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Effect of Mulching and Permanent Planting Basin Dimensions on Maize (*Zea mays* L.) Production in a Sub-Humid Climate

Alex Zizinga [1,*], Jackson-Gilbert Majaliwa Mwanjalolo [1,2], Britta Tietjen [3], Bobe Bedadi [4], Geofrey Gabiri [5] and Kizza Charles Luswata [6]

[1] Africa Centre of Excellence for Climate Smart Agriculture and Biodiversity Conservation, Haramaya University, Dire Dawa P.O. Box 138, Ethiopia; majaliwam@gmail.com
[2] Regional Universities Forum for Capacity Building in Agriculture, Makerere University, Kampala P.O. Box 317, Uganda
[3] Institute of Biology, Theoretical Ecology, Freie Universität Berlin, Königin-Luise-Str. 2/4, Gartenhaus, D-14195 Berlin, Germany; britta.tietjen@fu-berlin.de
[4] School of Natural Resource Management and Environmental Sciences, College of Agriculture and Environmental Sciences, Haramaya University, Dire Dawa P.O. Box 138, Ethiopia; bobedadi2009@gmail.com
[5] Department of Geography, Faculty of Arts and Humanities, Kyambogo University, Kyambogo P.O. Box 1, Uganda; geofreygabiri@gmail.com
[6] Department of Agricultural Infrastructure, Mechanisation and Water for Agricultural Production, Ministry of Agriculture, Animal Industry and Fisheries, Entebbe P.O. Box 102, Uganda; kizluswata@gmail.com
* Correspondence: azizinga@gmail.com; Tel.: +256-774284497

Abstract: In sub-humid regions, declining maize (*Zea mays* L.) yield is majorly attributed to unreliable rainfall and high evapotranspiration demand during critical growth stages. However, there are limited farm technologies for conserving soil water and increasing water use efficiency (WUE) in rainfed production systems amidst a changing climate. This study aimed at assessing the performance of different climate smart agriculture (CSA) practices, such as mulching and permanent planting basins (PPB), on maize growth, yield, water use efficiency and soil moisture storage. Field experiments involving mulches of 2 cm (M_2 cm), 4 cm (M_4 cm) and 6 cm (M_6 cm) thickness, permanent planting basins of 20 cm (PPB_20 cm) and 30 cm (PPB_30 cm) depths and the control/or conventional treatments were conducted for three maize growing seasons in the sub-humid climate of Western Uganda. Results indicate that maize biomass significantly increased under the tested CSA practices in the study area. Use of permanent planting basins relatively increased maize grain yield (11–66%) and water use efficiency (33–94%) compared to the conventional practice. Additionally, plots treated with mulch achieved an increase in grain yield (18–65%) and WUE (28–85%) relative to the control. Soil amendment with M_4 cm and M_6 cm significantly increased soil moisture storage compared to permanent planting basins and the conventional practice. Overall, the results highlight the positive impact of CSA practices on improving maize yield and water use efficiency in rainfed agriculture production systems which dominate the sub-humid regions.

Keywords: climate smart agriculture; maize; water use efficiency; soil moisture storage; rainfed

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1. Introduction

Water stress is the key limiting factor for crop production in rainfed farming systems, which dominate in sub-humid regions [1–3]. Climate change is projected to increase water scarcity and drought conditions, which are likely to compromise efforts to improve water management in sub-humid regions. In the sub-humid regions of sub-Saharan Africa (SSA), food production for poor communities accounts for more than 95% of farmed land [4], where maize (*Zea mays* L.) is one of the major food crops cultivated. In addition, maize is the most versatile crop grown for various uses, such as feed, fodder for livestock and in the recent past as a source of biofuel [5]. Generally, maize is continuously cultivated as a monocrop, yet it is an exhaustive crop in terms of soil water use and soil fertility depletion, hence causing low soil productivity and household income, especially with the absence of appropriate soil management practices [6].

With the increasing effects of climate change and variability, the frequency and severity of droughts has been reported in the rainfed agriculture systems of the sub-humid regions [7–10]. This is likely to exacerbate soil moisture stress and reduce crop production of maize. In fact, the authors of [11,12] report a reduction of approximately 50% of maize yield in sub-Saharan Africa by 2040–2070, attributed to climate change impacts. Currently, various adaptation strategies such as soil and water conservation practices have been adopted by the communities for efficient use of water under the rainfed agricultural production systems amidst the increasing droughts and shifts in rainfall seasons due to climate change. Recently, climate smart agriculture (CSA) as one of the soil and water conservation practices is being promoted in sub-humid regions to address the issue of water stress [13].

Climate smart agriculture refers to farm management practices that improve the water storage capacity or water use efficiency in agriculture [13]. Therefore, CSA practices sustainably increase soil productivity, resilience, and reduce greenhouse gas emissions to enhance the achievement of national food security and development goals [14]. Some of the major CSA practices being adopted include mulching [15] and implementation of permanent planting basins (PPB) [13] to enhance soil water retention for crop production. However, the former are faced with challenges of inadequate quantities of mulching materials due to multipurpose demands and competition in livestock and energy sectors [16]. Additionally, in some regions, mulches are expensive and inaccessible by the smallholder farmers [17]. On the other hand, permanent planting basins are associated with high establishment costs and frequent siltation, hence are often hard to implement in certain landscapes [18,19]. Therefore, some farmers have resorted to using unstandardized dimensions of CSA practices, such as the depth of the permanent planting basin and the thickness of mulch [20], to reduce on the costs of implementing the standardized dimensions, for instance, the 30 cm permanent planting basin depth and the width of 30 cm [13] recommended by the Food and Agriculture Organization.

Therefore, there is a need to understand the effect of these various unstandardized CSA dimensions compared to the standardized ones on the crop growth, yield and water use efficiency on maize production cultivated in these regions. This will harmonize the competition of resources for crop production and livestock feed, which enhances the effective utilization of the rising scarce mulch materials for optimum production.

Previous studies have also evaluated the effect of different mulch dimensions on banana yield and soil moisture in the sub-humid region of East Africa [21], wheat and rice in semiarid regions [22,23] and PPB on maize growth and yield in the arid and semiarid regions [24]. However, studies on mulching in the sub-humid region of Uganda have focused on the effect of selected soil physical properties (bulk density, hydraulic conductivity) and not on water use efficiency and its relation to crop yield. Additionally, limited studies exist on the use of PPB practice and improving water use efficiency and crop yield in the sub-humid regions of East Africa [25].

Improving soil water management is important for crop productivity. Climate smart agriculture practices can play a role as solutions for appropriate soil management. Studies [26,27] have demonstrated that proper soil management can enhance soil water availability in a landscape, and practices such as mulching and permanent planting basins are indispensable. The adoption of CSA practices such as mulching increases soil organic matter and soil water availability, hence crop growth and yield [28]. Studies [13,29,30] have investigated the application of CSA practices such as mulching and permanent planting basins in maize and sorghum cropping systems, where it was documented that there was no reduction in the yield and soil moisture retention increased, hence water use efficiency (WUE) improved. Mulching is also a soil management practice which improves soil health, WUE and water-holding capacity [31]. This also contributes to changes in soil water balance through a decrease in water evaporation and an increase in infiltration, and hence higher soil organic matter effects on the crop growth and higher WUE [28]. Mulching also has a potential effect on WUE and can amend soil conditions for improved productivity.

The permanent planting basins are key soil water management practices that increase water infiltration and harvest rainwater, which benefits plants for a longer time and improves yield [32,33]. It also reduces soil erosion and weeding intensity hence a potential booster for water use efficiency.

Most of the earlier studies of PPB have been conducted in the semiarid and not the sub-humid regions, which is apparently facing the impacts of climate change [25,32,34]. However, the PPB practice suits both semiarid and arid region areas, where rains are becoming scarce, variable and occur late in planting seasons. Furthermore, the promotion of CSA practices should be guided by evidence-based studies on the optimum dimensions of PPB and mulch for sustainable soil water management, efficient use of resources and crop yield increase. Therefore, this study aimed to determine the effects of mulching and permanent planting basin dimensions on soil moisture storage, maize growth, yield and water use efficiency. For this purpose, we conducted a field experiment with different thicknesses of mulch layers and different depths of the permanent planting basins in a sub-humid region of mid-western Uganda.

2. Materials and Methods

2.1. Experimental Site Description

The field study was conducted for three growing seasons from April 2019 to August 2020 at the Bulindi Zonal Agricultural Research and Development Institute (1°00′–2°00′ N and 30°30′–31°45′ E), located in the Albert region, mid-western Uganda (Figure 1).

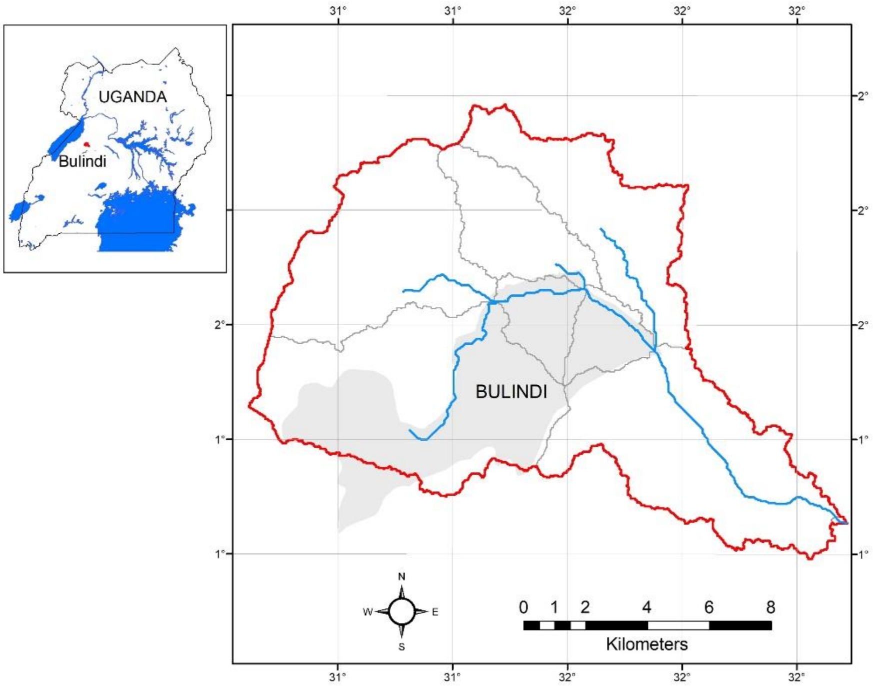

Figure 1. Location of the study area, Bulindi Zonal Agricultural Research and Development Institute, in grey color, where the experiment was conducted.

The first season (long rain season) ran from April to August 2019, the second season (short rain season) from October 2019 to January 2020 and the third season (long rain season) from March to August 2020 (Figure 2). The study area is characterized by a sub-humid climate with a bimodal pattern rainfall of 1300 mm annual average, with 39% (529 mm), 31% (416 mm) and 30% (406 mm) falling in each growing season during the study period

(Figure 2). Mean air temperature was 21.0, 24.4 and 20.9 °C, for the first, second and third growing seasons, respectively (Figure 2). The major soils of the experimental site are Acric Ferralsols [35].

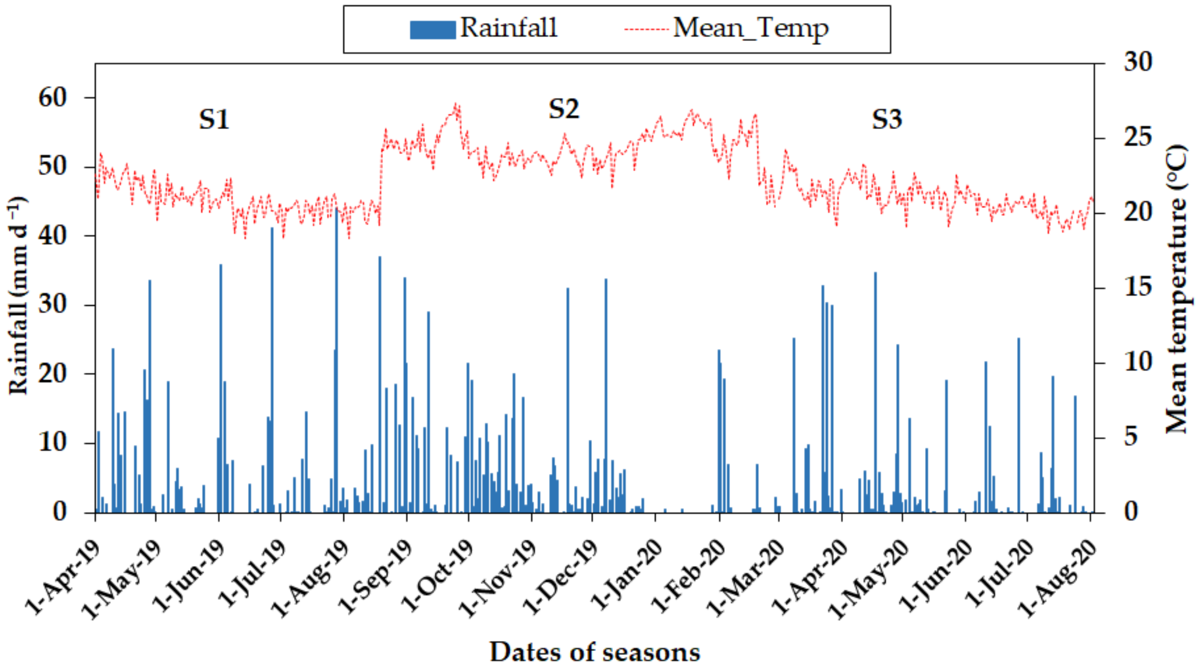

Figure 2. Daily rainfall and temperature during the three maize growing seasons 1 (**S1**), 2 (**S1**) and 3 (**S3**).

2.2. Experimental Design and CSA (Treatment Description)

The experiment was set up in a randomized complete block design with plot sizes of 5 by 5 m in four replications for each treatment (Figure 3). These included six treatments, which are: control—conventional maize farming without any CSA (C), permanent planting basins of 20 cm depth (PPB_20 cm) or 30 cm depth (PPB_30 cm) and straw mulch of 2 cm (M_2 cm), 4 cm (M_4 cm) or 6 cm (M_6 cm). For treatments M_2 cm, M_4 cm and M_6 cm, the soil in each plot was covered with dry grass materials to obtain a thickness of 2, 4 and 6 cm above the soil surface (Figure 3b–d). This was performed immediately after planting, such that the mulching materials were placed between the planted maize rows. The permanent planting basin treatments were established by digging circular pits of 15 cm diameter and depths of 20 cm (PPB_20 cm) and 30 cm (PPB_ 30 cm), respectively [13]. The permanent planting basins were established one day before planting maize (Figure 3e,f).

The control (C) treatment comprised of a bare surface field without any water management technique, and a typical conventional farming practice used in the study area for maize cultivation by smallholder farmers. In all treatments, maize (Longe 9H variety) was sown 5 cm deep at a spacing of 75 cm between rows × 30 cm between hills on 1 April 2019, 5 October 2019 and 17 March 2020 for seasons 1, 2 and 3, respectively. Plots of 5 × 5 m with borders of 1 m between plots and 2 m between blocks were used (Figure 3).

To cater for the maize nutrient requirements, diammonium phosphate (60 kg ha^{-1}) and muriate of potash (60 kg ha^{-1}) were basally applied at blanket rates during planting. At eight weeks after planting, top dressing was conducted using urea fertilizer applied at a blanket rate of 90 kg ha^{-1} [20]. The pests and diseases were controlled wherever they appeared, while weeds were controlled by hand pulling. The experiment was completely rainfed during the three consecutive maize growing seasons without any irrigation.

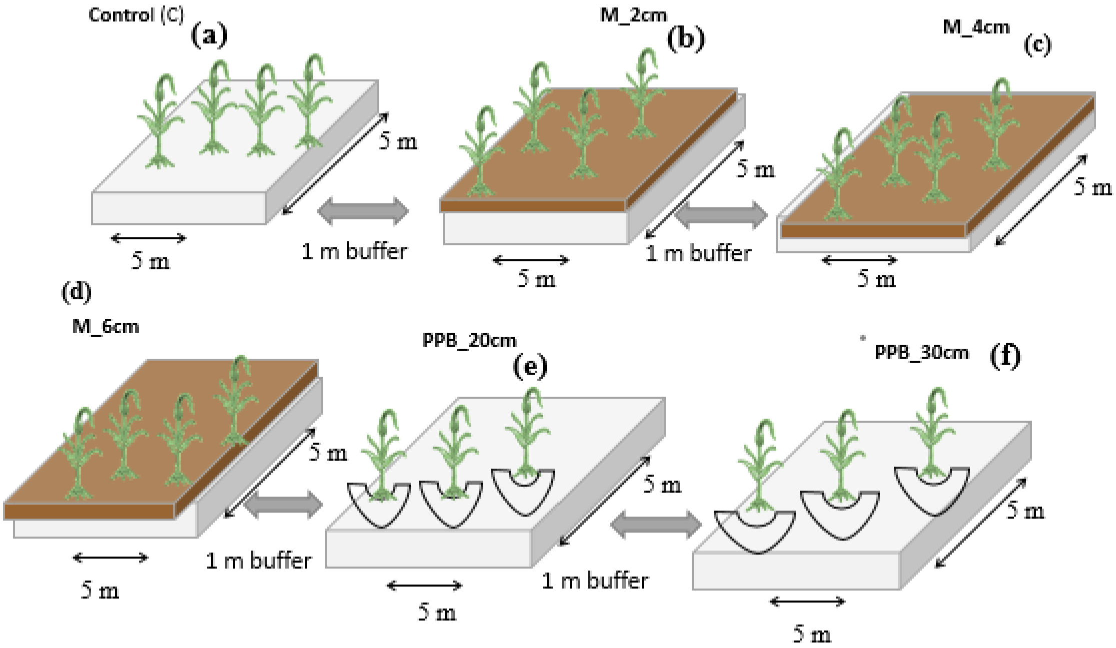

Figure 3. Schematic plot map illustration of the experiment: (**a**) control (C), (**b**) mulches of 2 cm thick (M_2 cm), (**c**) mulch 4 cm thick (M_4 cm), (**d**) mulch 6 cm thick (M_6 cm), (**e**) permanent planting basin 20 cm (PPB_20 cm) and (**f**) permanent planting basin 30 cm (PPB_30 cm).

2.3. Soil Moisture Content Measurements

Soil moisture content was monitored in each treatment plot at soil depths of 10, 20, 30 and 40 cm using the Frequency Domain Reflectometry (FDR) profile probe-type PR2/4 [36]. The profile probe-type PR2/4 consists of a sealed polycarbonate rod of about 25 mm diameter, with electronic sensors arranged at fixed intervals along its length, and has a measurement accuracy of ± 0.06 m^3 m^{-3}, at 0 to 40 °C under generalized soil calibration in normal soils [36]. For each treatment, eight (8) access tubes of 40 cm length were installed at the beginning of the experiment to measure daily volumetric soil moisture content. The volumetric soil moisture content readings were manually recorded using a handheld moisture meter connected to a profile probe sensor [37]. Soil moisture storage (SMS) for each soil depth was computed in all three consecutive growing seasons Equation (1).

The data were subsequently grouped into maize development growth stages for analysis based on the Biologische Bundesanstalt Bundessortenamt and Chemical Industrie scale (BBCH) [38] using Equation (1):

$$SMS\ (\%) = [SMC/(\ \rho_b \times d)] \times 100 \tag{1}$$

where,

SMC = soil moisture content ($m^3 m^{-3}$),
ρ_b= soil bulk density $\left(g\ cm^{-3}\right)$,
d = soil depth (cm).

2.4. Soil Data Collection and Analysis

Soil samples were collected for bulk density at a 10 cm depth interval to 40 cm soil depth using the core method. This was performed at a 15–25 cm distance from the soil moisture access tubes to minimize soil disturbances within the soil moisture sensor electromagnetic field. The soil samples were analyzed for bulk density using the core method [39], while the water-holding capacity (WHC) was also measured at 0–40 cm [40], after the harvest of maize.

2.5. Maize Biomass and Yield

The maize grain and stover yield data were collected at harvesting from a net area of 4 m^2 per CSA treatment plots at the maturity stage. Maize plants from the harvested area were cut from ground level, and cobs were removed and threshed. The fresh and stover yields were determined using a weighing scale in the field after harvesting. Subsamples of the harvested shoots at the growth stages were obtained and air-dried at the Makerere University laboratory to a moisture content of 12.5%, and this was used to calculate dry matter and grain yield (kg ha^{-1}). The grain yield from each treatment was used to calculate the water use efficiency (WUE) per kg ha^{-1} from each treatment, using the formula in Equation (1). Water use efficiency (kg ha^{-1} mm^{-1}) expresses maize yield per water that is lost through evapotranspiration [41], using Equation (2):

$$\text{WUE} = Grain\ yield/ET \tag{2}$$

where,

WUE = water use efficiency (kg ha^{-1} mm^{-1}),
ET = evapotranspiration (mm).

2.6. Estimation of Crop Evapotranspiration (ET)

The experimental field was flat (with a slope of <5%), and the groundwater table was deep (>7 m), therefore deep percolation and runoff of water in the field plots was neglected. Thus, seasonal evapotranspiration (*ET*, mm) for each treatment was determined based on soil water budget [41,42] using Equation (3):

$$ET(\text{mm}) = P + \Delta SWS \tag{3}$$

where, p is the total precipitation (mm) and ΔSWS is the change in soil water storage (mm) between the planting and harvesting stages. The water use efficiency (WUE) was calculated as the grain yield (kg ha^{-1}) divided by the total ET over the growing seasons.

2.7. Effects of CSA Practices on Grain Yield and Water Use Efficiency

The impact of CSA treatments on grain yield and water use efficiency (WUE) was calculated as the difference between CSA practice and control treatment relative to the value of the control treatment using Equation (4). This was calculated separately for each of the three growing seasons.

$$\Delta X_{CSA\ practice} = \left(X_{CSA\ practice} - X_{Control}\right)/X_{Control} \tag{4}$$

where X refers to yield or water use efficiency.

2.8. Data Analysis

To analyze the data and test for statistical significance, the R software version 3.6.0 was used. Analysis of variance (ANOVA) was applied to determine the effect of the CSA practices on soil moisture content at 10, 20, 30 and 40 cm, as well as the maize growth and yield parameters at the 5% significance level. The assumptions of normality and homoscedasticity were verified with the Shapiro–Wilk test and visual examination of the residuals against fitted values. The analysis of variance was performed on maize grain and stover yields and water use efficiency. In addition, a linear mixed-effect model with the ‘lmer’ function from the package ‘lme4’ in R statistical software was performed with soil moisture and growth stages as fixed effects, and replication as the random effect. Computation of least square means was carried out using the ‘lsmeans’ package. The post-hoc comparisons were performed using the Tukey’s HSD test, and this allowed to identify differences between specific treatments. For all statistical tests, $p < 0.05$ was considered significant.

3. Results

3.1. Effect of CSA Practices on Soil Properties and Water Use Efficiency

3.1.1. Soil Moisture Content

The dimensions of CSA practices had a direct impact on soil moisture content at the different soil depths and growth stages (Figure 4). The soil moisture content in the topsoil (0–10 cm and 10–20 cm depths) and subsoil (20–30 cm and 30–40 cm depths) differed significantly ($p < 0.05$) in the CSA treatments with respect to soil depth across the growth stages (vegetative, tasseling, silking and maturity).

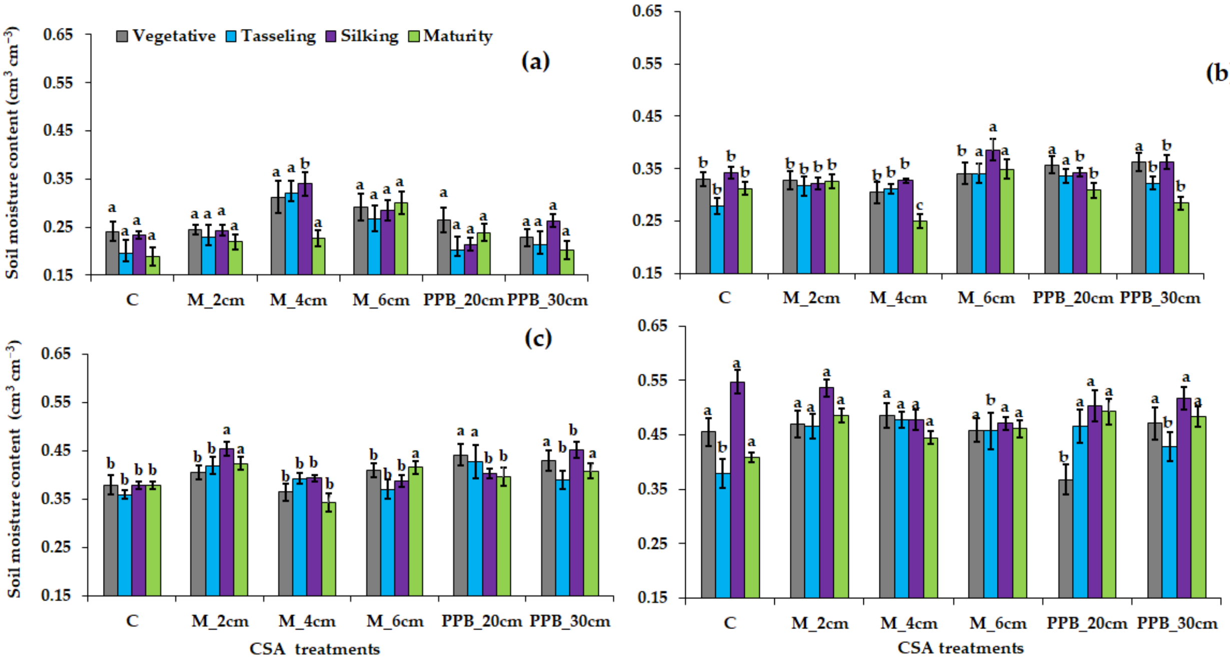

Figure 4. Soil moisture content at different growth stages of maize grown using adjusted dimensions of CSA practices and the control treatment over the study period. Soil moisture contents at soil depths of: (**a**) 10 cm, (**b**) 20 cm, (**c**) 30 cm and (**d**) 40 cm moisture distribution. Means ± standard error followed by the same letters are not significantly different ($p < 0.05$).

Figure 4 indicates soil moisture variations at the different soil depths across the growth stages. At the 0–10 cm soil depth, the different mulch dimensions significantly ($p < 0.05$) affected soil moisture content across the growth stages compared to PPB_20 cm and PPB_30 cm treatments. The M_2 cm increased moisture content by 2%, 16%, 4% and 16%, M_4 cm by 29%, 63%, 46% and 20%, while M_6 cm by 21%, 37%, 22% and 59% respectively, compared to the control treatment in the vegetative, tasseling, silking and the maturity growth stages, respectively (Figure 4a). The PPB_20 cm increased soil moisture by 10%, 4% and 26% for the vegetative, tasseling and maturity growth stages respectively, while PPB_30 cm increased soil moisture by 9%, 13% and 7% at the tasseling, silking and maturity growth stages, respectively. At the 10–20 cm depth, PPB_30 cm treatment had the highest increase of soil moisture by 10% compared to other CSA practices and the control treatment (Figure 4b).

At the depths of 20–30 cm, M_2 cm consistently increased soil moisture content by 7%, 17% and 20% for the vegetative, tasseling and silking growth stages (Figure 4c). The M_4 cm practice increased soil moisture content only during tasseling and silking growth stages by 9% and 4% respectively, compared to the other CSA practices which caused an increase in soil moisture content across the four maize growth stages (Figure 4c). At depths of 30–40 cm, soil moisture content increased by 3%, 23% and 19% under M_2 cm, 7%, 26% and 9% under M_4 cm, 1%, 21% and 13% under M_6 cm and 4%, 13% and 18% under

PPB_30 cm during the vegetative, tasseling and maturity growth stages, respectively. The treatment PPB_20 cm only increased moisture at tasseling by 23% and maturity by 21% (Figure 4d). Therefore, for all the CSA practices, soil moisture highly increased during the tasseling growth stage, except for the PPB_30 cm practice, which had its highest soil moisture content observed during the maturity stage.

3.1.2. Effect of CSA Practices on Bulk Density, Soil Water-Holding Capacity and Soil Moisture Storage

Significant ($p < 0.05$) effects of CSA practice dimensions on water-holding capacity (WHC) and soil moisture storage were observed across the different soil depths, except for the 0–10 and 30–40 cm soil depths (Table 1). Soils under the control treatment at all depths had a relatively lower WHC compared to the highest WHC observed under M_2 cm and M_6 cm. At 10–20 cm depths, two groups of CSA practices were observed, each indicating no significant effect on WHC, albeit significant differences across the two groups were observed. The first group includes the Control, M_2 cm and PPB_20 cm, and the second CSA group involves M_4 cm, M_6 cm and PPB_30 cm treatments. The second CSA group with higher dimensions had a greater WHC than the first group with lower dimensions. Therefore, increasing the dimension of the tested CSA practices has the advantage of increasing the soil water-holding capacity in these sub-humid regions, with PPB_30 cm and M_6 cm having a superior positive effect on the soil WHC. Despite a relatively higher bulk density under C and M_2 cm, there were no significant differences between treatments ($p > 0.05$). The M_6 cm thickness had the highest soil moisture storage (15.08 mm cm^{-1}), followed by M_4 cm (15.02 mm cm^{-1}) and PPB_30 cm (14.28 mm cm^{-1}), and the lowest was observed in the control/conventional practice.

3.2. Effect of Adjusting CSA Practices on Maize Growth

3.2.1. Biomass

Maize biomass varied significantly ($p < 0.001$) across the CSA practices for the different growth stages (Figure 5). The biomass from all the CSA practices followed an increasing trend across the growth stages (days after planting) and the increase in biomass accumulation ranged from 161% to 693%. The PPB_30 cm CSA practice accumulated higher biomass compared to other CSA practices and the control treatment. At the silking growth stage (87 days after planting), the PPB_30 cm CSA practice had higher biomass (9624 kg ha^{-1}) compared to other CSA practices. Overall, maize plants continuously accumulated higher biomass under CSA practices after the 40 days of planting until the maturity stage (100 days) towards harvesting. The control treatment had the lowest plant biomass across all growth stages (Figure 5).

Table 1. Effect of adjusting climate smart (CSA) practices on the selected soil physical properties.

CSA	**Water-Holding Capacity (%)**				**Bulk Density (g cm^{-3})**				**Soil Moisture Storage (40 cm^{-1})**
	Soil Depth (cm)				**Soil Depth (cm)**				
	0–10	**10–20**	**20–30**	**30–40**	**0–10**	**10–20**	**20–30**	**30–40**	
C	20.98 ± 0.76 d	30.51 ± 0.30 c	35.44 ± 1.85 b	44.00 ± 0.56 a	1.45 ± 0.03 a	1.46 ± 0.04 a	1.42 ± 0.01 a	1.41 ± 0.01 a	13.09 ± 0.37 c
M_2 cm	23.03 ± 1.16 d	30.63 ± 0.81 c	38.64 ± 0.69 b	44.56 ± 0.73 a	1.47 ± 0.01 a	1.41 ± 0.05 a	1.40 ± 0.02 a	1.43 ± 0.02 a	13.69 ± 0.54 abc
M_4 cm	34.58 ± 1.44 b	33.42 ± 1.11 b	35.63 ± 0.67 b	46.59 ± 1.28 a	1.30 ± 0.14 a	1.29 ± 0.10 b	1.32 ± 0.06 b	1.32 ± 0.07 b	15.02 ± 0.72 ab
M_6 cm	31.62 ± 1.47 c	37.02 ± 0.60 b	37.87 ± 0.95 b	44.33 ± 0.69 a	1.31 ± 0.08 b	1.18 ± 0.01 b	1.30 ± 0.11 c	1.30 ± 0.10 b	15.08 ± 0.51 a
PPB_20 cm	22.27 ± 0.88 d	32.46 ± 1.43 c	39.10 ± 1.21 b	46.88 ± 1.34 a	1.29 ± 0.09 b	1.25 ± 0.1 b	1.20 ± 0.03 a	1.40 ± 0.07 a	14.07 ± 0.49 abc
PPB_30 cm	22.92 ± 1.04 c	38.20 ± 0.36 b	38.20 ± 0.36 b	43.46 ± 0.55 a	1.16 ± 0.01 c	1.14 ± 0.01 b	1.18 ± 0.08 a	1.12 ± 0.02 c	14.28 ± 0.40 ab

Note: C = control (without CSA), M_2 cm = mulch of 2 cm thickness, M_4 cm = mulch of 4 cm thickness, M_6 cm = mulch of 6 cm thickness, PPB_20 cm = permanent planting basin of 20 cm depth and PaPB_30 cm = permanent planting basin of 30 cm depth. Within the same row per CSA, means ± stand error followed by the same letters are not significantly different at $p < 0.05$.

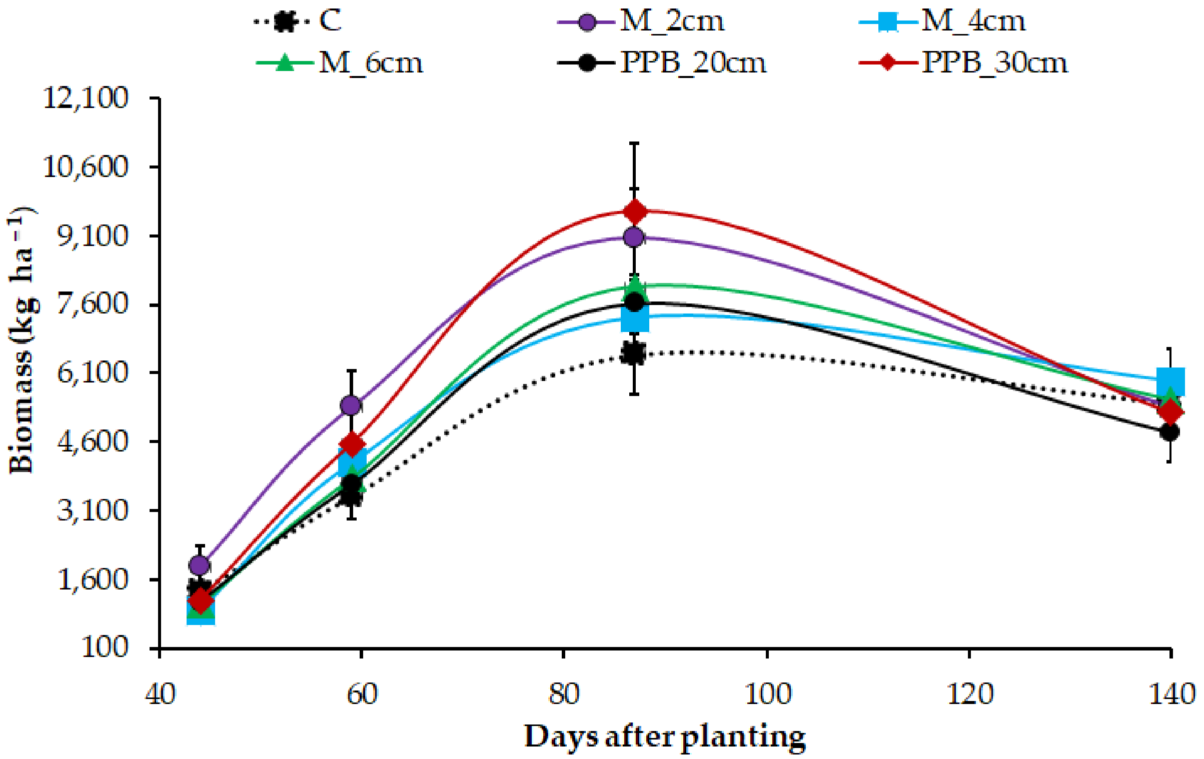

Figure 5. Effect of various CSA treatments on maize biomass accumulation. C = control, M_2 cm = mulch of 2 cm thickness, M_4 cm = mulch of 4 cm thickness, M_6 cm = mulch of 6 cm thickness, PPB_20 cm = permanent planting basin of 20 cm depth and PPB_30 cm = permanent planting basin of 30 cm depth. Means ± stand error followed by different letters are significantly different at $p < 0.05$.

3.2.2. Grain Yield

The different CSA practices had significant ($p < 0.001$) effects on maize grain and stover yields (Figure 6). CSA application increased maize grain yield by 31–136% higher than the control treatment. The highest grain yield (7498 kg ha^{-1}, 64%) was produced from maize grown under the PPB_30 cm treatment (Figure 6). There was no significant difference ($p < 0.05$) in the maize grain yields across plots under M_2 cm, M_6 cm and M_4 cm. Maize stover yield also varied significantly ($p < 0.001$) across the CSA treatments. The M_2 cm, M_6 cm, M_4 cm, PPB_30 cm and PPB_20 cm had higher stover than the control treatment (Figure 6). In summary, PPB_30 cm and M_2 cm had the highest grain and stover yield compared to the other CSA practices and the control treatment. The grain yield under PPB_30 cm and M_2 cm increased by 66% and 65% in comparison to the control/or conventional practice (Figure 6).

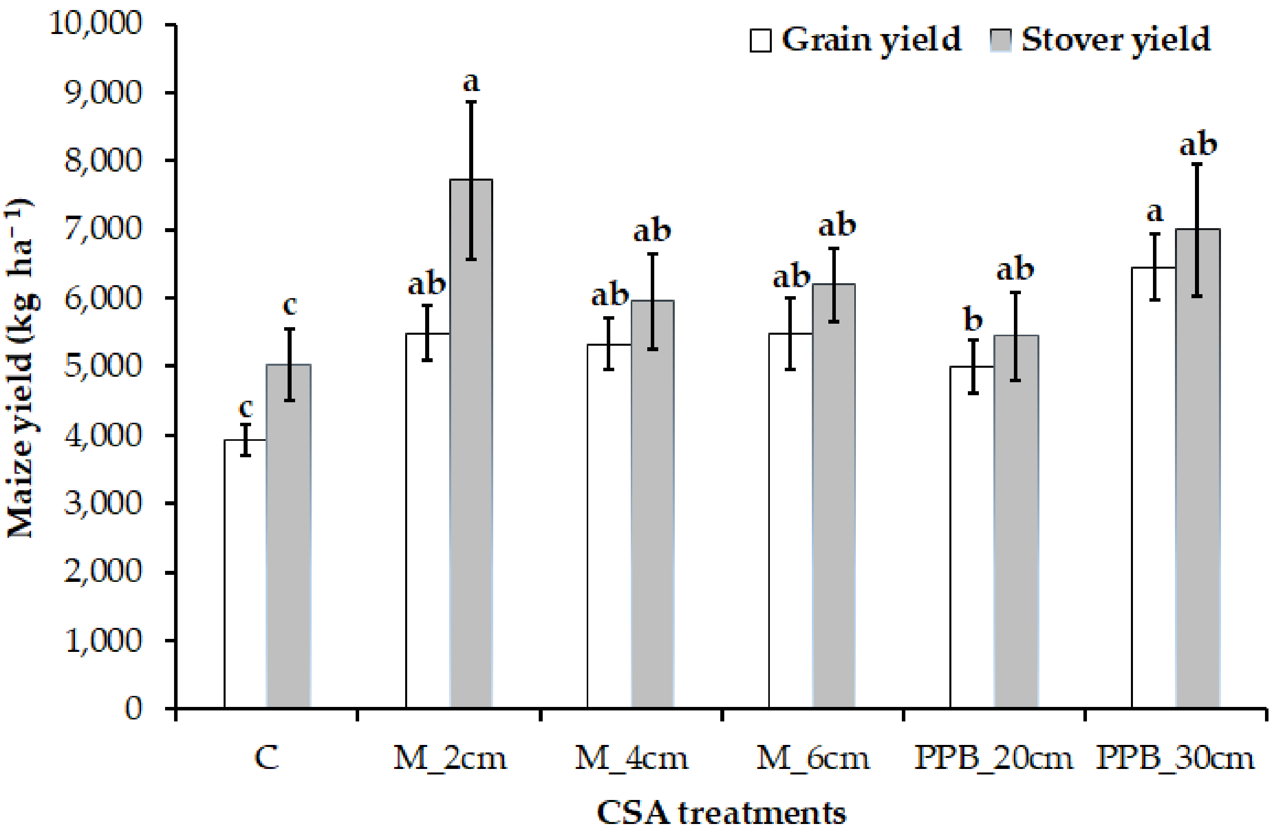

Figure 6. Effect of various CSA treatments on maize grain and stover yields. C = control, M_2 cm = mulch of 2 cm thickness, M_4 cm = mulch of 4 cm thickness, M_6 cm = mulch of 6 cm thickness, PPB_20 cm = permanent planting basin of 20 cm depth and PPB_30 cm = permanent planting basin of 30 cm depth. Means ± stand error followed by different letters are significantly different at $p < 0.05$.

3.2.3. Effect of CSA Practices on WUE of Maize

The water use efficiencies (WUE) of maize across the adjusted CSA practices and the control treatment are presented in Table 2 and Figure 7a. Overall, WUE was significantly higher ($p < 0.05$) under the PPB_30 cm and M_2 cm dimensions compared to the other CSA treatments (Table 2).

Table 2. Effects of different CSA treatments on maize grain yield and water use efficiency.

CSA	Grain Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})
C	4516 ± 233.43 c	8.54 ± 0.63 d
M_2 cm	7469 ± 408.11 a	15.79 ± 0.80 b
M_4 cm	5323 ± 378.15 b	10.91 ± 0.96 c
M_6 cm	5485 ± 524.97 b	12.17 ± 1.19 c
PPB_20 cm	4996 ± 393.33 bc	11.35 ± 0.95 c
PPB_30 cm	7498 ± 468.74 a	16.58 ± 0.85 a

Notes: C = control (without CSA), M_2 cm = mulch of 2 cm thickness, M_4 cm = mulch of 4 cm thickness, M_6 cm = mulch of 6 cm thickness, PPB_20 cm = permanent planting basin of 20 cm depth and PPB_30 cm = permanent planting basin of 30 cm depth. Means ± stand error followed by different letters are significantly different at $p < 0.05$.

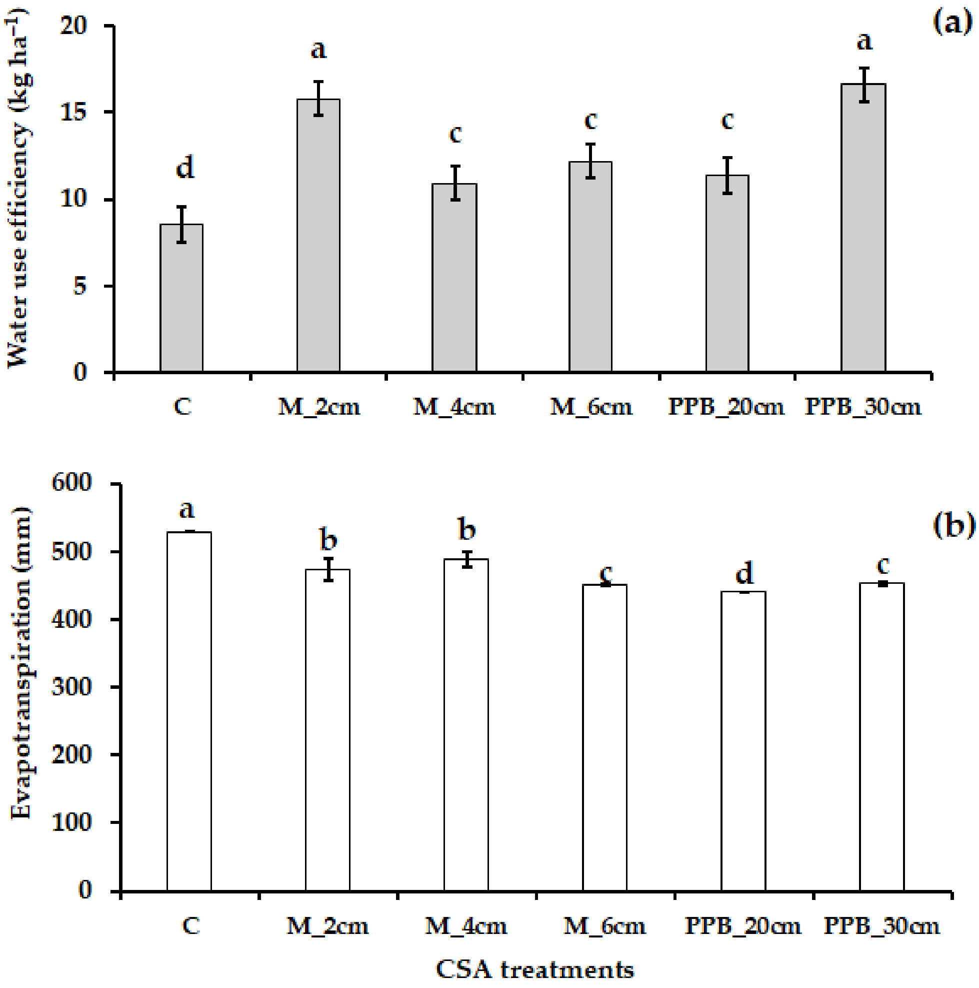

Figure 7. Effect of CSA treatments on water use efficiency (**a**) and evapotranspiration (**b**). C = control, M_2 cm = mulch of 2 cm thickness, M_4 cm = mulch of 4 cm thickness, M_6 cm = mulch of 6 cm thickness, PPB_20 cm = permanent planting basin of 20 cm depth and PPB_30 cm = permanent planting basin of 30 cm depth. Means ± stand error followed by different letters are significantly different at $p < 0.05$.

There were also significant differences ($p < 0.001$) in the maize grain yield and water use efficiency in different CSA treatments (Table 2). The PPB_30 cm and M_2 cm treatments increased water use efficiency by 85–94% from the control treatment (Table 2). Plots treated with M_6 cm, M_4 cm and PPB _20 cm increased grain yield by 21%, 18% and 11% and 43%, 28% and 33% for water use efficiency, respectively (Table 2).

Therefore, adjusting the dimensions of the CSA practices enhanced WUE compared to the control treatment, although the magnitude was different among the respective dimensions of CSA practices. WUE greatly increased under PPB_30 cm (94%), followed by M_2 cm (85%), M_6 cm (43%) and PPB_20 cm (33%). The lowest change in water use efficiency (24%) was obtained under PPB_20 cm with regard to the control treatment.

The increase in evapotranspiration (ET) affected water use efficiency across the CSA treatments (Figure 7). The control treatment had the highest ET (529 mm) compared to all the CSA treatments, while PPB_20 cm, M_6 cm, PPB_30 cm, M_2 cm and M_4 cm had the lowest ET (440, 451, 452, 473 and 488 mm), respectively (Figure 7b). The significantly ($p < 0.05$) higher ET in the control treatment decreased the water use efficiency (Figure 7a) and the maize grain yield in Table 2.

4. Discussion

The observed increase in soil moisture content in each of the CSA treatments is beneficial for improved maize production under limited rainfed conditions, especially for high water use crops such as maize. Soil moisture increase and conservation is key in improving maize yield, and this has been reported in China, were straw mulch increased maize yield by 16.9% compared to the conventional planting practice under insufficient rains [43]. Additionally, mulch has been used as a strategy on agriculture lands in the Mediterranean cropping systems of citrus to control soil water losses and soil erosion discharge, which increased infiltration [44].

The effect of soil moisture availability in the CSA treatments such as mulching enhanced maize growth, which improved transpiration through high water use efficiency [33], and this is also similar to other studies where soil moisture has improved maize growth in rainfed regions [45]. The increase in soil moisture observed in CSA practices could also be attributed to the reduced evaporation as a result of surface insulation in mulched plots and increased soil water retention for the permanent planting basin plots [46]. Our findings have clearly shown that the dimensions of mulching (M_2 cm, M_4 cm, M_6 cm) and permanent planting basins (PPB_20 cm, PPB_30 cm) can enhance soil moisture storage and infiltration for better maize productivity under rainfed cropping systems. The mulch cover reduced the impact of raindrops, which increased water infiltration and retention, which is beneficial for crops, especially in rainfed agriculture systems [46–50].

Mulch thickness dimensions effectively cover the ground to reduce exposure of soil surface to the sun and evaporation, and this might be attributed to the relatively higher soil moisture content in treatments M_2 cm, M_4 cm and M_6 cm dimensions compared to the control treatment. Previous studies [49–51] report high soil moisture due to adequate soil surface ground cover in the sorghum- and maize-based cropping systems. Additionally, soil moisture storage and water-holding capacity were significantly higher in the CSA practices than the control treatment, where mulches (M_2 cm, M_4 cm and M_6 cm) were applied. Additionally, under permanent planting basins, the soil moisture storage and WHC were relatively higher than the control treatment. This might be attributed to lower bulk density and retained crop residues with minimum tillage effects in the CSA treatments, which insulated the soil surface and increased water infiltration. In previous studies [52,53], the relatively higher soil moisture storage under mulches and permanent planting basins is also attributed to higher infiltrability of the soil surface and reduction in soil evaporation. For example, permanent planting basins and the mulching treatments with the varying thickness and cover in the present study may have reduced the rainwater flow speed, which increase infiltration. This is also in tandem with the studies of [44,54], where straw mulch cover reduced overland flow speed, which affected the runoff movement.

Soil moisture variability across the CSA dimensions has a remarkable effect on maize growth, yield and biomass. The present results reveal increases in maize biomass with increases in high soil moisture retention, where there was CSA application and respective dimensions which enhanced biomass better than the control treatment. This is in agreement with previous studies [55], were availability of moisture in soil conservation practices improved maize biomass.

Soil moisture stress declines maize plant performance, which generates lower plant biomass and stunts growth [56]. Furthermore, under moisture stress, the percentage of biomass yield decline is higher [57,58]. Soil moisture is a major component of plant biomass accumulation and growth on crops such as maize, and moisture also controls plant phenology and morphology, and hence it affects growth stages majorly indicated by biomass. Similar to the current study, higher biomass contents were found in CSA practices which had higher soil moisture retention throughout the growing seasons. This implies that the biomass and growth for maize increased with increasing soil moisture availability across the CSA practices. These findings are in tandem with [59], which indicated that the highest biomass was recorded at 75% soil moisture content in *Lactuca serriola* weed.

Soil moisture for maize growth is highly dependent on rainfall, especially in the rainfed agriculture systems of sub-Saharan Africa. In the Albert sub-humid region where the study was conducted, the amount and distribution of seasonal rainfall play an important role in maize growth and development. Although the total rainfall was different by 113 mm between seasons one and two, and 14 mm between seasons two and three, there was still enhanced soil moisture storage in plots with different dimensions of mulches and permanent planting basins compared to the control plots. Shortage of soil moisture storage during maize growth stages was detrimental to maize yield, especially during the second growing season, and most pronounced in the control treatment.

The higher water use efficiency (WUE) and maize yield differences observed across dimensions of CSA practices and control treatments could be attributed to the high soil moisture storage and effects of evapotranspiration, which might have stimulated maize growth and nutrient acquisition. In this study, the dimensions of mulches (M_2 cm, M_4 cm, M_6 cm) varied in the yield and WUE, where M_2 cm and M_6 cm presented slightly higher grain yield than M_4 cm. The recommended PPB_30 cm practice by the Food and Agriculture Organization had significantly higher grain yield, while the PPB_20 cm had significantly lower grain yield and WUE. This could be attributed to the high soil moisture storage of PPB_30 cm for maize uptake, which easily stimulates growth and grain yield [60,61], and thus, the higher WUE and stover yield. The increase in yield is also indicative of the efficiency of CSA practices to enhance soil moisture storage and WUE [5].

In addition, maize is a “high water use” crop, and water use increases even during long rain seasons (seasons 1 and 3). During the tasseling and silking growth stages, high soil moisture storage in the CSA treatments may be beneficial for obtaining large grains, and thus may improve yield. However, this may also result in reduced oxygen concentrations in soil due to prolonged wet conditions, which can cause stomatal closure of maize plants [62]. Similarly, in our study, in the long rain seasons (seasons one and three), WUE was significantly higher than in season two, resulting in higher grain yield and water use efficiency.

During the study, soil moisture was lower in the control treatment and relatively high in mulch and permanent planting basin dimensions, but water use efficiency varied significantly for all treatments. Therefore, under the sub-humid regions, mulches and permanent planting basin dimensions improve soil moisture storage, which increases crop growth, yields and WUE. The PPB_30 cm was, however, superior in increasing WUE and grain yield. The M_2 cm, M_4 cm and M_6 cm CSA practices were also significantly greater than the control treatment in the maize growing seasons. This also indicates that a proper mulch thickness dimension of M_2 cm, M_4 cm and M_6 cm benefits to improve WUE and crop yield.

5. Conclusions

It is clear that climate smart agriculture practices in their respective dimensions significantly increased maize growth, yield and water use efficiency in rainfed production systems of sub-humid regions of Uganda, as indicated by improved maize yield and water use efficiency, respectively. In comparison to the conventional farming practice (control treatment), mulch of 2 and 6 cm thickness and PPB_30 cm led to higher soil moisture storage for maize growth, yield and water use efficiency across all three growing seasons. Therefore, the current study recommends the use of 30 cm deep permanent planting basins and 6 cm mulch thickness for higher maize yield and water use efficiency. However, due to the increasing scarcity of mulch materials in these sub-humid regions, application of 2 cm mulch thickness would also be an alternative, especially due to the scarcity of mulching materials, as it is cost-effective and environmentally viable. More studies should also be carried out across sub-humid regions to validate the results for wider application in maize cropping systems. In addition, the effects of these climate smart agriculture practices on soil erosion control and nutrient conservation along toposequences of sub-humid regions should be further investigated.

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