International Journal of Agriculture Innovations and Research
Volume 7, Issue 2, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 28/08/2018 | Accepted on: 06/09/2018 | Published: 22/09/2018

Effect of Dry Cropping Season of Sorghum on Selected Physico-Chemical Properties in West Africa

Pane Jeanne d'Arc Coulibaly[1*], Daniel Okae-Anti[2], Badiori Ouattara[1], Jacques Sawadogo[1] and Michel Papaoba Sedogo[1]
[1:] Centre National de la Recherche Scientifique et Technologique/Institute de l' Environment et de Recherches Agricoles (CNRST/INERA)/ Ouagadougou- Burkina Faso.
[2:] University of Cape Coast, Ghana.
[1*:] Corresponding author: Pane Jeanne d'Arc Coulibaly, Junior Researcher in Soil Science in INERA/CREAF, Department of Natural Resources Management/Production Systems /Tel: (+226)71530607/ (+226)77729799
*Corresponding author email id: panecoul@yahoo.fr

***Abstract* – Nowadays, the rainfed agriculture is at a high risk of being severely affected by climate change because of its strong dependence on natural resources and the climate itself. This study was therefore undertaken in order to explore a wide range of adaptation strategies that could enhance the sustainable production of sorghum and contribute to its security. Two experiments were conducted in 2014 and 2015 at Saria in the Central region of Burkina Faso to assess the effect of two dry cropping seasons and selected physico-chemical properties on the production of two varieties of sorghum. The study used a randomized split-plot design under irrigation, with fertilization and two climatic conditions of hot and cold dry seasons. Physico–chemical characterizations were done on soils at the 0-20 cm and 20-40 cm depth for particle size distribution, pH, nitrogen (N), phosphorus (P), potassium (K), organic carbon (Org C), exchangeable bases (Ca^{2+}, Mg^{2+}) and cation exchange capacity (CEC). The analysis showed an acidic sandy loam soil with low levels of total N, P, available P, Org C, Ca^{2+}, Mg^{2+} and CEC. Irrigation regime had no significant effect on soil pH and chemical characteristics. However, correlation analysis showed a positive impact of temperature on soil pH, Org C, Ca^{2+}, Mg^{2+} CEC, K and C:N ratio. On the contrary, N, P and available P were negatively affected by temperature. Nitrogen fertilization negatively correlated with soil pH and Mg^{2+} whereas a positive significant impact of sorghum genotype was recorded with available P and Org C content.**

***Keywords* – Climate Change, Dry Cropping Seasons, Soil Fertility, West Africa.**

I. INTRODUCTION

Sorghum production depends much on the fertility status of the soil. In West Africa, many environmental stresses and the cropping system can negatively or positively affect the production of Sorghum [1].

The cropping system using fertilization worldwide, is noted to increase crops yields. Nitrogen, Phosphorus, Potassium and some bases (Mg, Ca, Na) are some elements brought into the soil when fertilized. Nitrogen is the main determinant nutrient for soil to produce high grain yield [2], [3. Some research findings also asserted that nitrogen fertilizer was a way to restore soil fertility level in Kenya [4] and to increase sorghum yield [5]. It has been one of the most limiting nutrients in lowland rice production in Iran [6]. In Cameroun, its application contributed to increase crop yield but it was found as a nutrient difficult to manage in fertilization [7]. Nitrogen with phosphorus application could stimulate crop growth and productivity [8] however, the excess use of the nutrients could increase their noxiousness to the environment [9]. Moreover, it was supported that the continuous use of nitrogen was harmful since it led to the rapid soil acidification indicated by the decrease in soil pH [10]. Long term experiments of 40 years [11] and of 14 years [12] were laid out in Germany and on Cambisols to assess the effect of nitrogen fertilization on soil chemical properties. The results reported a decrease in soil pH as confirmed by other studies, an increase in soil carbon content and in soil CEC content. An increase in nitrogen, phosphorus and potassium, and a decrease in Mg and Ca content were also obtained in this soil [11].

In the context of climate change, some soils could be sources of atmospheric C leading to the decrease of soil organic matter levels [13], [14]. Climate change might affect rainfed agriculture through incidents of droughts, floods and violent winds [15]. According to some researchers such as, some soils would be the sources of atmospheric C leading to the decrease of soil organic matter levels. Through climate change, rainfed agriculture is expected to experience many droughts, floods, and violent winds. Some simulations done in arid areas showed that water runoff would increase significantly up to 5 times more than the increase in rainfall [16]. A strong correlation between climate change and soil erosion was reported [17]. According to these authors, climate change is likely to negatively affect soil aggregate stability, bulk density, water holding capacity, pH, organic matter, total N and soluble P. This decrease in soil fertility could be the major problem to food security especially in Africa [18].

Therefore, this study was to assess strategies for sustainability and adaptation of sorghum cropping systems and related effects of these strategies on selected physico-chemical properties of soil.

II. MATERIAL AND METHODS

A. *Description of the Study Site*

The study was conducted in 2014 and 2015 at Saria in the Central region of Burkina Faso, in an agro climatic zone with annual rainfall between 700 and 900 mm. The potential evapotranspiration (PET) is about 6-7 mm day-1 from March to June and 3-4 mm day-1 from October to February according to the meteorological reports at the site. The average monthly minimum temperatures during the study were 23.9 °C and 19.7 °C in the hot and cold dried season respectively and the average maximum temperatures were 41.1 °C and 38.1 °C in the hot and cold dried seasons respectively. The study was done on the tropical ferruginous soil or Luvisols according to the World Base Reference for Soil Resources [19]. This is the most dominant soils on which sorghum is produced in Burkina Faso. These soils had developed from granite rock as parent material and have upper horizons of sandy loam to sandy clay textures and generally with continuous and massive structure, slightly acidic and low in N, P, K, Ca, Mg and CEC.

B. *Methodology*

Two experiments were set up under two different growth conditions in the dry season: first under temperatures of 23.9 °C to 41.1 °C with a potential evapotranspiration of 7 mm day-1 and irrigated permanently; this was called "a hot dry experiment"; the second was under temperatures of 19.7 °C to 38.1 °C and with potential evapotranspiration of 3 mm day-1 and irrigated permanently; this was labeled "a cold dry experiment". These hot and cold dry season experiments were started on 17th March and 20th October, 2014, respectively. The randomized split-plot design was used.

For each experiment, two composite soil samples were taken before sowing from depths of 0-20 cm and 20-40 cm. After harvest, soil samples were again taken from all treatment plots and at the same depths. The samples were air-dried and ground to pass through a 2 mm and 0.5 mm sieve. The samples were analyzed at the INERA Kamboinse soil, water and plant analysis laboratory for physico–chemical which included particle size distribution, pH, N, P, K, Org C, Ca, Mg, and CEC. These analyses were done using standard analytical procedures.

Soil organic C was determined using the Walkley and Black [20] method; the pH was measured with a pH-meter (WTW InoLab, Weilheim, Germany) according to Afnor [21]; P and N were determined in the digest with a SKALAR automatic colorimeter (Skalar SANplus Segmented flow analyser, Model 4000-02, Breda, Holland); soil available phosphorus was determined by the Bray-1 Method and CEC and exchangeable bases (Ca, Mg) were determined using the silver thiourea method [22].

C. *Statistical Analysis*

An analysis of variance using GenStat 9th edition and a correlation analysis using XLSTAT version 2016.01.26779 were done to study the effect of the cropping systems, levels of temperature, potential evapotranspiration, the irrigation regimes, nitrogen fertilization and sorghum varieties on selected physic-chemical properties. The means were compared using the L.S.D. at a probability level of 0.05.

III. RESULTS AND DISCUSSION

D. *Initial Soil pH, Soil Physical and Chemical Properties*

Before starting the experiment, the laboratory analysis on the samples collected showed the following results in Table 1 and 2.

The analysis showed an acidic sandy loam soil with low levels of total N and P, and available P, low organic carbon, low exchangeable bases and low cation exchange capacity. The low level of the chemical characteristics in soils from these two cropping seasons could be due to the level of acidity. This acidity could decrease the nitrification and the content of P into the soil [23]. In addition, soil Org C is inactive for the low value of pH, as the microorganism activity is highly limited [24]. When mineralization is low, the organic matter is intensified and this could also lead to soil acidification.

A soil with poor organic matter is also poor in carbon and nitrogen since these two elements are major components of soil organic matter [25]. In addition, a deficiency of soil organic matter reduces the capacity of soil to hold water, decrease soil CEC and hence lead to poor soil structure and poor nutrient supply to the soil ecosystem [13].

The initial carbon: nitrogen ratios for the dry hot and dry cold experiments were 18.5 and 15.5 respectively. The ratio determines the decomposability of soil organic matter. This ratio is used to infer the status of soil quality and to assess the carbon and nitrogen nutrition balance of soils [26]. High C:N ratios slow down the decomposition rate of organic matter and organic nitrogen and low C:N is indicated to be the best to the process of this microbial decomposition of organic matter and nitrogen [27].

Table 1. Initial soil physical properties.

Experiments	Clay (%)	Silt (%)	Sand (%)	Texture
Hot dry experiment	14.2	23.33	39.65	Sandy loam
Cold dry experiment	18.51	23.75	35.55	Sandy loam

Table 2. Initial soil chemical properties.

Characteristics	Horizons (cm)	Dry hot experiment	Dry cold experiment.
pH	0-20 cm	4.66	4.62
	20-40 cm	4.6	5.77
	Average	4.63	5.20
P (g kg^{-1})	0-20 cm	0.13	0.08
	20-40 cm	0.08	0.07
	Average	0.11	0.08
P avail (mg kg^{-1})	0-20 cm	6.48	5.56
	20-40 cm	4.17	1.85
	Average	5.33	3.71
K (g kg^{-1})	0-20 cm	0.39	0.37
	20-40 cm	0.44	0.53
	Average	0.42	0.45
Total N (g kg^{-1})	0-20 cm	0.23	0.20
	20-40 cm	0.2	0.23
	Average	0.22	0.22
C (g kg^{-1})	0-20 cm	4.25	3.21
	20-40 cm	3.55	3.41
	Average	3.9	3.31
C:N	0-20 cm	19	16
	20-40 cm	18	15
	Average	18.5	15.5
Ca^{2+} ($cmol_c$ kg^{-1})	0-20 cm	0.86	1.19
	20-40 cm	0.94	2.84
	Average	0.9	2.02
Mg^{2+} ($cmol_c$ kg^{-1})	0-20 cm	0.43	0.45
	20-40 cm	0.42	1.10
	Average	0.43	0.78
CEC	0-20 cm	3.57	4.62
	20-40 cm	4.55	7.29
	Average	4.06	5.96

E. *Soil Chemical properties at the end of the Experiments*

Correlation analysis is shown in Table 3:

Table 3. Correlation among growth conditions, irrigation regimes, nitrogen levels, sorghum varieties and soil properties.

Variables	Horizon	T °C	PET	Ir regime	N level	Varieties	pH	N	P	Avail P	K	C	C/N	Ca^{2+}	Mg^{2+}	CEC
Ho	**1**															
T °C	0.000	**1**														
PET	0.000	**0.922**	**1**													
Ir regime	0.000	0.000	0.000	**1**												
N level	0.000	0.000	0.000	0.000	**1**											
Varieties	0.000	0.000	0.000	0.000	0.000	**1**										
pH	**0.184**	0.014	**-0.223**	0.114	**-0.164**	-0.149	**1**									
N	0.079	**-0.263**	**-0.214**	-0.037	-0.037	0.077	-0.044	**1**								
P	-0.010	**-0.283**	**-0.200**	0.150	0.022	0.144	**-0.171**	**0.430**	**1**							
Avail P	0.020	**-0.267**	**-0.347**	0.148	-0.053	**0.161**	**0.247**	0.010	**0.366**	**1**						
K	**0.334**	**0.160**	**0.333**	0.051	-0.005	-0.012	**-0.262**	**0.185**	0.127	**-0.235**	**1**					
C	-0.028	0.108	**0.178**	-0.063	-0.043	**0.200**	-0.123	**0.588**	**0.298**	-0.080	0.127	**1**				
C/N	-0.106	**0.409**	**0.453**	-0.012	0.011	0.133	-0.129	**-0.386**	-0.108	-0.104	-0.024	**0.500**	**1**			
Ca^{2+}	**0.163**	0.039	0.051	0.103	-0.068	0.029	**0.236**	**0.262**	-0.154	**-0.410**	**0.177**	0.137	-0.117	**1**		
Mg^{2+}	**0.190**	0.099	0.123	0.088	**-0.245**	-0.044	**0.259**	**0.405**	0.043	**-0.246**	**0.246**	**0.226**	**-0.165**	**0.702**	**1**	
CEC	0.154	0.127	**0.286**	0.038	-0.012	-0.061	**-0.169**	**0.306**	0.101	**-0.281**	**0.357**	**0.259**	-0.005	**0.451**	**0.523**	**1**

The bold values indicate that the correlation is significant at the 0.05 level (2-tailed test)
Ir: irrigation; PET: potential evapotranspiration; T °C: temperature; Ho: horizon

Apart from the irrigation regimes, soil chemical properties were more or less affected by the current cropping system (Table 3).

No significant effect of irrigation was noted on soil properties. Some studies confirmed this result [28], some others found a positive correlation between irrigation and soil quality [29]. However, other studies reported the unsustainability of irrigation for agricultural soil [30]. These differences among the results could be due to the irrigation practices, water quality, method of application and the nature of soils of the study region.

Temperature significantly affected soil N, P, P available, K and C:N ratio. The correlation also showed a positive impact of temperature on soil K and C:N ratio, whereas N, P and available P were negatively affected by temperature and PET. These results confirmed the findings indicating that the conditions in which sorghum crop is produced can negatively affect the environment including soil fertility itself [1]. The variations in soil chemical properties due to the high temperature (> 38 °C) and other natural stresses in these experiments increase the concerns on the impact of climate change on sorghum production. As temperature is expected to increase over the years, this will affect soil fertility and food security. It would be therefore preferable to crop sorghum in the dry cold condition (under temperature from 19.7 °C to 38.1 °C and the PET of 3 mm day-1) than in hot dry condition (under temperature from 23.9 °C to 41.1 °C and the PET of 7 mm day-1) as this cold dry condition contributed to improve significantly the yield of sorghum compared to the hot dry condition [31]. Using therefore appropriate agricultural practices would be one sure way of reducing the negative impact of climate change [32].

With regards to N fertilization, the results showed a negative significant effect of nitrogen application on soil pH and Mg^{2+} i.e. soil pH and Mg^{2+} decreased. In addition, a slight decrease was observed in the content of the other properties. However, nitrogen is the main determinant nutrient for soil to produce high grain yield [3], [33]. Adequate nitrogen levels were used to improve soil fertility in Kenya and to enhance sorghum yield [4], [5]. In this experiment, the observed decline in soil fertility despite nitrogen fertilization could be explained by the incidence of the drought condition. As a result of the high temperature, the evaporation demand was also high and nitrogen might have evaporated. This situation was not suitable for the environment as had been observed earlier [9]. This result is in accordance with the findings supporting that the continuous use of nitrogen led to soil acidification [11] [12].

Varietal effect positively and significantly correlated with available P and Org C contents according to Table 3.

Variations in the selected chemical properties in plots where *Kapelga* and *Sariaso 14* varieties were sown are shown in Table 4.

Table 4. Soil chemical properties as affected by varietal performance.

Characteristics	Genotypes	Sample1	Dry hot exp.	Sample 2	Dry cold exp.
pH	*Kapelga*	4.63	4.68	5.20	5.22
	Sariaso 14	4.63	4.62	5.20	5.07
P (g kg^{-1})	*Kapelga*	0.11	0.10	0.08	0.10
	Sariaso 14	0.11	0.11	0.08	0.11
P av (mg kg^{-1})	*Kapelga*	5.33	2.23	3.71	4.82
	Sariaso 14	5.33	2.27	3.71	6.00
K (g kg^{-1})	*Kapelga*	0.42	0.48	0.45	0.31
	Sariaso 14	0.42	0.51	0.45	0.31
N (g kg^{-1})	*Kapelga*	0.22	0.23	0.22	0.24
	Sariaso 14	0.22	0.24	0.22	0.26
C (g kg^{-1})	*Kapelga*	3.90	3.76	3.31	3.11
	Sariaso 14	3.90	3.90	3.31	3.65
C:N	*Kapelga*	18.5	16.59	15.5	12.97
	Sariaso 14	18.5	16.42	15.5	14.11
Ca^{2+}(cmol$_c$ kg^{-1})	*Kapelga*	0.9	1.55	2.02	1.40
	Sariaso 14	0.9	1.50	2.02	1.52
Mg^{2+}(cmol$_c$ kg^{-1})	*Kapelga*	0.425	0.70	0.78	0.63
	Sariaso 14	0.425	0.71	0.78	0.63
CEC	*Kapelga*	4.06	5.30	5.96	3.57
	Sariaso 14	4.06	5.21	5.96	3.36

exp.: experiment; sample 1: sample collected before setting the hot dry experiment; sample 2: sample collected before setting the cold dry experiment

This analysis also showed that sowing the genotype *Sariaso 14* in the dry cold experiment might have improved soil available P, Org C, P and N contents. The observed improvement in soil chemical properties and yield in the dry cold experiment underscored the importance with regards to the adoption and use of improved seed varieties and the choice of appropriate time of production [31]. Some findings also reported the positive effect of the use of improved varieties in sorghum production. By using two improved varieties, sorghum yields increased by 3.3667 t ha^{-1} and 2.4733 t ha^{-1} over the local variety [34]. It was also found that growth and yield parameters were better expressed in the improved sorghum variety than with the local variety [35]. In Kenya, it was observed that sorghum variety influenced seed vigour, viability and yield [36]. Cropping therefore of improved varieties is expected to be beneficial to farmers.

IV. CONCLUSION

Cropping sorghum in hot dry condition under a temperature of 41.1°C and PET of 7 mm day^{-1} led to soil fertility depletion at the study site; the high temperature significantly affected negatively soil N, P, and P available. However, cropping sorghum during the cold dry season at 38 °C and PET of 3 mm day^{-1} proved to maintain adequate levels of chemical nutrients in the soil which contributed to the improvement of yield of sorghum. Moreover, the irrigation system adopted was suitable as no negative effect was noted on soil chemical properties. Also, the use of the improved variety *Sariaso 14* enhanced the content of available P, Org C, P and N contents.

ACKNOWLEDGMENT

The lead author is grateful to the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) programme for providing funds for her PhD study. She is also grateful to the staff of the Institute de l' Environment et de Recherches Agricoles (INERA)/ Kamboinse especially to her field assistants and to the laboratory assistant who contributed a lot to the success of the study during data collection and analyses.

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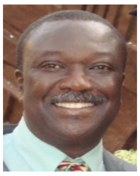
AUTHORS PROFILE'

Pane Jeanne d'Arc Coulibaly, Junior Soil Scientist, INERA/CREAF de Kamoinsé Department of Natural Resources Management and Farming System, E-mail panecoul@yahoo.fr/ Tel: (+226) 71530607/ (+226) 77729799

Badiori Ouattara, Senior Soil scientist (soil Physics), INERA/CREAF de Kamboinsé, Departement of Natural Resources Management and Farming System, email id: alwatdior58@gmail.com



Daniel Okae-Anti Senior Soil Scientist, University of Cape Coast, Ghana, email id: dokaeant@yahoo.co.uk

Jacques Sawadogo, Junior Researcher in Physiocs, Chemistry and Electrochemistry, INERA/ CREAF de Kamboinse, Department of Natural Resources Management and Farming System, email id: jacquischimie@gmail.com

Michel Papaoba Sedogo
Centre National de la Recherche Scientifique et Technologique/Institute de l' Environment et de Recherches Agricoles (CNRST/INERA)/ Ouagadougou- Burkina Faso. email id: michel_sedogo@yahoo.fr