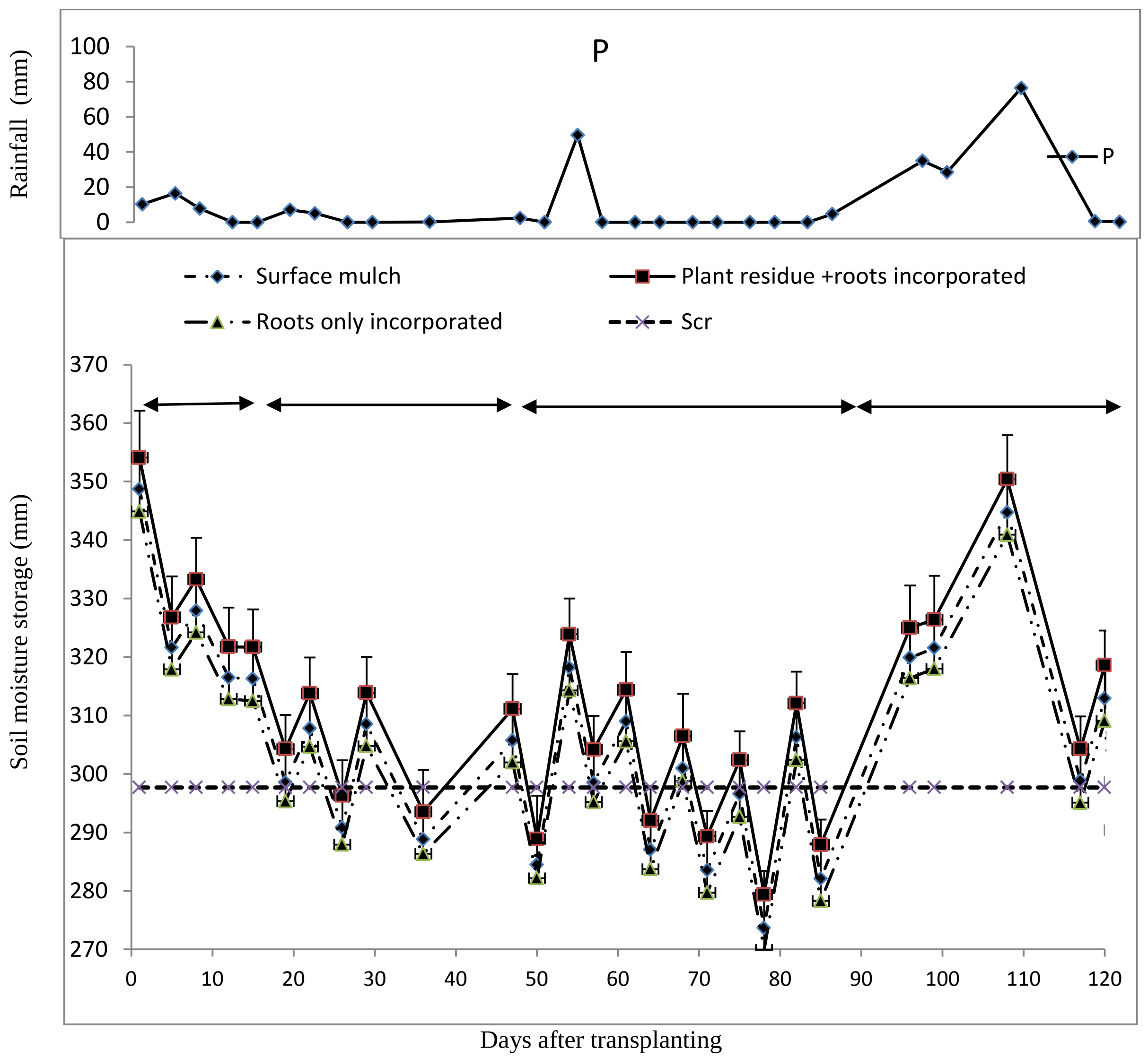

Figure 3. Soil moisture storage under different residue management practices during tomato development stages in the 0 - 100 cm depth

White (2009) and Tijani *et al*. (2008) observed an increment in soil water content after rainfall or irrigation when stubble was incorporated, and this was related to stubble quantity and consequently suggested that stubble incorporation increased the volume of large soil pores which were filled rapidly by rain. This could be the reason for the high water storage observed under vetch residues compared to the other treatments. The crop residues may have influenced soil water content as a result of reduced surface evaporation due to the residue effect, increased infiltration and retention of precipitation, and transpiration from cover crop canopy. Adekalu *et al.* (2007), Dahiya *et al*.(2003), Li, (2003) and Huang *et al.* (2005) showed that surface mulching significantly reduced soil evaporation and increased water storage and that the mulch effect depended on rainfall and evaporative demand among other factors (Ji and Unger, 2001; Lampurlanes *et al.*, 2002).

Effect of cover crop residue material on change in soil moisture storage

Change in soil water storage (ΔS) in 0-15 cm depth during the tomato growing period of 120 days is shown in Table 5. The ΔS was highest under vetch residue treated plots (-66.2 mm). Cover crop residue treated plots had significantly higher ($p \leq 0.05$) ΔS compared to fertilized (F) and non-fertilized plots irrespective of residue management.

However, ΔS was higher ($p \leq 0.05$) in vetch residue treated plots compared to the other two cover crops. The ΔS was negative in all treatment combinations during the entire tomato growing period. The high and significant ΔS indicated soil moisture depletion was highest in vetch-residue treated plots. The vigorous tomato growth observed at initiation stage may have contributed to higher water extraction from the soil.

The ΔS in 100 cm depth during the tomato development stages are shown in Table 6. The initiation, vegetative, reproductive and maturity stages lasted 15, 30, 40 and 35 days, respectively. The ΔS at initiation stage was highest under vetch residue treatment at -46.8 mm and was significant ($p \leq 0.05$) compared to all other treatments. Non fertilized treated plots had low change in moisture storage (-10.9 mm) though not significantly different from mucuna residue treated plot. In the vegetative stage, vetch residue treated plots showed the highest ΔS (-38.4 mm) and was significantly higher ($p \leq 0.05$) compared to all other treatments irrespective of residue management.
The positive ΔS observed at reproduction stage suggests a profile water recharge where water additions exceed extractions from the soil. The F, NF and sunhemp treated plots that had low water depletion in initiation and development stages had significantly ($p \leq 0.05$) higher ΔS compared to vetch and mucuna-treated plots. This was expected to have a negative ΔS. However, two facts seem to play a role: first, though there was higher water uptake, there was a greater ground coverage that effectively reduced direct water losses from the soil surface in all treatments.

Second, the amount of rainfall experienced at the time increased to 49.5 mm. Rain water positively contributed to soil water storage between 50 and 60 days (Figure.2) with 25.8 mm received in one day. The rest of the reproductive stage remained dry receiving only trace amounts of rainfall.

Table 5 Effect of residue treatment on changes in water storage (mm) during the tomato growing period in the 0-15 cm depth

Management/ Treatment	Velvet bean	Vetch	Sunhemp	Fertilizers	Non-fertilizers	mean
Surface mulch	-0.3 a (14.3)	-6.2a (14.3)	-4.3a (14.3)	-7.0a (14.3)	-13.4a (14.3)	-28.3a (2.5)
Above and below ground biomass	-9.5a (14.3)	-5.8a (14.3)	-4.1a (14.3)	-8.4a (14.3)	-12.4a (14.3)	-8.1a (2.5)
Roots-only incorporated	-26.1 a (14.3)	-66.6a (14.3)	-26.2a (14.3)	-19.3a (14.3)	-13.7a (14.3)	-0.4a (2.5)
Mean	-22.0 b (9.2)	-66.2c (9.2)	-24.9b (9.2)	-18.3a (9.2)	-13.2a (9.2)	-28.9

An l.s.d. of 15.9 is used when comparing means at same management levels. Mean figures followed by same letter either in a row or a column in each respective case are not significantly different at $p = 0.05$

Table 6. Effect of cover crop treatment on changes in mean soil water storage (mm) in the 100 cm depth

Stage/Treatments	Velvet bean	Vetch	Sunhemp	Fertilizers	No fertilizers
Initiation	-17.6c(7.5)	-46.8d(7.5)	-6.7ab(7.5)	-3.8a(7.5)	-10.9bc(7.5)
Vegetative	-24.5b(4.7)	-38.4c(4.7)	-27.2b(4.7)	-26.3b(4.7)	-15.3a(4.7)
Reproductive	8.4a(4.5)	19.9b(4.5)	24.6c(4.5)	23.8bc(4.5)	23.3bc(4.5)
Maturity	6.3a(5.6)	-3.9b(5.6)	-6.8b(5.6)	-13.7c(5.6)	-8.4b(5.6)

Mean figures followed by same letter either in a row or a column in each respective case are not significantly different at p = 0.05

Effect of cover crop residue material on actual evapotranspiration

Evapotranspiration values for individual tomato development stages are shown in Table 7. In vetch residue and NF treated plots, ET values were significantly higher ($p \leq 0.05$) compared to those of other treatments at initiation stage of development (Table 7). Low tomato ET values were observed in vegetative compared to those at initiation stage and these reflected the low soil water content available at this period. Crop water demand was increasing but supply was low leading to low transpiration. Vetch treated plots yielded highest ET (1.32 mm d^{-1}) followed by sunhemp (1.26 mm d^{-1}) and then velvet bean (1.19 mm d^{-1}). These were significantly different ($p \leq 0.05$) from NF treated plot. The low tomato ET values observed at reproductive stage (7) despite increased rainfall amounts (49.5 mm) indicated the profile was still not adequately recharged. Mucuna residue treated plots had the highest ET values (1.89 mm d^{-1}) that were significantly different compared to all other treatments ($p \leq 0.05$).

The values observed at reproductive stage (Table 7) though low among the three cover crops, were significantly different ($p \leq 0.05$) from each other. Poor water recharge of the soil profile meant all plots were generally drying at the same rate and that the crop's transpiration potential was reduced to a minimum for crop survival. ET for F and NF plots were significantly different ($p \leq 0.05$) from each other. On average, the ET was lowest in this stage at 1.12 mm d^{-1}. Cover crop treatment seems to have a positive effect on ET at this stage. Klocke (2007) indicated that the largest rates of soil water evaporation occur when the soil surface is wet as observed in the study where the soil water evaporation rates were controlled by radiant energy.

Klocke (2007) also observed that crop residues had the capacity to modify the radiant energy reaching the soil surface and reduce the soil water evaporation during the "energy" limited phase of evaporation as was observed in this study. Low ET values were expected at initiation stage as most losses are by direct evaporation from soil surface with low percent ground cover. Lescano and Baumhardt (1996) observed that crop residues suppressed soil water evaporation by intercepting irradiance early in the growing season when the crop leaf area index (LAI) was low.

The ET at maturity ranged from 3.78 to 4.46 mm d^{-1} in velvet bean residue and F treated plots, respectively (Table 7). Towards the end of season, tomato crop reached senescence and water demand declined as leaves fell off and water loss was mostly due to direct evaporation as ground cover decreased. Generally, tomato grown under residue management practices had low ET values during the growing period. Generally the ET values were not significantly different and were below the amount required to meet the ET tomato (between 400 and 600 mm) during its normal growing period at optimal conditions.

Table 7. Actual ET during tomato development stages in mm d^{-1}

Treatment/ Stage	Initiation	Development	Reproductive	Maturity
Velvet bean	2.30 a (0.9)	1.190bc(0.2)	1.896c(0.1)	3.780a(0.2)
Vetch	4.19 b (0.9)	1.321c(0.2)	1.644b(0.1)	4.180b(0.2)
Sunhemp	2.17 a (0.9)	1.256bc(0.2)	1.524a(0.1)	4.187b(0.2)
Fertilizer	3.09 a (0.9)	1.140b(0.2)	1.591ab(0.1)	4.466c(0.2)
Non- Fertilized	3.60 a (0.9)	0.693a(0.2)	1.639ab(0.1)	4.354c(0.2)

Mean figures followed by same letter either in a row or column in each respective case are not significantly different at p = 0.05

Effect of cover crop residues on tomato yields

Tomato yields under the different treatments are shown in Table 8. Tomato yields were low in all the treatments and this could be explained by the low ET values observed in 6.3.4 above during the study. Yields ranged from 4.1 in NF to 7.4 Mg ha^{-1} in vetch treated plots. Among the treatments, vetch, velvet bean and sunhemp treated plots had 39, 41 and 80 % yield respectively, above the control. Vetch above and below ground biomass treated plots had the highest and significant ($p \leq 0.1$) yield of 11.4 Mg ha^{-1} compared to all other management practices. Vetch above and below ground biomass had the most water stored (326.4 mm) at beginning of vegetative stage (Figure 3) and this could have contributed to the high yields observed under this treatment. Velvet bean residue and roots incorporation followed with 7.3 Mg ha^{-1} and this was significantly higher than sunhemp and F and NF. Velvet bean and sunhemp treated plots though not statistically significant, had higher yield compared to F and NF plots.

Results seem to suggest that there is potential for cover crop residue to increase tomato yields. Incorporated vetch may have improved the tomato crop nutrition as well as water content explaining the higher yields obtained in this treatment. It has been observed elsewhere that mulch increased soil moisture and nutrients availability to plant roots, leading to higher grain yield (Liu *et al*., 2002; Bhatt *et al.* 2004; Olfati *et al.* 2008). Low yield realized in this study could have been due to low water availability throughout the growing period and more so at critical development stages (vegetative and reproduction). Higher tomato yields were also reported with hairy vetch in no tillage systems compared to plastic and paper mulches under conventional tillage systems (Abdul-Baki and Teasdale 1993). Akemo *et al.* (2000) concluded that tomato grown following cover crop systems had better yields and that cover crops enhances the overall productivity and soil quality (Sainju *et al.*, 2001; 2002).

Velvet bean above and below ground biomass gave the second highest and significant yields compared to the other treatments even though the water storage at the beginning of the vegetative stage was similar to that of sunhemp above and below ground biomass treated plots. However, velvet bean roots only incorporated plots had the lowest yields among cover crop residue combinations, a fact attributed to the allellopathetic nature of velvet bean roots. followed with 7.3 Mg ha^{-1} and this was significantly higher than sunhemp and F and NF. has been reported to exert allelopathic effect on tomatoes by producing “allelochemicals” that suppress tomato growth and yields (Igue *et al*, 2006; Wang *et al.*, 2003; Casini and Olivero, 2001). However, incorporation of aboveground material from velvet bean probably counteracted the allelopathic effects leading to the observed yields in velvet bean above and below ground biomass.

In plots under F and NF treatments, the low water content available could have contributed to the low tomato yields observed. According to Shaxson and Barber (2003), lack of water reduces nutrient uptake by crops largely because nutrients can only move to the roots through water films within the soil. This means that fertilization alone did not improve conditions for tomato growth. In the fertilized plots, the osmotic effect created by the fertilizers under reduced moisture conditions could have caused poor tomato establishment and growth leading to low ground cover. This consequently could have led to higher moisture loss through direct evaporation from the soil surface. Siborlabane (2000) pointed out that the yield and quality of the fruit for the fresh tomato market varies according to the type of mulch used on the plantation and this could further explain the differences in the yields obtained from the three cover crop treated plots.

Table 8. Effect of cover crop residues on tomato yield (Mg ha^{-1})

Management/ Treatment	Velvet bean	Vetch	Sunhemp	Fertilizer	Non-fertilized	Mean
Surface mulch	5.3a(3.3)	5.3a(3.3)	6.2b(3.3)	3.9a(3.3)	3.5a(3.3)	4.8a(2.1)
Above and below ground biomass	7.3b(3.3)	11.4c(3.3)	5.6a(3.3)	4.8a(3.3)	5.8a(3.3)	7.0b(2.1)
Roots only incorporated	4.8a(3.3)	5.5a(3.3)	5.4a(3.3)	4.0a(3.3)	3.0a(3.3)	4.6a(2.1)
Mean	5.8a(1.9)	7.4b(1.9)	5.7a(1.9)	4.2a(1.9)	4.1a(1.9)	5.5

Mean figures followed by same letter either in a row or column are not significantly different at p = 0.05 unless other significant levels are specified

Effect of cover crop residues on tomato water use efficiency

Water use efficiency (WUE) values for various residue treatment and residue management practices are shown in Table 9. Vetch residue treatment had the highest WUE (22.7 kg mm^{-1} ha^{-1}) followed by velvet bean treated plots (20.7 kg mm^{-1} ha^{-1}) and both treatments were significantly different ($p \leq 0.05$) compared to the others irrespective of residue management. Sunhemp treated plots were however not significantly different from F and NF treated plots or the other cover crops residue treatment. The WUE values for cover crop residue treated plots were higher compared to the F and NF plots. The data suggests that the cover crops treatments were superior to the other two treatments though results in some plots were not significantly different. Among the residue management practices, the above and below ground biomass incorporated had significantly higher WUE ($p \leq 0.05$) values (23.4 kg mm^{-1} ha^{-1}) compared to the other two management practices. Though surface mulch had a higher WUE than roots only incorporated, it was not statistically different. Results in this study suggest that the above and below ground biomass improved soil water content that enhanced tomato yields more than the other residue management practices. This was further attested by the significant yields realized under the same residue management practices. Decomposition of both roots and leaves in vetch cover crop could also have improved the tomato growth conditions by providing plant nutrients. Unlike mulching, incorporation of manure has been shown to have favorable effects on crop performance (Eneji, *et al.,* 2008).

Wang *et al.* (2001) observed an increase in corn WUE where corn stover was incorporated into the soil. Application of organic materials also improves soil properties, and thus increases WUE (Arriaga and Lowery, 2003; Edmeades, 2003).

CONCLUSIONS

The rainy season was shorter than normal and the rainfall could not sustain the full length of the tomato growing period leading to low ET values in all treatments that in turn resulted in low tomato yields. However, cover crops residue treatment showed some potential in improving yields and WUE. Vetch residue treatment increased tomato yields and WUE efficiency through enhancement of soil moisture storage. Vetch above and belowground biomass incorporated in the soil would be recommended for the study area. However, the results indicate there were direct crop growth benefits from use of crop residues either as mulch or through incorporation into the soil. Incorporating the above and below ground biomass into the soil during the short rainy season fallow period could be a sustainable residue management strategy for the sub humid areas of Kenya. The study was conducted in the very dry period where the termites consumed part of the mulch and this could have had an effect in water storage. Also it would be necessary to undertake same research under different Agro-ecological zones, different soil types and seasons to get a true picture of the findings and also to research on the adaptability of the technology and its impact to the small scale farmers.

ACKNOWLEDGEMENTS

The authors acknowledge Belgian Technical Cooperation for funding the research and to both the University of Nairobi and the University of Ghent for the technical support during implementation.

Table 9. Effect of cover crop residues on tomato water use efficiency (kg mm^{-1} ha^{-1})

Management/ Treatment	Velvet bean	Vetch	Sunhemp	Fertilizer	Non-fertilized	mean
Surface mulch	18.8a(11.0)	16.4a(11.0)	21.3a(11.0)	13.4a(11.0)	12.2a(11.0)	16.4a(6.7)
Above and below ground biomass	26.1b(11.0)	34.7b(11.0)	19.1a(11.0)	16.8a(11.0)	20.4a(11.0)	23.4b(6.7)
Roots only	17.3a(11.0)	17.1a(11.0)	18.6a(11.0)	14.0a(11.0)	10.6a(11.0)	15.5a(6.7)
Mean	20.7b(6.4)	22.7b(6.4)	19.7ab(6.4)	14.7a(6.4)	14.4a(6.4)	18.4

Mean figures followed by the same letter either in a row or column in each respective case are not significantly different at p = 0.05

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Submitted March 05, 2011 – Accepted September 17, 2014