Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension
Volume 22 Number 4 (October 2023) pp. 82 - 90

ISSN 1119-745

SURFACE MULCHING EFFECTS ON SOIL TEMPERATURE OF JUMBO-SIZE POTTED COARSE-TEXTURED ULTISOLS AND EVALUATION ON SORGHUM AND SOYBEAN GROWTH

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ABSTRACT

In poticulture, surface mulching to conserve moisture is rarely practised even when it could help elongate watering intervals, while moderating soil temperature and crop growth, benefits of which are potentially huge when large volumes of drought-prone soils are involved. This study compared, under glasshouse conditions, mulched and no-mulch jumbo-size potted droughty Ultisols for differences in soil temperature, soil structure, and sorghum (Sorghum bicolor) and soybean (Glycine max) growth responses. After layer-wise filling of the 63-cm high 123.75-L jumbo-size pots to the 60-cm mark using excavated 40-60, 20-40 and 0-20 cm soil layers, mixed dry grass was surface-applied at 10 t ha^{-1} equivalent. Sorghum and soybean were grown separately in mulched and no-mulch potted soils for two nine-week cycles. Soil thermal and agronomic data were collected weekly at certain growth stages, while soil structure was assessed after the second cycle. Soil temperature was always lower in mulched than no-mulch potted soils, being significant at four and eight sampling times for sorghum and soybean, respectively. Plant height of sorghum was consistently unaffected by the mulch treatment; however, mulched potted soils produced higher above-soil dry matter than the no-mulch ones (87 vs 49 g pot^{-1}) in the second cycle. By contrast, soybean plants were always shorter and dry matter lower (11 vs 34 g pot^{-1}) due to mulching in the first cycle; plant height response was reversed in the second, being evident during the last three weeks. Notably, both crops grew better in the second than the first cycle. Mulching only tended to improve soil structure under both crops. The mulch-induced increases in sorghum above-soil dry matter were, however, due to cooler soil temperature-driven enhanced aggregation; the reverse effect in soybean was due to cooler soil temperatures. Our data suggest that grass mulch-induced lowering of temperature of large-volume potted drought-prone soils would have pronounced positive and negative influence, respectively, on productivity of cereal and leguminous crops. Considering the initial tillage-like disturbance of such potted media, this influence, for soil structure-sensitive cereals, is largely due to temperature-mediated temporal enhancement of aggregation.

Key words: drought-prone tropical soils, grass mulch, soil thermal regime, aggregate stability, dry matter production

INTRODUCTION

The situation of global changing climate will adversely affect the productivity of vital food crops (Vara Prasad *et al*., 2006), sorghum (*Sorghum bicolor* L. Moench) and soybeans (*Glycine max* L. Merrill) inclusive (Hatfield *et al*., 2011). Soil and water management efforts toward moderating soil hydro-thermal regime can increase agronomic production among smallholder farmers in the humid and sub-humid tropics. This assertion is particularly true for the concept of surface mulching in the production of sorghum and soybeans in tropical Africa (Obalum *et al*., 2011a, b), a sub-region known for its unequalled vulnerability to climate change (Kotir, 2011).

Mulch is a layer of material(s) that covers the soil surface (Chalker-Scott, 2007; Obalum *et al*., 2011c), with lots of ecological and agronomic benefits, such as reduction of soil moisture loss to evaporation, regulation of soil temperature, as well as increases in plant available water, soil microbial biomass, and crop yields (Arora *et al*., 2011; Obalum *et al*., 2011c; Luo *et al*., 2015; Pramanik *et al*., 2015). Use of organic materials of plant origin (straw and grasses) as protective mulch reduces evaporation to enhance soil moisture and nutrient levels while maintaining soil temperature at levels that favour crop growth (Balwinder-Singh *et al*., 2011; Ni *et al*., 2016; Kader *et al*., 2017; Du *et al*., 2022).

Osakwe U.C., Nnadi A.L., Ede L.C., Obi J.O., Okolo C.C. and Obalum S.E. (2023). Surface mulching effects on soil temperature of jumbo-size potted coarse-textured Ultisols and evaluation on sorghum and soybean growth. *Agro-Science*, **22 (4),** 82-90. DOI: https://dx.doi.org/10.4314/as.v22i4.12

Straw- and grass-based surface mulching also protects the topsoil from physical disintegration, decline in physico-chemical fertility status, and facilitated biological deterioration of organics in the soil (Mulumba and Lal, 2008; Jordán *et al*., 2010; Simonsky *et al*., 2013). By so doing, it helps in climate change mitigation by off-setting greenhouse gases emission and increasing soil organic carbon sequestration (Bajorienė *et al*., 2013), while still ensuring the mineralisation and release of essential plant nutrients (Kader *et al*., 2017). Surface mulching with straw/grass in agronomic production systems thus enhances overall soil quality and crop productivity (Malhi and Lemke, 2007; Su *et al*., 2014).

All the above beneficial effects of surface mulch are based on field data. Mulching technology adoption in pot trials has been limited to seedlings emergence for horticultural crops (Fillols and Staier, 2015) and use of biodegradable or bio-based liquid mulches (Amoroso *et al*., 2010; Shen and Zheng, 2017; Juhos *et al*., 2023). Although organic mulching offers a fairly inexpensive and environment-friendly option (Kader *et al*., 2017), we are not aware of any research data on its effects in poticulture. This is despite the increasing need for glasshouse crop production to complement open-field production, if contemporary agriculture must ensure food security. By elongating the intervals of watering and suppressing weed, mulching of potted soils can also be viewed a water- and labour-saving option in glasshouse production.

In the humid and semi-arid tropical locations, grass-based surface mulching has severally been demonstrated to be an effective and sustainable agro-technology for sorghum and/or soybean production. This is because surface mulching manipulates the growing environment of these crops by promoting water infiltration while minimizing runoff and soil loss (Obalum *et al*., 2020), thereby conserving soil nutrients and water, controlling soil temperature, and ensuring favourable soil-water relations under them (Obalum and Obi, 2010; Obalum *et al*., 2012; Ezenne *et al*., 2019). Such improvements in soil conditions often lead to increases in vegetative growth and yields and/or water use efficiency of these two crops (Chiroma *et al.,* 2006; Al-Rawahy *et al*., 2011; Arora *et al*., 2011; Obalum *et al*., 2011a, b).

Notably, sorghum and soybean are among the most important low-input arable crops worldwide. Sorghum, a C4 crop species, can adjust to different climatic and edaphic-conditions (Qu *et al*., 2014). It is an excellent energy resource for both livestock (Qu *et al*., 2014; Pereira and Hawkes, 2022) and humans (de Asevedo Soares *et al*., 2023). Soybean, a C3 crop species, is a major oilseed crop. As such, its demand is high, and there have been concerted efforts to increase its production globally especially in sub-Saharan Africa (Sedibe *et al*., 2023). Besides their ecological, agronomic and economic importance, sorghum and soybean represent cereals and legumes, respectively which dominate the cropping systems of this region and also serving as food security crops.

Pot agronomic trials are known for artificiality, with the drainage pattern of the potted soils often differing from that under field conditions. Therefore, the needed seminal research efforts toward adopting straw/grass-based surfacing mulching in glasshouse crop production in the tropics must strive to highlight this drainage anomaly of potted soils, so as to allow effects of the mulch treatment on their hydrothermal properties adequate chances to manifest. In this study, we achieved this condition not only by using field well-drained soil, but also by using jumbo-size pots for increased free drainage. Jumbo-size pots also offer adequate rooting volume, such that shoot growth and development to the extent of giving economic yield, where desired, would not be limited by poor rooting.

The objective of this study was to evaluate the modifications in hydrothermal regime and hence structure evolution of coarse-textured tropical soils in jumbo-size pots due to surface mulching with grass on the growth of sorghum and soybean. The aim was to provide data on the prospects of adopting grass-based surface mulching in glasshouse production of cereal and leguminous crops in these soils.

MATERIALS AND METHODS

Soil of the Study

The study was carried out with soil collected from the University of Nigeria Teaching & Research Farm at Nsukka campus of the University. The university town of Nsukka is in the derived savannah of southeastern Nigeria. The Farm is located by 06°52′ N and 07° 24′ E, and is on an elevation 447 m asl. The climate of the area is characterized by mean annual rainfall of about 1600 mm, with a bimodal distribution pattern, and mean minimum and maximum air temperatures of 21 and 31°C, respectively. Relative humidity can be variable throughout the year, often in the range of 55-90%. The soil is deeply weathered, reddish brown, and coarse in texture. It belongs to the order Ultisols, by the USDA Soil Taxonomy. The coarse texture of the soils, coupled with the granular structure of the surface horizons, renders them ‘porous’ and well-drained (Obalum and Obi, 2014).

Collection and Potting of the Soil

The soil used for the study was collected from a plot in the Farm cropped to cassava (*Manihot* spp.) and fluted pumpkin (*Telfeiria occidentalis*) in the previous farming season. Excavations were made from the 0-20, 20-40 and 40-60 cm layers, using a spade. These were spread to air-dry in the glasshouse for one week, after which the soil crumbs were manually broken and crushed. They were then used fill to jumbo-size (63 cm tall, 50-cm wide; vol., 123.75 L) plastic pots in a reverse order, such that soil collected from the 40-60 cm layer was placed at the first 20-cm segment of the pots from the bottom, before the ones from the 20-40 and 0-20 cm layers. This filling pattern brought the depth of the potted soils to 60 cm, leaving about 3 cm from the soil level to the brim for watering.

The above soil collection and potting sequence was to ensure that the vertical textural cum fertility trend of the jumbo-size potted soils was close to the field condition. Most cereal and leguminous crops have their roots grow beyond the usually ploughed 0-20 cm layer into the 20-40 cm layer, with some fine roots extending into the deeper 40-60 cm layer, which serves as a major reservoir of soil nutrients in all terrestrial ecosystems (Lal *et al*., 2012). Some pre-potting physical and physicochemical properties of the three soil layers are presented in Table 1.

To allow for proper drainage of the potted soils, the pots were strategically perforated six times at the bottom before use. In order to raise the pre-planting soil fertility status of the coarse-textured Ultisols of the study, manure (cured poultry litter) was added to all potted soils at a rate of 10 t ha^{-1}, after Obi and Ebo (1995). The equivalent of this application rate for the potted soils (196.50 g pot^{-1}) was computed on a soil surface area basis. The manure was mixed with the soil from the 0-20 cm layer before being used to fill up the pots. Thereafter, potted soils were adequately watered and allowed to equilibrate for two weeks, during which they were watered to pre-determined field capacity every other day.

Mulch Treatment Implementation and Design

At the end of the two-week soil equilibration period, mulch comprising a mixture of dry grasses dominated by *Pennisetum purpureum* (elephant grass) was applied to the surface of the potted soils at 10 t ha^{-1} equivalent. A sample of the pre-planting mulched and no-mulch jumbo-size potted soils is shown (Plate 1).

Sorghum and soybean served as test crops. For each crop, treatments were replicated six times in a completely randomized design (CRD), with the randomization done for sorghum and soybean.

Planting and Routine Watering of the Potted Soils

The soil potting and the subsequent agronomic trials took place at the ambient-temperature glasshouse of the Department of Soil Science situated within the University of Nigeria Teaching & Research Farm. Seeds of both sorghum (var. CSR-01) and soybean (var. TGF-1987-10F) for the study were procured from the National Cereals Research Institute (NCRI), Badeggi, Niger State, Nigeria. The seeds were sown at three per potted soil and later thinned down to one seedling 12 days after germination. There were two crop growth cycles without re-application of mulch; from 31 Dec. 2014 to 04 Mar. 2015 and from 31 Mar. to 02 Jun. 2015. From sowing to harvest, potted soils were watered to field capacity at two-day intervals. Potted soils were kept weed-free throughout the crops' growth phase by periodic manually weeding, as the need arose.

Plate 1: Sample of mulched and no-mulch jumbo-size potted soils of the study

Collection of Crop and Soil Data

Plant height was measured weekly from the soil level to the tip of the plant with the aid of a measuring tape during 6-9 and 3-9 weeks after sowing (WAS) in the first and second crop growth cycles, respectively. While measuring plant height, soil temperature was also measured with thermometers that were inserted 10-cm deep and equidistant from the edge of the potted soil and the plant growing in it. At 9 WAS in each of the first and second cycles, the growing sorghum and soybean plants were harvested by cutting off from above the soil level. They were labeled and allowed to air-dry in the glasshouse for about six weeks and, thereafter, weighed to determine the above-soil dry matter of the crops.

At the end of the second crop growth cycle, potted soils were sampled from the surface using cylindrical core samplers of dimension 5 cm × 5 cm. Loose soil samples were also collected and used to assess treatment effects on some indices of soil structure (bordering on aggregation) and soil pH.

Laboratory Methods

Soil bulk density was determined on the soil cores after oven-drying at 105^{o}C for 48 h. Sub-samples of the soil from three layers used for the glasshouse pot trials, taken before potting, were analysed, following standard laboratory procedures, to determine the pre-planting physical and physicochemical properties of the soil. To analyse the samples of the potted soils collected at the end of the study for soil structure and soil pH, they were first air-dried at room temperature to constant weight. They were then passed through joined 4.75- and 2-mm mesh sieves. Soil pH was determined on the <-2-mm fine-earth fractions in suspensions of the soil in H_2O (soil-liquid ratio of 1.0:2.5), using the pH meter. The 4.75-2-mm aggregates were wet-sieved, following which some indices of aggregation were derived.

Table 1: Selected physical and physicochemical properties of the soil used for the study

Soil depth (cm)	Clay	Silt	Sand	Texture class	Soil pH-H_2O	Soil org. matter, SOM (g kg^{-1})	Total N (g kg^{-1})	Available P (mg kg^{-1})	Cation exch. capacity, CEC (cmol kg^{-1})
	(g kg^{-1})								
0-20	172	20	808	Sandy loam	5.0	15.10	0.70	18.60	7.20
20-40	212	20	768	Sandy loam	4.2	7.60	0.70	7.40	8.00
40-60	232	20	748	Sandy loam	4.1	9.60	0.56	9.30	6.40

The wet sieving to separate the aggregates into size fractions was done by the procedure described by Kemper and Rosenau (1986). In this technique, 25 g of the air-dry soil aggregates in the range of 4.75-2 mm was placed on the topmost of a nest of four sieves (2.0, 1.0, 0.5 and 0.25 mm). The whole set-up was placed inside a wet-sieving machine, allowing water in the machine to slowly pre-wet the soil aggregates from the bottom for 5 min. At the end of the 5 min., the machine was oscillated at 4-cm amplitude for 35 times in 1 min. Resistant aggregates on the sieves were washed into containers and oven-dried at 105°C for 48 h. Sand content of the >-0.5-mm aggregates was determined after soaking to disperse them in 0.1N NaOH and washing through 0.50-mm sieve to obtain sand > 0.50 mm which was oven-dried at 105°C for 24 h and weighed.

The data from this wet-sieving exercise were used to calculate three indices of soil aggregation, two of which are mean-weight diameter (MWD) of wet-sieved soil aggregates and aggregate stability as percent water-stable aggregates corrected for sand (% WSA_{cfs}), computed, respectively, by the following equations (Obalum *et al.*, 2011d, 2019):

$$\text{MWD} = \sum_{i=1}^{n}(X_i W_i) \text{ and}$$

$$\%\ \text{WSA}_{\text{cfs}} = \left(\frac{\text{WSA} - M_{S>0.50}}{M_i - M_{S>0.50}}\right) \times 100;$$

where X_i the mean diameter of a given size fraction (mm), W_i is the proportion by weight of aggregates in the size fraction (g g^{-1}), and n is the total number of size fractions for both the water-stable aggregates (otherwise called the resistant aggregates) on the four sieves and the water-dispersed ones passing through the last sieve, totaling 5; and *WSA* is the mass of water-stable aggregates (g), M_i is the initial mass of aggregates subjected to wet sieving (g), and $M_{s>0.50}$ is the mass of sand > 0.50 mm (g). The third index of soil aggregation computed, somewhat related to %WSA_{cfs}, was percent state of aggregation (% SOA), as follows (Ezeaku *et al.*, 2020):

$$\%\ \text{SOA} = \left(\frac{\text{WSA} - M_{S>0.50}}{M_i}\right) \times 100;$$

with components as explained for %WSA_{cfs}.

Data Analysis

Data were subjected to one-way analysis of variance test for CRD experiments. For soil temperature and plant height, a repeated measures analysis was done to analyse mulch effects. Mean values were tested for significant differences by the least significant difference at $p < 0.05$ ($LSD_{0.05}$). The mean values for plant dry matter and post-planting soil properties were presented alongside their coefficient of variation (CV) known to normalise variability, for comparison between the sorghum and soybean trials as regards the extent of variability in these properties. For the soil properties, additionally, the sorghum and soybean trials were compared by t-test. All analyses were implemented in *R* software version 3.4.

RESULTS AND DISCUSSION

Surface Mulching Effect on Soil Temperature

The effect of surface mulching on soil temperature of the jumbo-size potted coarse-textured Ultisols is shown (Figure 1). Soil temperature values were higher in no-mulch than mulched potted soils for both sorghum and soybean, the differences being significant ($p \leq 0.05$) at four occasions for sorghum (two each in the first and second crop growth cycles) and eight occasions for soybean (four each in the first and second crop growth cycles). This observation, being a more commonly reported effect of surface mulch on soil temperature (Sinkevičienė *et al.*, 2009; Liang *et al.*, 2011; Yordanova and Gerasimova, 2015; Du *et al.* 2022), was expected. The generally reduced soil temperatures under mulch are partly due to surface roughness and a change in albedo as well as higher soil moisture at the soil surface (Buerkert *et al.*, 2000; Awe *et al.*, 2015; Tang *et al.* 2022). Organic mulches also control soil temperature by retaining incoming solar radiation thereby reducing heat flow onto the surface soil (Komariah *et al.*, 2008; Awe *et al.*, 2015). Apart from this forming of an isolation layer between solar and earth thermal radiation, preventing heat exchange between them, surface-applied organic mulches are known to also have a soil-shielding effect with respect to evaporative losses. The water so conserved helps moderate the soil temperature, water being of high thermal capacity.

The many and few cases of non-significant decreases in soil temperature due to the surface mulch under sorghum and soybean, respectively somewhat agree with grass-based surface mulch effect on profile moisture storage for these crops under field conditions in the study environment (Obalum *et al.*, 2012). The effect of surface grass mulch on soil hydro-thermal regime of coarse-textured soils of the study area under field and potted soil conditions could thus be said to be congruent.

Comparing the sorghum and soybean trials using t-test showed that, irrespective of soil mulch status, the mean soil temperatures under sorghum (28.92°C) and soybean (28.91°C) in the first crop growth cycle were similar. However, the jumbo-size potted soils showed higher mean temperature under sorghum (27.27°C) than soybean (26.55°C) in the second cycle. This could be attributed to greater plant cover due to soybean than to sorghum (Obalum *et al.*, 2012).

Surface Mulching Effect on Crop Growth

Treatment effect on sorghum and soybean growth was indexed by plant height sampled at the various growth stages of the crops (Figure 2). The two mulch treatments consistently showed similar ($p \geq 0.05$). Surface-mulched potted soils only tended to produce taller plants than no-mulch ones during the end of the first and the early stages of the second crop growth cycles. Though the differences were marginal, this observation may be suggesting when to expect the peak effect of mulch on sorghum growth.

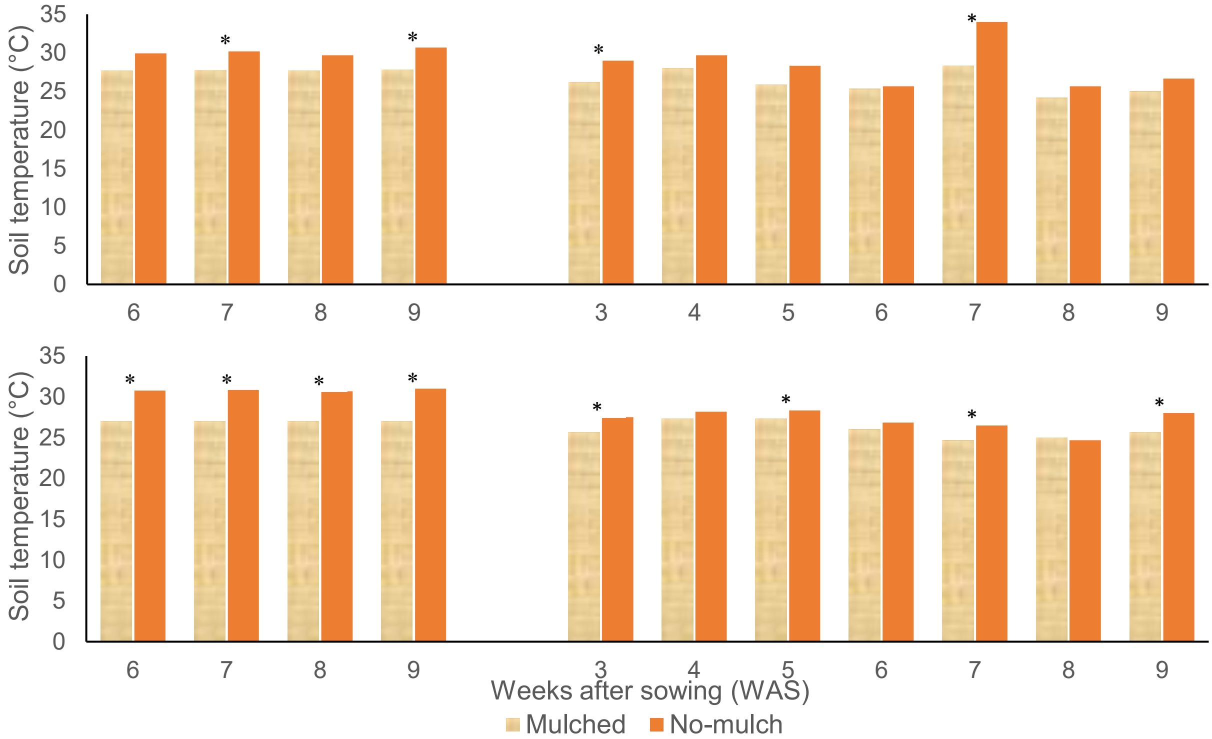

Figure 1: Soil temperature under mulched and no-mulched conditions of the jumbo-size potted coarse-textured Ultisols cropped to sorghum (upper) and soybean (lower) during their first (left) and second (right) growth cycles Significant ($p \leq 0.05$) means are indicated with "*"; non-significant ($p \geq 0.05$) ones bear no symbol.

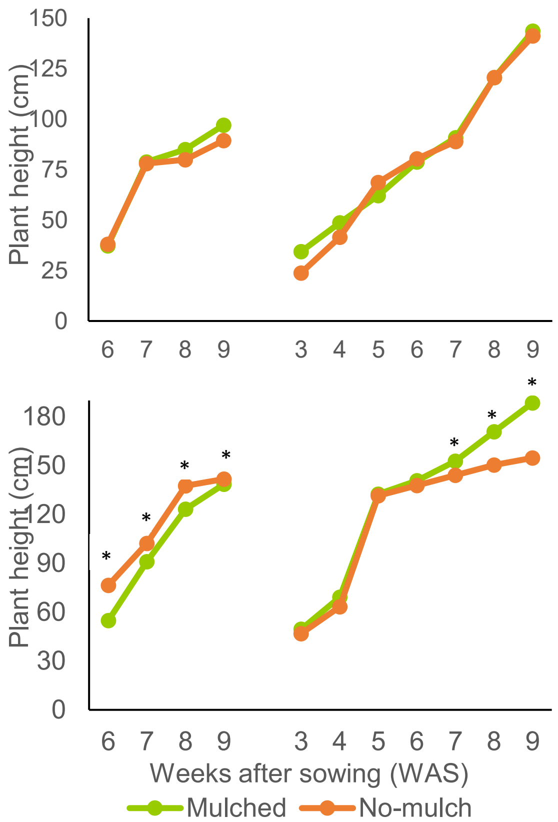

Figure 2: Plant height of sorghum (upper) and soybean (lower) under mulched and no-mulched conditions of the jumbo-size potted coarse-textured Ultisols during their first (left) and second (right) growth cycles. Significant ($p \leq 0.05$) means are indicated with "*"; non-significant ($p \geq 0.05$) ones bear no symbol.

The results for soybean showed contrasting trends in the first and second crop growth cycles, with significant ($p \leq 0.05$) differences during 6-8 WAS in the former and during 7-9 WAS in the latter (Figure 2). Soybean plants growing shorter with than without mulch in the first growth cycle is inexplicable, especially considering the mulch-induced lowered soil temperatures for the crop in this cycle.

Dry matter of sorghum and soybean from the jumbo-size potted soils at 9 WAS as affected by treatment is presented (Table 2). The data show that mulched > no-mulch for sorghum in the second cycle with higher values and no-mulch > mulched for soybean in the first with lower values. The increase in sorghum dry matter due to the grass mulch sorghum in the second growth cycle could be

Table 2: Above-soil dry matter of sorghum and soybean as harvested from the mulched and no-mulch jumbo-size potted soils 9 weeks after sowing (values are means ± standard deviations)

	First growth cycle	Second growth cycle
	Sorghum	
Mulched	17.01 ± 8.19	87.26 ± 7.89
No-mulch	17.59 ± 4.32	49.00 ± 7.83
$LSD_{0.05}$	ns	17.81
% CV	*37.86*	*11.53*
	Soybean	
Mulched	10.71 ± 1.40	59.62 ± 19.85
No-mulch	34.14 ± 7.31	64.79 ± 5.28
$LSD_{0.05}$	11.93	ns
% CV	*23.47*	*23.35*

attributed to a favourable soil hydrothermal regime for root growth during the nine-week period. This is especially with the crushed soil structure having appreciably reformed in this second growth cycle, a situation that would offer enhanced water/nutrient retention and uptake relative to the first cycle.

From manually tilled plots in the study location, Obalum *et al.* (2011a) reported increases in sorghum yield to surface grass mulch under field conditions. Similar increases in wheat yield as a result of mulch application were reported from North West India (Balwinder-Singh *et al*., 2011; Ram *et al*., 2013). By reducing evaporation to enhance soil moisture status, surface mulch increases soil quality and crop yields (Malhi and Lemke, 2007; Obalum *et al*., 2017). The positive effect of the surface-applied grass mulch on sorghum dry matter in the second growth cycle thus suggests increased crop establishment due to the mulch-induced reductions in soil temperature (Bunna *et al*., 2011; Cai *et al*., 2022).

However, the above scenario of mulch-induced improvements in soil hydrothermal regime leading to increases in crop yields may not have applied here. Wood-chip mulch was reported to improve olive tea dry matter, reflecting improved plant growth, likely through improvements in soil organic matter and soil moisture contents (Ni *et al*., 2016). In our case, the mulch-induced lowering of soil temperature (translating into increased soil moisture) under sorghum did not reflect in the plants' heights, suggesting that the higher dry matter produced by the mulched jumbo-size potted soils compared to the no-mulch ones may not be attributed to any improvements in soil moisture status due to the mulch. These contradictory findings might be due to differences in location (climate and soil), growth environment (field or glasshouse), study nature, mulch material, its application method, and crop type.

Surface mulching of the jumbo-size potted soils had a negative effect on soybean dry matter, being significant in the first crop growth cycle (Table 2). The dry matter thus reflected treatment effect on plant height, particularly for the first cycle. Again, these results in the first cycle when mulch more pronouncedly lowered soil temperatures for the soybean crop defy explanation. In the study location, soybean yield was found marginally higher with grass mulch than without, regardless of tillage status, under field conditions (Obalum *et al*., 2011b). However, from a field study in Lublin – Poland, application of straw mulch was reported to reduce soil temperature and negatively affect soybean yields in the first year with extended drought but not in the subsequent years with good water supply (Siczek *et al*., 2015).

The reduction in soybean dry matter due to the surface-applied grass mulch in the present study was significant in the first crop growth cycle. Intuitively, the low level of soil structure reformation in this first cycle relative to the second cycle, earlier alluded to, implied greater droughtiness of the jumbo-size potted soils in the former than the latter. This situation probably led to the more pronounced negative effect of mulch on soybean dry matter in the first than the second cycle (Siczek *et al*., 2015). It could be that soybean exhibits differential growth-yield responses to improved soil hydrothermal regime under mulch, depending on the extent of water supply and retention in the soil supporting it and onto which mulch is applied. Haapala *et al*. (2014) posited that, under certain conditions, farmers need to lower soil temperature for higher crop yields; under some others, they need to raise it for the same purpose.

Surface Mulching Effect on Soil Properties

Soil pH and selected indices of soil structure under the mulched and no-mulch jumbo-size potted soils cropped to sorghum and soybean, as determined at the end of the second cropping, are shown (Table 3). None of these soil properties was influenced by the mulch treatment, both for the sorghum and soybean trials. Our results contrast with those of Billeaud and Zajicek (1989) that some non-grass organic mulches decreased soil pH of a fine sandy loam. However, Lutaladio *et al.* (1992) reported similar no differences in soil pH between mulched and no-mulch treatments after first and second years of cropping.

Contrary to our data on soil bulk density, Pervaiz *et al*. (2009) reported reduced values in mulched maize plots. Also, Ram *et al*. (2013) reported that straw mulching decreased surface soil bulk density from 1.47 to 1.37 g cm^{-3}. Supporting our data are the findings of Obalum and Obi (2010) in the location of the present study and Ni *et al*. (2016) in a sub-tropical Nanjing - China that mulching had no effect on soil bulk density. Kader *et al*. (2017) noted that mulch effect on soil bulk density depends on specific situations of land management and nature and quality of the mulch material.

The non-significant effect of the grass mulch on mean-weight diameter (MWD) of soil aggregates agrees with the findings under sorghum and soybean in the study location (Obalum and Obi, 2010). With five mulch application rates implemented yearly for 11 years (0, 2, 4, 8 and 16 t ha^{-1} $year^{-1}$) elsewhere, a strong correlation was reported between mulch rate and MWD (Mulumba and Lal, 2008). The present effect could thus be explained by the situation of only two mulch rates (0 and 10 t ha^{-1}), by the actual application rate being relatively low, and/or by the one-off implementation of mulching in our study. The reasons just adduced may also explain the similar values of the other two indices of soil aggregation namely % WSA_{cfs} and % SOA between mulched and no-mulched potted soils of this study finding is in sharp contrast with the findings of (Mulumba and Lal, 2008; Lenka and Lal, 2013). Increased application rate of mulch of good material, by increasing soil organic matter content, is known to not only improve soil aggregate stability but to also reduce soil bulk density (Kader *et al*., 2017).

Table 3: Soil properties under mulched and no-mulch conditions of the jumbo-size potted soils cropped to sorghum and soybean at the end of the second cropping (values are means ± standard deviations)

	Soil pH-H_2O	MWD (mm)	% WSA_{cfs}	% SOA	Soil bulk density (g cm^{-3})
			Sorghum		
Mulched	7.3 ± 0.2	20.60 ± 3.82	76.96 ± 6.00	51.91 ± 3.66	1.15 ± 0.07
No-mulch	7.3 ± 0.2	17.99 ± 4.83	65.10 ± 11.10	45.20 ± 2.44	1.18 ± 0.02
$LSD_{0.05}$	ns	ns	ns	ns	ns
% CV	*2.86*	*22.58*	*12.56*	*6.40*	*4.42*
			Soybean		
Mulched	7.4 ± 0.1	23.64 ± 1.57	73.85 ± 12.99	47.69 ± 7.77	1.28 ± 0.04
No-mulch	7.3 ± 0.1	17.25 ± 5.92	67.90 ± 10.18	47.29 ± 4.30	1.29 ± 0.05
$LSD_{0.05}$	ns	ns	ns	ns	ns
% CV	*1.47*	*21.19*	*16.47*	*13.23*	*3.55*
Mean for sorghum	7.3	19.29	71.03	48.55	1.16
Mean for soybean	7.4	20.45	70.87	47.49	1.29
t-test (sorghum vs soybean)	ns	ns	ns	ns	**

MWD - mean-weight diameter of soil aggregates, WSA_{cfs} - water-stable aggregates corrected for sand, SOA - state of aggregation; **significant at $p \leq 0.01$

When the soil properties shown in Table 3 were compared for the sorghum and soybean trials by t-test, soil bulk density was the only one that differed due to these two crop types. The value was lower under sorghum than soybean, suggesting greater prospects of averting densification of potted coarse-textured soils with cereal than leguminous crop production.

Insight into Crop Growth Responses to Mulch-Induced Changes in Potted Soils

This study thrived on limited number of observations (n = 12) for each of sorghum and soybean, and the soil structure and soil pH were analysed only once (after the second crop growth cycle). Because of this, only an insight into how the crops' growth related to the mulch-induced changes in these soil properties was possible. Separately for sorghum and soybean, mean plant height at the sampled growth stages and dry matter at 9 WAS for each growth cycle were tested for correlations with the corresponding mean soil temperature and the analysed soil properties.

The results showed that plant height had no correlation with soil temperature under sorghum but had under soybean in the first and second cycles (r = 0.859* and –0.810*, respectively) when soybean plants generally grew shorter and taller with mulch, respectively. Sorghum dry matter correlated with soil temperature in the second cycle (r = –0.915**) when mulching increased the former; soybean dry matter correlated with soil temperature in the first cycle (r = 0.841**) when mulching decreased the former. Mulch-based lowering of temperature of jumbo-size potted soils may, therefore, be needed for glasshouse production of sorghum but not soybean. This aligns with the inference that crops can differ in their soil temperature needs (Haapala *et al*., 2014). Notably, dry matter of both crops depended on plant height in the first (r = 0.853*-0.957**) but not the second cycle.

Between plant parameters and soil properties, the only meaningful correlation was that sorghum dry matter correlated with % SOA of the potted soil (r = 0.735*) which in turn correlated soil temperature (r = –0.815*) in the second growth cycle. Therefore, soil temperature influenced dry matter accumulation in sorghum through its influence on % SOA in this second cycle when mulch had significant positive effect on its dry matter. The inverse relationship of % SOA with soil temperature in the second crop growth cycle is logical. This is because appreciable increases in soil temperature would be expected to expedite soil organic carbon mineralisation. Over time, the ensuing decreases in soil organic carbon would decrease aggregation in especially sandy-loam soils of the derived savannah (Igwe *et al*., 2013).

The % SOA (which is an index of soil structure) influencing sorghum but not soybean dry matter in this study is remarkable. This is akin to the reported effects of tillage (known to destroy soil structure) on sorghum and soybean yields in the location of the present study (Obalum *et al*., 2011a, b). These authors found, concurrently, that the structure-preserving no-till produced higher yield of sorghum than the structure-destroying conventional tillage in the second year of their study (Obalum *et al*., 2011a), while the two tillage methods produced similar yields of soybean in both years (Obalum *et al*., 2011b).

CONCLUSION

In the increasingly popular arable crops production using potted soils in ambient-temperature glasshouse (poticulture), application of grass mulch on drought-prone tropical soils in pots offering ample rooting volume can ensure moister and cooler soils. However, this option may be promoting the production of only cereals mostly through cooler soil temperature-driven enhancement of soil aggregation, while demoting that of legumes through cooler temperatures. This study further suggests that the use of grass mulch in cereal poticulture with coarse-textured soils has prospects of averting densification of the potted soils for ease of establishment and growth of subsequent crops.

Future studies should focus on the effects of mulch application rate (and hence mulch-layer thickness) and non-grass mulch materials, as well as their interactions with effective soil-conditioner manures on agronomic performance of cereals and legumes in tropical poticulture, including the underlying influence of changes in soil properties.

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