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Review

Prospects of alternative copping systems for salt-affected soils in Ethiopia

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Soil salinization is one of the major constraints in achieving food security and environmental degradation in Ethiopia. Restoration of salt-affected lands into productive lands and protection of newly developed areas from the spread of salinity is therefore of paramount importance. In high salinity areas where technical solutions to soil rehabilitation are expensive and time consuming and growth of normal field crops is restricted, use of bioremediation methods including planting halophytic forages could bring these soils back into production. This paper identifies different causes of salinity and characterizes soils based on severity of salinity levels. The paper suggests that biosaline agriculture is an economical and effective approach to use unproductive lands for growing different food and fodder crops in Ethiopia. This approach, if prudently adapted, can help in improving livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. The paper has recommended many unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crop species. Productivity of marginal lands can be maximized for field crops and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality.

Key words: Soil salinity, halophytes, biosaline agriculture, food security, salt-tolerance, marginal lands.

INTRODUCTION

Ethiopia is heavily reliant on agriculture sector for its overall economic growth and social sector development because it accounts for 40% of the GDP, 80% of the total employment and 70% of the export earnings (African Economic Outlook, 2015). The development of agriculture sector over the last decade has brought food self-sufficiency in the country with grain production reaching up to 27 million tons. This was the result of a strong commitment by the government, which allocated more than 15% of the total budget and introduced effective policies and programs for the development of agriculture sector (Yohannes et al., 2017).

The semi-arid and dry sub-humid agro-ecological zones of the country, which account for nearly 47% of the

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country's 113 million ha, are marginal environments for crop production and are highly vulnerable to droughts and a significant proportion of population continues to rely on food aid and safety net programs (Mekonen, 2007). Major causes of low agricultural productivity in these are declining soil fertility and increasing soil salinity, lack of improved crop varieties and lack of irrigation water. The depletion rate for the major plant nutrients is estimated to be 40, 6.6 and 33.2 $kgha^{-1}year^{-1}$ for N, P and k, respectively (Stoorvogel and Smaling, 1990). Other problems related to lower agricultural productivity are limited choice of crop varieties that are tolerant to soil salinity and water stress (Kidane, 1999). The traditional major crops are sorghum, tef, maize and finger millet and lowland pulses. Grain yields of these crops are generally low and varied in different regions (Getachew, 1986).

Soil salinity is one of the major land degradation problems in Ethiopia. It is estimated that salt-affected lands (salinity and alkalinity) cover a total area of 11 million ha, being the highest in any African country (Fantaw, 2007). Most of these soils are concentrated in the plain lands of arid, semi-arid and desert regions of the Rift valley system including Afar, the Somali lowlands, the Denakil plain and valley bottoms throughout the country (Heluf, 1995; Fantaw, 2007). Most of the export crops such as cotton, sugarcane, citrus fruits, banana and vegetables are being produced in the Rift valley. The development of large-scale irrigation projects in Rift valley in the absence of proper drainage systems for salinity control has resulted in increasing severity and rapid expansion of soil salinity and sodicity problems leading to complete loss of land for crop cultivation in these areas.

Despite this alarming situation, attempts to resolve land degradation problems could not get due attention. With a 3% average population growth, future food security as well as the livelihood source for a considerable portion of the population remains a challenge to the governments. The soil salinity problems in Ethiopia stems from use of poor quality water coupled with the intensive use of soils for irrigation, poor on-farm water management practices and lack of adequate drainage facilities (Gebremeskel et al., 2018). Restoration of salt-affected lands into productive lands and protection of newly developed areas from the spread of salinity through improved irrigation and crop management is therefore of paramount importance. In the high salinity areas where growth of normal field crops is restricted, use of bioremediation methods including planting halophytic forages could bring these soils back into production.

There is also a need to identify best adaptation and mitigation practices for salinity management, increasing farmer incomes and improve livelihood of poor rural communities. This is particularly important for Ethiopia considering their large livestock sector. The financial and technical resources needed to reclaim these soils for crop production are beyond the capacity of smallholder farmers. Therefore, there is every motivation to designate more resources by the government agencies to tackle this problem to ensure future food security and poverty reduction for millions of rural poor. This paper reviews the status and characterization of salt-affected lands in Ethiopia and recommends alternative cropping systems to increase crop productivity and reclamation of these lands.

EXTENT AND CHARACTERIZATION OF SALT-AFFECTED LANDS IN ETHIOPIA

The detailed information on the extent and nature of degraded soils in Ethiopia is either missing or inadequate. The soil classification described by FAO (1984e) is widely used for all practical reasons. According to this classification, the soils in arid and semi-arid areas (typically Regosols, Xerosols and Yeromosols) are less developed; tend to be stony and shallow saline (Solonchaks, Solonetz). The soils in the valley bottoms and flat plains are dominantly Vertisols, while in the undulating to gently rolling plateau, Luvisols, Nitosols and Acrisols soil types are more common. The mountains and tarnished landscapes are known as Leptosols and the major alluvial plains are dominantly Fluvisols and Vertisols with saline and sodic phases.

The arid and semi-arid agro-ecologies which account for nearly 50% of the country's land area are regarded as marginal environments for crop production mainly due to soil and water salinity. Low levels of annual rainfall and high daily temperatures have led to high water evaporation rates and consequently contributed to high concentrations of soluble salts in these lowland areas (Sileshi et al., 2015). In Ethiopia, about 44 million ha (36% of the total land area) is potentially susceptible to salinity problems of which 11 million ha have already been affected by different levels of salinity and mainly concentrated in the Rift valley. Ethiopia ranked as 7th in the world in terms of percentage of the total land area affected with salinity. This has resulted in the degradation of natural habitats, ecosystems and agricultural lands. This has threatened the productivity of irrigated lands, which is producing more than 40% of the total food requirement of the country (Mohammed et al., 2015). A map of Ethiopia is as shown in Figure 1.

The soils of the Melka Sedi-Amibara Plain of the Middle Awash Valley are highly saline with EC_e ranging from 16 to 18 dSm^{-1} (Table 1). Soluble Na^+, Ca^{2+}, Cl^-, and SO_4^{2-} are the dominant soluble salt constituents throughout the depths of the profile. Accordingly, chloride and sulphate salts of sodium and calcium (mainly NaCl and $CaSO_4$) are assumed to be the major soluble salts contributing to the very high salinity level of these soils (Auge et al., 2018).

The high salinity and sodicity levels are due to poor drainage conditions in most of the valley. In the Middle

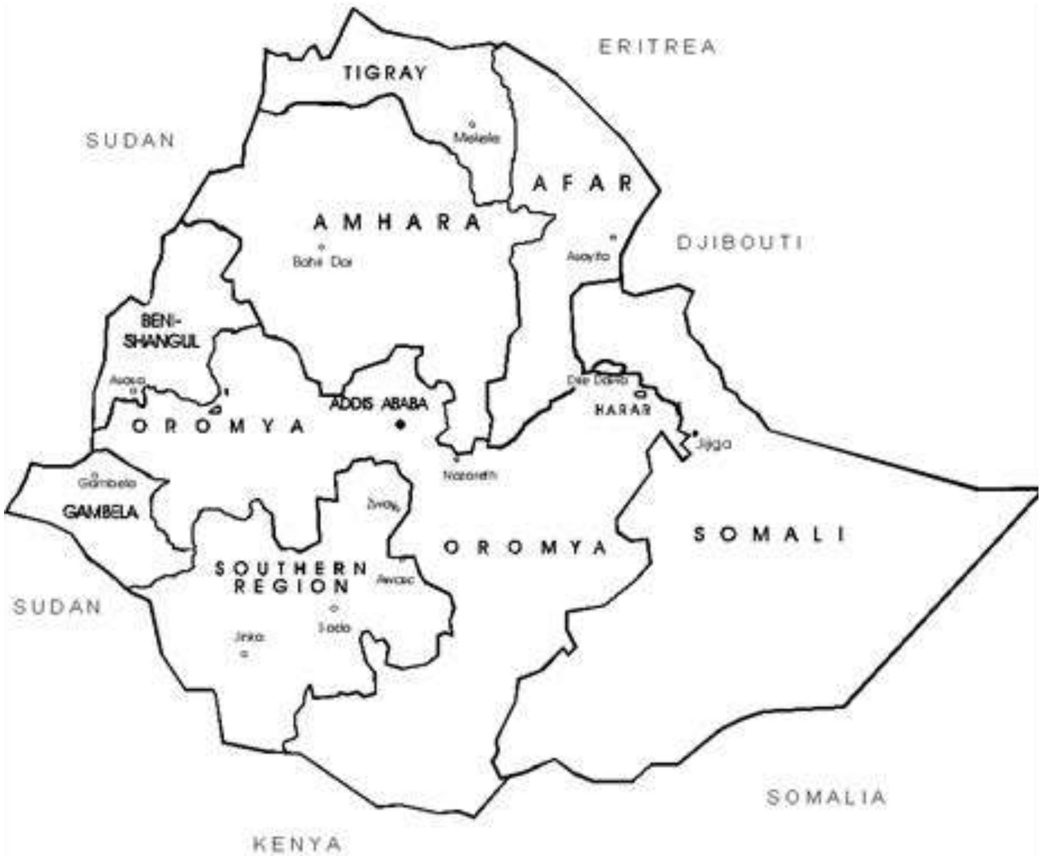

Figure 1. Map of Ethiopia with regional boundaries.

Table 1. Chemical composition of soil profile of Melka Sedi-Amibara Plain of the Middle Awash valley.

Depth (cm)	pH H_2O	EC (dS/m)	Soluble cations (me l^{-1})				SAR	Soluble anions (me l^{-1})			
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0-25	7.2	18.6	59.4	3.7	208.1	15.4	37.0	Nil	1.1	165.8	77.1
25-50	7.2	17.8	55.5	3.3	197.6	14.4	36.4	Nil	1.0	160.2	71.8
50-70	7.2	17.5	53.1	3.7	197.5	14.1	37.0	Nil	1.0	157.0	68.5
70-90	7.2	17.2	51.5	3.4	120.0	13.7	22.9	Nil	1.4	147.0	64.3
90-120	7.2	16.6	47.3	3.1	132.5	10.6	26.4	Nil	1.0	132.4	59.9

Awash Valley of the Rift Valley System, the large state-owned irrigated farms are also fast going out of production due to increasing soil salinity (Fantaw, 2007). The problems of soil salinity are more pronounced in the irrigated areas. The increasing salinity problems in arid and semi-arid regions of Ethiopia have also caused physically and chemically degradation of irrigated lands due to compaction and structural breakdown.

According to the recent estimates, about 80% of Dubti/Tendaho State farm is affected by soil salinity (that is, 27% saline, 29% saline sodic and 24% sodic soils). The historical trend shows that the extent of salt-affected soils has increased significantly from 1972 to 2014 due to different reasons such as poor irrigation practices, use of poor quality irrigation water and lack of drainage facilities. Sardo (2005) has revealed that increase in groundwater levels due to excessive irrigation has caused salinity development in these soils. In irrigated areas of arid and semi-arid regions, the ascending motion of capillary water is generally greater than the descending motion and it facilitates the buildup of salt in soil profiles due to the large evapotranspiration rates. The changes in the area affected by soil salinity from 1972 to 2014 at Dubti/Tendaho State farm are shown in Table 2.

Table 2. Temporal changes in the area affected by soil salinity at Dubti/Tendaho state farm.

Salinity level	1972		1994		2014	
	Area (ha)	Change (%)	Area (ha)	Change (%)	Area (ha)	Change (%)
Normal soil	3783	35	2930	27	2189	20
Saline-Sodic	2178	20	2423	23	3154	29
Saline	4035	37	4138	38	2929	27
Sodic	797	8	1302	12	2521	24
Total	10,793	100	10,793	100	10,793	100

CAUSES AND EFFECTS OF SOIL SALINITY DEVELOPMENT IN ETHIOPIA

In the saline lands of Ethiopia, agricultural production is increasingly faced with environmental constraints resulting in reduced crop productivity. The variation in crop production in different salinity prone areas is linked to the changes in local environmental, socio-economic and edaphic conditions. Major factors causing salinity development in Ethiopia are summarized in the following.

Water shortage for irrigation

Salt-affected lands in Ethiopia are mainly located in arid, semi-arid and lowland dry areas (60% of total land area of the country), where rainfall is neither sufficient nor reliable for sustainable crop production. In these areas, irrigation is necessary for stabilizing agricultural production. In many areas, farmers used to develop flood-based farming systems, also called as spate irrigation. Spate irrigation is beneficial in mountain catchment border lowlands, where farmers can make use of short duration floods. However, as water comes often either long before or late after the cropping season, crop productivity is severely affected. The success of spate irrigation depends on availability of good infrastructure and cooperation of farmers. Based on the review of the spate irrigation systems in Tigray region, Van Steenbergen et al. (2011) listed the following problems with the spate irrigation.

(1) Upstream and downstream users do not share the flood flow equitably;
(2) Technical faults in developing local diversion canals generate changes in the river course;
(3) Improper secondary and tertiary canals leading to in-field scour and creation of gullies in the fields - which reduces available soil moisture.

In the arid lowlands of the country, the option of conventional irrigation is limited to the few perennial rivers, which are in most cases heavily challenged. Other forms of irrigation such as based on temporary flows and floods, have more potential but are not fully developed. In parts of the lowlands there is a considerable groundwater potential, but it is challenging to exploit this for irrigation due to its existence at deeper depths and lack of drilling facilities.

Declining irrigation water quality

The increasing demand of water for domestic and industrial uses has put enormous pressure on agriculture sector to decrease its share of good quality water use. The hot and dry climates of saline areas require that the irrigation water does not contain soluble salts in amounts that are harmful to the plants or have an adverse effect on the soil properties. Studies done to evaluate the impact of irrigation on soil salinity and crop production in Gergera Watershed, Atsbi-Wonberta, Tigray, Northern Ethiopia have shown potential risk of soil sodification due to the use of surface water for irrigation and suggested the need for adopting alternative water and crop management practices for sustaining crop productivity in these areas (Yeshitela et al., 2012).

Soils of Central Rift valley are naturally sodic in the subsurface horizons and the use of marginal quality groundwater for irrigation has exacerbated the salinity problems. In North Shewa, the widely irrigated areas of the zone are the lowlands of Kewet and Efratana Gidim are also facing growing threats of soil salinity especially in small-scale irrigated farms (Tilaye and Mekonen, 2002). Development of soil salinity in this area is often associated to the use of poor quality water for irrigation from dug wells during the dry season when fresh water availability from the river is not sufficient to meet irrigation demand. The quality of these wells is only marginally fit for irrigation (Yonas, 2005).

Deterioration of water quality along major river streams of the Awash River is also becoming an important ecological concern because water from this river is extensively used for more than 3000 hectares of farm land along the River Basin (EIAR Annual Report, 2015).

Figure 2 shows spatial trend of Awash River water quality at different diversion weir and pump sites along the stream flow. The water quality is deteriorated as we move from upper to lower river streams due to increase in salt concentration over time (Figure 3). This means that the

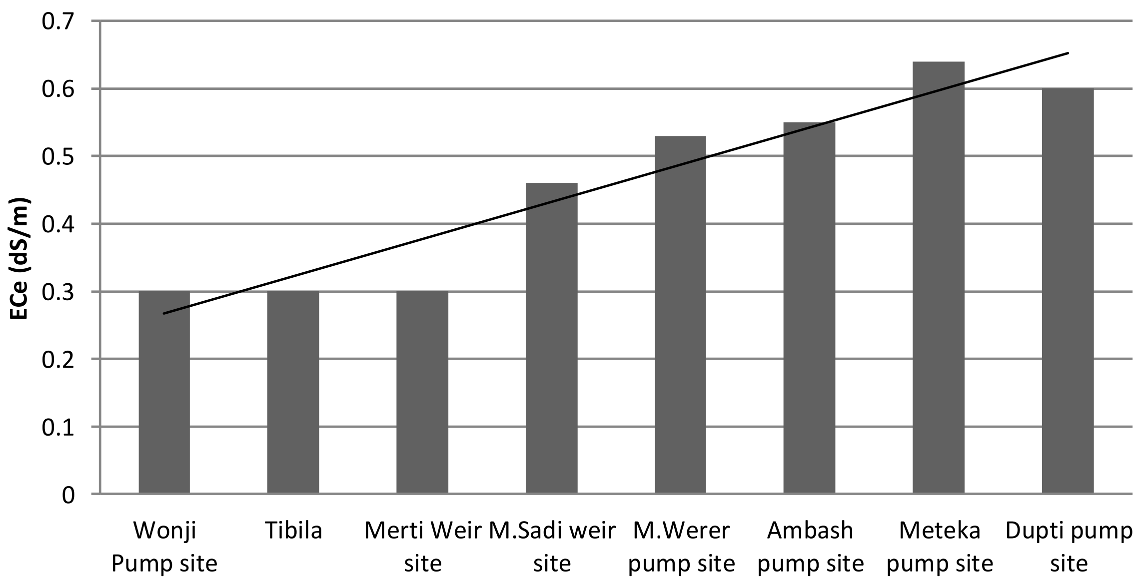

Figure 2. Trends in surface water quality along the Awash River (from upper to lower stream).

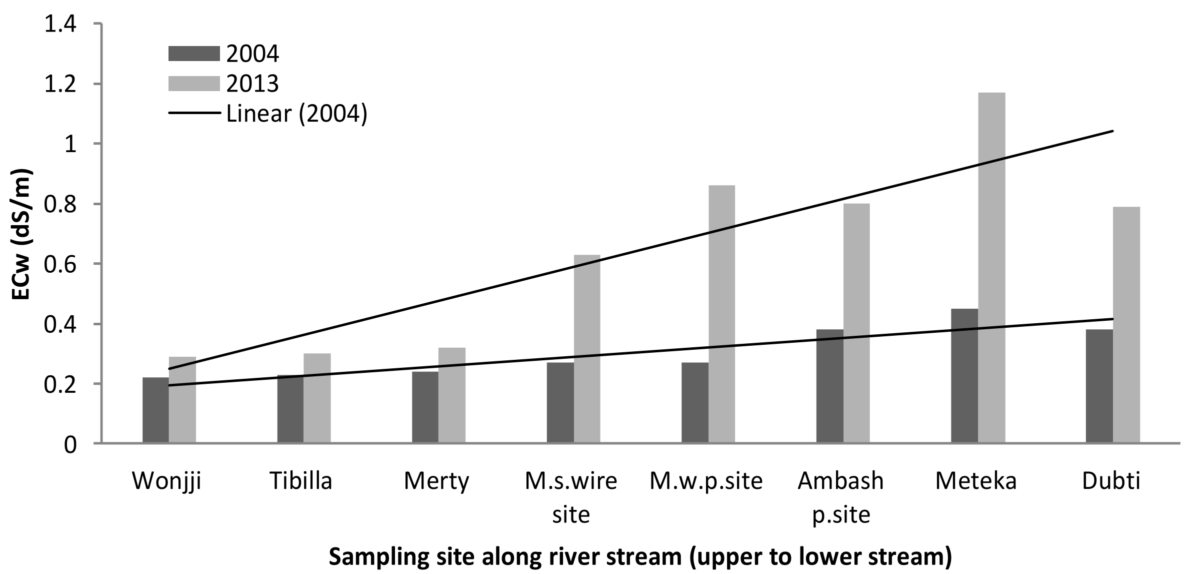

Figure 3. Changes in Awash River water quality from 2004 to 2013.

suitability of Awash River water for irrigation at down streams is continuously deteriorating, which may cause further soil degradation in future.

Waterlogging and soil salinization problems

Salinity problems are increasing in the irrigated areas of arid and semi-arid lowlands of Ethiopia, which is causing huge social (that is, migration and diseases) and economic problems (reduction in crop production and increase in poverty) for the country. Farmers are increasingly abandoning part of their farms in irrigation schemes due to rising salinity problems. This problem is more acute in arid and semi-arid regions, where salinity strongly limits crop development. In many parts of the country, high salinity and sodicity levels from increasing groundwater levels are threatening the sustainability of irrigated agriculture (Kidane et al., 2003). Increasing secondary salinization and alkalization is preventing farmers to bring more area under cultivation in these arid and semi-arid regions of the country.

Waterlogging and salinity problems have aggravated due to poor drainage facilities and on-farm water management practices that have caused excessive seepage of irrigation water resulting in elevated groundwater levels. The combined effect of waterlogging, salinity and sodicity has emerged as the major constraint for crop production in Zeway Dugda around Lake Zeway, farms around Gerjele and Tumuga swampy area, irrigated farm areas of Abaya and Arbaminch, etc. Due to this situation, many farms in these areas have gone out of production leading to increased migration, declining farm incomes and poor living standards. Therefore, for environmentally and socially sustainable development and to produce enough food for the rising population, there is a strong need to bring these salt-affected lands back to their production potential.

POTENTIAL ALTERNATIVE CROPS FOR MARGINALIZED ENVIRONMENTS IN ETHIOPIA

The limited capacity of rainfed agriculture to sustain crop production due to erratic nature of the rainfall has persuaded farmers to look for alternative ways of improving the availability of food (Tesfaye and Fassil, 2011). Due to increasing soil salinity, per capita land availability has reduced to 0.2 ha in Ethiopia (Spielman et al., 2011). Abiotic stresses such as water scarcity, temperature extremes, waterlogging, salinity, and increasing marginality of production systems are the major constraints to enhance productivity at the farm level, resulting in food and nutrition insecurity in many arid and semi-arid regions of the country. Since new agricultural land will be scarce, increasing food production will require utilization of marginal land and water resources.

With a 3% average population growth in Ethiopia, future food security as well as the livelihood source for a significant proportion of the population will remain a challenge to the governments (Ringheim et al., 2009). Increasing the productivity of existing salt-affected lands and protecting newly developed areas from the spread of salinity is therefore of paramount importance. The smallholder farmers in Ethiopia have the potential to increase their agricultural productivity and farm incomes if they get proper guidance on the improved irrigation and salinity management strategies and access to modified salinity-tolerant seeds for crops and forages. Therefore, for millions of farm families in Ethiopia, access to improved knowledge and inputs will be a dividing line between poverty and prosperity.

Saline and sodic soils are marginally productive for commonly grown food crops. Therefore, for sustainable agricultural production, new agricultural practices and cropping systems should be adopted considering changing environmental conditions. One of the approaches for this purpose is to investigate and include in the cropping system plant species which can tolerate abiotic stresses. Moreover, the competition for fresh water resources will increase in future due to increasing demand from domestic and industrial sectors, leaving agriculture to use low-quality water with adverse effects on agricultural productivity as most of the commonly cultivated crops are salt-sensitive. In this scenario, diversification of production systems based on more salt and water tolerant crops could be an important strategy to sustain agricultural productivity and increase economic returns at the farm level. The potential alternative crops that can be used in salt-affected lands of Ethiopia are summarized in the following.

Salt tolerant field crops

Crop plants differ a great deal in their ability to survive and yield satisfactorily when grown in saline soils. Information on the relative tolerance of crops to a soil environment is of practical importance in planning cropping patterns for optimum returns. The areas of low to moderate salinity levels can be restored by introducing improved irrigation and crop management practices. However, in areas where increased salinity levels have restricted the growth of normal field crops, use of Biosaline approach could be a potential solution. This approach is based on adaptable technology packages composed of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems (on-farm irrigation, soil fertility, etc). These integrated crop and forage-livestock feeding systems have the capacity to increase resilience of small scale crop-livestock farms, particularly in Ethiopia where livelihood of smallholder farmers is largely dependent on the development of livestock sector. Biological approach is one of the easiest approaches of reclamation and management of salt-affected soil; especially for small farmers who do not have the resources to implement costlier corrective measures. The judicious selection of salt-tolerant crops that can grow satisfactorily under moderately to highly saline or sodic soil conditions has merit in most cases.

Barley (*Hordeum vulgare* L.), sorghum, wheat, mustard and oilseeds (safflower and sunflower) are among economically important crops with diverse genetic diversity for better adaptation under saline soil conditions. Barley is among cereal crops widely grown in high land areas of Ethiopia and currently it is about to expand to mid altitude areas as well. Even though barley, among commonly grown cereal crops, has been well described for its potential ability to tolerate stress induced by salinity, its introduction and potential use under marginal environment is not common in the country. For instance, farmers at Zeway Dugda area in Ethiopia used to grow barley instead of maize and other horticultural crops when the soil is getting more salinized.

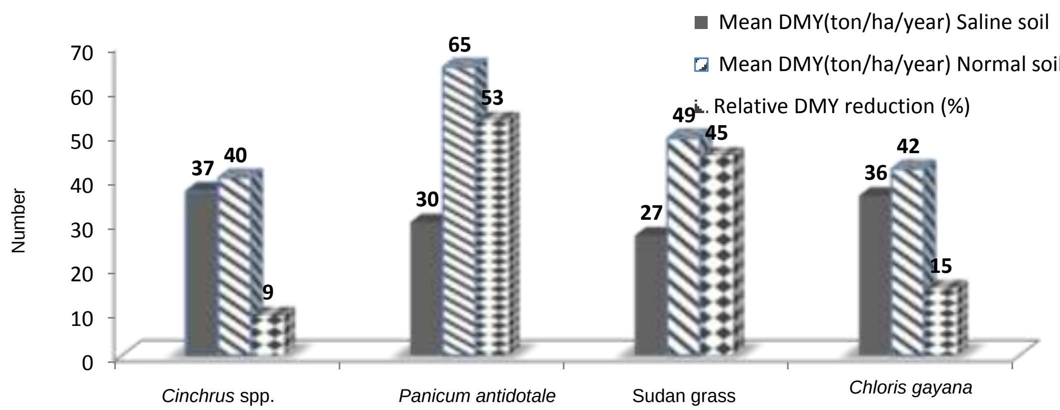

Figure 4. Comparison of mean dry matter yield for different grass species under saline and normal soil conditions.

Existence of genetic variation for salinity stress tolerance among different barley genotypes is well documented in which possibility of improvement of salinity tolerance in barley attains bright future for its wider use potential as alternative crop under salt affected soils. Result from pot trials have shown the potential ability of some sunflower cultivars to high salinity stress level of 19 dS/m with 50% decrease in growth. Safflower is among important multi-purpose oilseed crops with great potential as source of edible oil and feed source. From field plot trials conducted over two seasons to evaluate salinity tolerance of among 52 genotypes using irrigation water of different qualities, it was found that safflower is moderately salt-tolerant and cultivation on salt-affected lands can prove beneficial to farmers (ICBA, 2014)

Prospects for improving salt tolerance in barley, wheat, sorghum and oilseed include, among others, the use of intra-specific variation and screen out resistant varieties that suits to saline areas. Ethiopia being a country of center of origin of barley and wide genetic diversity for sorghum and some oilseed crops have potential for identification of genotype among available gen pool and introduction into cropping system that best suit to salinity stress condition as an alternative to less salinity tolerant crops.

Salt tolerant legumes and forage grasses

Under high saline soil conditions, planting salt-tolerant forage grasses and legume crops is more practical. Field and greenhouse studies have shown that Karnal grass (*Diplachne fusca*), Rhodes grass (*Chloris gayana*), Para grass (*Brachiaria mutica*) and Bermuda grass (*Cynodon dactylon*) are highly salt-tolerant and can be successfully grown in saline and sodic soils. Karnal grass grows extremely well in highly sodic soils (ESP = 80) even when no amendments are applied. In Pakistan, dry matter yields of 7.5 tons per hectare have been reported (Chang et al., 1994). In trials of the performance of a range of summer grasses on saline soils in Saudi Arabia, Rhodes grass yielded 8.9 tons of dry matter per hectare in 188 days; this was more than double the yield of any other tested species (Rozema, 2013).

Studies done by Werer Agricultural Research Centre in Ethiopia during 2011-2014 have shown promising results in terms of salinity tolerance, biomass yield and ameliorative effects for four forage crop species, that is, *Cinchrus* species, *Panicum antidotale*, Sudan grass and *C. gayana* and 3 legume species *Desmodium triflorum, Sesbania sesban* and *Medicago sativa* (Alfalfa). Salt stress levels under which *Cinchrus* spp., *P. antidotale,* Sudan grass and *Chloris gayana* were subjected to contain mean EC_e values of 8.2, 10.4, 12.7 and 17.9 dS/m, respectively. The biomass yields obtained under saline soil conditions were closely comparable with that obtained under normal soil condition (Figure 4) (EIAR annual report, 2016). Under saline stress condition *C. gayana* (Rhodes grass) gave the highest mean fresh biomass yield (127 tons/ha/year), closely followed by *Cinchrus* spp. (118 ton/ha/year). Dry matter yield obtained under saline soil was also higher in *C. gayana* (36 tons/ha/year) and *Cinchrus* spp. (37 tons/ha/year) than both *P. antidotale* (30 tons/ha/year) and Sudan grass (27 tons/ha/year).

Under Ethiopian conditions, effect of salinity stress was less pronounced in *C. gayana* and *Cinchrus* spp. The dry matter forage yield reductions under saline conditions were only 15 and 9%, respectively. However, dry matter yield reduction of *P. antidotale* and Sudan grass under saline conditions was found to be 53 and 45%, respectively. Therefore, for Ethiopian salt-affected areas, *C. gayana* is the most suitable salt-tolerant forage crop as compared to other grass species. These results confirm earlier findings of Deifel et al. (2006) who indicated *C. gayana* as the most salt-tolerant forage grass. In the salt-affected lands of United Arab Emirates, high dry matter yields of *C. gayana* (Rhodes grass) have also been achieved by applying irrigation water up to 23 dS/m (ICBA, 2014).

The growth of these salt-affected grasses also results in remarkable improvement in soil quality. Soil salinity generally decreased markedly in all grass treatments from a mean ECe value of 12.3 to 3.7 dS/m in upper 0-30 cm soil layer. Rhodes grass (*C. gayana*) and Blue panic (*P. antidotale*) were reported as promising grasses for sodic soils (Akhter et al., 2003*).* There was also an improvement in soil pH and bulk density characters resulting from growing of salt tolerant grass species. Thus, growing salt-tolerant grasses will not only provide much needed forage but also improve the soils resulting in increased absorption of rain water, reduced runoff and soil losses due to erosion.

Cultivation of salt-tolerant grasses also helps in restoring soil structure and permeability through penetration of their roots and increased solubility of native-soil $CaCO_3$, resulting in enhanced leaching of salts. In addition to buildup of biomass, their cultivation and growth can improve the water retention and infiltration characteristics of saline soils because of root penetration and root decay to loosen the otherwise compacted soil. The net result is enhanced leaching of salts to deeper layers and decreased salt concentration in the upper soil layers of the soil profile. This increases the potential of reclamation of salt-affected lands.

Among the tested forage legume species *Susbania susban* has been shown to have excellent potential for its salinity and moisture stress tolerance and remarkable biomass yield. *Susbania,* in addition to its tolerance to salinity requires less water to grow and have a wide range of uses such as feed and fire wood. This makes it promising candidate for legume forage production system and economic use of marginal quality soil and water resources. Alfalfa has also shown proved salinity tolerance with remarkable biomass yield. Alfalfa because of its salinity tolerance, high water use with deep-rooted system would be best alternative crop for the areas where salinity and canal seepage losses are a problem. Both forage and legume crops gave economically reasonable biomass yield indicating their ability to tolerate high level of soil salinity under which no yield is expected from cultivating other field crops.

Bio-drainage to control waterlogging

The recent emphasis on additional sources of energy has demanded that a sizeable fraction of available land resources be diverted to forestry. Due to increasing competition for good land to grow food crops, use of marginal lands for tree plantation is desirable. Plant species such as *Eucalyptus hybrid*, *Prosopis juliflora* and *Acacia nilotica* can successfully be grown on salt-affected soils by creating favorable conditions for seed germination. All major irrigation schemes in Ethiopia face problems of waterlogging and soil salinity which can partly be tackled by planting trees. The excessive use of water by these trees can help control groundwater table rise to the critical depth, where it can harm the crop growth (Qureshi, 2016). However, this would require that the annual rate of discharge is equal or exceeds the rate of recharge to groundwater. The tree plantation for bio-drainage is suitable where engineering approaches to control groundwater table are not feasible due to economic and technical reasons. The tree plantation for bio-drainage also provides additional economic benefits for farmers.

In the desert area of Rajasthan, India, this technique has successfully been used for lowering groundwater table. The annual evapotranspiration from tree plantations (eucalyptus) with a density of 1900 trees/ha was estimated to be 3446 mm (Dagar, 2009). The annual water use of eucalyptus forest was found to be two times higher than that of agricultural crop such as finger millet. Calder et al. (1994) have also found that fully developed plants like *Eucalyptus camaldulensis*, *A. nilotica*, and *Prosopis cineraria*, with a tree density of 1100 trees/ha or more can be expected to transpire water in a year equal to annual Class A Pan evaporation.

Conversion of marginal lands, that produces low yields or have been abandoned from cropping, to tree plantation is a feasible option because it produces economic benefits for farmers and does not compete with the food crop production. The advantages of bio-drainage as an eco-friendly technique for combating waterlogging and salinity are cost-effective strategies as compared to the expensive conventional drainage systems (Qureshi, 2017). However, to make it attractive for farmers, long-term objectives need to be combined with short term incentives.

Halophytes plantation for highly salt-affected lands

The increasing pressure on land and water resources makes it necessary to make better use of available fresh water resources and to expand agriculture in non-traditional areas where extreme soil and water conditions exist. Under extreme conditions of soil or water salinities where normal agricultural crops cannot be grown, dedicated halophyte plantations for forage production can be practiced. Halophyte plantation may help in rehabilitation of saline lands, landscaping, bioenergy generation, carbon dioxide sequestering and many other useful purposes (Sardo, 2005). The presence of halophytes has long been recognized, however much of the scientific work has been carried out during the last four decades, which has demonstrated unsuspected value of halophytes (Michalk et al., 2013).

Because of their diversity, halophytes have been tested as vegetable, forage and oilseed crops in agronomic field trials. The oilseed halophyte, *Salicornia bigelovii*, yields 2 tons/ha of seed containing 28% oil and 31% protein, like soybean yield and seed quality (Girma et al., 2007).

Halophytic forage and seed products can replace conventional ingredients in animal feeding systems, with some restrictions on their use due to partially high salt content and antinutritional compounds present in some species (Khan and Duke, 2009).

The facultative halophytic species such as Quinoa, with a high protein content and unique amino acid composition can successfully be cultivated in saline lands. Quinoa (*Chenopodium quinoa* Willd.) is an edible seed species of the family Chenopodeaceae, which originates from the Andean region of South America, and has dietary importance due to its richness in proteins, fiber and fat, and gluten free characteristics. Quinoa has considerable resistance to several important stresses including drought, frost and high soil salt content. In recent years, quinoa has received worldwide attention as a multi-purpose agro-industrial crop that can thrive in marginal environments characterized by poor soils and poor-quality irrigation water (ICBA, 2014).

Timothy et al. (2015) suggests that selecting plants tolerant to salinity is an alternative strategy for a sustainable agriculture in saline degraded soil lands. Meanwhile, soil reclamation could be done using bioremediation method through planting halophyte plant which can absorb salt from soil and utilize these plants as fodder. According to Khan and Duke (2001), the use of halophytic plants in pasture and fodder production on saline soils is the best economically feasible solution.

Studies conducted by ICBA (2014) have shown that high salinity tolerance ability of Atriplex makes it useful for use as feed source bioremediation to improve soil salinity. Their finding also indicates that soil salinity was improved by 40% under Atriplex treatment for one-year experiment. ICBA (2014) has also successfully investigated the benefits of growing Atriplex for feed production in highly salt-affected areas and valued as a high-protein animal feed.

In Ethiopia, there is wide area of barren and abandoned marginal lands that are commonly believed useless; on the contrary, a huge research and activity in the last decades has demonstrated their unsuspected value. Research is in progress in Ethiopia with the major aim of collecting and evaluating the potential of local halophytes for wide economic use in arid and semiarid regions in the light of the progressive shortage of fresh water resources and expanding soil salinization. Collection of halophytes made during 2016 from limited salt affected farm area of Middle Awash in Ethiopia indicates widely distributed halophyte species which is of interest because of existence of potential possibility for different economic uses under such environmental stress condition.

CONCLUSION AND FUTURE PERSPECTIVES

This paper suggests that biosaline agriculture is an economical and effective approach to use unproductive lands for growing different food and fodder crops in Ethiopia. This approach, if prudently adapted, can help in improving livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. This discussion reveals that there is an abundant unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crop species. Through proper identification of field crop and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality, productivity of marginal lands can be maximized. In Ethiopia, this approach is of special importance because of the following reasons:

(1) Pressing shortage of livestock feed is among major reasons claimed for low productivity gains from this sector. Forage production under saline soil conditions without competition of other farm land for field crops is important for Ethiopia to increase the productivity of livestock sector particularly for pastoral and agro-pastoral communities in the moisture stress dry regions. The aforementioned alternative crops, in addition to their tolerance to salinity and ameliorative effect, require less input to produce which make them promising candidates for the diversification of production system and economic use of marginal quality soil and water resources.

(2) Irrigated agriculture in Ethiopia faces the problems of waterlogging and soil salinization. Engineering solutions to overcome these problems are expensive and technically complex and often cause water pollution and environmental degradation. Therefore, bio-drainage can be a viable option to control the rising groundwater table above critical depth for crop growth. Exploring the possibility of bio-drainage for waterlogged saline lands through the plantation of salt tolerant trees can reduce the volume and cost of drainage.

(3) In Ethiopia, large tracts of agricultural lands have become barren and abandoned due to poor soil and water quality conditions. Since growth of normal crops in these areas has become difficult due to increasing soil salinity, plantation of halophytes can be a viable solution to produce food, fuel, fodder, fiber, essential oils, and medicine. At the same time, halophytes can be exploited as significant and major plant species bearing potential capability of desalination and restoration of saline soils through phytoremediation. By adopting these strategies, unused and marginal lands can be brought under cultivation to improve livelihood of poor rural communities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of organic fertilizer (NPK 5-9-19) and mineral (NPK 12-11-18) on soil chemical properties in tomato crop in the South and Mid-west of the Ivory Coast

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A study on mineral and organic liquid fertilizer was carried out in the South and Central West of Ivory Coast during a period of two years in order to improve soil fertility in tomato crop. More specifically, it evaluated the effects of 4 doses of organic fertilizer (NPK 5-9-19), associated or not with mineral fertilizer (NPK 12-11-18) on the content of soil organic matter, C/N ratio, the sum of exchangeable bases, available phosphorus, CEC and pH. The experimental design was a split-plot, with four repetitions with mineral fertilizer as the primary factor, and organic fertilizer as secondary factor, at 4 doses (Lha^{-1}): C0 = 0 (control), C1 = 2 5; C2 = C3 = 3.75; and 5. The results showed that 3.75 Lha^{-1} of fertilizer organic (NPK 5-9-19), associated with the low dose of mineral fertilizer (NPK 12-11-18) had the best positive impact on organic matter, sum of exchangeable bases, and available soil phosphorus. The treatment with 3.75 Lha^{-1} of organic fertilizer alone increased more CEC and soil pH while the contributions of 2.5 and 3.75 Lha^{-1} had the advantage of increased C/N ratio of the soil.

Key words: Organic fertilizers, mineral fertilizers, chemical property, fertility, soil.

INTRODUCTION

The culture of the tomato constitutes a gainful employment for many producers. Its production worldwide was estimated at 117,000 tons in 2016 with an average output of 37 tha^{-1} (FAOSTAT, 2016). In Ivory Coast, the total production is of 52,000 tons and the average output is 10 Tha^{-1} (Minagra, 1993). This poor yield is due to many constraints with which this culture is confronted. Those are, inter alia, land pressure, poor of the soil nutritive elements and high cost of mineral fertilizers (Asogba et al., 2007), to the diseases pressure

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Table 1. Chemical characteristics of the liquid organic fertilizer.

pH	C/N	Content of biogenic salts (%)					
		C	N	P	K	Ca	Mg
5.9	13	59.8	4.6	8.5	18.99	5.73	0.40

and insects which devastate the cultures (Soro et al., 2015). Many producers make more and more use of liquid organic fertilization due to these constraints (William et al., 2004; Yorinori et al., 2004). These producers act thus, in the direction of improving the soil fertility and allowing a better availability of the soil nutrients for the plant, in order to guarantee a better productivity. The work of Zaoui and Brun (2011) showed that fertilization with liquid fertilizers increased in a clear way, the effectiveness of the fertilization of soils which are difficult to work. Research on liquid organic fertilizers used in tomato culture showed an increase amount fruit by seedling (Chambre of Agriculture of Rhône-Alpes, 2016). The present study aims to determine which amount of liquid organic fertilizer (NPK5-9-19) associated or not with mineral fertilizer (NPK12-11-18) would improve the most, the chemical properties of the soil for a better availability of biogenic salts for the plant and to increase production. This will allow the recommendations of an effective and rational use of organic manure near by the users.

MATERIALS AND METHODS

Study site

The study was performed at two sites (Bimbresso and Bouaflé) from July to November for two years. These sites are characterized to a warm and humid climate, with loose soil, well-drained and sandy in texture-clayey silt. The site of Bimbresso (4° 10 'W, 5° 30' N) is located in the south of Ivory Coast between Abidjan and Dabou. The precipitations were of 819.82 and 560.10 mm, respectively in 2010 and 2011. Average minimum and maximum temperatures were of 23.86 and 30.08°C and 23.76 and 29.74°C, respectively in 2010 and 2011 during the test period. The soil was very acidic (4.7 pH ≤ 4 ≤ in 2010 and 4 ≤ pH ≤ 4.9 in 2011). The site of Bouaflé (5° 75'W, 7° N) is located in the transition zone between the dense forest and savanna in the center, west of Ivory Coast. It had 556.22 and 376.73 mm of rainfall in 2010 and 2011, respectively, and a temperature average between 22.1 and 31.6°C in 2010 and between 20.96 and 31.56°C in 2011, during the test. At this site, the soil was slightly acidic (pH ≤ 5.6 ≤ 6 in 2010 and 5.4 ≤ pH ≤ 6.1 in 2011).

Soil sampling

Before planting, a morphological and chemical characterization of soils in each study site was done. This was to set “toposéquences” on which soil pits were opened at 25 m intervals. Thus, a pit was opened on each site, at the top of slope, mid-slope and down slope making a total of three pits 1 m deep. Surveys using an auger were also made. A detailed description of the pits was then made in order to have an idea of the soil fertility status before cultivation. Soil samples 0 to 40 cm were collected to be analyzed in laboratory. Finally, the cultivation was set up, according to the experimental design in Split-plot. At the end of each experiment (2010 and 2011), soil samples of 0 to 40 cm were also taken with an auger from different treatments and analyzed to determine the physical and chemical properties of the soil. These samples were used to assess treatment effects of the four doses of organic fertilizer, with or without mineral fertilizers on soil fertility.

Measured parameters

Soil tests focused on the content of soil organic matter, C/N ratio, and sum of exchangeable bases, available phosphorus and pH. Analyses were made in the laboratory of soil and plants in Yamoussoukro (Ivory Coast). Organic carbon was determined using the method of Walkley and Black (1934) used by ORSTOM (1970). The soil was submitted to an oxidation with a bichromate standard solution of K in excess ($K_2Cr_2O_7N$) at the presence of sulfuric acid. Dichromate K transforms the soil carbon in CO_2. The reduction of the amount of bichromate is proportional to the carbon content. The organic matter (MO) of the soil was calculated as follows: % MO = % C × 1.72 for organic agricultural soils. The dosage of total N was made by the Kjeldahl method (1965), including two phases, namely the mineralization which converts all forms of nitrogen substrate ammonia N and the dosage which consist of a distillation of an aliquot of the mineral deposit, introduced into a Kjeldahl flask at the presence of 10 N NaOH.

Exchangeable bases were measured according to the method of Anderson (1993). Cations were displaced absorbent complex with a silver thio-urea solution [$Ag(H_2NCSNH2)_2^{+2}$]. Available phosphorus was determined by the method modified by Dabin Olsen (1967) using ammonium fluoride (0.03 N) and hydrochloric acid (0.025 N) as the extraction solution. Finally, soil pH_{water} was measured on a suspension by the electrometric method pH-meter glass electrode.

Experimental design

Experiments were done following a split-plot design with four repetitions. The main factor and secondary factor were respectively the mineral fertilizer and organic fertilizer. In 2010, the mineral factor had two levels of fertilization. There was F0 = control (without fertilizer) and F1 = 400 kg.ha^{-1} of NPK 12-11-18 (recommended dose of fertilizer). This dose 400 kg.ha^{-1} of NPK 12-11-18 was brought into two doses of 200 kg.ha^{-1} and supplied the 7 and 37th days after tomato plants transplanting. As F1, 200 kg ha^{-1} Nitrabore (15.5% (N), 26.5% (CaO) + 0.2% B) was supplied into two doses of 100 kg.ha^{-1}. First and secondary supply were made, respectively by the 47 and 62th days after tomato plants transplanting. In 2011, the main factor had 3 levels of fertilization. There were F0 = control, F1 and F2 = ½ F1. During the two years of experimentation, the dose of secondary factor did not changed. There were 4 doses: C0 = control (without fertilizer), C1 = 2.5 L.ha^{-1}, C2 = 3.75 L.ha^{-1} and C3 = 5 L.ha^{-1}. Every 15 days, these doses were supplied.

The different chemical characteristics of the liquid fertilizer are shown in Table 1. 2010 had a factorial combination of two factors in

Table 2. Identification of the differnt treatments used.

Treatment	Dose of mineral fertilizer (kg ha^{-1}) : (F)	Dose of mineral fertilizer (%) : (F)	Dose of organic fertilizer (L ha^{-1}) : (C)	Code
T0 (Control)	0	0	0	F0C0
T1	0	0	2.5	F0C1
T2	0	0	3.75	F0C2
T3	0	0	5	F0C3
T4	400 (NPK) + 200 Nitrabore	100	0	F1C0
T5	400 (NPK) + 200 Nitrabore	100	2.5	F1C1
T6	400 (NPK) + 200 Nitrabore	100	3.75	F1C2
T7	400 (NPK) + 200 Nitrabore	100	5	F1C3
T8	200 (NPK) + 100 Nitrabore	50	0	F2C0
T9	200 (NPK) + 100 Nitrabore	50	2.5	F2C1
T10	200 (NPK) + 100 Nitrabore	50	3.75	F2C2
T11	200 (NPK) + 100 Nitrabore	50	5	F2C3

T0 (control : 0% M.f. dose and O.f.); T1 (0% M.f.+ 2.5 Lha^{-1} O.f.); T2 (0% M. f. + 3.75 Lha^{-1} O.f.); T3 (0% M. f. + 5 Lha^{-1} O.f.); T4 (100% M. f. + 0 Lha^{-1} O. f.); T5 (100% M.f.+ 2.5. Lha^{-1} O. f.); T6 (100% M. f. + 3.75 Lha^{-1} O.f.); T7 (100% M. f. + 5 Lha^{-1} O.f.); T8 (50% M. f + 0 Lha^{-1} O.f.); T9 (50% M. f. + 2.5 Lha^{-1} O. f.); T10 (50% M. f. + 3.75 Lha^{-1} O. f.); T11 (50% M. f. + 5 Lha^{-1} O. f.). M. f.: Mineral fertilizer; O. f.: Organic fertilizer.

with 8 treatments randomly assigned in 4 replicates in each study site. Thirty two experimental plots of 24 m^2 each were obtained. In 2011, we had 12 treatments distributed randomly in 4 replicate sites obtain for a total of 48 basic plots, each with an area of 24 m^2. 70 plants were planted in 5 lines of 6 m long, with 0.80 m between rows and 0.50 m between plants on the line. The increase in 2011 of treatments was due to the fact that we wanted to test the effect of the half-dose of mineral fertilizer (F2) and the effect of its combination with organic fertilizer on soil acidity and on agronomic parameters of the tomato crop, in order to draw appropriate conclusions. The various treatments have been designated as shown in Table 2.

Statistics analysis

All data collected were analyzed using the software "XLSTAT- Pro 7.1". An analysis of variance was performed for the whole treatment. Treatment effects and doses of fertilizers were considered significant at the probability of $p < 0.05$. Duncan's test was used to separate means.

RESULTS

Content of soil organic matter, C/N ratio and available phosphorus in Bimbresso and Bouaflé

The results in 2010 presented in Table 3 show that organic fertilizer (NPK 5-9-19) and the combined effect of mineral fertilizer was significantly improved at the threshold of 5%, soil organic matter content and available phosphorus. Figure 1 shows that in 2010 in Bimbresso, treatments T6 and T7 had the highest increase in the content of soil organic matter with 2.90 and 2.92 g kg^{-1}, respectively, an increase of 2.7 times as compared to the control. In Bouaflé also, Figure 1 shows that the T6 and T7 treatments improved the content of soil organic matter when compared with other treatments, with values of 3.17 and 3.27 g kg^{-1}, respectively, an increase of more than 2.50 times relative to the control.

Table 4 shows that in 2011 the organic fertilizer and the combined effect of both fertilizers significantly increased ($p < 5\%$) organic matter and soil available phosphorus. Figure 3 shows that in 2011 in Bimbresso, the combined effect of fertilizers in treatments T6, T7, T10 and T11 had the best effect in improving soil organic matter with 2.99, 3.04, 2.98 and 3.01 g kg^{-1}, respectively, as compared to the control that had the lowest content (1.36 g kg^{-1}). These values correspond to a gain of at least 54.36% relative to the control. In Bouaflé (Figure 3), the treatments T6, T7, T10 and T11 had also the highest soil organic matter, with 3. 27, 3.30, 3.22, and 3.29 g kg^{-1}, respectively. These contents were upper than the control content (1.55 g kg^{-1}), an increase of at least 51.86% as compared to the control.

Available soil phosphorus had increased the most with T6 and T7 treatments, obtaining a gain of 26.47 and 25.37%, respectively over the control in Bimbresso (Figure 2), while in Bouafle, these treatments favored an increase respectively of 34.57 and 32.05% over the control in 2010.

Treatments of T6, T7, T10 and T11 significantly increased soil available phosphorus in 2011 (Figure 4). In Bimbresso, these treatments increased soil available phosphorus, respectively 54, 56, 50, and 52% as compared to the control. While in Bouafle, this increase was respectively of 62.26, 64.15, 69.81 and 75.47%.

The C/N ratio (Table 3) changed significantly ($p < 5\%$) at different doses of organic fertilizer (NPK5-9-19). In Bimbresso and Bouafle, in 2010 treatments with different doses (C1, C2, C3) of organic fertilizer had better results as compared to the control. In Bimbresso, doses C1, C2

Table 3. Effects of the organic and mineral fertilizers on the content of soil organic matter, C/N ratio and available phosphorus in 2010.

Treatment	Bimbresso			Bouaflé		
	MO (g kg^{-1})	C/N	P assi. (ppm)	M.O (gkg^{-1})	C/N	Passi. (ppm)
Mineral fertilizer (%)						
0	2.15	11.60[a]	58.25	2.24	11.82[a]	64.25
100	2.43	12.68[a]	61.50	2.70	13.08[a]	70.75
PPDS (at 5%)	0.45	1.20	4.48	1.59	2.07	5.45
Organic fertilizer (L ha^{-1})						
0	1 ?35	9.78[b]	51.00	1.45	10.50[b]	54.00
2.5	2.27	12.59[a]	58.00	2.53	12.20[a]	64.50
3.75	2.75	12.79[a]	65.50	2.92	13.07[a]	76.00
5	2.77	13.42[a]	65.00	2.99	13.38[a]	75.50
PPDS (at 5%)	0.21	1.29	5.06	0.34	1.32	6.07
Mineral fertilizer	NS	NS	NS	NS	NS	NS
Organic fertilizer	S	S	S	S	S	S
Mineral fertilizer × organic	S	NS	S	S	NS	S
Means	2.29	12.14	59.88	2.47	12.35	67.5
CV (p.c.)	5.9	9.6	7.34	7.8	6.78	6.77

PPDS: Smallest significant difference at 5%; NS: not significant; S: significant at 5% threshold. Means followed by the same letters (a, b) in the same column are not significantly different at 5%, in accordance with Duncan test. P.assi.: Available phosphorus; M.O: organic matter; CV: coefficient of variation.

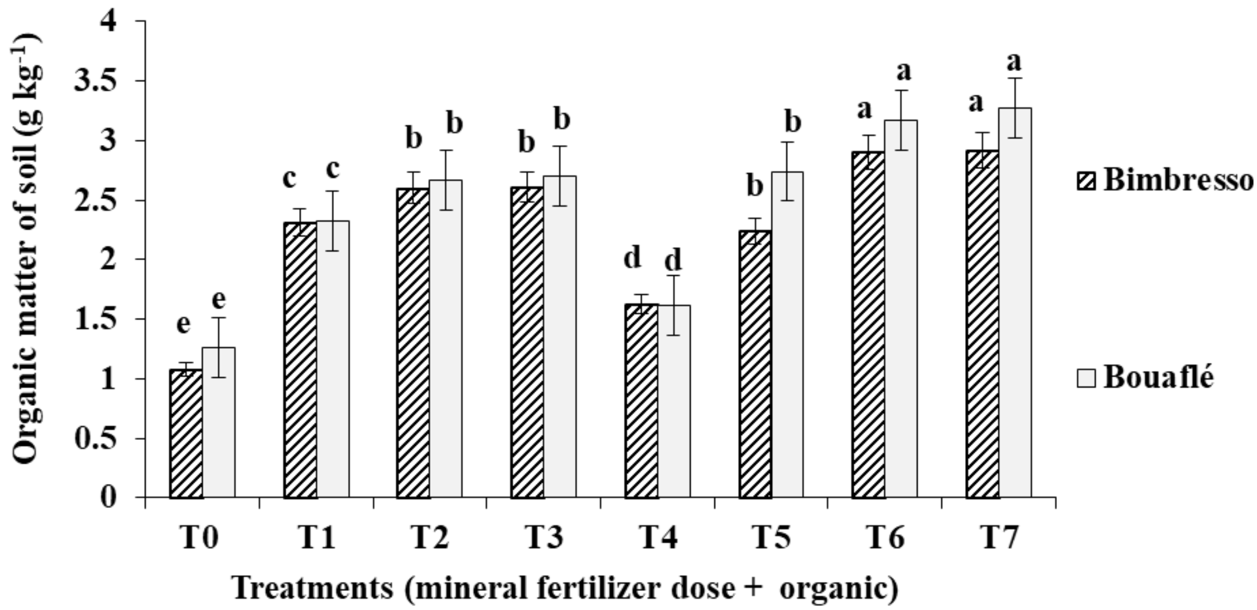

Figure 1. Effects of the organic and mineral fertilizers on the soil organic matter to Bimbresso and Bouafle in 2010.

and C3 of organic fertilizer alone have yielded C/N ratios of 12.59, 12.79 and 13.42, a gain of 28.73, 30.77 and 37 22%, respectively as compared to the control. In Bouafle, the doses C1, C2 and C3 of organic fertilizer had C/N ratios of 12.07, 13.07 and 13.38 also, an improvement of 16.19, 24.48 and 27.43%, respectively as compared to control. The soil organic matter content, available Phosphorus and C/N ratio was higher than in Bouaflé than in Bimbresso.

In 2011, the C/N ratio (Table 4) was significantly influenced by the organic fertilizer. Treatments with doses 2.5, 3.75 and 5 L.ha^{-1} of organic fertilizer had the best

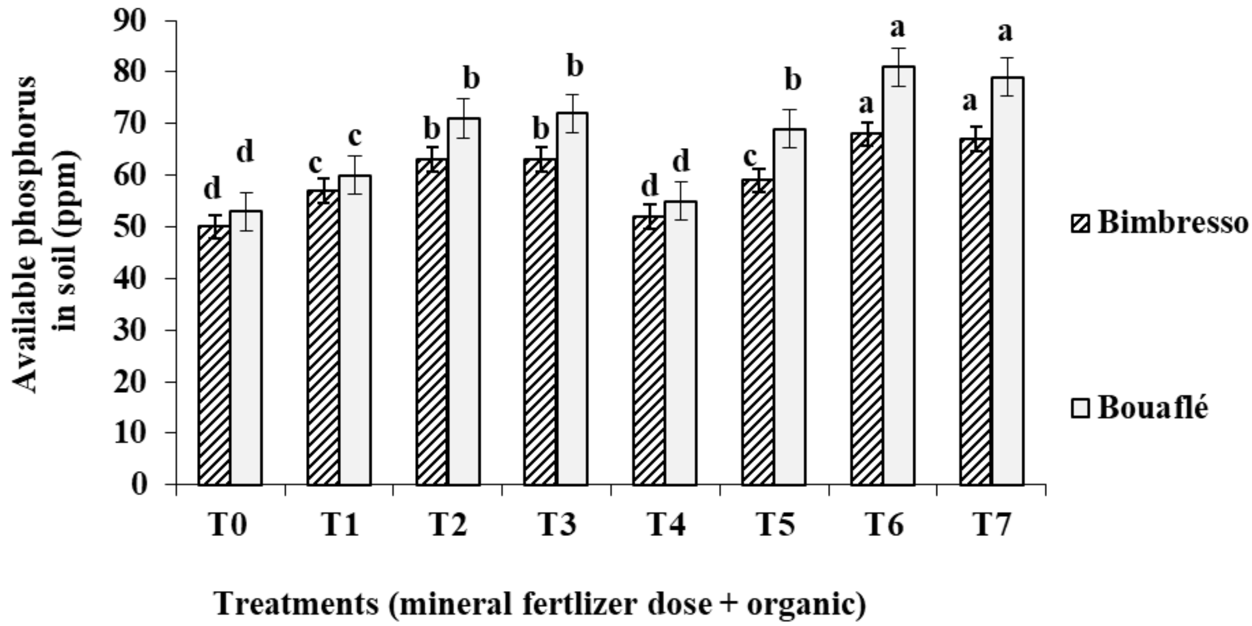

Figure 2. Effects of the organic and mineral fertilizers on the soil available phosphorus to Bimbresso and Bouafle in 2010. Means followed by the same letters (a, b, c, d) at each site were not significantly different ($p < 5\%$); T0 (control: 0 M.f. dose and O.f.); T1 (0% M.f.+ 2.5 Lha^{-1} O.f.); T2 (0% M. f. + 3.75 Lha^{-1} O.f.); T3 (0% M. f. + 5 Lha^{-1} O. f .); T4 (100% M.f. + 0 Lha^{-1} O.f.); T5 (100% M.f.+ 2.5. Lha^{-1} O.f.); T6 (100% M.f. + 3.75 Lha^{-1} O.f.); T7 (100% M.f. + 5 Lha^{-1} O.f.); M.f. = mineral fertilizer; O.f.: organic fertilizer

Table 4. Effects of the organic and mineral fertilizers on the content of the soil organic matter, C/N ratio and available phosphorus in 2011

Treatment	Bimbresso			Bouaflé		
	MO (g kg^{-1})	C/N	Passi. (ppm)	M.O (g kg^{-1})	C/N	Passi. (ppm)
Mineral fertilizer (%)						
0	2.25	11.91^{a}	51.75	2.37	11.50^{a}	56.50
50	2.48	11.08^{a}	57.50	2.74	12.23^{a}	64.75
100	2.49	11.15^{a}	59.25	2.77	12.38^{a}	64.75
PPDS (at 5%)	0.72	1.72	6.10	1.71	0.60	7.32
Organic fertilizer (L ha^{-1})						
0	1.36	9.88^{b}	42	1.62	10.4^{b}	48.00
2.5	2.31	12.1^{a}	52.33	2.67	12.9^{a}	60.00
3.75	2.87	11.9^{a}	64.67	3.13	13.0^{a}	70.33
5	2.77	12.0^{a}	65.67	3.15	13.0^{a}	69.66
PPDS (at 5 p.c.)	0.44	1.08	5.83	0.29	0.44	6.82
Mineral fertilizer	NS	NS	NS	NS	NS	S
Organic fertilizer	S	S	S	S	S	S
Mineral fertilizer × organic	S	NS	S	S	NS	S
Means	2.4	11.46	56.17	2.64	12.22	62
CV (p.c.)	6.7	9.6	8.3	7.1	8.08	7.2

PPDS: Smallest significant difference at 5%; NS: not significant; S: significant at 5% threshold; Means followed by the same letters (a, b) in the same column are not significantly different ($p < 5\%$), in accordance with Duncan test. P assi.: Available phosphorus; M.O.: organic matter; CV: coefficient of variation.

response. In Bimbresso, C/N ratio increased by 22.47, 20.41 and 21.46%, respectively as compared to the

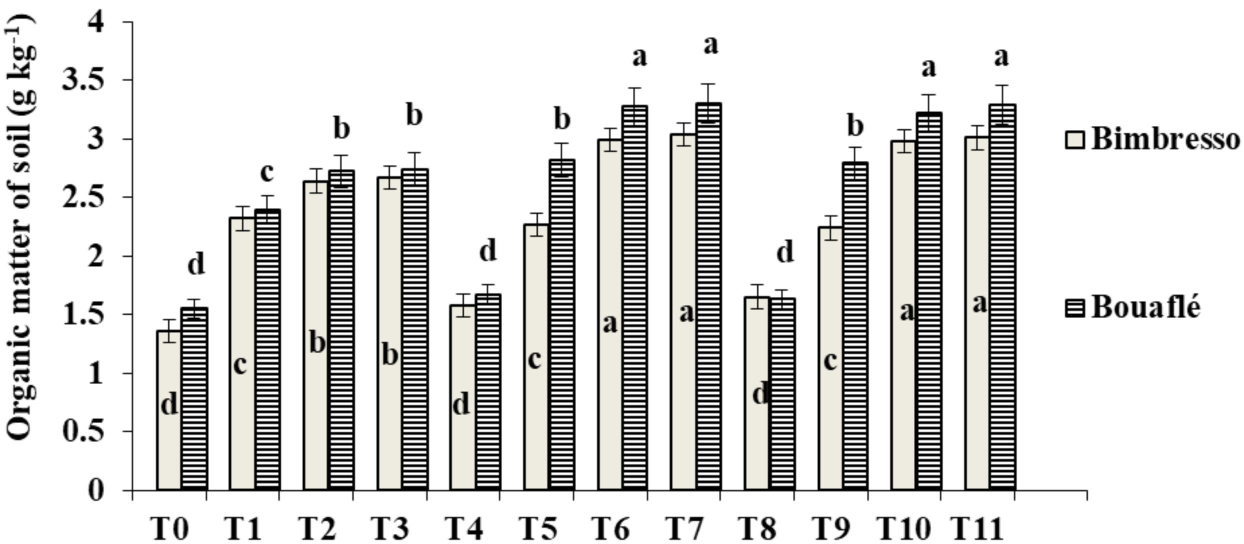

Figure 3. Effects of the organic and mineral fertilizers on the content of the soil organic matter to Bimbresso and Bouaflé in 2011. Means followed by the same letters (a, b, c, d) at each site were not significantly different ($p < 5\%$). Treatments (mineral fertilizer dose+ organic)

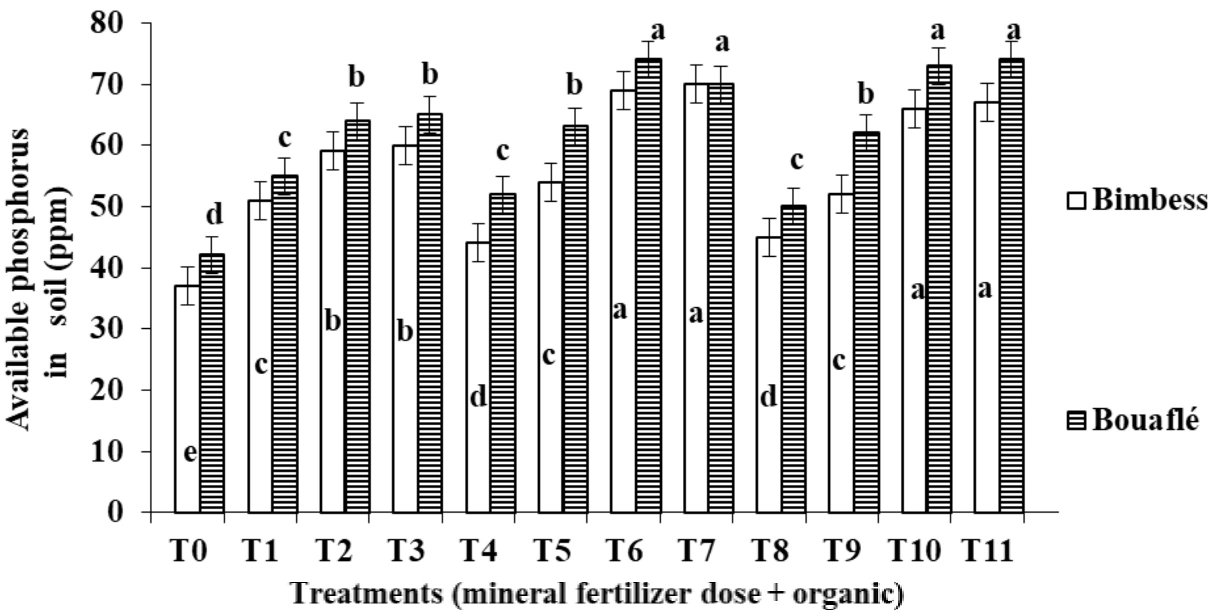

Figure 4. Effects of the organic and mineral fertilizers on the content of the soil available phosphorus to Bimbresso and Bouaflé in 2011. Means followed by the same letters (a, b, c, d, e) at each site were not significantly different ($p < 5\%$). T0 (control : 0 M f. dose and O.f.); T1 (0% M.f.+ 2.5 Lha^{-1} O.f.); T2 (0% M.f. + 3.75 Lha^{-1} O.f.); T3 (0% M.f. + 5 Lha^{-1} O.f.); T4 (100% M.f. + 0 Lha^{-1} O. f.); T5 (100% M.f.+ 2.5. Lha^{-1} O.f.); T6 (100 % M. f. + 3.75 Lha^{-1} O.f.); T7 (100% M.f. + 5 Lha^{-1} O.f.); T8 (50% M. f + 0 Lha^{-1} O.f.); T9 (50% M.f. + 2.5 Lha^{-1} O.f.); T10 (50% M.f. + 3.75 Lha^{-1} O.f.); T11 (50% M.f. + 5 Lha^{-1} O.f.). M. f. = Mineral fertilizer O.f. : Organic fertilizer

control. While in Bouafle, the increase was 24.04 and 25%, respectively as compared to control. The content of soil organic matter, available phosphorus and C/N ratio was higher in Bouaflé than in Bimbresso.

Sum of exchangeable bases, CEC and soil pH to Bimbresso and Bouafle

As shown in Tables 5 and 6, mineral fertilizer had no

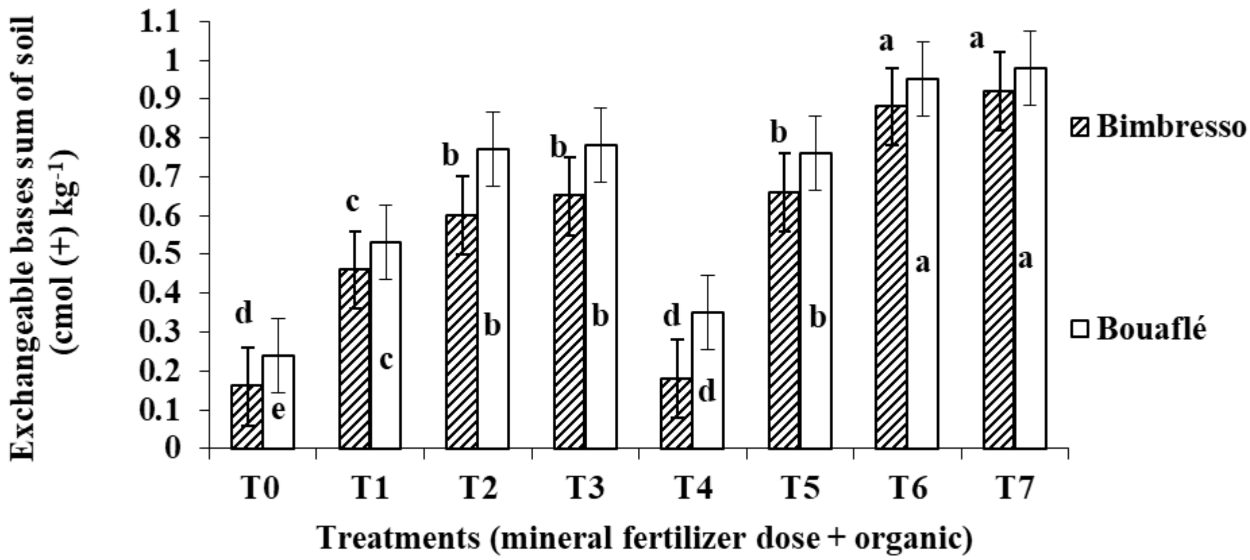

Figure 5. Effects of the mineral organic fertilizer and on the content of soil exchangeable bases sum to Bimbresso and Bouafle in 2010. Means followed by the same letters (a, b, c, d, e) at each site were not significantly different (p<5 p.c.); T0 (control: 0 M f. dose and O.f.); T1 (0% M.f.+ 2.5 Lha^{-1} O.f.); T2 (0% M. f. + 3.75 Lha^{-1} O.f.); T3 (0% M. f. + 5 Lha^{-1} O. f.); T4 (100% M. f. + 0 Lha^{-1} O. f.); T5 (100% M.f.+ 2.5. Lha^{-1} O. f.); T6 (100% M. f. + 3.75 Lha^{-1} O.f.); T7 (100% M. f. + 5 Lha^{-1} O.f.); M.f.: mineral fertilizer; O.f.: organic fertilizer.

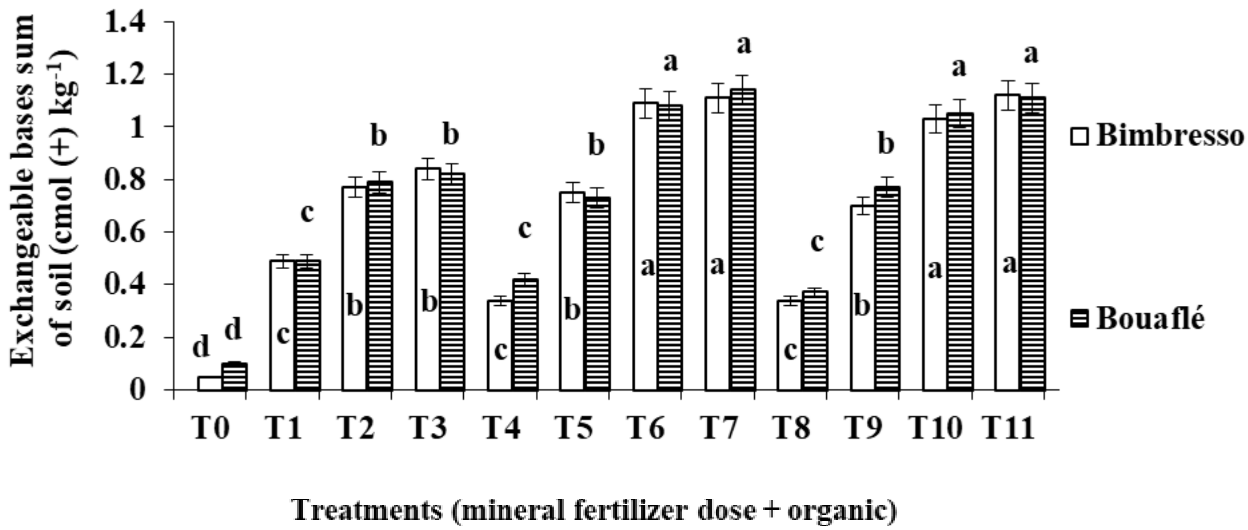

Figure 6. Effects of the organic and mineral fertilizers on the content of the soil exchangeable bases sum to Bimbresso and Bouaflé in 2011. Means followed by the same letters (a, b, c, d) at each site were not significantly different (p < 5 %); T0 (control : 0 M f. dose and O.f.); T1 (0% M.f.+ 2.5 Lha^{-1} O.f.); T2 (0% M. f. + 3.75 Lha^{-1} O.f.); T3 (0% M. f. + 5 Lha^{-1} O.f.); T4 (100% M. f. + 0 Lha^{-1} O. f.); T5 (100% M.f.+ 2.5. Lha^{-1} O. f.); T6 (100% M. f. + 3.75 Lha^{-1} O.f.); T7 (100% M. f. + 5 Lha^{-1} O.f.); T8 (50% M. f + 0 Lha^{-1} O.f.); T9 (50% M. f. + 2.5 Lha^{-1} O. f.); T10 (50% M. f. + 3.75 Lha^{-1} O. f.); T11 (50% M. f. + 5 Lha^{-1} O. f.). M.f.: Mineral fertilizer ; O.f.: Organic fertilizer

significant influence on the content of soil sum of exchangeable bases (S) and cation exchange capacity (CEC), in Bimbresso as well as in Bouafle in 2010 and 2011. On the other hand, during the two years the treatments with doses 3.75 and 5 L.ha^{-1} of organic fertilizer had best improved soil CEC. In 2010, at least 26.50 and 38.26% in Bimbresso and in Bouaflé respectively as compared to control. In 2011, these doses (C2 and C3) of organic fertilizer had an increasing soil CEC upon 56.27 and 45.11% at Bimbresso and

Table 5. Effects of the organic and mineral fertilizers on the content of the soil exchangeable bases sum, CEC and pH in 2010.

Treatment	Bimbresso			Bouaflé		
	(S)	CEC	pH	(S)	CEC	pH
Mineral fertilizer (%)						
0	0.47	6.85[a]	4.58[a]	0.58	8.88[a]	5.93[a]
100	0.66	7.05[a]	4.33[b]	0.76	9.76[a]	5.75[b]
PPDS (at 5%)	0.24	0.81	0.22	0.32	1.91	0.15
Organic fertilizer (L ha^{-1})						
0	0.17	5.85[c]	4.15[b]	0.30	7.45[c]	5.70[b]
2.5	0.56	7.08[b]	4.45[a]	0.65	8.98[b]	5.85[a]
3.75	0.74	7.40[a]	4.65[a]	0.86	10.30[a]	5.90[a]
5	0.79	7.48[a]	4.55[a]	0.88	10.55[a]	5.90[a]
PPDS (at 5%)	0.15	0.30	0.20	0.18	1.02	0.12
Mineral fertilizer	NS	NS	S	NS	NS	S
Organic fertilizer	S	S	S	S	S	S
Mineral fertilizer × organic	S	NS	NS	S	NS	NS
Means	0.57	6.95	4.45	0.67	9.32	5.83
CV (%)	4.2	5.9	7.3	6.5	7.81	6.2

PPDS: Smallest significant difference to 5%; NS: not significant; S: significant at 5% threshold ; Means followed by the same letters (a, b) in the same column are not significantly different ($p < 5\%$), in accordance with Duncan test. (S): The sum of exchangeable bases; CV: coefficient of variation.

Bouaflé, respectively as compared to the control. However, the organic fertilizer and the combined effect of fertilizers increased significantly ($p < 5\%$), which is the sum of exchangeable bases (Tables 5 and 6). T6 and T7 treatments have the best results in 2010 (Figure 5). The T6 treatment had a sum of exchangeable bases of the soil that varied from 0.88 to 0.95 (cmol (+) kg^{-1}), an increase of 3.96 and 5.5 times higher than the control in Bimbresso and Bouaflé, respectively. And the T7 treatment had values equal to 0.92 and 0.98 (cmol (+) kg^{-1}), a gain of 5.75 and 4.08 times higher than the control, for Bimbresso and Bouaflé, respectively.

Figure 6 shows that in 2011 in Bimbresso, treatments T6, T7, T10 and T11 had a sum of exchangeable bases content between 1.03 and 1.12 (cmol (+) kg^{-1}), either 20.6 or 22.4 times higher than the control. In Bouafle, this value was between 1.05 and 1.11 (cmol (+) kg^{-1}), either 10.5 or 11.1 times higher than the control.

In 2010, soil pH (Table 5) experienced a significant drop with mineral fertilizer. While the organic fertilizer promoted a significant increase at the threshold of 5%. In fact, treatment with 100% mineral fertilizer dose recorded a soil pH of 4.33 and 5.75 in Bimbresso and Bouaflé, respectively, a decrease in pH of 5.46 and 3.04% as compared to the control. Moreover, treatments with doses 1, 2 and 3 of organic fertilizer without mineral fertilizer had the highest pH of the soil, between 4.45 and 4.65 and between 5.85 and 5.9 in Bimbresso and Bouaflé, respectively. The soil exchangeable bases, CEC and the pH was higher than in Bouaflé and Bimbresso.

In 2011, soil pH of the sites (Table 6) was negatively impacted by processing 100% mineral fertilizers. A pH of 4.35 to 5.68 for Bimbresso and Bouaflé recorded a decrease of 5.32 and 4.22% at Bimbresso and Bouaflé, respectively compared to the control. Moreover, treatments with doses 3.75 and 5 L.ha^{-1} of organic fertilizer better improved soil pH. In Bimbresso, they caused an increase in soil pH of 15.50 and 14.55%, respectively as compared to the control. While at Bouaflé, it raises the pH by 7.18% higher than the control. The soil exchangeable bases, CEC and the pH were higher than in Bouaflé and Bimbresso.

DISCUSSION

Organic matter plays a determining role in the soil fertility as it is essential to retain the nutritive elements and soil moisture. It stabilizes the structure, nourishes and shelters the organizations of the soil. Organic agricultural producers must try to reach at least 4% of organic matter and to consider stable or increasing values as a proxy of a good management of their soil (Désiré, 2012). This organic matter then will enrich the soil by producing humus which will be mineralized to provide sufficient biogenic salts to the plants for their development. According to Anne and Jean (2009), the highest the organic matter content, the highest the CEC and more nutrients are retained in the soil for plant growth.

Besides, works of Akanza and Yoro (2003) showed that

Table 6. Effects of the organic and mineral fertilizers on the content of the soil exchangeable bases sum, CEC and pH in 2011.

Treatment	Bimbresso			Bouaflé		
	(S)	CEC	pH	(S)	CEC	pH
Mineral fertilizer (%)						
0	0.54	7.52[a]	4.70[a]	0.55	8.82[a]	5.93[a]
50	0.80	7.84[a]	4.63[a]	0.83	9.85[a]	5.93[a]
100	0.82	7.98[a]	4.35[b]	0.84	9.92[a]	5.68[b]
PPDS (at 5%)	0.42	1.73	0.25	0.48	1.20	0.21
Organic fertilizer (L ha^{-1})						
0	0.24	5.74[c]	4.13[c]	0.30	7.36[c]	5.57[c]
2.5	0.65	7.49[b]	4.60[b]	0.66	9.45[b]	5.83[b]
3.75	0.96	8.93[a]	4.77[a]	0.97	10.63[a]	5.97[a]
5	1.02	8.97[a]	4.73[a]	1.02	10.68[a]	5.97[a]
PPDS (at 5%)	0.27	1.40	0.11	0.30	1.14	0.13
Mineral fertilizer	NS	NS	S	NS	NS	S
Organic fertilizer	S	S	S	S	S	S
Mineral fertilizer × organic	S	NS	NS	S	NS	NS
Means	0.72	7.78	4.56	0.74	9.53	5.84
CV (%)	8.1	7.5	6.6	4.2	5.4	8.4

PPDS: Smallest significant difference to 5%; NS: not significant; S: significant at 5% threshold; Means followed by the same letters (a, b) in the same column are not significantly different ($p < 5\%$), in accordance with Duncan test. (S): The sum of exchangeable bases; CV: coefficient of variation.

the low dose of mineral fertilizers, associated with 20 tha^{-1} of poultry droppings caused an increase in total C content of the soil of 32% and an improvement of the content of organic matter. These researches carried out on the two campaigns showed that the dose of 3.75 $L.ha^{-1}$ of organic manure liquid, associated with the dose of 50% mineral fertilizer, is more efficient to improve the content of the soil organic matter and improved soil fertility. Lal (2009) showed also that organic fertilization improves soil organic matter. The works of Jacques (2014) shows even that liquids from wastes stimulate the biological activity of the soil.

The ratio C/N is determining for litter decomposition. Indeed, a litter which breaks up too slowly can block the cycle of the biogenic salts. The C/N ratio was higher in Bouaflé (≤13) than in Bimbresso (≤11.9) during the two campaigns, with the contribution of the amount of 3.75 $L.ha^{-1}$ of liquid organic fertilizer. These ratios were normal. According Assa (2005) and Tossou et al. (2006), process of mineralization is more or less normal, when the C/N ratio is situated between 8 and 15 ($8 \le C/N \le 15$).

Within sight of these values, although they are normal, the decomposition of the organic matter could be faster in Bimbresso than in Bouaflé. The risk of leaching of the biogenic salts could thus be greater in Bimbresso than in Bouaflé. Because in Bouaflé, the decomposition could be done a little more slowly and the nutritive elements could be supplied gradually at the disposal of the plant, it justifies the higher availability of the biogenic salts of the soil of Bouaflé as compared to Bimbressso. According to Ettien (2004), although the decomposition of the organic matter is normal on certain toposequences, the content of N of the tropical grounds is generally weak. Liquid organic fertilizer (NPK5-9-19) could then play the part of manure and of amendment with the amount of 3.75 $L.ha^{-1}$ of better pedoclimatic conditions joined together. However, it remains more effective when it is associated with the ½ dose of mineral fertilizer.

The soil pH influences the availability of the nutrients. According to FAO (1989), tomato is not very tolerant to soil acidity. A pH ranging between 5.5 and 6.8 is more favorable to the tomato culture. On the two sites, treatment with the amount 3.75 Lha^{-1} of organic manure was most effective to improve the soil pH. This treatment made it possible to have a pH of 4.65 Bimbresso and 5.9 in Bouaflé, either an increase of 12.04 or 3.51%, respectively as compared to the control in 2010 or a pH of 4.77 and 5.97 in Bimbresso and Bouaflé, or a profit of 15.50 and 7.18%, respectively as compared to the witness in 2011. In Bimbresso, the soil pH being very acid is not appropriate for tomato culture, as compared to Bouaflé where the pH is more favorable to this culture. These results show that, adding an amount of 3.75 $L.ha^{-1}$ of organic fertilizer could amend the soil pH improving the availability of the nutritive elements of the soil for the plant. Increase of soil pH from Bouaflé as compared to Bimbresso during the two years could be due to the season. Indeed, the strong grains, making the soil very wet, increase the replacement of Ca^{2+} ions by H^+ ions, intensifying the leaching of the exchangeable bases and causing a strong acidity of the soil. In 2010, during the farming period, the pluviometry was higher in Bimbresso (819.82 mm) as compared to Bouaflé (556.22 mm). In 2011 also, it rained more in Bimbresso (560.10 mm), than in Bouaflé (378.73 mm). This might have caused the strongest leaching in Bimbresso, the lower precipitation registered in Bouaflé could also explain the rise in pH on this site. This low pH of the soil in Bimbresso, could explain the low content of nutritive element on this site, in particular the sum of the exchangeable bases and the CEC (cmol (+) kg^{-1}), which gave a median value (10.63) in Bouaflé and a weak value (8.93) in Bimbresso. However, available phosphorus was satisfactory (73 ppm with Bouaflé and 66 ppm with Bimbresso) on the two sites with the T10 treatment according to the values of the following parameters.

Indeed according to Assa (2005), the thresholds values for exchangeable bases (S), available phosphorus, and CEC are: (S) < 1.5: very weak; (S) = 1.5 to 3: weak; (S) = 3 to 6: average; CEC = 5 to 10: weak; CEC = 10 to 15 average and according to Olsen-Dabin, as proposed by Gigou (1987) and Akanza and Yoro (2003), the minimum available phosphorus threshold is 60 to 70 ppm. The work of Koulibaly et al. (2015) also showed that soil conditioning in compost improves available phosphorus of the soil.

With regards to our results, the amount of 3.75 Lha^{-1} of organic fertilizer, associated or not with the ½ amount of mineral manure seems to support a good biological activity on the level of the soil, in order to better consolidate the effectiveness of mineral fertilizer, while making more available the biogenic salts to improve the soil fertility. According to Rutigliano et al. (2014), an addition of biochar to an agricultural soil stimulates in the short run the activity and the microbial diversity of the soil which are important in the cycles of the nutrients.

LIMITATIONS

The tomato culture is confronted with many constraints which impact its production negatively. However, tomato is the object of a strong consumption in rural environment as well as in urban area and in development countries as well as in those developed. To cope with these difficulties, much research efforts were concentrated on fertilization. Thus, many producers make use to the fertilization more and more, in particular, liquid organic, to improve the production of their cultures, because liquid organic manures are less expensive, their transport are easy and available for the wide fields. It is in this context of improvement in the fertility of the ground and the production of tomato, that this study is proposed. Many studies were conducted on the response of vegetable crops to organic manures; the use of liquid organic fertilizer (NPK5-9-19) needs to be noticed in association with mineral fertilizer (NPK12-11-18). This study is thus necessary and needs to be constant, because it will make it possible for the farmers to apply the suitable treatment through this liquid organic fertilizer (NPK5-9-19), to improve soil fertility and tomato production.

Conclusion

The dose of 3.75 $L.ha^{-1}$ of organic fertilizer (NPK 5-9-19), through the combined effect of T10 treatment (50% mineral fertilizer + 3.75 L ha^{-1} organic fertilizer) has better enhanced the effectiveness of the ½ dose of the mineral fertilizer in 2011 to improve significantly ($p < 5\%$) the levels of soil organic matter, available phosphorus, and sum of exchangeable bases, as compared to 2010 with T6 treatment (100% mineral fertilizer + 3.75 Lha^{-1} organic fertilizer). During the two campaigns, a dose of 3.75 Lha^{-1} of organic fertilizer has only increased significantly ($p < 5\%$) contents of soil pH and CEC. The C/N ratio of the soil instead was significantly increased ($p < 5$ %), by doses 2.5 and 3.75 L ha^{-1} of organic fertilizer, over the two years of study. However, treatment with dose of 100% only mineral fertilizer significantly reduced the soil pH and the soil became more acidic as compared to the control. The Bouafle site of study had the best contents of the soil over that of Bimbresso.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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