



Influence of *Staymoist* on soil water stress management and productivity of maize in Guinea savannah zone of Ghana

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ABSTRACT

Intermittent droughts have in recent years become more frequent and more prolonged in the Guinea savannah agro-ecological zone (GSZ) due to climate change, contributing to increasingly severe yield losses of maize (*Zea mays* L.), a key food crop in Ghana. The goal of this work was to minimize the negative impact of drought induced soil water stress on maize productivity in the GSZ through the integrated use of early drought tolerant cultivars of maize (*Dorke SR* and *Dodzi*), the application of soil conditioner *staymoist* (SM) and NPK (15-15-15) fertilizer. Experiments were carried out during the period of 2010-2011 cropping seasons at Council for Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR-SARI), Ghana. A trial comprised five treatments laid in a randomized complete block design with four replicates. The treatments were: T₁-No SM+No NPK (Control); T₂-0 kg/ha SM+NPK; T₃-7.5 kg/ha SM+NPK, T₄-15 kg/ha SM+NPK and T₅-22.5 kg/ha SM+NPK. *Dorke SR* generally out yielded *Dodzi* in grain and stover yields and in total biomass accumulation in all five treatments. *Dodzi* grain yields for T₃, T₄ and T₅ were 1176, 1559 and 1734 kg/ha, respectively while *Dorke SR* grain yields for the same treatments were 1386, 1865 and 1971 kg/ha respectively, which were all significantly (P<0.05) higher than the treatments without SM (T₁ and T₂) for both cultivars. *Dodzi* total biomass yields for T₃, T₄ and T₅ were 3148, 3591 and 3885 kg/ha respectively while *Dorke SR* total biomass accumulation for the same treatments were 4970, 6909 and 7302 kg/ha respectively, which were all significantly (P<0.05) higher again than the treatments without SM (T₁ and T₂). The results obtained indicate that relatively small amounts of SM were required together with recommended maize fertilization rate to alleviate drought spells and improve maize yields. The optimum treatment was 15 kg/ha SM+NPK. Beyond this rate positive profit declined.

Full Length Research Article

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INTRODUCTION

Maize (*Zea mays* L.) is the most important and the widely cultivated staple crop in Ghana. It is prepared and served in many local meal forms such as *Tuwo Zafi*, *kenkey*, *banku*, *koko*, etc. In the southern parts of the country, because of the bimodal rainfall pattern maize can be produced in two cycles, that is, two crops of maize may

be raised in a year. It is however cropped only once, in the rainy season, in the Guinea savanna zone of Ghana (GSZ). Medium to full season cultivars such as *Obatampa* and *Okomasa* are a few of the preferred cultivars in the country but are more likely to be challenged by terminal drought situations in the GSZ than

early maturing maize cultivars such as *Dorke SR* and *Dodzi*.

Study area

Ghana has six agro-ecological zones defined on the basis of climate, natural vegetation and the influence of the soils (SRID, 2002). Rainfall distribution is bimodal in the transitional, forest and coastal zones in southern Ghana, giving rise to a major and minor growing season. The remaining Guinea and Sudan savannah agro-ecological zones in the north constitute 64% of the total land area of Ghana. The uni-modal rainfall distribution in this area gives rise to only one growing season (150-200 days) which is bedeviled by terminal droughts associated with climate change (IPCC, 2007).

Agriculture in the Guinea savannah zone of Ghana is mostly rain fed and rainfall exceeds potential evaporation in relatively short periods. Unreliable and erratic rainfall distribution (Figure 1) is the bane of agricultural productivity in the zone. Complete crop failures can be expected in most of these areas in about one in every five years. This risk can even rise to one in every three years during low rainfall periods (SRID, 2002).

Drought is prevalent in all rain fed cropping systems and often limits maize yields (Meeks et al., 2012). As high as five weeks of drought (without rain) has been documented during rainy periods in the Guinea savannah zone of Ghana. Sudden droughts in the rainy season frequently lead to total maize crop failures, especially when this stress coincides with drought sensitive stages of plant development, for example, during the tasseling of maize (Benneh, 1993; NAES, 1993).

Significant work has been done by the Council for Scientific and Industrial Research (CSIR) maize breeders to address drought stress which also aggravates the phenomenon of "Hunger Gap" (famine in the growing season) in the north of Ghana. These efforts included the development of early maturing cultivars of maize such as *Dorke SR*, *Dodzi*, *Abeleehi* and *NAES Pool 16* in the mid 1990s (CSIR-SARI, 1996).

More recently in March 2010, four new drought tolerant (DT) varieties of maize were released as a result of collaborative work between the CSIR and the International Institute of Tropical Agriculture (IITA). The released extra early DT maize varieties were noted to be capable of bridging the "Hunger gap" during the planting season and farmers could plant early, harvest and sell or use it as food before the main season began. The new varieties all gave better yields than their local

counterparts under droughty conditions (CIMMYT/IITA, 2010).

The above notwithstanding, intermittent droughts remain a regular feature of most rainy or cropping seasons in the Guinea savannah agro ecological zone in northern Ghana (Figure 1). The importance of developing an integrated strategy of sustainable technologies to further minimize the negative impact of soil water stress on maize yields and productivity and possibly eliminate hunger gaps and reduce poverty in the GSZ cannot be under estimated. This work therefore envisaged the integrated use of early drought tolerant cultivars of maize (*Dorke SR* and *Dodzi*) together with appropriate application of water conservation technologies (soil conditioner *staymoist*) as a strategy to ameliorate drought stress in maize production and improve the yields and productivity of the crop in the GSZ in Ghana.

A new generation of potentially effective tools from the early 1980s, including hydroabsorbent polymers and copolymers from the propenamide and propenamide-propenoate families opened up new perspectives in the use of environmentally safe soil amendments (Entry and Sojka, 2003; De Boodt, 1990; Abdelmagid and Tabatabal, 1982). In 1983, Prof. Dr. Willem Van Cotthem and a team from the Laboratory of Plant Morphology, Systematics and Ecology at the University of Ghent (Belgium) started a ten year research program to grow plants in the Sahel region of Africa using less water. This research effort resulted in the TerraCottem soil conditioner, a mixture of more than twenty components that work in synergy to improve growing conditions and plant growth. The product was made available commercially on an international scale.

The new generation of "acceptable" soil conditioners includes products variously named as *staymoist* (SM), *Jalma*, *poly-DADMAC* and so on collectively called Superabsorbent Polyacrylamides (SAPs). A host of researchers have demonstrated that this group of so-called SAPs have many attributes that can be utilised to improve soil physical properties and enhance crop production, especially in arid and semi-arid agro-ecological zones such as the Guinea savannah agro-ecological zone of the northern regions of Ghana (Li et al., 2009; Mahana et al., 2000; Prado and Claudio, 2000; Sojka and Entry, 2000; Al-Darby, 1996; Johnson, 1985). Some of the attributes of these SAPs including SM are: Absorption of water, many times their own weight and thus can be used to improve moisture storage in sandy soils and mitigate drought (Akhter et al., 2002; Al-Omran and Ak-Hardi, 1998). In surface irrigated crops and where crops have been grown in soil-less media, SAPs have been useful in the reduction of nutrients and pesticides losses from the soil (Barh et al., 1996; Bres and Weston, 1993; De Boodt, 1975). SAPs are widely used in many products such as in diapers, feminine napkins, gel actuators, water blocking tapes, medicine for drug

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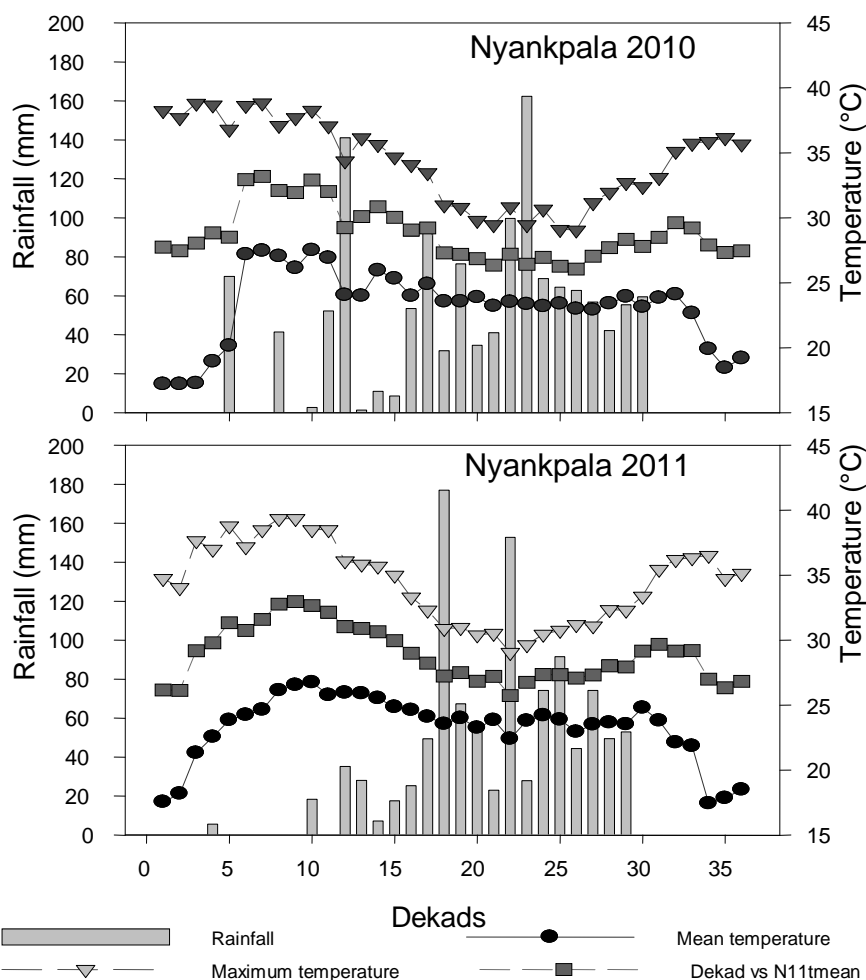


Figure 1. Weather graphs for Nyankpala for 2010 and 2011.

delivery systems, absorbent pads, soils for agriculture and horticulture etc, where water absorbency and retention is important (Entry et al., 2003; Bacalski et al., 2003; Alexander, 1994; Brown et al., 1982).

Published studies on the toxicity of SAPs on an acrylate basis have shown these substances have a positive toxicological profile and can be considered environmentally compatible (Fiume, 2002; Haselbach et al., 2000; Hamilton, 1995).

Staymoist (SM) was identified at the CSIR–SARI laboratories as equivalent to AgraGel for all intents and purposes. It also has all the soil ameliorating properties of the new generation environmentally friendly soil conditioners (Figure 2).

In physical form, SM comes as 100% white granular crystals with particle sizes between 100 and 2000 microns. The product has a bulk density of $540 \pm \text{kg m}^{-3}$, a pH value of 6 to 8 and a moisture content of less than 5%. It stores indefinitely under dry conditions and the

crystals are completely non-toxic.

Staymoist is manufactured outside Ghana. It therefore also became necessary to validate its performance for soil moisture absorption and retention for use in intermittent drought mitigation in maize production under our local conditions before it may be promoted for farmers' use.

MATERIALS AND METHODS

On station experiments were carried out during the 2010 and 2011 rainy or cropping seasons (from early June to late November) at the uplands fields of the Council for Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR-SARI) at Nyankpala (latitude $9^{\circ} 25' \text{ N}$, longitude $0^{\circ} 58' \text{ W}$ and altitude 183 m above sea level). The main soil of the upland fields of the CSIR-SARI at Nyankpala is Ferric luvisols (FAO-UNESCO,



Figure 2. Demonstration of *Staymoist* application with NPK₁₅₋₁₅₋₁₅ fertilizer by dibbling and burying the two products together.

2002). It is reported to have been derived from concretionary ground water laterite soils described as Kpalsugu series (A1) and Changnayili series (A2) which are both sandy loamy soils with pH of 5.8. It is however shallow with low moisture holding capacities. The type A soil which is widely found in many parts of the GSZ is suitable for cereal production, for example, maize and sorghum (NAES, 1993). The trial fields had previously been used for traditional upland rice cultivation without any nutrient additions (either manure or plant residues). Some physical and chemical properties of soils in the study before, and after the trials are summarized in Table 1.

Weather graphs for Nyankpala for 2010 and 2011 (Figure 1) were constructed by means of *SigmaPlot* programme. Maximum, mean and minimum temperatures are represented by line graphs while rainfall distribution is illustrated by column graphs. Temperature and Rainfall are plotted against Days (partitioned in ten day-groups or Decads). Key weather indicators are shown over 35 decades in a year representing January to December (a

decade comprises ten days).

Treatments

The trial comprised five treatments (T) laid in a randomized complete block design with four replicates namely; No *staymoist*+No NPK (Control) (T1); 0 kg/ha *staymoist*+NPK (T2); 7.5 kg/ha *staymoist*+NPK (T3); 15 kg/ha *staymoist*+NPK (T4) and 22.5 kg/ha *staymoist*+NPK (T5). Treatment plot size was 3 m × 2.5 m or 7.5 m². Two maize cultivars were used in the trial, namely; early maturing *Dorke SE* (100-115 days) and early extra maturing *Dodzi* (85-90days). Both are varieties released by the CSIR. The trials were planted in the middle of June in both 2010 and 2011. Spacing was 60 cm × 20 cm and stands were thinned after germination to one plant per stand. Compound fertilizer NPK (15-15-15) was used as basal fertilizer all in the appropriate treatments. The product *staymoist* was applied together at the basal fertilization stage to the appropriate

Table 1. Physical and chemical properties of Changnayili series soils at the start and the end of experiment (top 0-20 cm).

Parameter	Before trial	After trial (SM plot)
pH (CaCl ₂)	6.2	6
PH (water)	5.8	5.6
Organic carbon (%)	0.43	0.42
Total N (%)	0.042	0.055
Available P (mg kg ⁻¹)	11	12
Exchangeable cation		
K (cmol kg ⁻¹)	0.24	0.25
Ca (cmol kg ⁻¹)	2.3	2.4
Mg (cmol kg ⁻¹)	0.5	0.5
Na (cmol kg ⁻¹)	0.11	0.15
(Al+H) (cmol kg ⁻¹)	1.1	1.15
ECEC (cmol kg ⁻¹)	4.35	4.5
Base saturation (%)	74.8	75.2
Particle size		
Sand (%)	75.5	75
Silt (%)	12.5	12.5
Clay (%)	12	12.1
Moisture content (%)	0.2	0.3
Bulk density (g cm ⁻³)	1.45	1.1

treatments. Treatment plots (7.5 m²) received the following dosage rates of fertilizer and SM: T₁: No NPK fertilizer, No SM; T₂: 200 g NPK only, T₃: 200 g NPK+6g SM; T₄: 200 g+12 g SM and T₅: 200 g NPK+18 g SM. Where applicable NPK and SM were applied together by side application in the plant root zone, at a depth of 5-7 cm. Hand hoes were used for dibbling and burying the two products (Figure 2). This was done 15 days after planting of the maize. Top-dressing fertilizer was applied to all treatments at the tasseling stage of maize, using ammonium sulphate (S/A) fertilizer (N_{21.5}) at the recommended rate of N₂₀ or 93 kg/ha S/A.

Weeds were controlled early in the trial fields immediately after planting by manual knapsack spray of the plots with a combination of herbicides *Round Up* (Glysohate 480 g l⁻¹)(at 4 l ha⁻¹ product) and *Arrow 75 WDG* (Nicosulfuron or Sulfonyl Urea 750 g kg⁻¹) (at 200 g ha⁻¹ product). This was followed by an early hand hoe weeding 15 days after germination. Treatments were imposed on the trial after the second weed control exercise. All other agronomic practices were carried out as in standard maize production under rain fed conditions in northern Ghana.

Biological data collection and analyses

Data collected included plant height, days to maturity, grain, stover and total biomass yields of maize. All agronomic data collected was subjected to statistical analysis of variance (ANOVA) using the GENSTAT Discovery software (Lawes Agricultural Trust, Rothamsted Experimental Station, 2007). Where statistical significance was measured, means were separated using the Fisher protected LSD at P<0.05 (Steel and Torie, 1984).

Rainfall distribution, maximum, mean and minimum daily temperatures, evapotranspiration and other agro-climatic data for the area were monitored at the CSIR-SARI Agro-meteorological station for the growing seasons from May to September for both years. Figure 2 depicts a demonstration of the application time and method for SM, carried out at the IFDC Technology Park, in 2011.

Economic analysis

In order to make sound recommendations about the use

of the SM, economic analysis of the respective profitability of the treatments were conducted. To do this, additional data on the quantities and prices of inputs used were collected. Market prices of the harvested maize were also collected. Key indicators included the operations costs, profit and their respective changes. The benefit-cost ratios and marginal rates of returns of the technologies were also computed (Ojehomon et al., 2012).

In addition to the trial results, data used for the economic analysis was obtained from the database of Statistics, Research and Information Directorate (SRID) of Ministry of Food and Agriculture (MoFA) in Ghana. Other sources included key informant interviews and existing farm household database at the Savannah Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR-SARI). Dominance analysis was also conducted to identify the most superior technology (CIMMYT, 1988).

RESULTS

Agronomic parameters

Dorke SR generally out yielded *Dodzi* in grain and stover yields and in total biomass accumulation in all five treatments. The mean grain yield was for instance 1.23 times higher in *Dorke SR* than in *Dodzi* (Table 2).

Days to maturity

Figures 3 and 4 below show the effects of different dosage rates of SM plus NPK fertilizer on the days to maturity and plant height of maize, cultivars **Dorke SR** and *Dodzi*. In all the treatments Days to maturity for *Dorke SR* were slightly but significantly ($P < 0.05$) higher than those of *Dodzi* (Figure 3). This appears to be a varietal trait. Significant differences ($P < 0.05$) in days to maturity were detected in T_1 and T_2 , that is, the No SM treatment plots, considering each variety separately. For both *Dorke SR* and *Dodzi*, increasing SM dosage beyond 7.5 kg/ha contributed to a relatively significant increase in days to maturity in T_3 , T_4 and T_5 treatments. Beyond this point, on the basis of individual varieties, days to maturity in all three treatments (T_3 to T_5) were similar statistically (Figure 3).

Plant height

Soil conditioner SM effect on plant height varied for the two cultivars of maize. *Dorke SR* plants in all treatments were significantly ($P < 0.05$) taller than *Dodzi* plants. For both cultivars of maize, the least plant height was seen in

the Control treatment (No NPK, No SM); followed by the NPK Only plots. For cultivar *Dodzi*, the SM treatments produced plants either equal in height or slightly taller than the No SM plot plants, but increasing amounts of SM beyond 7.5 kg/ha did not to significantly ($P < 0.05$) increase plant height relative to the first two treatments (Figure 4).

For cultivar *Dorke SR*, the trend was similar but not the same. All SM treatment plots were generally taller than those without SM. For all treatments, *Dorke SR* plants were taller than *Dodzi* plants, but increasing amounts of SM beyond 7.5 kg/ha resulted in plants which were significantly taller than those of the Control and the NPK only treatments. Here again, significant differences in plant height were not detected between these three treatments (Figure 4).

Table 2 summarizes the effect of SM and NPK treatments on maize grain, stover and total biomass productivity for 2010 and 2011.

Grain yield

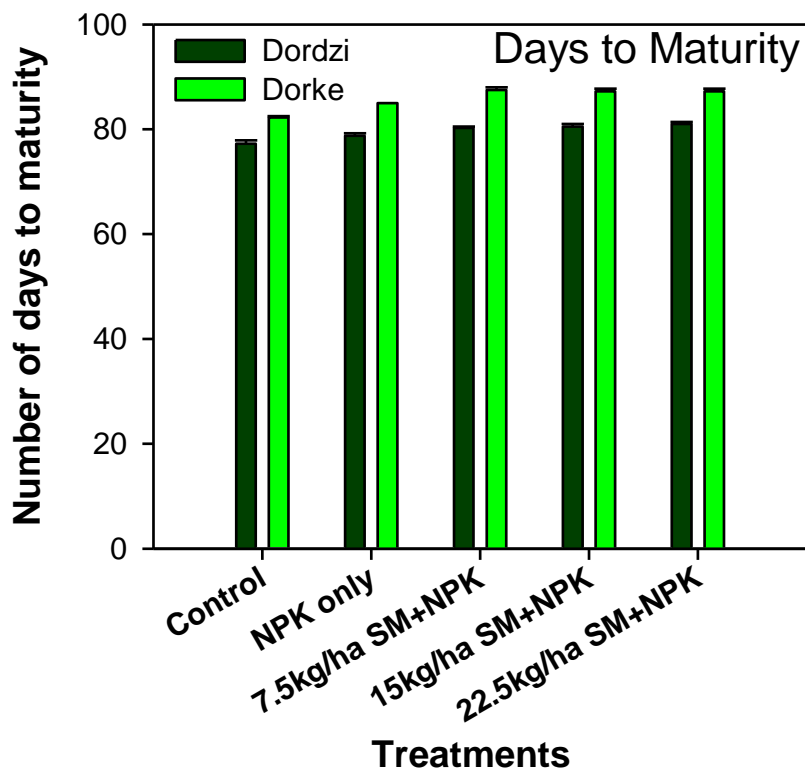
For both maize varieties the control (No SM, No NPK) treatment together with the NPK only treatment produced the least grain yield values of between 170 and 925 kg/ha. The remaining treatments with increasing amounts of SM with NPK all showed significant ($P < 0.05$) increases in grain yield from 7.5 to 22.5 kg/ha increments in SM. T_5 gave the highest grain yield for both varieties 1734 kg/ha for *Dodzi* and 1971 kg/ha for *Dorke SR* at that treatment level (Table 2).

Stover yields

The effect of SM and NPK treatments on the stover yields of the two maize cultivars followed a similar pattern to that of maize grain yields. SM incremental with NPK positively reflected in significant stover yield increases for *Dorke SR* and *Dodzi* for successive treatments (from T_1 to T_5). Stover yields in all other three SM treatments (T_3 - T_5) in the trial were higher significantly ($P < 0.05$ and physically much higher) than for both the Control and the NPK only treatments for both varieties (Table 2).

Total biomass

The total biomass production for each treatment is the sum of the grain and stover yields. This parameter for both varieties of maize followed the same trend as for grain and stover yields. Total biomass values for the treatments here were again higher in *Dorke SR* than in *Dodzi*. The mean total biomass yield for *Dorke SR* was for instance 1.82 times higher in *Dorke SR* than in *Dodzi*



Figures 3. The effects of different dosage rates of *staymoist* plus NPK₁₅₋₁₅₋₁₅ fertilizer on the days to maturity of maize cultivars, *Dorke SR* and *Dodzi*.

Table 2. Influence of *staymoist* and NPK (15-15-15) fertilizer treatments on the grain, stover and total biomass mean yields of two cultivars of maize(*Dorke SR* and *Dodzi*).

Treatment	Symbol	Grain yield (kg/ha)		Stover yield (kg/ha)		Total biomass yield (kg/ha)	
		Dodzi	Dorke SR	Dodzi	Dorke SR	Dodzi	Dorke SR
No SM, No NPK (Control)	T1	107	311	807	1930	914	2241
NPK Only	T2	670	925	1495	2577	2165	3502
7.5kg/haSM+NPK	T3	1176	1386	1972	3584	3148	4970
15kg/haSM+NPK	T4	1550	1865	2041	5044	3591	6909
22.5kg/haSM+NPK	T5	1734	1971	2151	5331	3885	7302
Statistical analysis							
Mean		1048	1292	1693	3693	2741	4985
^a LSD (0.5)		6.002	30.82	2.746	14.42	6.057	38.53
^b s.e.		3.896	20	1.783	9.36	3.932	25.02
^c CV%		0.4	1.5	0.2	0.3	0.3	0.5

^aLSD (0.5), Least significant difference (5% level); ^bs.e.,stratum standard error; ^cCV%, coefficient of variation.

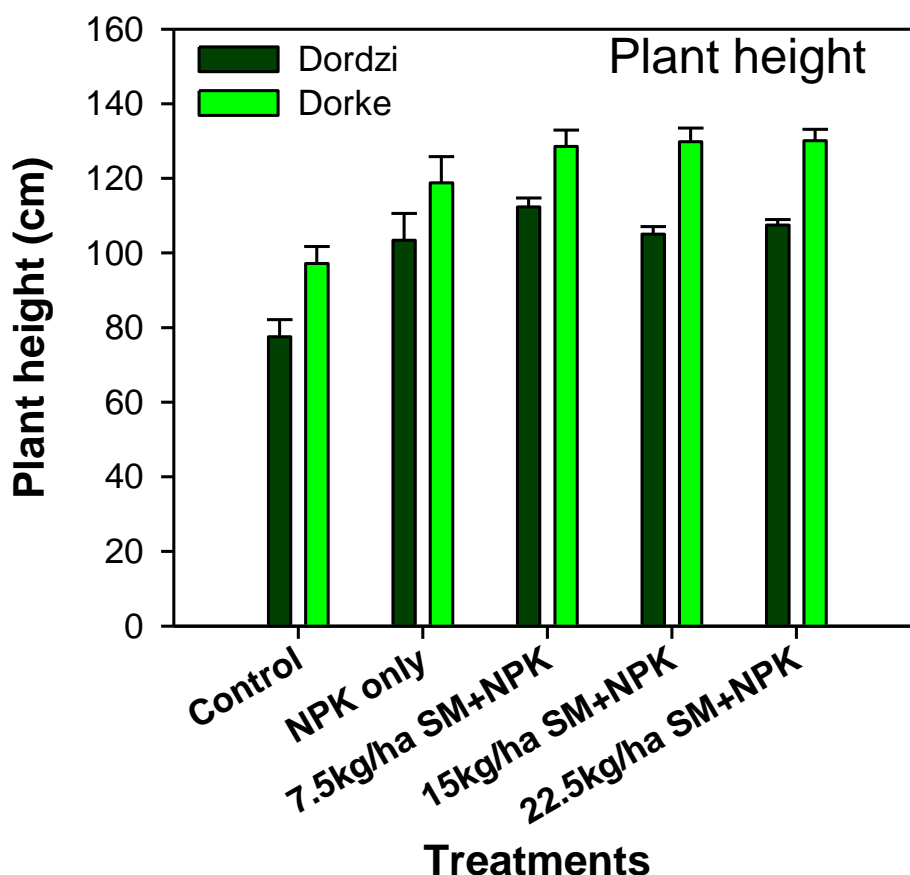


Figure 4. Effects of different dosage rates of *staymoist* plus NPK₁₅₋₁₅₋₁₅ fertilizer on plant height of maize cultivars, *Dorke SR* and *Dodzi*.

(Table 2).

Partial budget and dominance analysis for trial

The results of the partial budget analysis for the trial are presented in Table 3. At a constant rate of fertilizer application, operation cost is shown to increase with additional kilograms of SM. Even with the application of fertilizer, maize production was shown to yield negative profit in the absence SM.

Table 1 shows some physical and chemical properties of Changnayili series soils at the start and after the experiment (top 0-20 cm). The indications are that the pH of all the treatment plots was increased slightly and this may be attributed to the residual effects of the top dressing fertilizer, ammonium sulphate used in all the plots. Positive profit was recorded with the application of SM up to 15 kg/ha beyond which profit declined. The dominance of T₄ over the others is confirmed by the estimated marginal rates of returns and dominance analysis. This is followed by T₃ and T₅, respectively (Figure 5).

DISCUSSION

Weather and soil conditions

The maize growing season in the study area is between May and September (15-27 decades as shown in Figure 1). A look at the two weather graphs shows a generally erratic distribution of rainfall in both years of the study. Further, five decades in 2010 and seven in 2011, from a total of 13 decades in each growing season, recorded less than 50 mm of rainfall with at least 4 decades in each season recording very low amounts of precipitation (less than 30 mm/decade), with corresponding very high mean temperatures inferring high rates of evapotranspiration, thus indicating droughty situations. Hamidou et al. (2013) have demonstrated that high temperatures and water stress in semi-arid regions predispose yield loss up to 72% in grain legumes such as groundnuts.

Against this background, the trials were planted in both years in the second week of June. Now, 15-30 days after planting (DAP) and 35-45 DAP represent active vegetative growth and tasseling phases which are two critical and most drought vulnerable stages in the maize

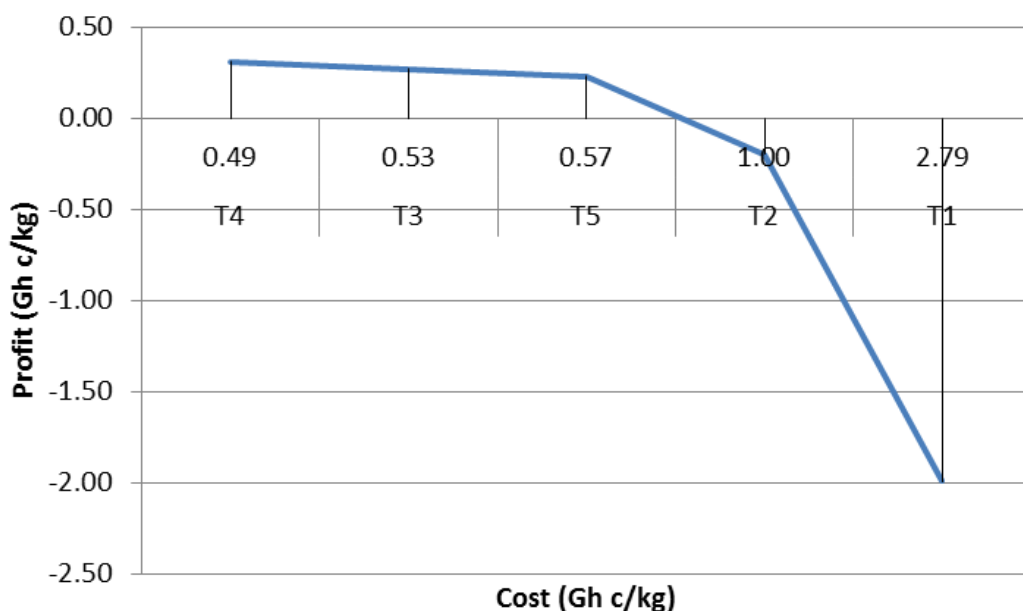


Figure 5. Dominance analysis for staymoist trial.

Table 3. Partial budget for staymoist and NPK fertilizer trial.

Treatment	Operations cost Ghc/ha	Profit Ghc/ha	Benefit cost ratio	Marginal rate of return
T ₁	566.81	-404.41	-0.71	-
T ₂	792.12	-156.92	-0.20	1.10
T ₃	823.44	418.96	0.51	3.21
T ₄	851.92	540.88	0.63	3.32
T ₅	871.25	347.95	0.40	2.47

crop development (Benneh,1993). Both drought sensitive periods in each year occurred in at least four decades with distinct droughty conditions, when mean rainfall was less than 30 mm/decade (Figure 1).

In most soils of the GSZ ammonium sulphate fertilizer tends to leave a slight acidic residue after the cropping season (NAES, 1993). Apart from this, SM+NPK treatments did not change the chemical properties of the soil in any significant manner. The bulk density of the SM plots was however slightly reduced with some enhancement of the moisture content of all the plots that received SM (Table 1).

Agronomic parameters

The effects of SAPs on media water retention, water loss, nutrient availability to plants, and net photosynthesis during water stress have been reiterated in the works of a number of authors (Taylor and Halfacre, 1986; Tu et al.,

1985; El-Hardi et al.,1981). They express an opinion that water stress adversely influences nutrient availability to crop plants and normal growth cycle while appropriate amelioration with SAPs positively influenced growth and development of several crops.

Varieties

Zed et al. (2013) have opined that overcoming mild to medium levels of abiotic stresses might be done by using crops of increased drought and salinity tolerance and utilizing their stress adaptation mechanisms to optimise crop productivity. This study has shown that under conditions of recurrent drought, crop productivity would be better enhanced by:

1. Cultivating drought tolerant maize cultivars such as *Dorke SR* and *Dodzi* and;
2. Ameliorating the soils for maize production with soil conditioners such as SM.

Selection of a more appropriate cultivar such as *Dorke SR* is clearly more advisable (Tables 2 and 3).

Days to maturity

Slightly earlier maturity, and inhibited plant growth of the 'no soil conditioner' treatments (T_1 and T_2) for both cultivars is explained by the commonly known ecological adaptation of most higher-flowering plants to high levels of stress such as drought. Most higher-flowering plants as an ecological adaptation would usually curtail their vegetative growth and hasten their reproductive phase when confronted with acute stress such as terminal drought (Rudall, 1994; Benneh, 1993, Webster and Wilson, 1980). But the significant difference in days to maturity for the two varieties confirms that as far as days to maturity (DTM) is concerned *Dorke SR* has as a cultivar trait and a longer maturity period than *Dodzi* (NAES, 1993; CSIR-SARI, 1996).

Plant height

Dorke SR plants were significantly taller than *Dodzi* plants (Figure 4); and this has also been confirmed to be a varietal trait associated with the two early maturing maize cultivars released by the CSIR (CSIR-SARI, 2009). Unlike *Dodzi*, *Dorke SR* responded well to SM+NPK treatments and had taller plants than treatments without SM. Plant heights in treatments 3 to 5 did not significantly differ from one another. This suggests additional SM beyond 7.5 kg/ha rate had no significant bearing on this agronomic parameter. The explanation this suggests is that each maize cultivar, at an optimum water requirement state will attain a given height within the prescribed limits of its varietal physical trait in the given environment.

Grain, stover and total biomass yields

In general, variety and key agronomic characteristics of maize such as grain, stover and total biomass yields were influenced significantly by the different treatments of SM. *Dorke SR* proved to be a longer maturing and bigger plant than *Dodzi*, and consequently, across all treatments in the trials produced higher yields of grain, stover and total biomass. *Dorke SR* therefore appeared to be the more resilient or responsive variety under 2010-2011 droughty conditions than its close relative *Dodzi*.

The consistently very low grain, stover and total biomass yields in the Control (No NPK, No SM) for both maize cultivars was clearly attributable to insufficient nutrients (NPK) and the influence of intermittent drought. It has been well documented that that maize grain yields

in most growing areas including the Guinea savannah zone are low and uneconomical when cultivated without fertilizers and intermittent droughts which usually contribute to low maize yields (Gholipour et al., 2013; CSIR-SARI, 1996, NAES, 1993). In Braunschweig Germany, Schittenhelm (2010) has indicated that forage sorghum and sunflower produce higher biomass (dry matter) than maize under imposed drought stress and this was attributed to the slower early growth of maize under conditions of low water supply. T_2 yields were generally better than those of T_1 but significantly lower than those of T_3 , T_4 and T_5 , indicating that all the SM treatments were better than those fertilized as recommended but without the soil conditioner.

The significantly improved yields for T_3 , T_4 and T_5 as compared to treatments without SM (T_1 and T_2) can be attributed to the ameliorating role of SM in these treatments. In assisting to improve soil physical properties, SM enhanced maize production. Soil amendment with relatively small additives of soil conditioners such as "Jalma", "Poly-DADMAC" and others, have similarly been demonstrated by a number of researchers to improve the yields and productivity of various crops under water stress conditions (Li et al., 2009; Mahana et al., 2000; Prado and Claudio, 2000; Sojka et al., 2000; Al-Darby, 1996; Ingram and Yeager, 1987; Johnson, 1985; Martin et al., 1952). In the SM treatments, SM was able to absorb and retain sufficient soil moisture which was available to the plants to withstand the drought spells that occurred in the growing seasons (Figures 3 and 4) at those critical times.

The mechanism of operation by which hydrogels are able to ameliorate soil water stress due to recurrent drought has been detailed by several workers: When water comes into contact with SM crystals, an electrical force that pushes the inward structure of the particle away from the centre via electrical repulsion. Small voids are created inside the particle drawing the water inward, which results in rapid swelling of the crystal. When the water evaporates or is taken up by the plant, the particle shrinks and is ready for the process to repeat. These reservoirs of water (hydrogels) are evenly dispersed throughout the plant's root zone. When the soil dries out and reaches 50% of field capacity, the crystals of SM are engineered to release their moisture to compensate for the outside soil pressure on the gel wall. This promotes the hydrophobic roots to grow to the new found moisture source provided by the presence of hydrogels. Usually the roots grow right through the hydrated crystals, extracting the moisture before moving on to the next closest one. This process also significantly minimizes the leaching away of fertilizers from the root zone and in sum, promotes increased root mass resulting in larger plants and increased crop yields (King et al., 1996; Woodhouse and Johnson, 1991; Wang and Boogher, 1987; Taylor and Halfacre, 1986; Johnson, 1984;

Polyakova, 1976).

The results also underline that relatively small amounts of SM were required to get around drought spells and improve maize yields in the GSZ. The Hydraulic properties of a similar gel forming SAP called "*Jalma*" were evaluated for sandy soils at four treatments namely 0.0, 0.2, 0.4 and 0.8% dosage rates. The optimum dosage rate for limiting deep water percolation losses and maintaining adequate filtration and water retention characteristics was relatively low at 0.4% of the product (Al-Darby, 1996). Small but effective amounts of SM will generally be relatively cheaper and affordable to small and medium scale farmers in the GSZ who constitute a large majority of maize farmers in the area. The relatively small amounts of SM required for effective amelioration, all things being equal, should impact less on the environment than if larger quantities were required and a minimum impact of any soil amendment on the environment should be desirable.

Economic analysis indicated that maize production even with the application of recommended fertilizer rates, was not profitable in droughty years (Table 3) and farmers in the GSZ are well advised to ameliorate their fields to sustain maize productivity.

The optimum dosage rate of soil conditioner with NPK combination was 15 kg/ha SM. Beyond this rate positive profit declined. This suggests that relatively small dosage rates of SM are required to optimize productivity of maize in the GSZ. The effects of different levels of synthetic soil conditioners on soil water retention, yields and mineral nutrition of plants have been well documented (Ben-Hur, 2001; Choudhary et al., 1995; Wallace and Wallace, 1986; Wallace et al., 1998). Their findings corroborate the fact that SAPs such as *staymoist*, at relatively low recommended dosage rates, are not only safe, economical products for improving water retention, nutrient availability and other physical properties of limited soils such as sandy-loam soils of GSZ of Ghana, but can be important for making maize production in this environment more profitable.

The estimated marginal rates of returns and dominance analysis confirmed the dominance or superiority of T₄ over all the others (Table 3 and Figure 5).

CONCLUSION AND RECOMMENDATIONS

Mitigating terminal drought

From the above results, there is ample evidence that *staymoist* when used as a soil amendment can absorb and retain moisture for the uptake by plants during intermittent drought as demonstrated by the responses of the two maize varieties in the trial to different treatments levels of SM and NPK fertilizer.

For many small farmers in the Guinea savannah zone,

bridging the "Hunger Gap" between August and September in the cropping calendar is crucial. For them, it may be more strategic to plant *Dodzi* with the recommended dosage rates of SM and NPK₁₅₋₁₅₋₁₅ since this variety is much earlier than *Dorke SR* but still performs well in droughty conditions if ameliorated with SM. For the majority of maize farmers in the zone, for whom increased yields, productivity and economic sustainability are equally important, and considering the increasing vagaries in weather associated with climate change, they will be best advised to crop *Dorke SR* with the optimum dosage rate of SM and NPK₁₅₋₁₅₋₁₅ because even though *Dorke SR* would be slightly longer maturing the stratagem would still be more productive.

Enhancing nutrient use efficiency

Agronomic and productivity results of the trial are indicative of the fact that *staymoist* can absorb nutrients released by fertilizers incorporated in the soil with the product. Plant roots access to the minerals must necessarily be closely linked to the availability of water in the root zone of the maize plant. *Staymoist* by its mechanism of action holds on to water in the plant root zone and in so doing significantly reduces leaching away of fertilizers and enhancing nutrient use efficiency.

Grain and biomass yields of maize are enhanced

The obtained data underline the positive influence of *staymoist* on the agronomic characteristics and yields of both *Dorke SR* and *Dodzi*, under intermittent drought situations. Data presented clearly indicated that grain and stover yields of all three SM treatments were significantly higher than both the Control and NPK only treatments which did not receive NPK fertilizer and were not ameliorated with soil conditioner SM.

Effective insurance at relatively low dosage rate

Security against a dryer than normal rainy/cropping seasons

Since the results of the treatment with the 15 kg/ha SM were comparable in several aspects with the one with 22.5 kg/ha SM, one can conclude that it would be preferable to recommend the former to farmers because of cost implications, inconvenience of handling bulky materials and impact on the environment. In a situation of intermittent or even terminal drought, a farmer may be able to avoid a complete disaster by combining appropriate use of variety such as *Dorke SR* in combination with optimum dose of 15 kg/ha SM.

Several parts of the world are predicted to suffer from increasingly severe droughts in the future due to climate changes. The Guinea Savannah agro-ecological zone of Ghana is no exception. In order to optimize crop productivity, a range of crop (stress adaptation mechanism) and management strategies such as melioration with *staymoist* need to be combined for any specific target environment.

More work is still required to explore the effects of different dosage rates of *staymoist* on the yields and productivity of other upland crops such as upland rice (for example, 'NERICA' 1 and 2) and soya beans. The effects of much smaller dosage rates of SM on the yields and productivity of maize still need to be investigated. The medium and long term effects of *staymoist* to food quality and the environment in Guinea savannah zone are yet to be investigated in-depth.

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