International Journal of Plant & Soil Science
5(1): 10-24, 2015; Article no.IJPSS.2015.056
ISSN: 2320-7035

SCIENCEDOMAIN *international*
www.sciencedomain.org

Fertilizing Effect of Swelling Clay Materials on the Growth and Yield of Bean "*Phaseolus vulgaris*" on the Sandy Ferruginous Soils from Mafa Tcheboa (North Cameroon, Central Africa)

Basga Simon Djakba[1,2] and Nguetnkam Jean Pierre[2*]

[1]Institute of Agricultural Research for Development (IRAD), P.O.Box 12 Yagoua, Cameroon.
[2]Department of Earth Sciences, Faculty of Science, University of Ngaoundere,
P.O.Box 454 Ngaoundéré, Cameroon.

Authors' contributions

This work was carried out by author BSD under the supervision of author NJP. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2015/13180
Editor(s):
(1) Davide Neri, Polytechnic University of Marche - Via Brecce White, Ancona, Italy.
Reviewers:
(1) Anonymous, Hacettepe University, Turkey.
(2) Anonymous, Kanpur University, U .P, India
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=779&id=24&aid=7181

Original Research Article

Received 5th August 2014
Accepted 15th September 2014
Published 10th December 2014

ABSTRACT

Amendment of sandy ferruginous soils by swelling clay materials can be a promising solution to improve their fertility and thus enhance crop yield. In this study which aims at valorization swelling clay materials in the mineral fertility of ferruginous soils, a pot experiment was conducted using ferruginous soils from northern Cameroon which were sampled at Mafa Tcheboa, and amended by swelling clays materials collected also in the North Cameroon. The effect of swelling clay application on the growth and productivity of common bean "*Phaseolus vulgaris*" was followed by means of measures of growth and yield parameters. An experimental design which consisted in a randomized complete block design (RCBD) is constituted of two series of five treatments each one: the control (ST), the control mixed with 300 g of clay before sowing (SAS), the control with 20 g of clay in the hole of sowing (STS), the control with 20 g of clay at the germination stage (SAL) and the control with 20 g of clay at the approaching flowering stage (SAF). Each treatment was replicated ten times in every serie. The control treatment is only soils of Mafa Tcheboa without any clay application; they are sandy, acid and display a low CEC with kaolinite as main clay mineral,

---

*Corresponding author: E-mail: jpnguet@yahoo.fr;

while swelling clay materials are basic and display a cation exchange capacity (CEC) 3 times higher than that of controls, and made up mainly of smectites. On the geochemical point of view, both materials are constituted mainly by SiO_2, Al_2O_3, Fe_2O_3 as major elements; and Ba, Zr and Sr as traces elements. All the treatments were irrigated with 250 ml of water one time all two days during the growing stage. The growth and yield components were measured every three days. 14204 measures of growth components and 35440 measures of yield components were made. The results indicate an important increase of stem length and its branches, leaves number, leaflet length, leaflet width, main root length and number of its ramifications in the soils amended by swelling clay materials. About 2.5 times of yield were obtained from those treatments compared to control in one hectare. The germination stage and the flowering stage are the best periods to apply swelling clay materials. The overall results indicate that swelling clay material can be used to enhance bean's crop yield in ferruginous soils from Mafa Tcheboa and therefore are interesting alternative petrofertilizers to very expensive chemical fertilizers.

Keywords: North Cameroon; Mafa Tcheboa; ferruginous soils; bean; amendment; swelling clay materials.

1. INTRODUCTION

An increase of food production has to come at 90% from the areas already cultivated [1] while the fallow periods have been shortened in recent years or even abandoned due to increasing pressure on the land base [2,3,4,5]. As consequence, soil fertility is decreasing with time [6] and cannot allow to reach or to maintain food security. Decreasing soil quality is regarded by scientists as the fundamental cause for downward trend of food production in sub-Saharan Africa [7]. The use of imported fertilizers by farmers is constrained by high cost [7] and the manures by their poor availability.

The ferruginous soils have sandy texture, are acidic in nature and poor in plant available nutrients. The sandy soils which are widely represented in the world, covering more than 9000 million hectares [8] are found in north Cameroon as ferruginous soils [9]. At Mafa Tcheboa, they support large agricultural activities. Due to agricultural intensification and inadequate agricultural practices, they are subject to erosion which mobilizes fines particles and nutrients [9]. So, they display many cultivation constraints such as low fertility levels, low organic matter (OM) content, low water holding capacities and high infiltration rates. They are considered as infertile with poor crop yields that declined over a period of time. The restoration of soil fertility needs to address the problem of declining nutrients holding capacity and low OM which are largely dependent on the clay content [10]. Many studies reported that the only way to increase the low CEC of sandy tropical soils over the long term is to apply high CEC materials such as swelling materials [11]. An important way to increase the productivity of degraded soils lies in the fundamental problem of diminished nutrients holding capacity (indicated by CEC) coupled with the decline of soil OM [11].

A possible approach is through the application of geological materials that are easily available to poor farmers [12]. Plants nutrients like P, K, Ca and Mg are supplied by geological resources. Amendment of these soils by swelling clay materials can be a promising solution to improve their fertility and increase food production. [13] have shown that permeability of sandy soils can be reduced by adding small amount of clay; the clay substrate application in sandy soils improve soil water regime on the percolation processes [14]; clay application at the surface of sandy soil helps in reducing water repellency and increasing crop yield [15,16,17,11]. The chemical composition of swelling clays materials collected in the North Cameroon shows that they do not contain any toxic element which forbids their utilization in agriculture [18,19]. The present study which fit in valorization swelling materials in the mineral fertility of ferruginous soils consist to investigate their effect in the growth and productivity of common bean "*Phaseolus vulgaris*" on the sandy ferruginous soils from northern Cameroon.

2. MATERIALS AND METHODS

2.1 Soils Sites and Sampling

The ferruginous soils were sampled at different points of the surface horizon (0-20 cm), (Fig. 1) in Mafa Tcheboa (latitude 8º 56' N and longitude 13º 14' E) in northern Cameroon. Then a composite soil sample was obtained by mixing all the soil samples and quartered. Swelling clay materials were sampled from the topsoil of topomorphic vertisols in the North Cameroon (Fig. 1). Their main interest emanated from their local availability, accessibility, low exploitation cost and wide geographic extension [20,21,19].

2.2 Soil Analyses

The ferruginous soils were air-dried, mixed and quartered in order to obtain samples which are representative of ferruginous soils from Mafa Tcheboa and swelling clay materials. Physicochemical analysis were carried out on air-dried soils samples ground to pass through a 2mm sieve and were subsequently used to determine pH, particle size distribution, available phosphorus, exchangeable bases at IRAD soils, plants and fertilizers laboratory analysis. Cations exchange capacity (CEC), total nitrogen, and organic carbon and soil composition in Al, Fe, Mn and Si were determined at the Institute of soil sciences of Leibniz University at Hannover (Germany).

Particle size distribution was determined by the pipette method following dispersion with sodium hexametaphosphate. Soil pH_{H2O} was measured with pH meter equipped with a glass electrode in 1:2.5 soil-water suspensions. Cation exchange capacity (CEC) was determined by using Ag–Thiourea method. Organic carbon and total nitrogen were determined using CHNS-O (Vario El III) analysis. Available phosphorus was determined by Bray II method.

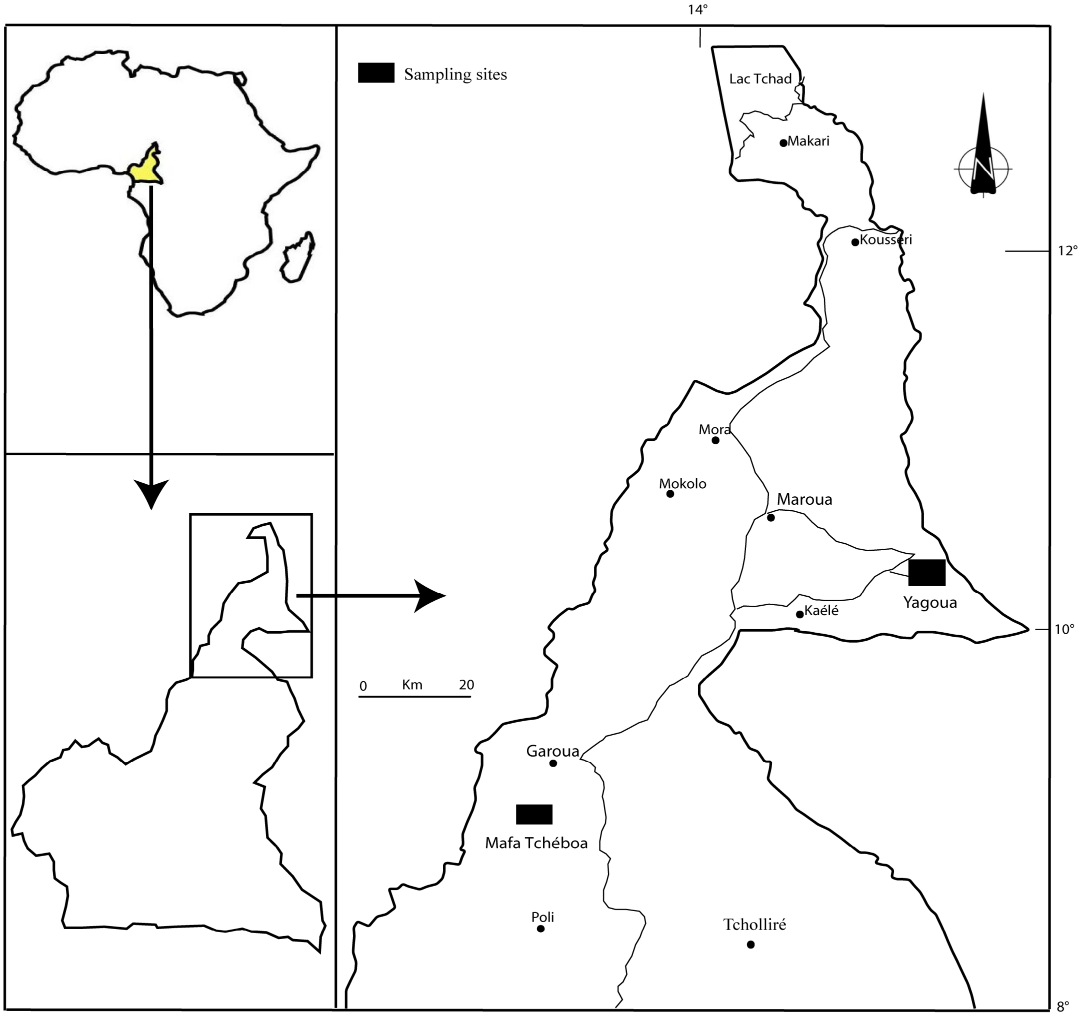

Fig. 1. Sites location

The percentage of organic matter was calculated by multiplying the organic carbon values by the factor 1.72. Soil crystalline elements (Fe, Al, Mn and Si) were extracted using dithionite- citrate-bicarbonate (DCB) method [22].

Mineralogical composition was determined on clay fraction (< 2µm) by X-ray diffraction (XRD) coupled to Fourier transform infrared spectroscopy (FTIR) at the Institute of soil sciences of Leibniz University at Hannover. The < 2µm particle size fraction was separated by dispersion in deionized water and sedimentation according to Stoke's law. The resulting clay suspension was freeze-dried. Geochemical composition was determined at Acme Analytical Laboratories in Vancouver, Canada by inductively coupled plasma source and atomic emission spectroscopy (ICP-AES) for major elements; by mass spectrometry (ICP-MS) for trace elements after fusion in $LiBO_2$ and dissolution in HNO_3.

2.3 Experimental Design and Treatments

A pot experiment carried out in the familial greenhouse at Dang near Ngaoundere university (N 07 41°; E 13 55°), located at about 15 km north of Ngaoundere town. 1.5 kg of composite ferruginous sample soil was put in pot containers. An experimental design is a duplicated randomized block design constituted by five treatments each one: (1) The control (ST); (2) The control mixed with 300g of clay before sowing (SAS); (3) Control with 20g of clay in the hole of sowing (STS); (4) Control with 20g of clay at the germination stage (SAL) and (5) Control with 20g of clay at the approaching flowering stage (SAF). The controls treatments are only soils from Mafa Tcheboa without any clay application. The pots were arranged in rows according to treatments and 5 cm spaced on two series in a completely randomized block. Each treatment was replicated ten times in every series and irrigated 3 times before sowing. These series which are spaced 50 cm apart were studied. In total, one hundred (100) pots were studied.

2.4 Plant Material and Data Recording

Plant material is a local variety of common bean "*Phaseolus vulgaris*". The bean seeds were soaked 24 hours first in water before sowing and pots were irrigated once every two days with 250 ml of water throughout the growth period. The growth and yield parameters were measured every three days. The growth parameters include stem length (SL) and number of its branches (SB), number of leaves per plant (LNP), leaflet width (W), leaflet length (L), main root length (RL) and number of its branches (NR). Root length and its branches were measured exclusively at the harvest step. Yield components are number of flowers (NF) and pods (NP), seeds by pod (NSP) and their weight (SW) and yield per plant (YP).

Leaf area was determined using non destructive method according to [23] model:

$$LA= 11.98+ 0.06x (L \times W)$$

Where L is the leaflet length and W is the leaflet width.

2.5 Statistical Analyses

Recorded Data on growth and yields components were subject to statistical analyses. So, XLSTAT software was used for standard principal component analysis. Pearson's correlation was used in order to determine the potential interrelationships between measured variables (growth components and yield components).

3. RESULTS

3.1 Amended Soils and Amendment Characteristics

Particle size results are shown in Table 1. Ferruginous soils have higher proportion in sand (72%) and a slight amount of fine elements (11.3% of clay and 14.9% of silt). These soils are sandy, slightly acid and displayed a low CEC (39.2 mmolc/kg). In contrast, swelling clay materials have a basic pH; high clay content (48.3%) and low sand content (26.6%). As consequence, they display a high CEC (244 mmolc/kg) which is 3 times higher than that of ferruginous soils. Organic C and total N levels are relatively low in amended soils while available P values are similar in both samples. Organic matter content is generally low in all studied samples but lower in sandy soils (1.066% in ferruginous soils and 1.3% in swelling clay materials). The C/N ratio fluctuate around 13 (Table 1). Dithionite extractable elements (Fe, Al, Mn, Si) are significantly higher in swelling clay materials while the lowest values are observed on Mafa Tcheboa soil.

X-ray patterns of swelling clay materials and Mafa Tcheboa soils are presented in Fig. 2. As one can observe, the swelling clays are made up mainly of smectites (identified by their broad basal spacing which are located at 14Å) associated to minor amount of kaolinite (Kaolinite is identified by its basal spacing at 7.2 Å and 3.57 Å) and quartz (identified by 4.46 and 3.36 Å basal spacing).

The study of swelling clay materials and Mafa Tcheboa soils by FT-IR spectroscopy confirms the presence of smectites, kaolinite and quartz as observed in X-ray patterns. The presence of smectites confirmed by the strongly vibration band around 3420 cm^{-1} (OH- stretching vibration) is reliable to the absorbed water by 2:1 clay minerals. Kaolinite is revealed in IR spectrums by wave's numbers at 3698 cm^{-1} and 3621 cm^{-1} assigned to νOH (Fig. 2).

Major elements are represented mainly by SiO_2; Al_2O_3 and Fe_2O_3. Except SiO_2 and K_2O which are relatively higher in ferruginous soil (77.08%SiO_2 and 4.09% K_2O); Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, TiO_2, MnO are higher in swelling materials. P_2O_5 are low and similar in both materials (Table 2).

Traces elements are dominated by Ba, Zr and Sr; these three elements are higher in control soil. Y, Nb, Sc and Ni are also present with low amount (Table 3).

Total sulfur is less than 0.02% in both soils. Total carbon is 1.54 and 0.79% respectively in control soil and swelling materials.

3.2 Growth Parameters

In general, germination of bean plants has started at least 6 days after sowing (DAS) in all treatments except in the treatment SAS in which it begins at 8 DAS. So mixing the soil with 300 g of swelling clays materials before the sowing did not enhance the germination of the bean seeds.

The results of change in stem length indicate that the stem length growth varies in accordance with treatments. In general, growth is stronger during the first 39 days, and then slightly diminishes at the end of the cycle.

The maximal mean values of stem length fluctuate between 41.3 and 30.82 cm. These values are 30.82 cm in ST, 36 cm in SAS, 41.3 cm in SAL, 35.44 cm in SAF and 37.57 cm in STS (Fig. 3). The highest values were observed in SAL and SAF treatments while the lowest appeared in control. It appears that an addition of swelling clay materials at the germination stage, at the flowering stage and in the hole of sowing induces stem elongation. ST, SAS and STS treatments have on average two main stem branches while SAL and SAF treatments in which swelling clays materials are widespread at the surface have three main stem branches each one.

The variation of the number of leaves per plant in different treatments during the farming cycle is summarized in Fig. 4. The number of leaves per plant increases strongly the 39 days after sowing (DAS). After that, the reduction of plant leaves begins in the control treatment around 45 DAS. This reduction begins belatedly in the amended soils; starting from 48 days after sowing in SAL and STS and from 54 DAS in SAF and SAS. The maximal number of leaves per plant (leaves densification) is 7 leaves in control; 9 leaves in SAS and STS; 10 leaves in SAF and 11 leaves in SAL.

The leave growth through the leaflet width and length showed that SAL and STS values were similar and high at the beginning while in ST, SAF and SAS there were no significant differences at beginning. These values increase dramatically in SAF after 27 DAS. The controls register the lowest values. As consequence, the highest leaves areas are obtained in amended soils (Fig. 5).

The leaf areas in SAF treatment, which are similar to those from SAS and ST at the beginning, increase strongly around 27 DAS while between SAS and ST leaves areas increase similarly during the growth phase.

The chlorophyll concentration was higher in SAL treatment because the leaves had very dark color under the said treatment. The plant leaves of control are the first to turn yellow and SAF is the only treatment which has green leaves at the harvest time.

Roots are important in plant growth as they absorb soil moisture and nutrients. The development of root system through the top root length and its branches (lateral roots) is presented in Table 4.

Table 1. Physicochemical characteristics of different soils used

	C %	FS %	CS %	FSd %	CSd %	OM %	Al g kg^{-1}	Fe g kg^{-1}	Mn g kg^{-11}	Si g kg^{-1}	P $mgkg^{-1}$	C g kg^{-1}	N g kg^{-1}	C/N	CEC $mmolckg^{-1}$	pH
ST	11.3	9.8	5.1	8.1	64.4	1.066	0.29	2.94	0.24	0.15	11.88	0.624	0.046	13.47	39.2	5.6
SM	48.3	16.8	9.8	12.4	11.8	1.32	0.81	7.95	0.58	0.51	11.36	0.766	0.058	13.05	244	7.7

ST: Ferruginous soils; SM: Swelling clay material; C%: Clay percentage; Fs%: Fine silt percentage; CF%: Coarse silt; percentage; FSd%: Fine sand percentage; Csd%: Coarse sand percentage

Table 2. Major elements, Loss on ignition (LOI) and Cr_2O_3 of control soil and swelling materials

	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	MnO %	Cr_20_3 %	LOI	Total
ST	77.08	9.78	1.44	0.10	0.19	0.21	4.09	0.66	0.05	0.07	0.004	5.9	100.01
SM	58.60	17.29	6.15	0.91	1.19	0.88	2.13	1.11	0.05	0.14	0.012	11.3	99.96

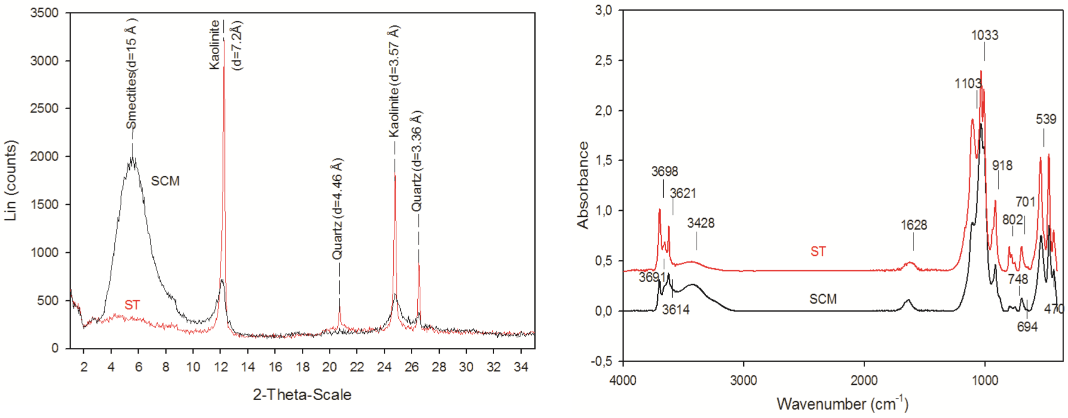

Fig. 2. XRD patterns and IR spectra of control soil and swelling materials

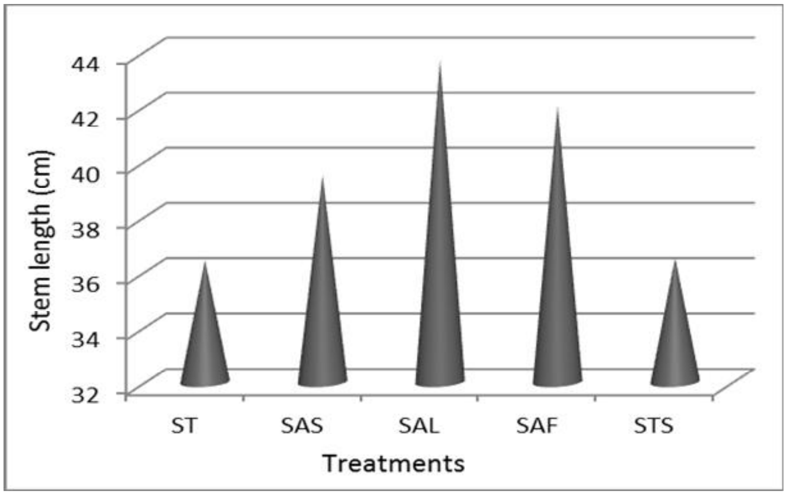

Fig. 3. Stem length variation in different treatments

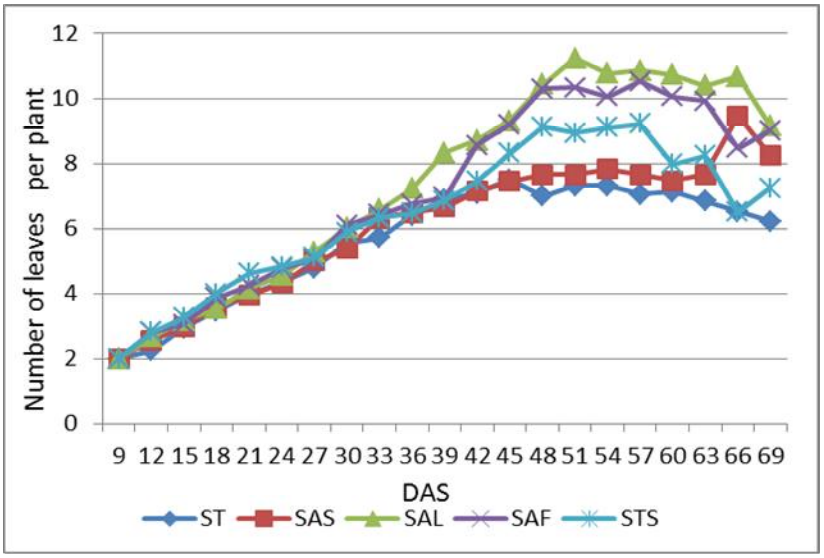

Fig. 4. Leaves number per plant in different treatments. DAS: Day after sowing

Table 3. Traces elements, total sulfur and total carbon of control soil and swelling materials

Elements	Ba ppm	Ni ppm	Sr ppm	Zr ppm	Y ppm	Nb ppm	Sc ppm	TOT/C %	TOT/S %
ST	1598	<20	283	1704	20	9	4	1.54	<0.02
SM	945	36	225	549	34	19	14	0.79	<0.02

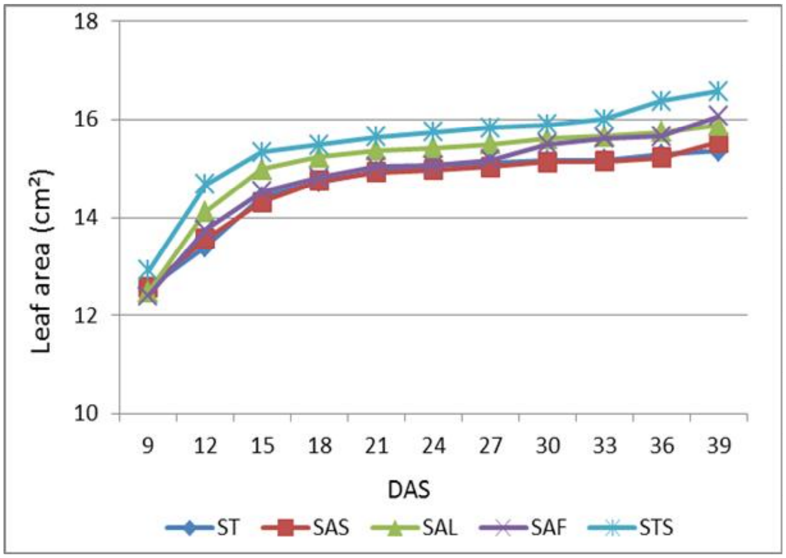

Fig. 5. Leaf area variation per plant in different treatments

Top roots length ranged from 13.7 to 21 cm. The longest roots are found in SAS treatment, follow by SAL, STS and SAF treatments. The control treatment recorded the shortest roots while the STS roots are the more ramified (in average 8 lateral roots by plant) followed by that from SAF, SAS and SAL treatments. Control roots are the less ramified (in average 6 lateral roots).

Table 4. Main root length and root ramifications number in different treatments

Treatments	Main root length (cm)	Root ramifications number
ST	13.7	6
SAS	21	7
STS	20.14	8
SAL	18.42	7.5
SAF	18.74	6.5

3.3 Yield Parameters

The flowering duration is strongly affected by different type of clay application (Fig. 6). During the flowering period, the control recorded a maximum 7 flowers with a flowering period duration of 15 days; the SAS and SAF display respectively 6 and 8 flowers with 20 days of flowering period duration. The SAL recorded 8 flowers for 23 days of flowering period duration, and eight flowers were recorded in STS for 20 days of flowering. The differences between flowering duration treatments lead to differences in bean production per plant (Fig. 7).

The maximum number of matured pods in a plant and the maximum number of grains by pods are obtained in amended treatments. There were some similarities in grain weight in different treatments. The cumulated seeds weight by plant (Fig. 8) showed that controls plants produce on an average 1.52 g/plant which is the less production by plant. The highest values are observed in SAL (5.45g) and SAF (3.63g) treatments. The cumulated seeds weight by plant had lead to the yield estimation in hectare under the conditions of bean's crop in greenhouse: 60 plants per meter square (Table 5).

SAS and STS treatments display similar yields respectively 1.782 and 1.791 ton/hectare respectively, while SAL and SAF have the best yields (3.267 and 2.232 ton/hectare, respectively). Control recorded 0.912 ton/hectare. The amended soils produced in average 2.5 times higher than the control.

Table 5. Yield in different treatments (ton/hectare)

Treatments	Series 1	Series 2	Average
ST	0.912	0.912	0.912
SAS	2.304	1.260	1.782
STS	2.66	3.87	3.267
SAL	1.944	2.52	2.232
SAF	2.214	1.368	1.791

3.4 Statistical Analyses

Statistical results are presented in Pearson's correlation matrix (Table 6). Significant relationships are observed between measured parameters: Stem length (SL) and maximal leaves number per plant (0.875); number of pods at maturity per plant (NP) and leaves number per plant (0.960); YP and maximal leaves number per plant (0.938); root ramifications and leaf area (0.871); SL and NP (0.924); SL and YP (0.930); root length and number of seeds per plant (0.904); NP and YP (0.997). One can observe relationships between some growth attributes and yield parameters such as YP and maximal leaves number per plant; yield and stem length. So, stem elongated and stem with high leaves number produced best yield. Also, root ramification positively affected leaf area while number of seeds per plant is deeply affected by root length. The others correlations are not significant such as negative correlation between number of seed per pod and seed weigh (-0.572); Root length and seed weigh (-0.213). No correlation exists between NR and SB; between NR and SW.

4. DISCUSSION

4.1 Soils Characteristics

Ferruginous soils display a silty sand texture while swelling clay materials are clayey. These results confirm the clay content obtained in swelling clay materials which are generally higher than 40% [23,24,21,19]. The pH value of ferruginous soils (5.6) confirms the acidic nature of sandy soils as reported in many studies [10]. Swelling clay materials had a highest CEC compared to that of amended soils. This may be due to their mineralogical composition dominated mainly by swelling minerals (2:1 clays). It is reported in many studies that their CEC varies between 20 and 45 meq/100 g [21,19].

Ferruginous soils are usually sandy at the horizon surface with clay content globally less than 10% [25,26], this is consistent with the result of particle size analysis obtained from soil sample of Mafa Tchaboa. The fact that OM is relatively high in swelling clay materials may be due to their fine texture. OM of cultivated or non cultivated soils is widely dependent on soil mineralogy and their decrease is more rapid in sandy than in clayey soils [25,10]. The high C/N ratio is indicative of slow decomposition. The high dithionite extractable elements (Fe; Al; Mn; Si) in swelling clay materials may be due to accumulations because these materials are formed in low landscapes [19].

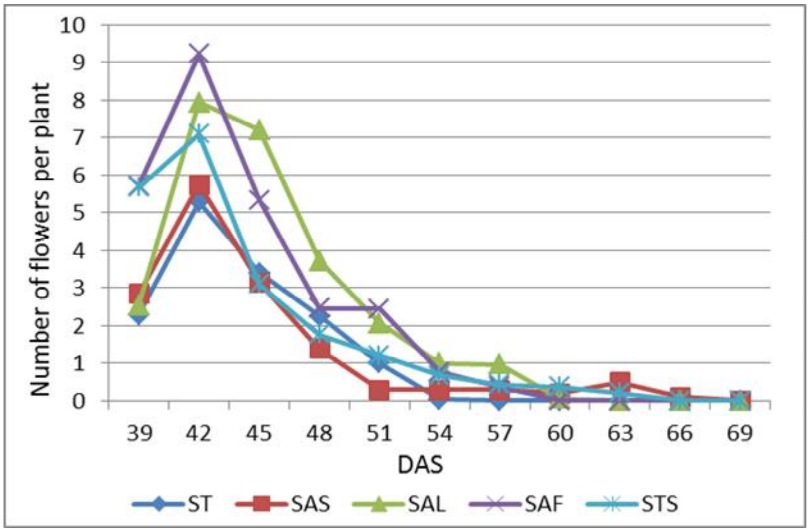

Fig. 6. Number of flowers per plant in different treatments

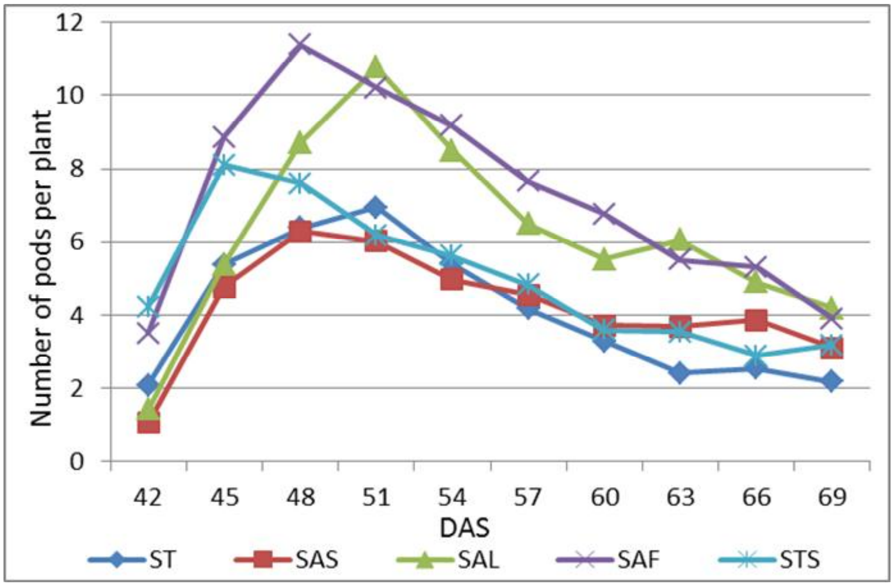

Fig. 7. Number of pods per plant in different treatments

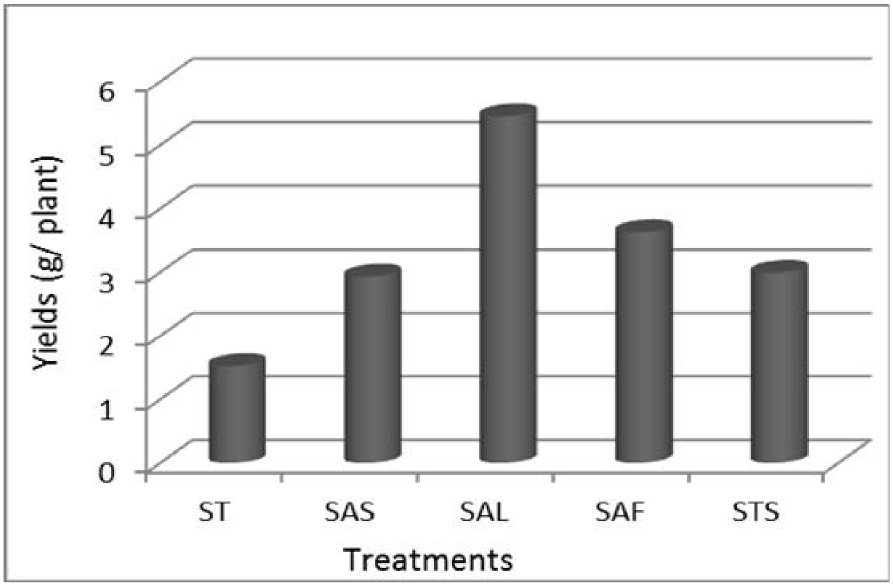

Fig. 8. Yield per plant in different treatments

X-ray patterns and IR spectrum showed that ferruginous soils are made up essentially of kaolinite; associated to quartz. The fact that these soils are developed on sandstone which naturally sand, can explain the importance of quartz in their mineralogy. It's reported in many studies that sandy soils are generally constituted of kaolinite as main clay mineral. In contrast, swelling clay materials are richer in smectites. Natural swelling materials are characterized by their high 2:1 clay content [20].

The predominance of SiO_2 in both samples is in accordance with an importance amount of quartz as observed in mineralogy particularly in ferruginous soils. The fact that Ba and Zr were high in ferruginous soil is the reflect of the composition of arkosic sandstone; parent rock in which these soils were developed. Br and Zr occur generally in sedimentary formations.

Table 6. Simple linear correlation matrix between beans growth parameters and beans yields components

Variables	LNP	LA	SL	SB	RL	NR	NF	NP	NSP	SW	YP
LNP	**1**										
LA	0,387	**1**									
SL	**0,875**	-0,011	**1**								
SB	0,598	0,328	0,608	**1**							
RL	0,733	0,334	0,541	-0,089	**1**						
NR	0,311	**0,871**	-0,181	0,000	0,467	**1**					
NF	0,752	0,777	0,447	0,757	0,345	0,638	**1**				
NP	**0,960**	0,351	**0,924**	0,592	0,712	0,174	0,653	**1**			
NSP	0,668	0,006	0,537	-0,157	**0,904**	0,277	0,192	0,579	**1**		
SW	0,062	0,480	0,126	0,504	-0,213	0,000	0,310	0,253	-0,572	**1**	
YP	**0,938**	0,329	**0,930**	0,596	0,685	0,124	0,621	**0,997**	0,539	0,303	**1**

Values in Bold character are significantly correlated at the level of 8%, LNP: leaves number per plant; LA: leave area; SL: stem length; SB: stem branches; RL: root length; NR: number of root ramifications; NF: number of flowers; NP: number of pods at mtaturiy; NSP: number of seeds per pod; SW: seeds weigh; YP: yield per plant

4.2 Growth Parameters

The germination of bean in the treatment SAS occurs two days after that of others treatments. Therefore it can be deduced that mixing the soil with 300 g of swelling clays materials does not give a preferential treatment to faster shot up. This fact might be due to soil compaction by swelling clays materials incorporation which makes late the spreading out of cotyledons during the germination.

The results on growth characteristics (number and size of leaves; main nervure length; stem length and root system development) showed that the best growth is observed in soils amended with swelling clay materials compared to control. This means that the use of swelling clay materials contributes to improve physicochemical qualities of the ferruginous soils. In fact, adding swelling clay materials at the surface or their incorporation in sandy soils increases their CEC on one hand and on the other hand the nutrients rate and water holding capacity which contributes to increase the growth of leaves, stem and root development. The water retention capacity of these swelling materials is high due to the presence of smectites [24,27,28]. Indeed, the use of swelling clay materials contributes to improve the water retention capacity of ferruginous soils. Some authors have reported that the addition of clay materials in sandy soils limits percolation losses while maintaining adequate infiltration rate and water retention [29,10,11]. Exchangeable sites are occupied mainly by Ca and Mg [30,24,19] which take part in growth and beans yield by increasing soil useful reserve. Smectites were also recognized for their strong anti-acid properties due to their ability to adsorb protons at their surface [19]. Swelling clay materials used in the present are formed in low landscape positions which are favorable for the accumulations of bases [31,32]. An important increase of leaves characteristics in the treatment SAF around the 27 DAS is observed as a consequence of the clay application at 24 DAS stage.

The "*Phaseolus vulgaris*" growth stage is significantly influenced by soil water regime. Intense radiations coupled with the high temperature increase plant transpiration rate which can cause water stress because plant water status is a function of the available water in the soil [33]. Water stress during the vegetative period decreases photosynthesis rate and stomacal behavior, affecting plant height and leaf area. Moreover, around the fair midday, an impact of evaporative demand is imposed on plant water balance and the competitive relationship between the higher evaporative demand and transpiration induces the water deficit in which 10% of shoot water content is lost [17]. The leaf area represents the photosynthesis surface; his reduction implies a decrease in dry matter accumulation [34]. According to the fact that sandy soils has less retention capacity; the plant is affected by hydraulic stress which reduces plant growth. Similar results were obtained by some authors who studied the relationships between plant growth and soil moisture [35,36,37]. Since the leaves of control plants are the first to turn yellow, this indicates that an application of clay materials contributes to hold leaf chlorophyll and reduces falling off. [38] have concluded in the study of the effect of water deficit on soybean leaf characteristics that water deficit accelerates leaves senescence by reducing nitrogen and chlorophyll content.

The differences between swelling clay application induced differences in root development system and the addition clay induced intensively root elongation and root proliferation. These differences may be due to soil water retention because low water retention reduces root system size and they are more developed when soil moisture is high [17]. The fact that the plants of STS are the most ramified can be explained by the presence of clay at the hole of sowing which increases soil moisture around the first roots. Several studies showed that roots growth intensively and branches profusely when they encounter areas high in moisture due to the less resistance of these areas [39,17,40]. The SAS and STS plants have the longest roots means that roots length increases with faster clay application. The application of swelling materials was thought to facilitate bean root system development by enhancing nutrients and moisture availabilities. More rapid nutrients acquisition responses may occur during moisture condition when nutrients become more available for plant growth [41]. So, high soil moisture created more suitable conditions to root proliferation which is in agreement with the results reported by [17] and by [40].

4.3 Yield

Yield results have shown clearly that the maximum number of matured pods and yield per plant were observed in amended soils (Fig. 8). The clay application increases their water retention on one hand and their nutrients stock on the other hand which promotes bean growth in amended soils (SAS; SAL; SAF and STS). Topomorphic vertisols are recognized as chemically fertile soils due to accumulations and retention of some nutrients [32,24,21,19]. It seems that the improvement of physicochemical characteristics of sandy soils increases physiological processes in plants. The soil water status directly affects the yield of bean plants which depends on the vegetative stage [34]. Clay application increased moisture and nutrients availabilities and contributed to increase bean yield in amended soils. In fact, the control is a sandy soil, and therefore has a low water holding capacity and nutrients rate which lead to reduce flowers production and pod production. The flowering stage and pod appearance are more sensitive to water deficit; the highest consumption of water by bean plants occurs during this period [34]. The beans plants need transpiration to produce yield and insufficient water supply for transpiration causes physiological alterations affecting yields [42,43,44,35,33,34]. Similar results on the positive effect of the soil amendment with clay materials on soil moisture were pointed out by some authors [11,39,17,10].

4.4 Interrelationships between Measured Parameters

The correlations between parameters showed that the leave area is a function of roots branches; the yield is a function of maximal number of leaves per plant and stem length. The development of aerial bean part has important effect on yield per plant because the photosynthetic organs play a crucial role on crop yield. Also, leaf area is affected by root ramifications.

5. CONCLUSION

An important improvement of the fertility of ferruginous soils of Mafa Tcheboa is obtained through an addition of swelling clay materials. This improvement resulted in an increase of length and ramifications of stem; densification and extension of leaves; development of root system and an increase of bean yield in amended soils; these soils produced on an average 2.5 times higher than the control. The best periods for applying swelling clay materials are germination and flowering stages. These results allow reporting that an application of swelling clay materials can be a substitute for chemical fertilizers under our conditions and also that they can be used to lower farmer’s costs and mitigate the negative effects of chemical fertilizers on the environment. The overall results indicate that amendment of ferruginous soils of Mafa Tcheboa by swelling clay materials is a promising solution to improve their fertility and increase crop yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. Les engrais et leurs applications. 4e édition, Rabat; 2003.

2. Yemefack M, Nounamo L, Njomgang R, Bilong P. Effects of natural fallow on topsoil properties and subsequent crop yields in a forest Oxisol of Southern Cameroon. Communication at the 17th WCSS, 14-21 August 2002, Thailand; 2002.
3. Bationo A, Kihara J, Vanlauwe B, Waswa B, Kimetu J. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agricultural system; 2006. DOI: 10. 1016/j.agsy.2005.08.011.
4. Ibrahima A, Nguetnkam JP, Pabame P, Tchimbi B, Gadawa G. Soil degradation in the soudano-guinea savannas of Mbe, Cameroon: Farmer's perception, indicators and soil fertility management strategies. Research Journal of Agriculture and Biological Sciences. 2007;3(6):907-916.
5. Masse D. Change of use of land in agro-systems in sub- Saharan Africa: Soil Properties and dynamics of organic matter. Mémoire HDR. Institut National Polytechnique. 2007;82.
6. Van der Pol. Soil mining and unseen contributor to farm income in Southern Mali. Amsterdam royal tropical Institute; 1992.
7. Sanchez PA, Shephend KD, Soulé MJ, Place FM, Mokwunye AU, Buresh RJ, Kwesiga FR, Izac AN, Woomer PL. Soil fertility replenishment in Africa: An investment in natural resource capital. In Buresh RJ, Sanchez PD. (éd). Replenishing soil fertility in Africa. Madison, USA, Soil Science Society of America and American Society of Agronomy, SSSA Special publication; 1997.
8. Driessen P, Deckers J, Spaargaren O, Nachtergaele F. Lecture note on the majors soils of the world. FAO world soil, Ressources report num. 2001;94:334.
9. Brabant P, et Gavaud. Soil and land resources in northern Cameroon. ORSTOM. 1985;369.
10. Mojid MA, Mustafa SMT, Wyseure GCL. Growth, yield and water use efficiency of wheat in silt loam-amended loamy sand. J. Bangladesh Agril. Univ. 2009;7(2):403-410.
11. Croker J, Poss R, Hartmann C, Bhuthorndharaj S. Effects of recycled bentonite addition on soil properties, plant growth and nutrient uptake in a tropical sandy soil. Kluwer Academic Publishers. Plant and soil. 2004;267:155-163.
12. Noble AD, Ruaysoongern S, Penning de Vries FWT, Hartmann C, Webb MJ. Enhancing the agronomic productivity of degraded soils in Notheast Thailand through clay-based interventions. In: Water and Agriculture. eds., Seng V, Craswel E, Fukai S, Fischer K. ACIAR proceedings No. 2004;116:147-160
13. Harper RJ, Gilkes RJ. Soil attributes related to water repellency and the utility of soil survey for predicting its occurrence. Australian Journal of Soil Research 1994;32:1109-1124.
14. Reuter G. Improvement of sandy soils by clay substrate application. Applied Clay Science. 1994;9.107-120.
15. Obst C. Non-wetting soils: Management problems and solutions at "Pineview". Mundulla. The theory and practice of soil management for sustainable agriculture. Wheat research council workshop. Australian government publishing service; Canberra; 1989.
16. Carter DJ, Gilkes RJ, Walker E. Claying of water repellent soils: Effects on hydrophobicity, organic matter and nutrients uptake. Procedings of World Congress of Soils Science; Montpellier, France. 1998;2:747.
17. Ismail SM, Ozawa K. Improvement of crop yield, soil moisture distribution and water use efficiency in sandy soils by clay application. Appl. Clay Sci. 2007;37:81-89.
18. Djoufac WE, Elimbi A, Panczer G, Nyada R, Njopwouo D. Physico- chemical and mineralogical characterization of vertisols Garoua (Northern Cameroon). Cachan, France. Annales de chimie. 2006;31(1):75-90.
19. Azinwi PT, Djoufac Woumfo E, Bitom D, Njopwouo D. Petrological, physic-chemical and mechanical characterization of the topomorphic Vertisols from the Sudano-sahelian Region of North Cameroon. The Open Geology Journal. 2011;5:33-55.
20. Ekodeck GE. Nature and geochemical behavior of swelling formations of northern Cameroon. Thèse Doct 3e cycle, Université de Grenobles. 1976;182.
21. Nguetnkam JP. Clay vertisols and soils fersialitic far northern Cameroon: Genesis crystal-chemical and textural properties, types and application to the discoloration of vegetable oils. Thèse Doct d'Etat, Université de Yaoundé I, Cameroun. 2004;216.

22. Jackson ML. Soil chemical analysis. Advanced course (M. Jackson, editor). University of Wisconsin, Madison, USA; 1975.
23. Bhatt M, Chanda SV. Prediction of leaf area in *Phaseolus vulgaris* by non destructive method. Bulg. J. Plant Physiol 2003;29:96-100.
24. Raunet M. Some morphopedological key for Northern Cameroon for use by agricultural scientists. CIRAD, Montpellier. 2003;24.
25. Boli Baboule Z. Operation of sandy soils and optimization of cultural practices in the Sudan region of northern Cameroon (experimentation erosion plots Mbissiri field). Thèse de doctorat en Sciences de la Terre à l'Université de Bourgogne. 1996;344.
26. Feller C, Fritsch E, Poss R, Valentin C. Effect of texture on the storage and dynamics of organic matter in some ferruginous and lateritic soils (in West Africa in particular). Cah. ORSTOM, Sér pédol. 1991;26(1):25-36.
27. Coulombe CE, Dixon JB, Wilding LP. Mineralogy and geochemistry of vertisols. American Journal of Soil Science, New York. 1999;15-20.
28. Seiny B, Floret C, Moukouri KH, Pontanier R. Degradation vertisols in Northern Cameroon: Modification of water regimes of land and attempt to rehabilitate. IN Utillisation rationnelle de l'eau des petits versants en zone aride. Ed AUPELF-UREF. Paris. 1991;287-294.
29. Al-Darby AM. The hydraulic properties of sandy soil treated with gel forming soil conditioner. Soil Technology. 1996;9:15-28.
30. Grunwald S. Vertisols: Environemental conditions, processes, pedogenetic models, properties and classification. Journal of Soil and Water Siences. Uni Florida, IUSS Soil bull. 2003;104:1-24.
31. Yerima BPK. Weathering and genesis of volcanic ash-influenced vertisols and vertisollike soils of El Salvador. Master's thesis, Texas A and M University, Texas, USA. 1983;247.
32. Duchaufour Ph. Abstract Soil Science. Masson (Eds), Paris. 1997;492.
33. Ramirez Builes Victor Hugo. Plant-water relationships for several common bean genotypes (*Phaseolus vulgaris* L.) with and without drought stress conditions. Master of sciences, University of Puerto Rico 2007;190.
34. Durigon Angelica. Soil-plant-athmosphère water transfert mechanism and their relation to crop water stress. Thesis of Doctorate, University of Sao Paulo, "Luiz de Queiroz" college of agriculture; Piracicaba. 2011;143.
35. Renquist AR, Breen PJ, Martin DW. Influence of water status and temperature on leaf elongation in strawberry. Scientia Horticulturae. 1982;18:77-85.
36. Roberts J, Nayamuth RA, Batchelon CH, Soopramanien GC. Plants water relations of sugareane (*Saccharum officinarum* L) under a range of irrigated treatments. Agricultural Water Management. 1990;17:95-115.
37. Hoffmann HP, Turner DW. Soil water deficits reduce the elongation rate of emerging banana leaves but the night/day elongation ratio remains unchanged. Scientia Horticulturae. 1993;54:1- 12.
38. De Souza PI, Egli DB, Bruening WP. Water stress during seed filling and leaf senescence in soybean. Agron J. 1997;89:807-812.
39. Al-Omran AM, Sheta AS, Falatah AM, Al Harbi AR. Effect of drip irrigation on squash (*cucurbita pepo*) yield and water use efficiency in sandy calcareous soils amended with clays deposits. Agricultural Water Management. 2005;73:43-55.
40. Almarshadi MS, Ismail SM. Improving light textured soil properties by water regimes and soils amendments under dry land conditions. Life Sci J. 2014;11(4):264-270.
41. Pedro Salvador Jorge M. Biomass production, nutrients and root characteristics of fallow species and the utilization of its biomass as a phosphorus source for the common bean (*Phaseolus vulgaris* L.). Ph.D thesis, University of Wales Bangor; 2005.
42. Ritchie JT. Efficient water use in crop production: Discussion on the generality between biomass production and evapotranspiration. In: Limitations to efficient water use in crop production. Edited by Howard M. Taylor, Wayne R. Jordan and Thomas R Sinclair. American society of agronomy/crop science society of America/soil science society of America. 1983;29-44.
43. Beebe SE, Rao IM, Blair MW, Acosta-Gallegos JA. Phenotyping common beans for adaptation to drought. Frontiers in plant

physiology 4. 2013;35(1-20). DOI: 10.3389/fphys.2013.00035.

44. Ghanbari Ali A, Mohammad Reza S, Mahmood Toorchi. Rajab Choukan. Nitrogen changes in the leaves and accumulation of some minerals in the seeds of red, white and chitti beans (*Phaseolus vulgaris*) under water deficit conditions. Australian Journal of Crop Sciences. 2013;7(5):706-712.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=779&id=24&aid=7181