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Full Length Research Paper

Effect of Cassava Starch Hydrogel on the Water Requirement of Maize *(Zea may)* Seedlings and Selected Properties of Sandy Loam Soil

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ABSTRACT
Effect of native cassava starch hydrogel on the Water Requirement of Maize (Zea may) seedlings and selected properties of Sandy Loam Soil was investigated. The hydrogel was prepared according to method described in literature. Soil samples collected were prepared and analyzed for physico-chemical properties in the laboratory using standard techniques. The physico-chemical properties of the hydrogel – soil mixture samples in which maize seedlings have been planted were measured as a function of hydrogel loading and compared with the values obtained in the control. The hydrogel showed significant improvement in the soil physical properties and the soil CEC ($p<0.05$). The results of the soil-hydrogel analysis at a monthly interval showed that there was significant ($p<0.05$) increase in the ability of the soil to retain moisture, thus reducing the water requirement for growth of the maize seedlings compared to the control.

Keywords: *Acrylonitrile, Cassava starch, Hydrogel, Maize, Soil*

INTRODUCTION
The continued threat to the world's land resources is exacerbated by the need to reduce poverty, climate change and unsustainable farming practices. Climate change is predicted to worsen the incidence of drought and desertification in sub-Saharan African in few years to come, Yazdani et al,(2007), Bhat et al, (2009), Okorie, (2003). During the last decade, food security was not a global priority, but studies such as the 2020 Vision, FAO, (1996), have shown that food security is one of the main global concerns in this century. Food security cannot be guaranteed unless the issue of soil erosion, drought, desertification, and soil water management are given the necessary consideration. Superabsorbent polymer hydrogels have a critical role to play here, particularly in the developing countries.

Superabsorbent polymers (SAPs) or hydrogels are loosely cross-linked, three-dimensional networks of flexible polymer chains that carry dissociated, ionic functional groups. They are basically the materials that can absorb fluids of greater than 15 times their own dried weight, either under load or without load, such as water, electrolyte solution, synthetic urine, brines, biological fluids such as urine sweat, and blood, Zohuriaan-Mehr and Kourosh, (2008).

Relatively few or no data are available in the literature on the effect of hydrogel on the physico-chemical properties of soil supporting crop production in developing countries. The present communication describes the investigation of the impact of cassava starch hydrogel on physio-chemical properties of soil supporting the growth of maize seedlings in Nigeria, by varying the loading concentration of the hydrogel while keeping soil load constant.

MATERIALS AND METHODS
Materials
Acrylonitrile (AN) used was supplied by B.D.H. as reagent grade and was distilled under reduced pressure and stored in the dark at 5°C before use, cassava starch was sourced from a local cassava starch processing factory in Benin City, Nigeria. The soil used was obtained from a farm site at Auchi Polytechnic campus, Auchi and maize grains were purchased from a local market in Auchi. Analar grade Cerium ammonium nitrate was obtained from BDH, Poole, England.

Characterization of the soil
The soil samples were characterized as follows: Bulk density was measured by core method, Grossman and Reinsch, (2002). Soil pH was measured in 1:1 soil-water ratio, Hendershot et al (1993). Soil organic carbon was estimated by combustion at 840°C, Wang, & Anderson (1998), while total nitrogen was obtained by microkjeldahl method. Cation exchange capacity was measured using ammonium acetate leaching at pH 7.0, Rhoades (1982). Available phosphorus was determined by Olsen method, Emteryd, (2007) and soil heavy metal content was determined using the AAS. The results are as presented in Table 2.

Synthesis of Hydrogel

The procedure for the preparation of the hydrogel was based on the method described by Hashem, et al, (2005).

Soil - Hydrogel mixing procedure

Measured quantities of the hydrogel (0, 3.0, 6.0, 9.0, 12.0g) were thoroughly mixed with 2 kg of soil each and designated as W_1, W_2, to W_5, placed in five-liter polyethylene containers. Two maize grains were planted in the center of each container. The soil was irrigated with water and the volume of water required to saturate the soil to field capacity was recorded. Subsequent irrigations were applied, the amount of water required to attain field capacity was recorded. Moisture content of the soil was determined by oven-drying aliquots of the soil at 110^{o}C. Soil samples from the container were collected at one month interval and analyzed for pH, moisture content; cations exchange capacity, soil acidity, Bulk density, water holding capacity, saturation water volume, total organic carbon, and nitrogen using recommended procedures, USDA, (1996).

Relative water content (RWC) of leaves was measured on fully expanded leaves at 2 weeks interval after sowing (WAS). Leaves were cut and collected at midday to determine fresh weight (FW). Leaf blades were then, placed with their cut end pointing down into a tube containing about 15 ml of 1 mM $CaCl_2$. The $CaCl_2$ was used to increase leaf cell integrity, with the aim of reducing cell lysis due to excessive rehydration.

The turgid weight (TW) was then, recorded after overnight rehydration at 4°C. For dry weight (DW) determination, samples were oven-dried at 70°C for 48 h. Relative water content was calculated according to Schonfeld et al. (1988) thus:

RWC (%) = [(FW – DW) / (TW – DW)] × 100

Experimental Conditions

The experiment was conducted for two months in an evaporatively cooled greenhouse. The indoor conditions during the initial phase of the experiment (Nov/December) were warm with average maximum and minimum temperatures ranging between 33 - 42^{0}C and 28 - 32^{0}C, respectively. The conditions became slightly moderate in January.

In all, 5 treatments per set (Hydrogel, 4 concentrations and one control) were replicated and arranged in complete randomized block design with five containers per treatment. The total amount of water used for irrigation was determined upon completion of the study.

Data were analyzed by two-way Analysis of Variance (ANOVA), and the means comparisons were made using the least significant differences (LSD) at the 5% level of probability using the Genstat 12 software. The SEM, C.V%, overall F value, and its significance are also presented.

RESULTS AND DISCUSSION

Physico-chemical characteristics of the experimental soil before planting

Textural analysis in Table 1 showed the preponderance of sand fraction (69.22%), followed by clay (16.38%), then silt (14.40%), thus classifying the soil as sandy loam soil, Soil survey staff, (1998), this is corroborated by the soil bulk density (1.33g/cm^3) which is an index of the textural nature of the soil. The slightly alkaline pH of 8.0 recorded for the soil is within the range of agricultural soils. The pH of soil influences ion-pair formation, solubility of organic matter, as well as surface charge of Fe, Mn and Al- oxides, organic matter and clay edges, Tokaliogu et al, (2006).The soil had an average cations exchange capacity (CEC) of 286.02mg/kg, as showed in Table 1. The relatively low levels of silt, clay and average level of CEC indicate the high permeability, hence leachability of heavy metals in the soil and suggest that it might be amenable to remediation by use of hydrogel, Ehsan et al, (2006). Cations (positively charged ions) useful to plant nutrition include Mg^{2+}(67.63mg/kg), Ca^{2+}(208.51mg/kg), K^+(2.70mg/kg),Na^+(7.18mg/kg) and Mn^+.

Table 1. Characterization of the soil sample used for planting

Analytical characteristics	Results
Particle size distribution (%)	Clay 16.38
	Silt 14.40
	Sand 69.22
pH	8.0±0.01
Bulk Density(g/cm^3)	1.33±0.02
Soil organic carbon, g/kg	0.544±0.05
Total Nitrogen, g/kg	0.048±0.002
Cation exchange capacity,mg/kg	286.02±0.92
Available Phosphorus, mg/kg	5.889±0.150
Sodium content, mg/kg	7.18±0.07
Potassium content, mg/kg	2.70±0.05

Magnesium content, mg/kg	67.63±0.25
Calcium content, mg/kg	208.51±0.55
Lead (mg/Kg)	0.05±0.001
Cadmium (mg/Kg)	ND
Arsenic(mg/Kg)	ND
Copper (mg/Kg)	0.002±0.0005
Total acidity	0.2±0.001

ND = Not Detected

Heavy metals analysis of the soil shows that Cadmium and arsenic were not present, as they were not detected by the AAS; however, low levels of Lead (0.05mg/kg) and copper (0.002mg/kg) were detected, showing the quality level of the soil. The soil organic carbon result, 0.544g/kg, in Table 1, is an indication of the amount of humus/organic matter present in the soil; this is also expressed in the total nitrogen level of the soil, 0.048g/kg (Table 1), which could be as a result of the high rate of organic matter decomposition in the soil. Phosphorus is second to nitrogen in importance in plant nutrient. The available phosphorus result of the soil (5.889mg/kg) gives the low level of phosphorus available for uptake by plants.

Effect on the Water Requirement of the zea may and Physicochemical properties of the soil by starch-based hydrogel

Sandy soils which are coarse-textured, are light soils and are easier to till, they drain better, and are warm. Crop production on sandy soil requires frequent irrigation to make up for its poor water retention capacity. Thus the idea of applying hydrogel therefore is to increase the water retention capacity of the soil as to reduce the frequency of irrigation and its cost implication. Table 2 shows that the water retention capacity of the soil increases significantly ($p<0.05$) on application of the starch hydrogel, 23% over the water applied in the control was applied in the low treatment, 46% for medium, 69% for high and 130% for the very high treatments in the first two weeks with subsequent decrease in water demand in the fourth and sixth week to as low as 46.7% below the water demand by the control, showing a cost effective system for crop production. However, the increase in WRC from W_1 to W_5 23 to 130% over the control in week 2, 10 to 60% in week 4, 0 to 20% in week 6 in the table is an indication of the ability of hydrogel applied to retain moisture. The change in WHC from week 2 to week 6 ending which is very significant ($p<0.05$) is due to the initial level of water uptake to field capacity of the soil. The capacity of hydrophilic polymers to provide water to plants depends on the proportion of water held by the polymer that is easily available to plants, the pressure the soil exerts on the polymers, the presence of soluble salts and the ability of the hydrogel to make use of gravitational water, water which is usually not available to plants, as well as capillary water, Islam*etal*,(2007).

Table 2. Water used by Zea may in polymer amended soil (ml)

Soil/poly. Conc. weeks	**Water 2**	**Applied to 4**	**Soil(ml) 6**
W_1 Control	325a	250a	150a
W_2	400b	200a	080b
W_3	475c	275b	100b
W_4	550d	375c	150c
W_5	750e	400c	180c
Mean	500	300	132
LSD(5%)	218.5	113.7	54.8
SEM	72.9	37.9	18.3
C.V%	32.6	28.3	31.0
F-value	3.70	4.30	15.9
Significance of overall F	*	*	*

**** Significant at the 0.05 probability level, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference, Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

Super absorbent polymers (SAP) have been used as water-retaining materials in the agricultural and horticultural fields, Johnson, (1984), Mikkelson, (1994), Yazdani et al , (2007), Pritchard and Quinn, (1981), because when incorporated with soil, they can retain large quantities of water and nutrients. These stored water and nutrients are released slowly as required by the plant to improve growth under limited water supply, Mikkelson, (1994), Yazdani et al, (2007), Azzam, (1983). The study showed that the applied hydrogel had a remarkable effect on maize seedlings growth.

Application of superabsorbent polymer could be an effective way of maize cultivation in the soils characterized by low water holding capacity where, rain or irrigational water efficiency by crops, Mikkelson, (1994), Yazdani et al , (2007), Pritchard and Quinn, (1981).

Tables 3, 5, and 7 shows that moisture content after irrigation increases from W_1 to W_5 due to the application of the hydrogel to the soil, indicating more water available to the plant and hence increases growth of the plant. Gehring and Lewis, (1980), reported that moisture stress of plants decreased by incorporation of a hydrogel into the medium. Wallace and Wallace, (1990); stated that generally the most favourable results for seed emergence and water infiltration came from hydrogel application.

Table 3: Effect of hydrogel on physical properties of the soil at the end of the 4th week

Soil/Polymer conc.(wt. poly/ 2kg soil)	Bulk density(g/cm^3)	Saturation water volume (ml/kg)	Soil moisture after irrigation (%)	pH	WRC (ml/kg)
W_1 Control	1.24a	125a	21.78a	7.8 a	0
W_2	1.42b	140a	25.56b	7.6b	15a
W_3	1.42b	152.5a	32.10c	7.5b	27.5b
W_4	1.62b	182.5b	32.34c	7.6b	57.5c
W_5	1.61b	205.5b	35.62c	7.9a	82.5d
Mean	1.46	161.1	29.48	7.7	36.5
LSD(0.05)	0.213	40.92	7.60	2.21	44.84
SEM	0.071	14.58	2.52	7.35	14.89
C.V%	10.8	20.24	19.13	2.14	91.21
F-value	1.08	71.8	33.8	3.42	71.8
Significance of overall F	NS	*	*	*	*

**** Significant at the 0.05 probability level, NS: Not Significant, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference, Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

Table 5 shows that as a result of the application of the hydrogel bulk density though increases but not significant ($p<0.05$) from W_1 to W_5, showing expansion of the hydrogel particles upon water absorption increasing aeration and improving drainage, providing faster growth and minimizes the danger of root rot. However, W_1 in which the hydrogel was not added shows a decrease from the initial value, because of the nature of the soil, nutrient uptake and leaching. Saturation water volume (SWV) is the volume of water required by the soil at field capacity. Table 5 shows that the SWV increases significantly at the 5% probability level from W_1 to W_5, this is expected because when water is added an electrical repulsion takes place between the hydrogel particles causing the main branches of the molecules to repel each other. Water is drawn in, resulting in a rapid swelling of each particle and a rapid absorption of water, Pritchard and Quinn, (1983). However, Table 7, shows that subsequent addition decreases from the initial amount of water absorb because of the ability of the hydrogel to store water for future plant use, thus the subsequent weeks water, the soil takes from W_1 to W_5 is lesser than the initial requirement.

Table 4: Effect of hydrogel on Chemical properties of the soil at the end of the 4th week

Soil/Polymer conc.(wt. poly/ 2kg soil)	CEC (mg/kg)	N(g/kg)	C(g/kg)	Total Acidity
W_1	273.72a	0.07a	0.544a	0.22a
W_2	328.52b	0.058a	0.615a	0.34b
W_3	359.57b	0.056a	0.643a	0.26a
W_4	384.45c	0.056a	0.687a	0.41c
W_5	446.98d	0.054a	0.721a	0.52d
Mean	358.65	0.059	0.642	0.35
LSD (0.05)	86.76	0.009	0.09	0.16

SEM	28.8	0.003	0.03	0.054
C.V%	17.96	10.92	10.59	34.29
F-Value	155.0	1.00	1.00	3.10
Significance of overall F	*	NS	NS	*

**** Significant at the 0.05 probability level, NS: Not Significant, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference, Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

Tables 5, and 7 show the variation of the pH of the soil for the period of the experiment, it also shows that there is a near neutral reaction in the soil, an indication of a balance ions availability and activity in the soil. The absorption capacity of hydrogels is affected by acidity and alkalinity (pH), conductivity, and other variables that inhibit expansion of the gel particles, Bearee and McCollum, (1977). The pH of the absorbed fluid did not present a problem to the plant since the pH in the growing environment is normally within the ideal range for optimum absorption. The pH values varied between the allowable pH of soils. However, the optimum pH range for maize growth is in the range of 6.5 to 8.0; an indication of the plant adaptation ability to the nature of the soil used for the experiment.

CEC increases significantly (p<0.05) from W_1 to W_5 in Tables 6, and 8, as a result of the soil ability to reduce leaching of cations from the topsoil due to the application of the hydrogel. The use of the hydrogel to enhance water retention capacity also increases the nutrient holding capacity of the medium, Martin et al, (1993). The increase can also be interpreted in terms of the counter ions exchange capacity of the hydrogel which increases the soil's; Ca^{2+}, Mg^{2+}, K^+ and Na^+ ions which constitute the CEC. The increase also is a reflection of the ability of the applied hydrogel to create microcosms that are rich in water and nutrients (counter ions).

Table 5: Effect of hydrogel on physical properties of the soil at the end of the 6th week

Soil/Polymer conc.(2kg soil/wt% poly)	Bulk density(g/cm^3)	Saturation water volume (ml/kg)	Soil moisture after irrigation (%)	pH	WRC(ml/kg)
W_1 (0)	1.20a	75a	19.48a	7.7a	0
W_2 (1.5)	1.41b	40b	22.34a	7.2a	26.5a
W_3 (3.0)	1.40b	50b	28.29b	7.4a	33b
W_4 (4.5)	1.61c	75a	31.36b	7.5a	50c
W_5 (6.0)	1.64c	90c	32.51c	7.8b	60d
Mean	1.452	66	26.796	7.52	33.9
LSD (0.05)	0.241	27.53	7.65	0.32	31.20
SEM	0.08	9.14	2.54	0.11	10.36
C.V%	12.33	30.76	21.20	3.17	10.36
F-Value	2.11	12.04	5.66	1.78	20.13
Significance of overall F	NS	*	*	NS	*

**** Significant at the 0.05 probability level, NS: Not Significant, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference, Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

When aqueous, nutrient-containing solutions are used to hydrate an hydrogel, a considerable amount of nutrient enters into the polymer structure during expansion, Mikkelson, (1994), Woodhouse and Johnson, (1991), Johnson and Veltkamp, (1985). Hydrophilic polymers generally contain micro pores that allow small molecules to diffuse through the hydrogel, Huttermann et al, (1999).The subsequent release of nutrient is then based on the diffusive properties of the polymer, its decomposition rate and the nature of the nutrient salt. The conditions of these microenvironments are favourable to roots and microorganisms. However Tables 6, and 8, show decrease in the variation of the CEC from week 2 to week 6 ending due to plant uptake of the limiting soil nutrients being a pot experiment. Total soil acidity is the sum total effect of available anions in the soil. Tables 6, and 8, show that there is no significant variation in the total soil acidity probably due to the slow enzymatic action of soil microorganisms, which act to decompose soil organic matter to produce CO_2-, NH_4^+, NO_3^-, SO_4^{2-}, $H_2PO_4^-$ and H_2O. The relative water content (RWC) in plant leaves at grain feeling stage was much higher in plants with the hydrogel treatment and increases as the week increased from week 4 to week 8 (Table 9). Although, the value increased under low and medium application of the hydrogel, it increased remarkably (p<0.05) under high and very high application, from week 4 to week 8 respectively

Table 6. Effect of hydrogel on chemical properties of the soil at the end of the 6th week

Soil/Polymer conc.(2kg soil/wt% poly)	CEC (mg/kg)	N(g/kg)	C(g/kg)	Total Acidity
W_1 Control	218.25a	0.060a	0.614a	0.15a
W_2	277.97b	0.057a	0.472a	0.31b
W_3	324.75c	0.046a	0.632a	0.38b
W_4	363.53c	0.067a	0.738a	0.35b
W_5	403.17d	0.071a	0.832a	0.46b
Mean	317.534	0.0602	0.658	0.33b
LSD (0.05)	97.43	0.013	0.183	0.154
SEM	32.34	0.0043	0.061	0.051
C.V%	22.8	16.1	20.67	34.75
F-Value	96.36	1.00	1.40	1.00
Significance of overall F	*	NS	NS	NS

**** Significant at the 0.05 probability level, NS: Not Significant, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference. Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

Table 7. Effect of hydrogel on physical properties of the soil at the end of the 8th week

Soil/Polymer conc.(2kg soil/wt% poly)	Bulk density(g/cm^3)	Saturation water volume (ml/kg)	Soil moisture after irrigation (%)	pH	WRC(ml/kg)
W_1	1.22a	70a	20.06a	7.7a	0
W_2	1.40b	45b	24.11a	7.5a	22a
W_3	1.41b	56b	32.05b	7.8a	29a
W_4	1.63c	78c	38.60b	7.9a	45b
W_5	1.66c	88c	43.73c	7.9 a	56c
Mean	1.464	67.4	31.71	7.76	30.4
LSD (0.05)	0.245	23.09	13.23	0.225	29.09
SEM	0.0814	7.67	4.39	0.075	9.66
C.V%	12.43	25.43	30.96	2.16	71.03
F-Value	1.00	28.52	3.05	1.00	28.51
Significance of overall F	NS	*	*	NS	*

**** Significant at the 0.05 probability level, NS: Not Significant, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference. Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

Table 8: Effect of hydrogel on chemical properties of the soil at the end of the 8th week

Soil/Polymer conc.(2kg soil/wt% poly)	CEC (mg/kg)	N(g/kg)	C(g/kg)	Total Acidity
W_1 Control	228.33a	0.069a	0.634a	0.18a
W_2	284.08b	0.067a	0.489a	0.34b
W_3	356.78c	0.054a	0.656a	0.36b
W_4	368.21c	0.076a	0.788a	0.39b
W_5	421.08d	0.078a	0.851a	0.48c
Mean	331.696	0.0688	0.684	0.35
LSD (0.05)	101.94	0.013	0.191	0.147
SEM	33.84	0.0042	0.063	0.049

C.V%	22.81	13.76	20.69	31.17
F-Value	96.04	1.00	1.68	1.68
Significance of overall F	*	NS	NS	NS

***** Significant at the 0.05 probability level, NS: Not Significant, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference.***

Table 9: Relative water contents (RWC) of Maize leaves at biweekly interval under different hydrogel treatments after sowing

Treatments(WAS)	4	6	8
W_1	59.5a	61.8a	68.5a
W_2	63.8b	66.5b	77.2b
W_3	68.4c	70.4c	81.6c
W_4	76.9d	78.1d	86.4d
W_5	83.2e	82.8d	88.6d
Mean	70.4	71.9	80.5
LSD (5%)	13.0	11.48	10.79
SEM	4.32	3.80	3.58
C.V%	13.7	11.9	10.0
F-value	48.67	48.67	48.67
Significance of overall F	*	*	*

***** Significant at the 0.05 probability level, C.V: coefficient of Variation, SEM: Standard error of the mean, LSD: Least square difference, WAS: Water after sowing. Different letters in the columns indicate significant differences between treatments at P < 0.05 level.***

CONCLUSION

The main aim of this work is to gauge the impact of starch-PAN hydrogel on the physio-chemical properties of the soil supporting the growth of maize seedlings in Nigeria, as well as the water holding capacity of the hydrogel-soil mix, under farming condition typical to developing countries. The results show that hydrogel prepared from native cassava starch-polyacrylonitrile influenced the physico-chemical properties of soil supporting the growth of maize seedlings, compared to the control. The results indicate that there is an improvement in the ability of the soil to hold water by reason of the introduction of the hydrogel, thus, this could become cost effective in irrigation of farmlands in Africa. These results are of interest for the development of hydrogel-based technologies for solving the problem of agriculture and water conservation management in sub-Saharan Africa.

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