

Full Length Research Paper

Agronomic practices in soil water management for sustainable crop production under rain fed agriculture of Drylands in Sub-Sahara Africa

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Water is one of the very important inputs necessary for the production of food crops hence, food security and rural livelihoods are essentially linked to the accessibility of water. Eighty percent of the world's global agricultural land area is under rain-fed; this contributes to 58% of the world's staple foods. In Sub-Sahara Africa (SSA), reliance on rain-fed agriculture is high with 97% of the moisture needs of crops fulfilled mainly by water stored in the soil through rainfall. Due to highly unpredictable and sporadic seasonal rainfalls in SSA, rainfall cannot meet the requirements for crop growth and development resulting in lower crop yields with consequent food insecurity. It is important that water in rain-fed agriculture is used efficiently and effectively through interventions that conserve soil water. Thus, water productivity under rain-fed agriculture must be enormously improved particularly in SSA where the climate is dry and over 90% of agricultural activities are rainfed. However, uncertainty in rainfall projections and magnitude makes rainfed crop production a real challenge. Therefore, water management through daily field activities (agronomic practices) is a critical constituent that needs to be adopted in the current challenge of rainfall variability, climate change and expected increase demand for food. This paper highlights potentials of some agronomic practices for improved soil water content. Agronomic practices such as crop selection, mulching, fertilization and soil tillage has the potential to improve soil water content for improved and sustainable crop production.

Key words: Soil water, drylands, sub-Sahara Africa, rainfed, agronomic practices.

INTRODUCTION

Dry lands in Sub-Saharan Africa, which includes arid, semi-arid and sub-humid areas account for nearly one-half (43%) of the regions land area, three-quarters of the poor and 50% of population (Cervigni and Morris, 2015) most of whom depend on agriculture. The number of

Africans dwelling in dryland regions is anticipated to rise from 460 to almost 800 million by 2030 (World Bank, 2017). The economies of most Sub-Saharan African (SSA) countries rely on agriculture which is found to be five times more active in decreasing poverty than non-

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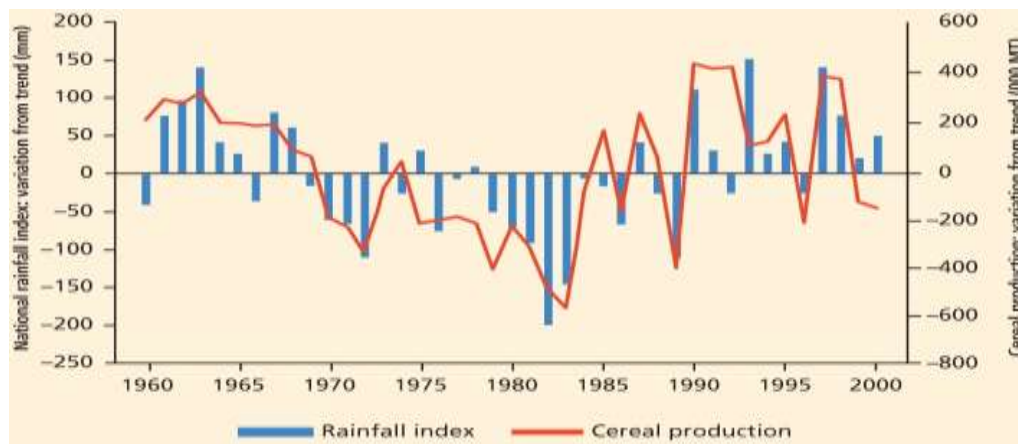


Figure 1. Dryland cereal production and rainfall in Burkina Faso, 1960-2000. mm = millimeters; MT = metric tons.

Source: Ward et al. (2016).

agriculture growth in low-income countries but 11 times more so in SSA (Christiaensen et al., 2011; FAO, 2012). However, about 97% of crop production in SSA is under rain-fed (Calzadilla et al., 2013) hence; the water needs of crop in SSA are achieved mainly by seasonal rainfall water stored in the soil.

Water is highly important for crop production and remains a critical input limiting global food production (D'Odorico et al., 2018). Although the concept of irrigation is not new, according to Makin (2016), about 5% of agricultural land (6 million ha) is under irrigation. Rain fed agriculture in SSA will continue to play an important role in food security. The challenge however is that, rainfall pattern and the amount is highly variable which leads to water deficit that negatively impact on crop growth and development (Guo et al., 2010; Alkaisi et al., 2015; Testa et al., 2016) resulting in low yield and productivity. Rainfall highly correlates with yield, especially in rainfed agriculture as illustrated in Figure 1.

According to Borgomeo et al. (2020), a decrease in seasonal rainfall generally translates into a decrease in yield. Shortage of water resources and its limitation in crop production is more compounded in SSA (Ren et al., 2016). According to Moyo et al. (2015), low use of irrigation and over-dependence on rain-fed agriculture in Africa accounts for the low agricultural productivity. The risk of food insecurity as a result of climate change and variability is increasing among many farming communities (Antwi-Agyei et al., 2013) and expected to hit harder (Open University, 2016). West Africa has already experienced a decrease of 20 - 40% in annual rainfall amount in the last decade (Nicholson et al., 2018) and expected to worsen in future (Anyamba et al., 2014). A meta-analysis of 52 studies indicated yield losses of 5, 10 and 15% in maize, pearl millet and sorghum respectively because of climate variability in Africa by 2050 (Kirtman et al., 2013).

Improvement in available water in rainfed agriculture is

critical to closing yield gaps (Jägermeyr et al., 2016) and resulting to improved food security. The desire to achieve food security and reduce poverty should be intensely linked to water management because it can more than double agricultural productivity in rain-fed areas with low yields. With climate change and expected increase in demand for food (Godfray et al., 2010), more importance need to be channel on addressing management of water in rain-fed agriculture as a key determinant for agricultural production and productivity. The key to successful rain-fed agriculture is to efficiently use stored rain water in the soil and improve its productivity through improved agronomic practices. A great deal can be done to reduce water losses and improve the efficiency of rainwater use through agronomic practices. A number of studies have shown that some agronomic practices can increase water availability to plants (Schmidt and Zemadim, 2015; Masunaga and Marques Fong, 2018). For instance, according to Mary and Majule (2009) enhancing soil tillage practices, soil fertility upgrading and mixed cropping is considered important adaptation techniques towards drought. The objective of this review was to highlight the potentials of some agronomic practices which have positive influence on soil water management for improved crop productivity.

Importance of soil water in crop production

The main source of water for crop production in SSA is rainfall. This makes seasonal rainfall variability has a deep effect on soil water availability especially for crop production. Every crop requires soil water for germination, growth and development as well as meeting its potential yield. Also, the amount of water required by each crop varies (Table 1) with both its excess and shortage directly affecting plant growth, development and yield. The effect of long term soil moisture stress includes

Table 1. Average crop duration (days) and water requirement (mm) for important field crops.

Crop	Average crop duration (days)	Water requirement (mm)
Rice	90-130	900-2500
Wheat	135	400-450
Pulses	90-120	250-300
Groundnut	105	450-600
Sugarcane	330	1400-3000
Banana	300	3000
Cassava	300	400-750
Maize	100	400-600
Sorghum	100-120	250-300
Cotton	165	600-700

Source: <http://www.keralaagriculture.gov.in>

cell enlargement and growth reduction, cellular and metabolic activities reduction, photosynthetic inhibition, decrease in chlorophyll, turgor loss and altered carbon partitioning (Osakabe et al., 2014). This eventually leads to a decrease in yield (Li et al., 2018; Ma et al., 2018). According to Azhar et al. (2018), a reduction of chlorophyll content in the crop directly or indirectly influences the photosynthetic capacity of plants. This reduction in transpiration and photosynthesis is ascribed to plant reaction to water shortage by stomata closure (Tian et al., 2018).

On the other hand, the influence of excess soil moisture varies considerably according to tolerance of the particular crop, the frequency, duration, and seasonality of rainfall (Rajanna et al., 2018). Excess soil moisture generally reduces oxygen concentrations in soil resulting to stomatal closure of plants. This decreases the rate of transpiration and yield, because they are strongly and linearly correlated. Prolonged excess moisture also negatively impacts rooting ability to absorb nutrients due to suffocation causing plant death and total crop failure (Rajanna et al., 2018). Excess soil moisture has diverse negative influence on crops worldwide (Velde and Van Der Tubiello, 2012; Li et al., 2019), however, inadequate soil moisture is more serious and rampant than excess soil moisture in drylands of SSA. There are over 150 different indicators to measure water demand, water stress, water productivity, and water scarcity in different sectors, especially agriculture (Berger et al., 2021; Blatchford et al., 2018) (Table 1).

Water footprint (WF) is the volume of freshwater required for producing goods and services. It is the consumptive use of water, and it is divided into green and blue water components (Nouri et al., 2020). According to Rost et al. (2008), green water accounts for 90% of all water consumed by agriculture in a process-based crop simulation models. Green water is the rains stored in

soils for crop use (Rockström and Falkenmark, 2015). Fresh water in surface and groundwater bodies available for irrigation is referred to as blue water. The sole source of water for global rain-fed agricultural system is green water. Therefore, improvements in green water management will improve water productivity of the global food systems (Rockström et al., 2007) especially in semi-arid regions of the developing world, where water productivity may be low.

Although the importance of food production and development under irrigation (blue water) has been growing in recent times, it is usually economically viable for production of staples in SSA only when a profitable cash crop is cultivated as part of a multi-crop rotation (Ward et al., 2016). Crop production in SSA depends entirely (97%) on green water however, there is often variation in rainfall frequency, distribution and amount resulting to green water availability not in harmony with the amount required by crops. A number of researchers have demonstrated the effects of rainfall variability on agricultural production using statistical models (Lobell and Asseng, 2017; Zaveri et al., 2020). However, crop yield in response to inadequate green water varies in wet area (wet green water) compared to dry areas (dry green water) (Borgomeo et al., 2020). Figure 1 shows percentage change in rainfed crop yield under wet and dry areas. This indicates that additional agronomic practices to increase green water availability is more favorable to crop yields especially in SSA where dry green water is more prevalent (Figure 2).

Crop water requirements

Crop water need/requirement is the quantity of water needed for evapotranspiration, when enough soil water is maintained by precipitation and/or irrigation so that it does not restrain plant growth, development and yield (Djaman et al., 2017). The quantity of water needed for crop growth and yield is dependent on the duration of growth, development stages, crop species and planting density (Wright and Bell, 1992). Crop water requirement varies from place to place, crop to crop, agro-ecological variation and crop characters. Crop, soil, climatic and agronomic factors mainly influence crop water requirement. Water requirements of important crops are seen in Table 1. Crops vary in their reaction to moisture scarcity. When a crop's water need is not met, those with low drought resistance suffer greater reductions in yields compared to those crops with high resistance.

Soil water management

Globally, the whole amounts of water kept within the soil are enormous, but at any given locality, they are comparatively small and quickly deplete through

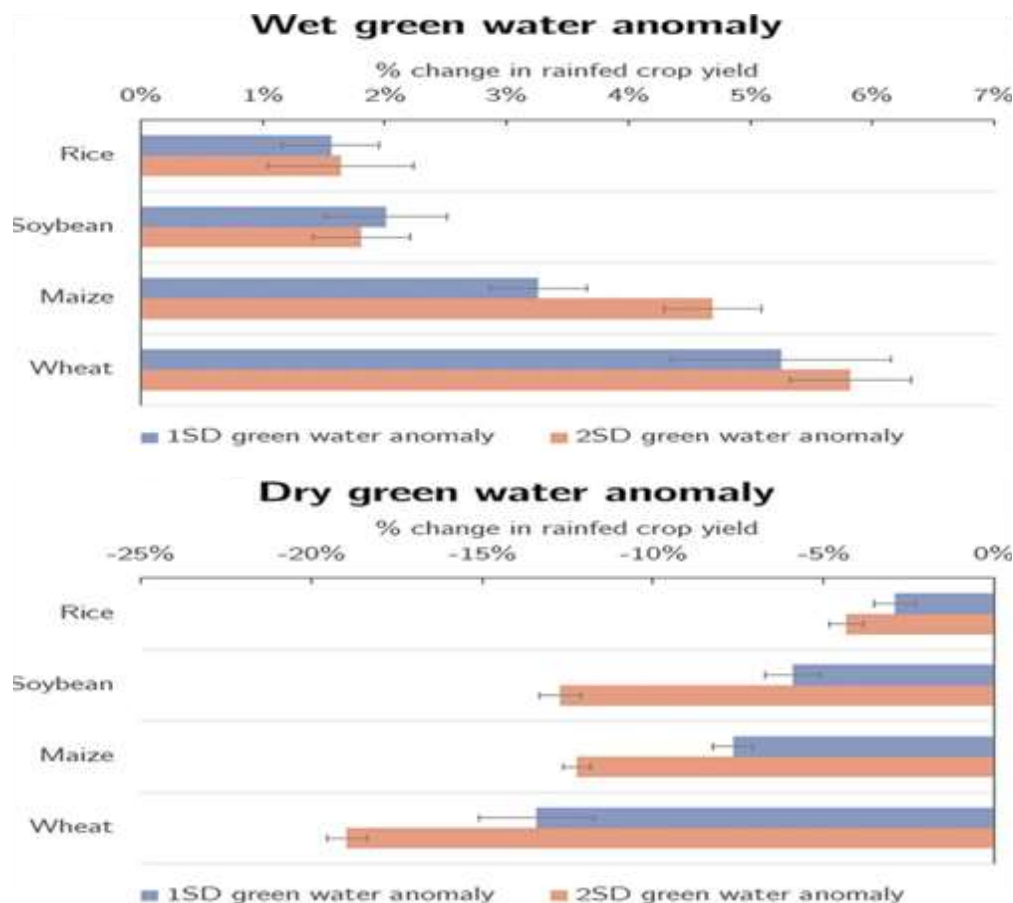


Figure 2. Percentage change in rain-fed crop yield under wet (top) and dry (bottom) areas. Error bars represent 95% confidence intervals. Source: Borgomeo et al. (2020).

evapotranspiration. Drought, aridity, and climate variability threatens food security in many countries around the globe (Meza et al., 2020). This has increased interest in various soil moisture management techniques in recent decades which can be an instrument to stabilize crop production under climate change. Countries in Africa have a relatively low ability to effectively manage with the changes that the climate brings and are thus has a great economic risk comparatively. It is of importance that water for food production is efficiently and effectively used as possible. Improving soil water management must focus on (a) increasing the productivity of water in crops, or (b) increasing water use efficiency through good management.

Improved water productivity in crops

Water productivity (WP) is defined as the physical or economic output per unit of water application (World Bank, 2003). The overall water consumption of a crop is referred to as evapotranspiration which includes water loss as a result of evaporation and crop transpiration.

Water productivity in crop or crop yield per unit of water consumed, is a key element in successful water resource management. WP improvement is one important approach for addressing the issue of future water scarcity. Water productivity under rain-fed agriculture, will have to extremely improve particularly in SSA to ensure food security for the teeming human population. Increased water deficits linked with overuse of surface water are threatening the sustainability of agricultural production in the region (Wang et al., 2007). Agronomic practices that improve water infiltration and storage capacity of the soil will improve water availability for crop use. According to Schmidt and Zemadim (2015) and Masunaga and Marques Fong (2018), enhanced management of the soil can increase infiltration, reduce surface runoff, and additionally increase readiness of water and nutrients to plants.

Improved water use efficiency

A measure of the amount of biomass produced per unit of water used by a plant is termed water use efficiency

(WUE). Crop water productivity (WP) refers to crop production in relation to total water used while WUE is a dimensionless ratio of total quantity of water applied. So, improved WUE would eventually results in better water productivity (Heydari, 2014). Water use efficiency is a significant physiological property identified with the capacity of plants to adapt to water stress. Previously, WUE was centered on plant output increasing with increasing water use; however, Basso and Ritchie (2018) demonstrated that productivity could be improved with no change in water use rate and results in enhanced WUE. Factors affecting water use efficiency are; nature of plant (based on their photosynthetic pathway), varieties (tall vs dwarf, short vs long duration), agronomic practices (sowing time, depth of sowing, pattern of sowing, optimum plant population, weed management, pest management) and soil condition which is a very critical observation for increased soil water.

Agronomic practices for improved soil water management

Recent studies have proved that cropping pattern have the potential to enhance water use efficiency, water productivity, and water footprint (Nouri et al., 2020; Konar and Marston, 2020). According to Simpson (2010), agronomic practices are management processes such as intercropping, contour cultivation, minimum tillage, mulching and manuring undertaken within the cropping area. Improved agronomic practices such as soil fertilization, soil cultivation, and crop selection can directly or indirectly improve infiltration, minimize surface runoff, and additionally increase availability of water and nutrients to plants (Schmidt and Zemadim, 2015; Masunaga and Marques Fong, 2018). The appropriate strategies to manage soil water must involve sustainable agronomic practices that enhance soil water while continuing to achieve improved yield. There are a number of agronomic practices but concentrating on those that have the potential to improve water storage for crop use during the dry spells as well as after cessation of the rain is of great importance to dryland rain-fed agriculture especially in SSA. Some will be more appropriate than others according to local farmer preferences and local conditions. Therefore, wise area specific adoption of agronomic practices, such as crop selection, early planting, crop stand, different cropping systems, mulching and reduced tillage are highly important to cope-up with water shortage. Some of the agronomic practices that have the potential to improve soil water are discussed as follows:

Crop selection

Proper selection of crop is very important in water

management because the crop water requirement should match the available amount of water in the soil for optimum production. Crops differ significantly in their water demand (Table 1). The selection of the right crop considering the availability of moisture and climate can improve yields and reduce water uptake resulting to improved soil water storage. The water need of a crop is mostly dependent on the crop type; crops like maize or sugarcane need more water than millet or sorghum. Selecting crops/varieties that suits the agro-ecology (Mubiru, 2010) of an area can also improve soil water storage and water use efficiency. Crops that are high-yielding and require minimum water should be selected because they have high water-use efficiency. Also, duration of the total growing season of the crop influences the water demand. For example, water melon daily water need may be less than that of cowpea. However, the total water need of melons for the whole growing season will be higher than that of cowpea because the melon has longer growing season. Table 1 gives seasonal water requirement (mm) of important field crops.

Varieties that do very well in high rainfall areas are usually not suitable for dry land conditions. Cropping areas with frequent or partial season droughts, usually prefers crops with reduced maturity period such as small grains, cool season oil seeds (e.g., mustards, camelina), or various pulse crops such as peas and lentils.

Crop density

To improve the water use efficiency, adopting a rational planting density is an effective agronomic measure. Key factors affecting evaporation are soil moisture content and ground cover. An increase in plant density usually results to increased leaf area index and accordingly water consumption. Therefore, using high plant density in limited water area may increase plant water stress, resulting to reduced yield depending on the stage of the crop. In considering optimum plant population, there is the need to consider available moisture in that particular region and cropping system microclimate (Lin, 2010). Approaches that employ these factors may be used to reduce water loss and increase the proportion of rainfall available to crops (Lin, 2010). According to Antonietta et al. (2014), high plant population result in interplant competition for resources which disturbs the vegetative and reproductive growth of crops.

Mulching

Mulching is a water-saving agronomic activity used to conserve soil moisture, regulate soil temperature, and reduce soil evaporation particularly in dry area (Kader et al., 2017a). This agronomic practice (mulching), is widely

Table 2. Effect of different soil amendment on soil water storage (mm) at flowering, milking and harvest in 2014, 2015 and 2016.

Treatment	Flowering	Milking	Harvest
Year (Y)			
2014	14.0 ^b	18.0 ^a	23.3 ^a
2015	19.9 ^a	18.8 ^a	17.8 ^b
2016	11.2 ^c	11.2 ^b	12.4 ^c
Amendment (A)			
NA	15.2 ^a	17.2 ^a	17.5 ^b
SM	14.3 ^a	15.2 ^b	17.8 ^a
MS	14.9 ^a	14.8 ^b	16.9 ^b
SC	15.4 ^a	16.9 ^a	19.2 ^a
Sources of variation	***	***	***
Year	ns	***	*
Treatments Y * A	ns	*	**

NA, No amendment; SM, swine manure; MS, maize straw; Swine manure+chemical fertilizer.

Source: Recalculated from Lamptey et al. (2019).

practiced in many countries (Donjadee and Tingsanchali, 2016). Mulching materials usually shade the soil surface to reduce temperature fluctuations to enhance soil moisture conservation. The main purpose of mulching should be to reduce evaporative losses and allow most of the water in the root zone to be transpired by crops. Apart from crops taking up water from the soil, the foremost source of water loss from the soil is through evaporation from bare soil and transpiration by weeds. Reduction in evaporation, soil temperature and weed infestation, can be achieved through soil mulching management techniques resulting to increased yield, and possibly water-use efficiency. An efficient tool to control soil water loss and improve water-use efficiency is through soil water management techniques such as mulching (Amitav, 2019).

Two types of mulches are usually used; these are organic mulch or biodegradable mulch which is made of organic materials and inorganic mulch, mainly made of plastic-based materials (Kader et al., 2017a). According to Adeboye et al. (2017), the use of organic and inorganic mulch has a consequence on crop production and soil hydrothermal environment in different climatic location under rain-fed conditions. Both conserve moisture in the soil, however, the organic contribute to the quality of the soil. Organic mulching decomposes into the soil that enhances organic matter resulting in increased soil water holding capacity (Kader et al., 2017b).

Fertilization

Fertilization is an agronomic practice essential for

improving the productivity of crops. It is the addition of organic or inorganic material to supply macro and micro nutrient to the soil for crop accessibility and uptake. Organic and inorganic soil amendment includes stubble application, biochar application and chemical fertilizer application. Through fertilization, soil physical properties (water retention, water infiltration, permeability, drainage, structure, and aeration) are improved. Improvement of these physical properties increases soil water storage.

A study on evaluating the impact of different nitrogen fertilizer rates on the blue and green water footprint (WF) declared up to 40% reduction in WF by appropriate fertilization rates (Chukalla et al., 2018). Talgre et al. (2012) have suggested the use of organic materials an effective way to improve soil organic matter and enhance soil moisture holding capacity. Soil organic matter was increased by 34% when Nyawade et al. (2018) intercropped *Dolichos lablab* with potato. Yeboah et al. (2017) reported 14 and 11% increase in soil moisture with straw and Biochar, respectively compared to no carbon treatments. Organic amendment is very important for increased soil water content (Cui et al., 2014). Higher soil water storage was recorded when organic and inorganic fertilizer was used in 2014, 2015 and 2016 (Table 2).

Soil tillage

One of the suitable ways of addressing soil moisture deficit in rain-fed agriculture is through soil tillage which is also considered a soil water conservation practice. Improved water infiltration is critical for increasing water storage in semiarid and arid areas (Williams et al., 2020) and the rate of soil infiltration is largely influenced by tillage systems (Ahuchaogu et al., 2015). To effectively increase soil water content, proper tillage systems with minimum disturbance to the soil is essential. Conservation agriculture has been reported to increase crop productivity and conserve water (Yeboah et al., 2019).

Conservation tillage systems reduces disturbances caused to soil while enhancing water infiltration and root development. Govindasamy et al. (2021) reported 26% increase in water-holding capacity with no-tillage (no soil disturbance) compared to conventional tillage. Reduced soil disturbance with straw addition has been revealed to improve water infiltration (Kirkegaard et al., 2014), reduce water loss by limiting evaporation (Govaerts et al., 2006), and increase crop water use efficiency (Fan et al., 2012). According to Lamptey et al. (2020), differences in soil water storage at different growth stages were mainly ascribed to different tillage systems (Table 3). From Table 3, tillage effect on soil water storage were more pronounced in the reduced tillage systems during the study years. In the Table below, Subsoiling (SS), no till (NT), and rotary tillage (RT) increased soil water content

Table 3. Effect of tillage systems on soil water storage (mm) in the 0–110 cm at flowering, milking and harvest in 2014, 2015 and 2016.

Treatments	Flowering	Milking	Harvest
Year (Y)			
2014	17.2 ^a	12.4 ^b	20.7 ^a
2015	12.0 ^b	13.1 ^a	13.4 ^b
2016	11.4 ^b	10.9 ^c	11.0 ^c
Tillage (T)			
CT	12.4 ^c	10.5 ^c	14.1 ^c
RT	13.3 ^b	11.8 ^b	14.8 ^b
SS	15.3 ^a	13.8 ^a	16.0 ^a
NT	14.0 ^b	12.4 ^b	15.2 ^b
Sources of variation			
Year	***	***	***
Tillage	***	***	***
Y * T	ns	ns	ns

CT, conventional tillage; RT, rotary tillage; SS, subsoiling; NT, no-till.

*, ** and *** indicate significant difference at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Source: Recalculated from Lamptey et al. (2020).

(SWC) at the different growth stages. This is an indication that reduce tillage system has the potential to increase SWC in cropping systems under rainfed. According to Lamptey et al. (2020), increased SWC with reduced tillage may be attributed to improved soil texture.

Conclusion

Sub-Saharan African countries have the potential to produce enough food to meet their own needs. Unfortunately, 95% of their potential cultivable land is rain-fed and most of which exists in dryland zones with highly variable rainfall. Water is critical to rain-fed agriculture and dry green water anomalies is more prevalent in dry areas such as SSA compared to wet green water anomalies in other continents. This is being compounded with climate change and its adverse effect on food security. Some agronomic practices have a major role in improving soil water for crop growth and development. As highlighted in this review, crop selection, mulching, organic soil amendment and reduced tillage could be used to store more rainfall in soil, improve soil water use and reduce water stress thereby increasing the resilience and sustainability of crop production in dry land rainfed agriculture.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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