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Full Length Research Paper

Soil attributes in agricultural uses and in the Semiarid RN-Brazil in eutrophic Cambisol

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Soil attributes are an important tool to identify appropriate practices for crop management. This study aimed at evaluating physical, chemical and mineralogical properties of soil in agricultural uses, regarding its potential and/or restrictions in the municipality de Governador Dix-Sept Rosado (RN). Soil samples with deformed structure were collected with the aid of an auger Dutch-type zigzag layers in the 0.00-0.10; 0.10-0.20 and 0.20-0.30 m layers. Four composite soil samples, derived from 15 subsamples, were collected in: native forest (AMN), orchard cajaraneiras (AP), a traditional cropping area (AC), and an area of colluvium (ACOL). Samples were placed in plastic, bags identified and referred to the Laboratory Analysis of Soil and Plant Water LASAP/UFERSA. Subsequently, samples were air dried, broken into smaller pieces, and sieved through 2.0 mm mesh to obtain the dried soil air (TFSA) for physical, chemical and mineralogical analyzes. Results were submitted to Principal Component Analysis (Multivariate Statistics) to distinguish attributes in different agricultural uses. The first factor generated for soil properties in the areas surveyed explained 48.33% of the total variation in the studied area, and the highest correlation coefficients (≥ |70|) identified were the variables: sand, silt, pH, Ca^{2+}, H+Al, SB, T, T, V in the layer 0.00-0.10 m. These variables are probably influenced by the source material, and consequently the management practices adopted in farming areas. Primary minerals type 2:1 such as illite and mica in the horizon A and the horizon Bi predominated in diffraction peaks of X-ray, which can be justified by the presence of clay minerals in the clay fraction, young soil characteristics and limited weathering. Properties differed between areas, and presented physical limitations on the soil resistance to penetration, and have excellent chemical characteristics such as high levels of exchangeable calcium and total organic carbon.

Key words: Mineralogical analysis, diffraction, environment, different management.

INTRODUCTION

Soil is an unconsolidated material and a product of action of physical, chemical and biological weathering. It contains living matter and can be vegetated. Soil consists of near parallel sections, arranged in horizons, or layers, that differ from the original source material. The horizons reflect soil formation processes from weathering of bedrocks or various types of sediment. The layers, however, could be to a limited extent affected or not by pedogenetical processes; maintaining in greater or lesser extent the characteristics of the original source material (Santos et al., 2013). The soil should be seen as a fundamental source of national wealth, because it contains minerals and organic materials indispensable to the existence of agriculture and livestock activities (Bertone and Lombardi Neto, 2010).

The degradation of soil's physical and chemical properties is one of the main processes responsible for the loss of structural quality, increased erosion and consequent reduction of its productivity. Some soil management practices cause changes in soil properties, mainly in its structure. Such changes may be permanent or temporary (Bertol et al., 2012). Depending on the level of degradation, intensive use of the soil, without observing agricultural suitability and lack of conservation practices, contributes to soil degradation processes (Tavares Filho et al., 2012). This study was conducted to evaluate physical and chemical properties of the soil on the basis of various agricultural uses, aiming to identify the potential use, and restrictions and conservation in Terra de Esperança Settlement Project in the Chapada do Apodil, located in the municipality of Governador Dix-Sept Rosado (RN).

MATERIALS AND METHODS

Study area

The study was conducted from November 2013 to May 2014 on the Terra da Esperança Settlement Project, located in the municipality of Governador Dix-Sept Rosado in the state of Rio Grande do Norte. It is located in the meso-region Oeste Potiguar, micro-region Chapada do Apodi, in the Brazilian semiarid region.

The city of Governador Dix-Sept Rosado islocated at coordinates; 05°27'32.4" S and 37°31'15.6" W. Its boundaries are the municipalities of Baraúna, Natal, Upanema, Caraúbas, Felipe Guerra, Apodi and the state of Ceará, covering an area with 1,263 km². Its climateis hot (indicate mean annual temperatures for summer and winter), semi-arid with an average rainfall of 712 mm during the months from February to May (Beltran et al., 2005).

The rural settlement consists of 113 families located on 6,297 ha, consisting of agro-ecological land and a forest reserve (20% legal reserve). Also indicate typical natural vegetation found in this area (– as it influences the soil characteristics, structure and mineral composition through cation exchange).

Study sites

The study was conducted in four areas with each having unique characteristics concerning management and agricultural use. One hectare from each study area was selected: (01) a traditional cropping area (CA) with tillage (one plowing and two diskings), and maize and cowpea intercropping; (02) a colluvium area (ColA), in a lower area cut by a temporary stream, which is responsible for the saturation of the site (the cultivation area is only worked at the end of the rainy season, when soil moisture decreases); (03) a trees cajaraneiras orchard area (SA), with numerous trees cajaraneiras of the genus *Spondia* (the harvesting of cajaraneiras occurs from mid-February to April; these plants are deciduous during this period, with little or no foliage, or inflorescences, and with dry leaves and fruit kernels shed, resulting in an increase of organic matter in the soil); and (04) a native forest area (NFA), with species from the hyper-xerophilic Semiarid RN-Brazil: *Combretum leprosum* L. ("mofumbo"), *Astronium fraxinifolium* (Aroeira), *Croton sonderianus* M. Arg. and *Mimosa hostilis* B. (Jurema-preta). In Mid-November 2013, the Semiarid RN-Brazil was in a good condition, with plant residues on soil surfaces even after a prolonged drought.

Data collection

Soil samples with deformed structures were collected with the aid of a zigzag Dutch type auger in the 0.00-0.10, 0.10-0.20 and 0.20-0.30 m layers, being four samples of soil from 15 subsamples of each area (CA, ColA, SA and NFA). The samples were placed in plastic bags, identified and forwarded to the Soil Analysis Laboratory. Subsequently, the samples were air-dried, soil clods were broken, and then sieved with 2.0 mm sieves to obtain an air-dried fine-ground (ADFG) in preparation of physical, chemical and mineralogical analyses.

The particle size distribution was obtained with a pipette using the chemical dispersant sodium hexametaphosphate in distilled water and 20 g of ADFG, with slow mechanical agitation in a shaker (Wagner 50 rpm) for 16 h (Donagema et al., 2011). The sand (2.00-0.05 mm) was measured by sieving; the clay (<0.002 mm) by sedimentation, and the silt (0.05-0.002 mm) by the difference between the sand and clay fractions.

The particle density analysis (ρ_p) was made with the volumetric flask method using greenhouse-dried fine-ground (GDFG) at 105°C and ethanol (Donagema et al., 2011):

$$\rho_p = \frac{m_s}{V_p}$$

Where: ρ_p = particle density (kg.dm^{-3}); m_s = dry mass at 105°C (kg); and V_p = solid volume (m³).

To evaluate mechanical resistance to soil penetration (MRSP), readings were taken directly into the ground in each treatment with a static penetrometer with a 1.28 cm diameter ferrule and a 1,287 m^2 cross-sectional area. Soil resistance readings were taken concurrently to penetrating the layers at 0-0.10, 0.10-0.20 and 0.20-0.30 m, at random locations within each area, taking as a reference the average of 30 reading repetitions. The results were expressed in kPa (Foster and Meyer, 1977). At the same time, soil samples were collected for evaluation of moisture for gravimetric measurements at the above-mentioned depths. The gravimetric water content (GWC), based on mass was obtained by the equation:

$$GWC = \frac{wsm - dsm}{dsm} * 100$$

where: GWC = gravimetric water content (%); wsm = wet soil mass (g.kg^{-1}); and dsm = dry soil mass (g.kg^{-1}).

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Table 1. Correlation coefficient of the main components (Factors 1 and 2) for physical and chemical attributes on the basis of potential and/or restrictions of agricultural uses in Terra da Esperança Settlement Project.

Variable	Layer (m)					
	0.00-0.10		0.10-0.20		0.20-0.30	
	F1	F2	F1	F2	F1	F2
Sand	0.82	0.49	0.84	-0.18	-0.83	0.47
Silt	-0.86	-0.26	-0.73	0.23	0.82	0.16
Clay	-0.64	-0.58	-0.85	0.12	0.65	-0.69
Dp	0.63	-0.6	0.04	-0.36	-0.53	-0.59
pH	-0.83	0.28	-0.93	-0.21	0.92	-0.06
EC	-0.47	0.66	-0.31	0.77	0.56	0.25
TOC	-0.32	0.78	-0.65	-0.24	-0.06	0.25
P	-0.56	-0.18	-0.95	-0.07	0.37	-0.56
K	0.32	0.76	0.15	-0.23	0.08	0.83
Na	-0.45	0.5	-0.46	0.59	0.37	0.28
Ca	-0.98	-0.07	-0.99	-0.03	0.98	-0.03
Mg	0.43	-0.4	-0.03	-0.75	-0.1	0.22
H+Al	0.81	-0.22	0.86	0.1	-0.92	-0.11
SB	-0.91	-0.19	-0.96	-0.2	0.96	0.05
t	-0.91	-0.19	-0.96	-0.2	0.96	0.05
T	-0.81	-0.28	-0.92	-0.22	0.9	0.02
V	-0.81	0.22	-0.88	-0.13	0.92	0.12
PST	-0.3	0.19	-0.45	0.66	0.17	0.53
Variance (%)	48.33	19.01	55.09	13.83	49.18	14.72
Accumulated variance (%)	48.33	67.34	55.09	68.92	49.18	63.9

Correlation coefficients > |0.70| are significant (Manly, 1994).

Soil consistency tests were determined based on the liquidity limits (LL) using the Casagrande apparatus, according to Donagema et al. (2011), and calculated by the equation: LL = GWC $(N/25)^{0.12}$, where LL is the liquidity limit ($g.100.g^{-1}$), represented by the gravimetric water content (%) adjusted to 25 device rotations; GWC is gravimetric water content ($g.kg^{-1}$), corresponding to the rotation of determination; and N is the number of rotations. The plasticity limit (PL) was determined with three replicates by withdrawing representative samples from the central part of the soil shear stress in the metal ball of the equipment. It comes from the determination of the liquidity limit, forming a ball that is pressed on a plate glass until forming a cylindrical rod with a 3.0 to 4.0 mm diameter without breaking or flowing. The gravimetric water content was determined in plasticity condition for soil rods. The plasticity index (PI) was determined by the difference between LL and PL.

The evaluated chemical elements were hydrogen potential (pH) in water, electrical conductivity (EC) in water, total organic carbon (TOC) by digestion of organic matter, exchangeable calcium content (Ca^{2+}) and exchangeable magnesium (Mg^{2+}) with a potassium chloride extractor. Potential acidity (H+Al) using calcium acetate, phosphorous (P), sodium (Na^{+}) and potassium (K^{+}) analyses were made with a Mehlich-1 extractor. Consequently, cation exchange capacity (CEC), base sum (BS) and base saturation (V) were calculated and analyzed according to Donagema et al. (2011).

In the mineralogical analysis, ADFG minerals, after being separated by sieving and sedimentation, were identified by X-ray powder diffractometry (XRPD). A diffractometer was used in the kα1 issuance of cobalt, with a wavelength of 0.17902 nm. The potential of the source was 40 kV and 30 mA current. A scan speed with a 0.02º pitch every second was used. The scanning range (2θ) was from 4° to 45° (Mehra and Jackson, 1958).

Multivariate analysis techniques, specifically Principal Component Analysis (Statistica, 2004), were used as a main tool to distinguish studied areas in the light of potential or environmental restrictions.

As agricultural use area distinction tools, two diagrams of the main components (Factor 1 and 2) were made for physical attributes (particle size and particle density) together with chemical properties (pH, EC, TOC, P, K, Na, Ca, Mg, H+Al, BS, t, T, V, PST).

RESULTS AND DISCUSSION

Factor 1 which was generated for the attributes of studied areas, explained 48.33% of the total variation of the studied attributes. The highest correlation coefficients (≥ |70|) identified were the variables; sand, silt, pH, Ca^{2+}, (H+Al), BS, t, T and V at a 0.00-0.10 depth (Table 1). These elements were more evident among agricultural uses.

In the 0.00-0.10, 0.10-0.20 and 0.20-0.30 m layers, the sand fraction was significant in Factor 1 (48.33, 55.09 and 49.18%, respectively) (Figures 1a, b and c). There was a variation in texture class according to the adopted management, because the native forest area presented a clay-sandy texture class, unlike the traditional cropping

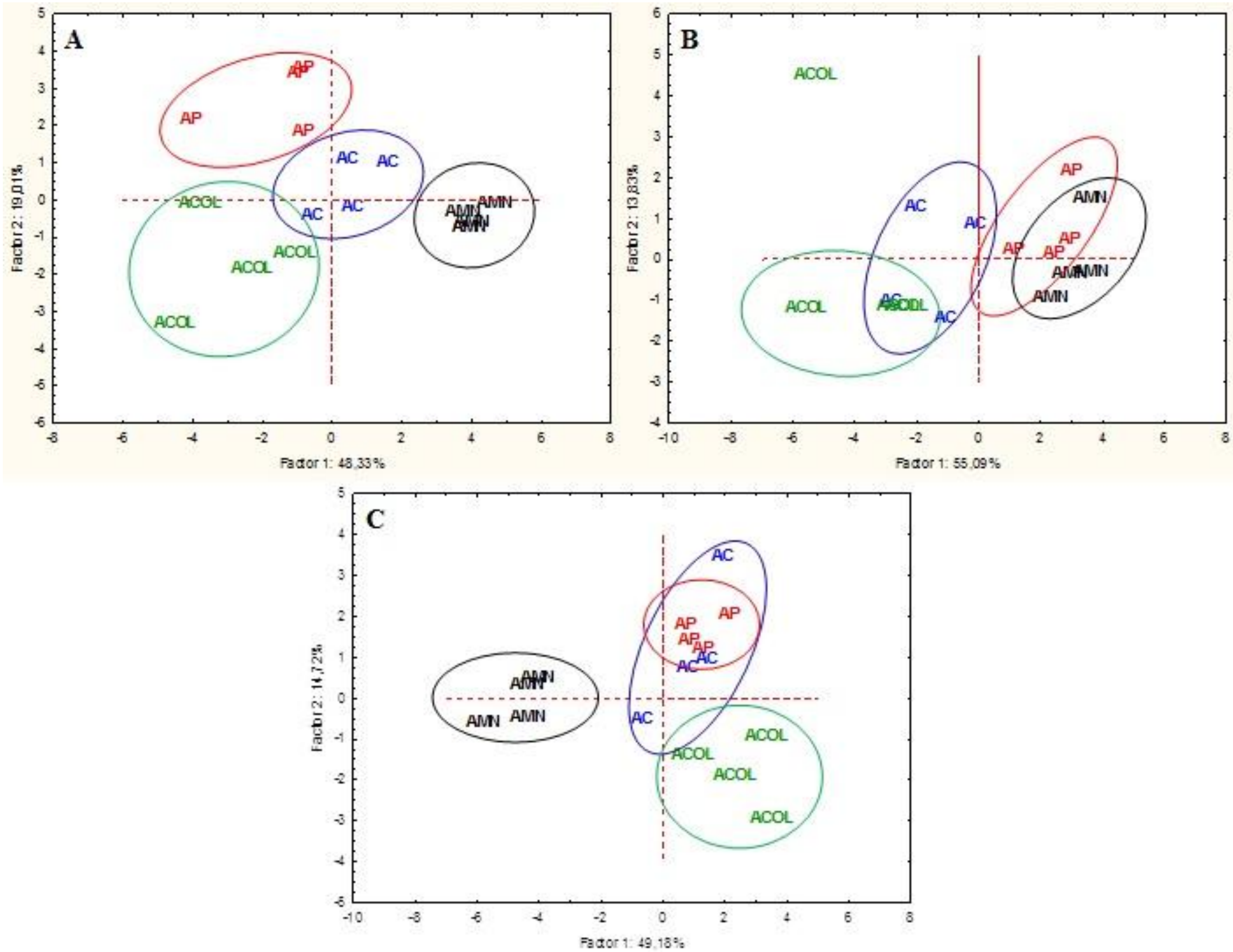

Figure 1. Ordination diagram of the main components of the native forest area (NFA), the Spanish plum orchard area (SA), the traditional cropping area (CA), and the colluvium area (ColA) in 0.00-0.10 m (A), 0.10-0.20 m (B) and 0.20-0.30 m (C) layers in Terra da Esperança Settlement Project.

area, the colluvium area (ColA) and the Spanish plum orchard area (SA), which showed a clay class texture (Table 2).

In NFAs, the sand fraction distinction is probably related to the preservation of the area over the years, since there was no disturbance of soil horizons via agricultural practices. It had contributions of plant residue to the surface, thus resulting the consolidation of surface material (Table 1). High sand fraction values were found in forest fragment soils when compared to degraded areas, being its significant values in the surface layer (Nogueira Junior, 2000).

The silt fraction was significant to distinguish the areas studied inside areas with agricultural use in the three analyzed layers (Table 1). In Table 2, a higher average of this fraction was observed in the colluvium area.

An increase in the silt fraction was found when a natural forest area was compared to an agricultural crop area, which supports the notion that an eroded soil can influence its texture. It is worth noting that soil texture changes occur over time, since its characteristics are difficult to be changed, because they are inherent to the original material. Silt fraction is very susceptible to water erosion, since the particles are small enough to be carried by active agents of erosion (Oliveira, 2009; Omuto, 2008).

The clay fraction was not significantly different over the studied areas. However, the areas surveyed showed a high clay content, with most areas with values above 35%, being texturally classified as clay soils (Table 2).

The clay soil fraction has colloidal properties (particle sizes less than 0.002 mm), and for this reason it is considered as an active fraction of soil due to its electric charges. However, it is more susceptible to compaction due to animal and machinery traffic, without observing essential criteria regarding inorganic fractions and water

Table 2. Physical attributes of the areas with agricultural uses in the Terra da Esperança Settlement Project.

Depth	Particle size			Texture classification	Dp	MRSP	GWC	Consistency		
	Sand	Silt	Clay					LL	LP	IP
m	-------kg.kg^{-1}-------				kg.dm^{-3}	kPa	----------------%-------------			
Native forest area										
0.00-0.10	0.514	0.113	0.373	Sandy clay	2.59	1030.10	4.81	34.95	28.57	6.40
0.10-0.20	0.459	0.105	0.436	Sandy clay	2.56	1837.70	7.98	34.96	18.58	16.40
0.20-0.30	0.456	0.107	0.437	Sandy clay a	2.60	2122.20	8.80	35.91	25.69	10.20
Trees cajaraneiras orchard area										
0.00-0.10	0.437	0.188	0.375	Sandy clay	2.41	1366.90	5.37	37.09	32.06	5.00
0.10-0.20	0.361	0.176	0.463	Clay	2.48	1196.80	8.45	34.95	29.75	5.20
0.20-0.30	0.336	0.186	0.478	Clay	2.45	1478.04	10.73	38.66	27.75	10.90
Traditional cropping area										
0.00-0.10	0.394	0.152	0.454	Clay	2.49	941.76	3.76	38.28	27.98	10.30
0.10-0.20	0.369	0.15	0.481	Clay	2.50	1883.50	12.32	34.35	23.76	10.60
0.20-0.30	0.359	0.152	0.489	Clay	2.49	1978.40	13.38	33.57	26.35	7.20
Colluvium area										
0.00-0.10	0.209	0.245	0.546	Clay	2.53	941.76	2.83	41.25	25.69	7.00
0.10-0.20	0.208	0.216	0.576	Clay	2.54	1883.50	8.61	39.97	31.65	8.30
0.20-0.30	0.195	0.181	0.624	High contents of clay	2.56	1978.40	10.71	39.51	32.49	7.00

content in the soil (Santos et al., 2009).

Regarding mechanical resistance to penetration (MRP), there was a tendency of increased values in trees cajaraneiras orchard areas (PA) and in native forest areas (NFA) in the 0.00-0.10 m layer: 1,366.90 kPa and 1,030.10 kPa, respectively (Table 2). In the 0.10-0.20 m layer, all studied areas presented values close to 2,000 kPa, considered as critical for root growth. This was also observed in the 0.20-0.30 m layer (Table 2). Such values of mechanical resistance to penetration in the deepest soil layers may be associated to low humidity and consequent packing of granulometric fractions of the soil (mainly clay), since the clay fraction obtained high averages considering depth (Table 2). Cruz et al. (2014) observed elevated MRP values regarding depth due to the clay fraction present in the soil, with critical values at 0.40 m in natural savanna areas in the state of Roraima. The compression indexes are divided according to the following: 0 - optimal environment or not limiting rooting (MRP <1000 kPa); 0.5 - good environment, with little limitation to rooting (MRP between 1000 and 2000 kPa); 1 - environment restrictive to rooting and not suitable for plant growth (MRP >2000 kPa) (Gomes and Filizola, 2006).

Low gravimetric water contents (GWC) were observed, possibly due to the dry season in the region. The following water content percentages were observed: GWC = 2.83% (lowest value) in the colluvium area, and GWC = 13.83% (highest value) in the conventional area (Table 2). This may have influenced cohesive forces of soil particles that are intensified in the dry season and certainly provided a greater mechanical resistance to penetration. Gravimetric water content values were lower in the CA (941.76 kPa) and ColA (941, 76 kPa) in the 0.00-0.10 layer, and higher in NFA (2122.20 kPa), PA (1978.40 kPa) and ColA (1978.40 kPa) in the 0.20-0.30 m layer, certainly due to the amount of clay in the subsurface and its water content retention capacity in the structural arrangement.

Regarding the liquidity limit (LL), the percentage of soil moisture needed to reach that threshold was observed (Table 2). This indicates that, upon achieving this percentage, the soil has no fluidity. From the moment that water content increases, certainly the soil will become saturated, occurring soil fluidity. Considering the percentage of humidity in the plasticity limit (PL), the soil will have reached its maximum water content capacity without compromising the structure. In ColA, the values of LL and PL were higher, influenced by the increase of clay in the underlying layers (Table 2). This increase in plasticity limits in the studied areas requires certain attention to crops and soil management with respect to excessive tillage influencing soil structure. Its physical properties are easily modified by the improper use, becoming thus difficult for the soil to be recovered. However, the sooner a set of practices aimed at maintaining and/or improving conservation on the ground is adopted, the better. Gravimetric water content found in PL is due to the increase in the clay fraction, increasing thus water retention in the soil micro-pores (Luciano et al., 2012).

As to the plasticity index (PI), its value was between 7

Table 3. Chemical attributes of areas with agricultural use in the Terra da Esperança Settlement Project.

Depth (m)	pH (water)	EC ($dS.m^{-1}$)	TOC ($g.kg^{-1}$)	P ($Mg.dm^{-3}$)	K^+	Na^+	Ca^{2+}
					----------- $cmol_c.dm^{-3}$	-----------	-----------
Native forest area							
0.00-0.10	6.95	0.07	37.60	0.38	0.27	0.03	11.54
0.10-0.20	6.63	0.03	28.93	0.28	0.19	0.02	9.29
0.20-0.30	6.59	0.02	27.79	0.58	0.17	0.03	9.27
Trees cajaraneiras orchard area							
0.00-0.10	7.95	0.29	125.97	4.48	0.33	0.08	18.26
0.10-0.20	6.63	0.03	28.93	0.28	0.19	0.03	9.29
0.20-0.30	7.78	0.06	26.42	0.13	0.27	0.04	15.63
Traditional cropping area							
0.00-0.10	7.41	0.06	31.98	1.43	0.32	0.07	15.11
0.10-0.20	7.59	0.03	29.79	1.84	0.26	0.08	15.14
0.20-0.30	7.55	0.02	27.16	1.78	0.21	0.06	15.98
Colluvium area							
0.00-0.10	7.79	0.14	32.55	9.01	0.17	0.06	19.80
0.10-0.20	8.03	0.04	29.86	2.53	0.14	0.05	17.53
0.20-0.30	8.01	0.04	26.92	5.53	0.11	0.04	17.44

Mg^{2+}	Al^{3+}	H+Al	BS	CEC	V	PST
----------- $cmol_c.dm^{-3}$	-----------	-----------	-----------	-----------	----------- %	-----------
Native forest area						
3.61	0.00	1.89	15.46	17.35	89.13	0.00
2.40	0.00	2.07	11.91	13.98	85.33	0.00
2.41	0.00	1.93	11.88	13.81	86.05	0.00
Trees cajaraneiras orchard area						
1.88	0.00	0.00	20.54	20.54	100.00	0.13
2.40	0.00	2.07	11.91	13.98	85.33	0.00
1.83	0.00	0.00	17.76	17.76	100.00	0.00
Traditional cropping area						
2.53	0.00	0.00	18.02	18.02	100.00	0.25
2.33	0.00	0.00	17.82	17.82	100.00	0.25
2.16	0.00	0.00	18.41	18.41	100.00	0.06
Colluvium area						
2.12	0.00	0.00	22.15	22.15	100.00	0.25
2.52	0.00	0.00	20.24	20.24	100.00	0.25
2.28	0.00	0.00	19.87	19.87	100.00	0.00

and 15 in most areas, indicating a moderately compressible type of clay (moldable). The plasticity of clay influences soil structures, especially when it is moistened beyond its capacity, with risks of compression if it is not properly handled. It is worth noting that the PI is a function of LL and PL by mathematical difference (Table 2).

The pH and the potential acidity (H+Al) were significant to distinguish the areas under study, especially NFAs (Table 1). It may be related to the greater abundance of vegetable waste from litter found in NFAs and to the dissociation of H^+ ions through organic acids, thus observing a lower pH when compared to other areas. In other areas with agricultural use, the pH had neutral to basic values. In the SA, this may have been influenced by the original source material. In ColA and CA, it may have been influenced by the fertilizer applied in previous years (Table 3). It should be considered that a neutral to basic pH may make some nutrients unavailable to plants (Souza et al., 2010).

The observed exchangeable calcium values varied in the areas with agricultural use for 0.00-0.10, 0.10-0.20 and 0.20-0.30 layers. They directly influenced the effective CEC results (t), CEC at pH 7.0 (T) and base

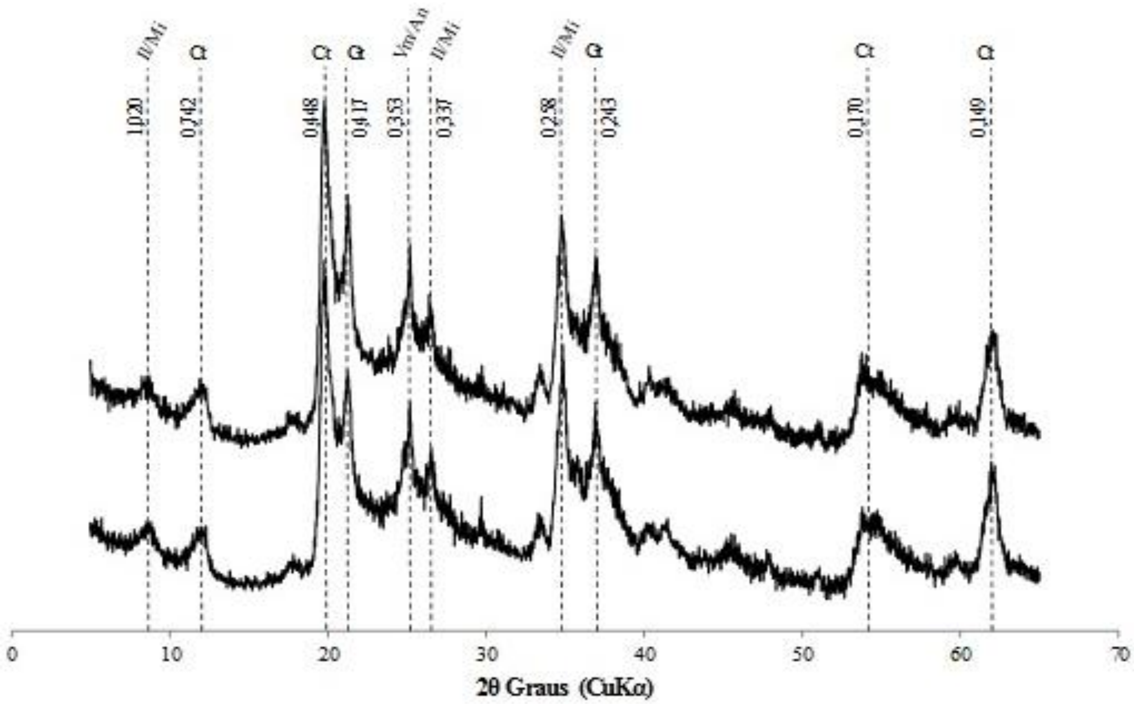

Figure 2. X-ray diffractometry of the clay fraction (natural) of eutrophic typical HAPLIC CAMBISOL profile, with interplanar distance in nanometers (nm). I1: Illite; Mi: Mica; Ct: Kaolinite; Gt: Goethite; Vm: Vermiculite; An: Anatase.

saturation (V) (Table 1). The exchangeable calcium values showed a variance of 48.33%, 55.09% and 49.18 on Factor 1 (with values of 0.98, 0.99, 0.98, respectively, in 0.00-0.10, 0.10-0.20 and 0.20-0.30 m layers) (Table 1). This behavior may probably be related to the original source material (jandaíra limestone), which, in the weathering process, dissociates calcium carbonate into the soil system. Because it is a semi-arid region, the environment has low weathering, irregular rainfalls and high temperatures, being conditioning factors for the maintenance of exchangeable bases (Beltran et al., 2005).

The cation exchange capacity at pH 7.0 (CEC) represents the nutrient release capacity favoring the maintenance of soil fertility. If most of the soil CEC is occupied by essential cations such as Ca^{2+}, Mg^{2+} and K^{+}, depending on the type of clay mineral from the original source material (jandaíra limestone), with predominance of clay minerals type 2:1 such as illite, mica and vermiculite, one can infer a larger natural soil fertility, especially in arid and semi-arid regions (Ronquim et al., 2010).

Base saturation values above 50%, as shown in Table 3, possibly indicate soil fertility conditions. Soils can be divided according to the percentage of saturation as eutrophic soils V% ≥ 50% and dystrophic soils V% < 50% (Ronquim et al., 2010).

The total organic carbon (TOC) in Factor 2 showed a correlation coefficient of 0.77 and a variance of 19.01%, being an important attribute to distinguish studied areas, mainly in the 0.00-0.10 m layer. High TOC values were observed mainly in Spanish plum orchard areas (SAs) in the 0.00-0.10 m layer, and lower values in other evaluated layers (Table 3). This may be related to the excess of plant organic materials found visibly (leaves and fruit cores). Another contribution may be related to animal grazing throughout the orchard area, releasing feces on the ground, a fact that may have influenced TOC values. In NFAs, the TOC showed high values and in CA and ColA low values. These values were nevertheless representative within an environment with semi-arid conditions (Table 3).

The X-ray diffractogram with 10-degree 2θ peaks and between 20 and 30-degree 2θ peaks (which indicates the occurrence of the primary mineral type 2:1 such as mica and illite), and in the Bi horizon are probably clay minerals that prevail in the clay fraction of studied areas, that is, characteristic of little weathered soils. The frequency of clay minerals found in horizons A and Bi may be related to its small thickness and to the intensity of weathering (Figure 2).

Conclusions

The attributes differed between areas and presented a physical limitation as to mechanical resistance to soil penetration and good chemical characteristics as to exchangeable calcium and total organic carbon. The soil properties influenced the distinction of areas with agricultural use due to local particularities.

Conflict of Interest

The authors did not declare any conflict of interests.

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Full Length Research Paper

Periods of competition between weeds and soybean crop in Cerrado

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This paper aimed to identify the periods of weed interference in soybean cultivar P98Y12, in the 2011/2012 harvest. The importance of this paper is that soybean is a commodity of great participation of the Brazilian economy and one of the largest contributions in the balance of exports. The assay was carried out in Oxisol, in the town of Campo Grande, Mato Grosso do Sul state, Brazil. The experimental design was a randomized block with four replications and fifteen treatments that consisted of periods of coexistence between the weeds and the crop. Additionally, phytosociological research was performed among the weeds. Under the conditions of the assay the Period Previous to Interference (PPI) was recorded at 7 DAE, the Critical Period for Prevention of Interference (CPPI) between 7 and 42 DAE and the Total Period for Prevention of Interference (TPPI) between emergence and 42 DAE. The infestation that occurred in the experimental area caused 90.42% of losses in grain yield. The weed species that showed the highest Importance Value Index (IV) were *Digitaria horizontalis* (94.2%) and *Ipomoea grandifolia* (71.9%).

Key words: *Glycine max*, grain production, productivity, weed competition, weed control, Brazil.

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is the most cultivated oleaginous crop in the world and one of the most commercialized commodities around the globe. According to Conab (2014), Brazil alone produced 86 million tons of this grain during the 2012/2013 harvest, in an area of approximately 30.1 million hectares, making the country the second largest producer of soybean worldwide. As with all crops, in order to achieve successful results and high grain yield, it is necessary to apply efficient and cost-effective production systems. Among many factors that integrate the production system, the management and control of weeds stand out, since the inefficient handling these, might decrease production (Pereira, 2004).

Pitelli (1985) classifies weeds as being those that emerge spontaneously in agricultural ecosystems, causing a series of interferences with the cultivated plants, which not only compromise productivity but also the execution of a chosen production system. Because of its soil and climate conditions, Brazil stands out as a

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country with a vast potential for soybean cultivation. However, the tropical climate is also very favourable to many weed species that interfere in the development and productivity of crops (Barros et al., 2000).

Weeds are competitive plants with aggressive characteristics that help them thrive and adapt to disturbed environments. Some of these features are the capacity to produce large quantities of seeds that can be easily disperse and have a long lifespan; and also their efficient propagation mechanisms, such as rhizomes and tubercles, that can endure long periods in soil (Lorenzi, 2008).

Oliveira Jr. et al. (2011) state that grain yield and profit in soybean cultivation are limited by weed interference, which tends to raise production costs, reduce profit margin and lower the quality of the product. Therefore, in order to manage these issues, it is necessary to study and determine the periods during which a crop can tolerate coexistence with weeds (Pitelli and Durigan, 1984).

In studies carried out by Silva et al. (2008), Costa et al. (2008) and Briguenthi and Briguenthi (2009) the critical periods of coexistence were established for weeds in annual crops. However, the values obtained were not agreed upon by the different authors. This lack of a pattern occurs due to the different development conditions in which the studies were conducted (crop, cultivar, management, cultivation system, soil and climate conditions, as well as specific compositions of weeds).

To measure the level of interference of the invader species, Pitelli and Durigan (1984) proposed the following concepts: period previous to interference (PPI), critical period for prevention of interference (CPPI) and total period for prevention of interference (TPPI). The PPI is the period in which, after emergence, the crop coexists with the invaders before its productivity, or other characteristics, are negatively affected. The CPPI is defined as the period of the cycle when the coexistence between the crop and weeds decreases productivity of the cultivated plants. The TPPI is the period after emergence in which the crop should be kept free of weeds so that its productivity is not negatively affected (Pitelli, 2014). This study aimed to identify the periods of interference of weeds in the soybean crop, cultivar P98Y12, under soil and climate conditions found in the Cerrado (Brazilian savannah), in order to provide helpful information that would optimize the soybean production.

MATERIALS AND METHODS

This study was carried out in Oxysol, with clay texture and slightly undulating relief, in the municipality of Campo Grande (Mato Grosso do Sul state, Brazil), during the harvest of 2011/2012. The statistical design adopted was random blocks with 4 repetitions and 15 treatments. The treatments were constituted by periods of coexistence between the infesting community and the crop, being of: 0, 7, 14, 21, 28, 35, 42, 49, 56, 70, 84, 98, 112, 126 and 133 days after emergence (DAE). At the end of each period of coexistence the invaders were eliminated from the sample area until harvest, by manual hoeing.

Each plot was 3.0 m in width by 5.0 m in length. The Soybean cultivar P98Y12, with a medium cycle and certain growth habit, is recommended for the region, according to Fundação (2012). The experimental area was fertilized with 300 kg.ha^{-1} of 00-20-20 formula. On the 11th of December, 2011, it was executed mechanical sowing, with 45 cm left between rows and 19 seeds per linear meter in a minimum-cultivation system. After germination, which occurred on the 17th of December, 2011, manual thinning was carried out so that 16 seedlings would remain per linear meter, obtaining a population equivalent to 355,500 plants.ha^{-1}. In order to characterize and carry out the phytosociological study of the invaders, a square (0.5 m x 0.5 m) was used as a sampling unit, which was set up randomly within each plot, before controlling the invaders from each period of coexistence. In each sample, the weeds were counted, weighed and identified, according to family, genus, species and common name.

Based on the numbers obtained on the count and classification, it is possible to determine a series of figures proposed by Mueller-Dombois and Ellenberg (1974): density (D), frequency (F), abundance (A), relative density (Dr), relative frequency (Fr), relative abundance (Ar) and importance value index (IVI).

During manual harvesting of the used area of the plots, which occurred on the 4th of May, 2012, it was registered the number of plants per linear metre, the number of pods per plant and the number of grains per pod, as well as the production of pods and grains. Based on the regression curves and the Tukey test at 5% probability, the PPI, TPPI and, by the difference, the CPPI of the weeds in the soybean crop were calculated.

RESULTS AND DISCUSSION

It was identified five families and eight species of weeds, as shown in Table 1. The species *Digitaria horizontalis* from the *Poaceae* family and *Ipomoea grandifolia* from the *Convolvulaceae* family both stood out; presenting high values for the IVI (importance value index), 94.2 and 71.9 respectively. The density results of the same species were also relevant, showing 11.5 plants.m^{-2} of *Digitaria horizontalis* and 8.2 of *Ipomoae grandifolia*.

As indicated on Figure 1, along the periods of coexistence there was an expected increase in the weight of weed dry matter, and the weed growth rate started to decrease and stabilized from the 56th DAE, according to the Tukey's analysis. This happened due to the closing of the crop, which occurred at 46 days after emergence, causing shade and reducing the competitive capacity of the invaders.

On the other hand, the maximum grain yield occurred when there was absolutely no coexistence with the invaders, resulting in 3,248.2 kg.ha^{-1}. From then on, there was no significant difference in this production until the seventh day of coexistence. Therefore, the period previous to interference, in these conditions, was recorded as being from emergence until the seventh day after emergence. However, Meschede et al. (2004) recorded the PPI as lasting until the 11th DAE, when the main infesting flora was *Euphorbia heterophylla*.

Following the Tukey test (Figure 1) it was observed that from the 42nd DAE there were no further significant

Table 1. Phytosociological characteristics of weeds, classified by family. Campo Grande-MS, 2012.

Species	D	F	A	Dr	Fr	Ar	IVI
Poaceae							
Digitaria horizontalis	11.5	100.0	39.0	38.8	16.4	39.0	94.2
Eleusine indica	1.6	60.0	5.4	5.4	9.8	5.4	20.7
Brachiaria decumbens	3.2	90.0	10.8	10.8	14.8	10.8	36.4
Convolvulaceae							
Ipomoea grandifolia	8.2	100.0	27.8	27.7	16.4	27.8	71.9
Ipomoeae nil	1.4	50.0	4.7	4.7	8.2	4.7	17.7
Asteraceae							
Bidens pilosa	1.4	80.0	4.7	4.7	13.1	4.7	22.6
Commelinaceae							
Commelina benghalensis	1.1	60.0	3.7	3.7	9.8	3.7	17.3
Amaranthaceae							
Amaranthus deflexus	1.1	70.0	3.7	3.7	11.5	3.7	18.9

D = Density (plants.m^{-2}), F = Frequency (%), A = Abundance (%), Dr = Relative density (%), Fr = Relative frequency (%), Ar = Relative abundance (%) and IVI = Importance Value Index.

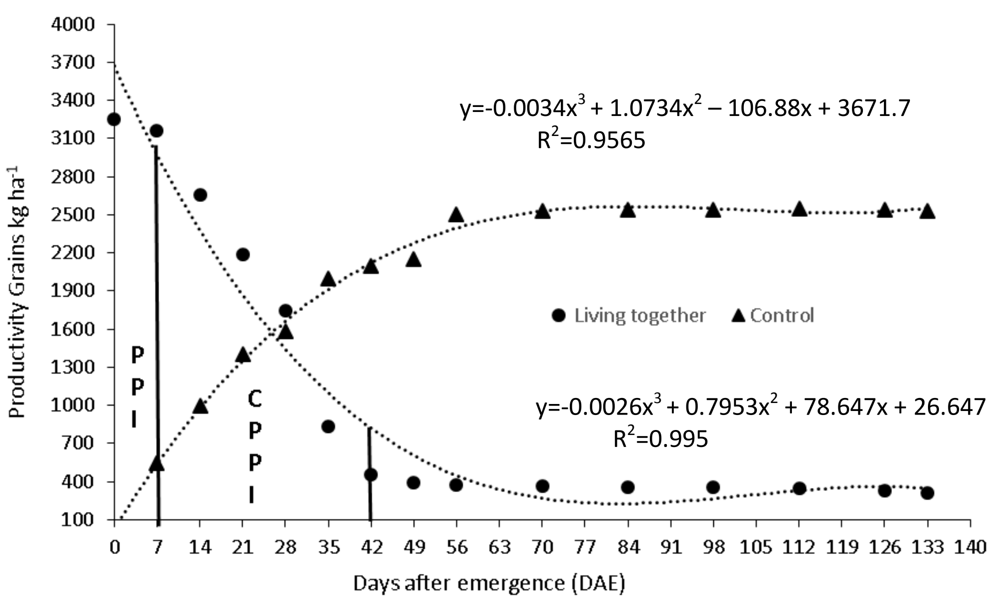

Figure 1. Productivity of soybean grains of living together and Control in function of the periods of coexistence with weeds (DAE).Campo Grande-MS. 2012.

differences in relation to subsequent treatments, which indicates the end of the TPPI, since from the emergence until this period it was possible to prevent the interference from weeds in the soybean crop. It is known that TPPI = PPI + CPPI, therefore the Critical Period for Prevention of Interference (CPPI) was considered to be from the 7th to the 42nd DAE. Under conditions of lower infestation, however, Meschede et al. (2004) indicates that the CPPI lasts from 17 until 44 days after emergence.

After the periods of interference were defined, it was noted that until the end of the TPPI (42 DAE) there was a linear decrease in grain yield and a linear increase in the

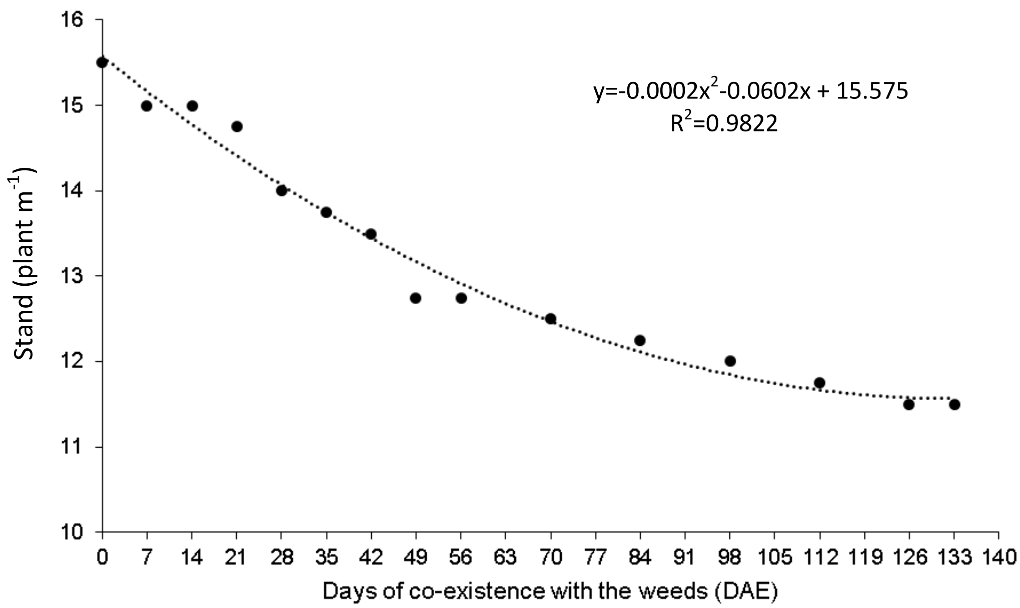

Figure 2. Effect of different periods of coexistence with weeds in the soybean crop on plant stand. Campo Grande-MS, 2012.

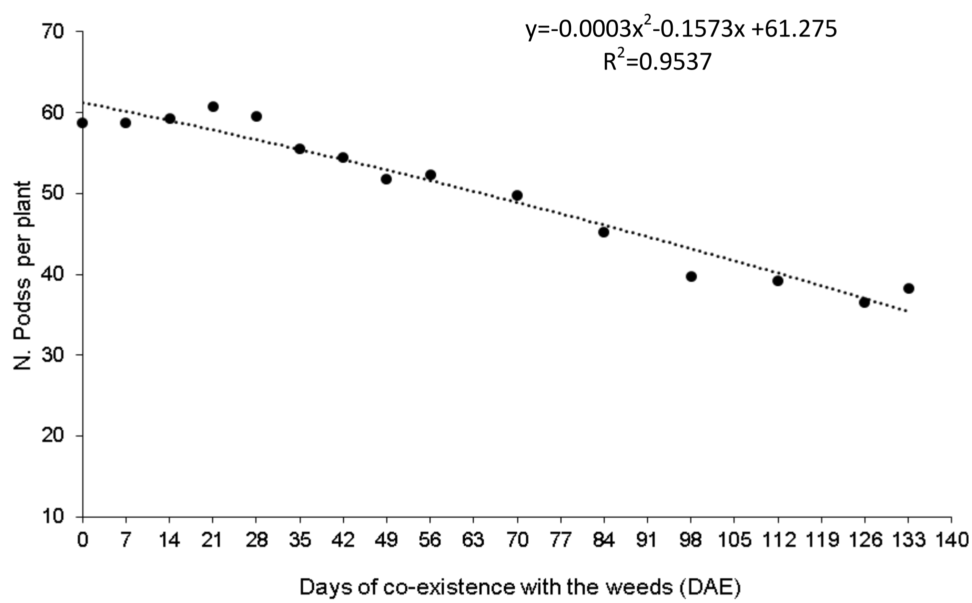

Figure 3. Effect of different periods of coexistence with weeds in the soybean crop on number of pods per plant. Campo Grande-MS, 2012.

dry mass of weeds. Meschede et al. (2004) obtained a daily loss of 6.45 kg.ha^{-1} with a density of 25 plants.m² of the specie *E. heterophylla*, while Pereira (2004) obtained a daily drop of 16 kg.ha^{-1} with an predominant infestation of *Bidens pilosa*.

This matches the data found by Blanco (1985), which stated losses between 42 to 95%, and contradicts the data by Lorenzi (2008), which indicated interference of 30 to 40%. The competition of *E. heterophylla* in studies carried by Meschede et al. (2004) reached a maximum of 38% loss. The crop stand was significantly compromised by the competition with the invaders. It dropped from 15.5 plants per linear metre to 11.50 (Figure 2). These values were similar to the data found by Meschede et al. (2004).

There was also a significant difference on the number of pods per plant (Figure 3), changing from 58.75 to

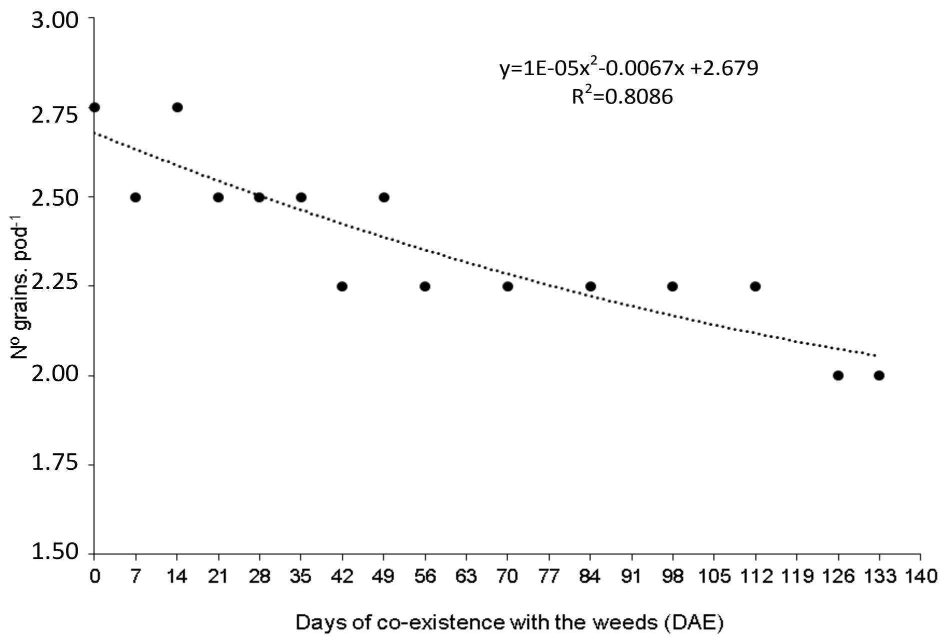

Figure 4. Effect of different periods of coexistence with weeds in the soybean crop on number of grains per pod. Campo Grande-MS, 2012.

38.25 between day 0 and day 133 after exposure of the crop to weeds. Oliveira Jr. et al. (2011) also observed a significant drop in the number of pods per plant (Figure 4). There was no significant change in the average number of grains per pod, nevertheless the grain yield was seriously compromised, reaching 310 kg ha^{-1}, during critical competition along the complete crop cycle.

Conclusions

It was concluded that the Period Previous to Interference (PPI) was from crop emergence until 7 days later; the Critical Period for Prevention of Interference (CPPI) was from 7 to 42 DAE and the Total Period for Prevention of Interference (TPPI) was from emergence until 42 DAE. The weeds that presented the highest Importance Value Index (IVI) were *Digitaria horizontalis* (94.2) and *Ipomoea grandifolia* (71.9), from the families Poaceae and Convolvulaceae, respectively. The infestation conditions studied caused up to 90.42% in productivity loss.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Agronomic and economic efficiency of nitrogen fertilization in garlic culture

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This study was aimed at evaluating the influence of nitrogen fertilization on the productivity of garlic culture. The experiment was carried out at Goiás State University, Ipameri Unit. The randomized block design was adopted for the experiment, with six treatments and four replications. The treatment consisted of nitrogen doses in cover crop (0; 40; 80; 160; 320 and 640 kg ha^{-1}), applied at 15, 30 and 70 days after planting. The cultivar used was *Allium sativum* L. cv. Ito, from the Roxo Nobre group. Before each N application, the plants components, the presence of photosynthetic pigments and of N content in leaves were assessed. The bulbs were harvested at 100 days after planting and evaluated as to total, commercial productivity, and economic viability. Among the components produced, the average bulb weight and the average number of cloves per bulb were mostly determinant to production. Nitrogen-based fertilization that enabled the predominance of classes 5 and 6 bulbs. There was no significant incidence of pseudo-stem tillers. The doses with maximum agronomic and economic efficiency were 251.7 and 267.2 kg of N ha^{-1}, respectively, though with a considerable safety margin.
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Key words: *Allium sativum*, pseudo stem tillering, productivity.

INTRODUCTION

In Brazil, garlic (*Allium sativum* L.) is the fourth most economically important vegetable, cultivated mainly by small farmers (Marouelli et al., 2002a). In the past decade, the Brazilian total production of garlic increased, under Goiás leadership, representing 30.0% of domestic production (CONAB, 2014). This achievement was due to several factors such as mechanization, rationalized irrigation, planting intensification, favorable climate, use of noble garlic cultivars, vernalization, and use of virus-free garlic (Resende et al., 2004).

In spite of the increasing national garlic production, Brazil is still the world's greatest importer. The deficit in production is a reflection of the low competitiveness of domestic garlic against Argentina, as they present lower production costs, enjoy more favorable climate, and have subsidy policies. Moreover, improper irrigation and fertilization management also constitute limiting factors to the production of good quality garlic (Souza and Macedo 2009).

According to Marcussi et al. (2004), mineral nutrition is

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a primary factor in the production of *oleracea* species, accounting for increased productivity and better quality of harvested products. Resende and Cecílio Filho (2009) point out that properly provided nutrients, in both quantity and quality, are very important in the cultivation of garlic, since most Brazilians soils have low natural fertility.

Therefore, optimizing the provision of nutrients for maximum productivity and quality of the garlic culture is the solution, especially when considering that the globalization of economy interferes significantly in the quality of traded garlic (Souza and Macêdo, 2009).

In terms of plant development and production, Nitrogen (N) is the most responsive nutrient, contributing to increased productivity and quality of bulbs. Macêdo et al. (2009) observed that an N dose of up to 180 kg ha^{-1} enabled linear gains in the total productivity of cv. Roxo Pérola de Caçador. Fernandes et al. (2010) observed increasing linear behavior, and the dose of 320 kg ha^{-1} of N yield values of 9.1 t ha^{-1} of total productivity of cv. Caçador LV. However, excessive Nitrogen-based fertilization are responsible for the occurrence of pseudo-stem tillering. Such anomaly is one of the biggest problems in the garlic culture, particularly in the cultivars that produce the so-called "noble garlic" (Büll et al., 2002). This variability in results may be related to diversification in the garlic production system. Thus, this study was intended for verifying the influence of Nitrogen fertilization in agronomic characteristics in the total and commercial productivity of noble garlic culture.

MATERIALS AND METHODS

The study was carried out at Goiás State University, Ipameri Unit, in the municipality of Ipameri, GO, whose geographic coordinates are: 17°43'20"S and 48°09'44"W. The altitude is 800 m, and the climate, according to Köppen's classification, is the Aw type, featuring high temperatures with summer rain and winter drought.

The soil in the experiment area is classified as Red-Yellow Distrophic Oxisol (Embrapa, 2006). Physical-chemical analysis of the 0 to 0.2 m-deep layer found the following characteristics: clay content = 405 g kg^{-1}; silt content = 153 g kg^{-1}; sand content = 442 g kg^{-1}; pH = 5.8; P = 5.5 mg dm^{-3}; K = 130 mg dm^{-3}; Al = 0.2 cmolc dm^{-3}; Ca = 1.9 cmolc dm^{-3}; Mg = 0.5 cmolc dm^{-3}; H + Al = 2.0 cmolc dm^{-3}; Co = 0.06 mg dm^{-3}; Zn = 1.3 mg dm^{-3}; B = 0.2 mg dm^{-3}; Cu = 2.1 mg dm^{-3}; Fe = 86.1 mg dm^{-3}; Mn = 21.9 mg dm^{-3}; Mo = 0.08 mg dm^{-3}; CTC = 4.7 cmolc dm^{-3}; Base saturation = 58%; Organic matter = 30 g dm^{-3}. Liming was accomplished by applying 1,225 kg ha^{-1} of dolomitic limestone (PRNT 92%) aimed at increasing the saturation of bases to 80%, 60 days before sowing, incorporated with chisel plow into the 0 to 0.2 m layer. Subsequently, the soil was harrowed twice for leveling the ground.

The treatment was comprised of Nitrogen doses in crop cover (0; 40; 80; 160; 320 and 640 kg ha^{-1}) applied through fertilizing irrigation sourced from urea (45% of N). The randomized block design was applied, with four replications. The plots consisted of six simple 2.0-m-long rows on a bed with 1.4 m width and 0.15 m height. The rows were spaced at 0.2 m, with 0.10 m between cloves and 0.80 m between beds. The plot usable area was 1.28 m^2, including the four central lines and excluding two plants from the edges.

The cultivar used was Ito, from the Noble Purple Group. The seed bulbs were submitted to pre-planting vernalization, being stored in a cold chamber at the average temperature of 4°C, for a period of 50 days. The cloves were sieved for size, and those retained in sieve 2 (10 x 20 mm mesh) were used for planting. Transplanting was carried out on 18 April 2012, aiming to obtain an average population of 450 thousand plants ha^{-1}. The cloves were previously treated in a solution of 2.5% Iprodione for prevention against soil pathogens.

Soil fertilization was accomplished during de preparation of beds, by applying 150, 750 and 450 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. The source of micronutrients was a leaf fertilizer containing 18.5% S; 0.5% B; 1% Cu; 25% Mn; 4% Zn, at a dose of 9 kg ha^{-1}, divided into three equal applications at 5, 35 and 65 days after planting (DAP). In cover Nitrogen fertilization was carried out according to the doses established in the treatments, calculated as per the crop phenological stage, by applying 25% of the dose at the 4-leaf stage, 25% at the 6-leaf stage, and 50% at the clove growing stage.

Weekly sprayings were made, aiming to prevent and control diseases, alternating fungicides based on 80% Mancozeb, 20% Tebuconazole, 50% Thiophanate-methyl, 50% Boscalid and 84% Copper Oxychloride. In order to control plagues, insecticides 5% Beta-cyfluthrin, 24% Chlorfenapyr and 70% Imidacloprid were applied through alternated sprayings. Weed control was mechanic, through houging.

The experiment irrigation was done every two days, by applying a 12 mm water blade through conventional sprinkling, and was interrupted when there was equal or superior precipitation than the established blade. At 45 DAP, irrigation was suspended for a period of 15 days in order to reduce excessive sprouting (Macêdo et al., 2006). At 14, 29, 69 and 97 DAP samples were collected, each composed of two plants harvested in the external rows of the plot usable area, one from each row, to determine the contents of chlorophyll *a* and *b* and N in leaves; the number of photosynthetically active leaves, stem diameter and plant height.

In order to determine the chlorophyll content, two 6 mm foliar disks were extracted from fully expanded leaves and placed in glass jars containing dimethylsulfoxide (DMSO). Subsequently, extraction was made in water bath at 65°C for one hour. Aliquots were then extracted for spectrophotometric reading at 480, 649 and 665 nm. Thus, the contents of chlorophyll *a* and *b* were determined through the equation proposed by Wellburn (1994).

In order to determine the total content of N in the leaves, the samples were dried out in a forced ventilation oven at 65°C for 72 h, and then the dry matter was weighed, ground and submitted to nitric and ammoniacal nitrogen analysis, according to the methodology described by Cataldo et al. (1974, 1975).

The number of photosynthetically active leaves was determined by mere counting of leaves per plant. The stem diameter was measured at the base of the pseudo stem, and the plant height was measured through the vertical distance between the pseudo stem base and the end of the junction of all the leaves. At 103 DAP the harvest was accomplished, when all the plants from the plot usable area were collected and submitted to the drying process (shadow drying of leaves) for 20 days. Then the bulbs were processed and cleaned. After the drying period, evaluations were made to the production components for total and commercial productivity, maximum economically efficient dose and economic viability. In order to do so, all the plants harvested by plot were analyzed.

The evaluated production components were the following: average mass of bulbs, average mass of cloves, average number of cloves per bulb, percentage of pseudo stem tillered bulbs, bulb transversal diameter, which were ranked in classes according to Ordinance no. 242, of 17 September 1992 of MAPA: class 3 (longer than 32 up to 37 mm), class 4 (longer than 37 up to 42 mm), class 5 (longer than 42 up to 47 mm), class 6 (longer than 47 up to 56 mm) class 7 (>56 mm).

The total production analysis took into consideration the bulbs free of plagues, diseases and abnormalities, and the commercial

Table 1. Basic minimum price of garlic class according to the bulb transversal diameter, stated in Reais per kilogram.

Class	Harvest					
	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	Average
	Basic minimum price (R$ kg^{-1})					
Class 7	3.17	3.17	3.17	3.53	3.77	3.36
Class 6	2.64	2.64	2.64	2.94	3.14	2.80
Class 5	2.20	2.20	2.20	2.45	2.62	2.33
Class 4	1.83	1.83	1.83	2.04	2.18	1.94
Class 3	1.47	1.47	1.47	1.63	1.75	1.56

Source: Adaptation of CONAB releases - Title 42, Specific Rules of Garlic - 2008 to 2012 Crops.

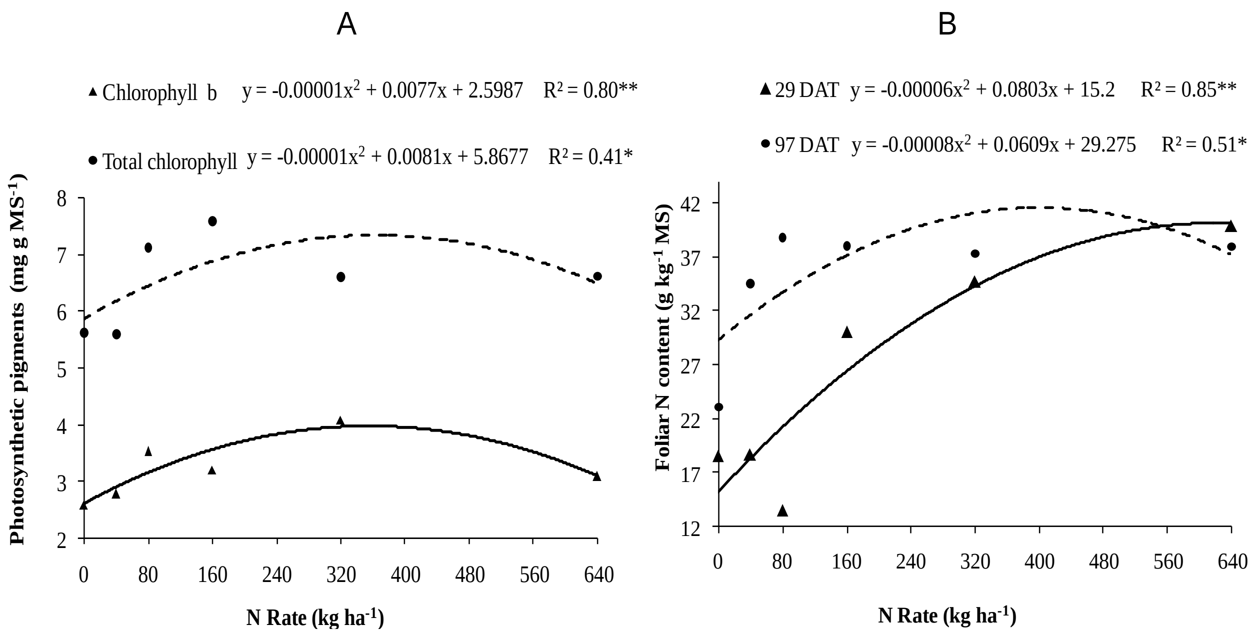

Figure 1. Effect of in-cover Nitrogen fertilization of garlic crop on (A) chlorophyll *b* content and total chlorophyll content; and (B) N content in leaves at 29 and 97 days after planting.

production analysis considered bulbs without pseudo-stem tillering and with transversal diameter longer than 32 mm.

In order to obtain the maximum economically efficient dose and the net revenue, apart from the in-cover Nitrogen-based fertilizer cost, all other fixed costs of the garlic crop production were taken into consideration.

Calculations of economic viability were based on the average price recorded along five years (2007 to 2012), considering the value charged by kilogram (R$ kg^{-1}) of each bulb class of the noble purple group (Table 1). As to the cost of the Nitrogen source applied in the in-cover fertilization, urea (45% of N), the average price per N ton (R$ ton^{-1}) was R$ 3,321.09 (IEA, 2012). The results referring to the ranking of bulbs by class were converted into arcsin functions before analysis and, together with the other results, submitted to variance and regression analyses.

RESULTS AND DISCUSSION

The content of chlorophyll *b* and total chlorophyll presented significant square adjustments only at 97 DAP, when doses of 385 and 405 kg de N ha^{-1} yielded values of 4.08 and 7.50 mg per g of MS^{-1} photosynthetic pigments, respectively (Figure 1A). In previous evaluations, the Nitrogen-based fertilization applied in the treatments is likely to have yielded enough chlorophyll contents for the plant development. Similar results were observed by Lima (2005), where chlorophyll contents in garlic crop were significant at 100 DAP with the application of a 360 kg of N ha^{-1} dose.

A square adjustment to the foliar N content was observed with in-cover Doses of N. The highest foliar concentration of N resulted from the estimated doses of 669.1 and 380.6 kg of N ha^{-1} at 29 and 97 DAP, respectively (Figure 1B). These results are higher than those found by Fernandes (2008), who observed maximum N content (30.8 g kg^{-1} of MS) with a dose of 320 kg ha^{-1}. Nonetheless, they are consistent with those obtained by Lima (2005), who observed a foliar N content

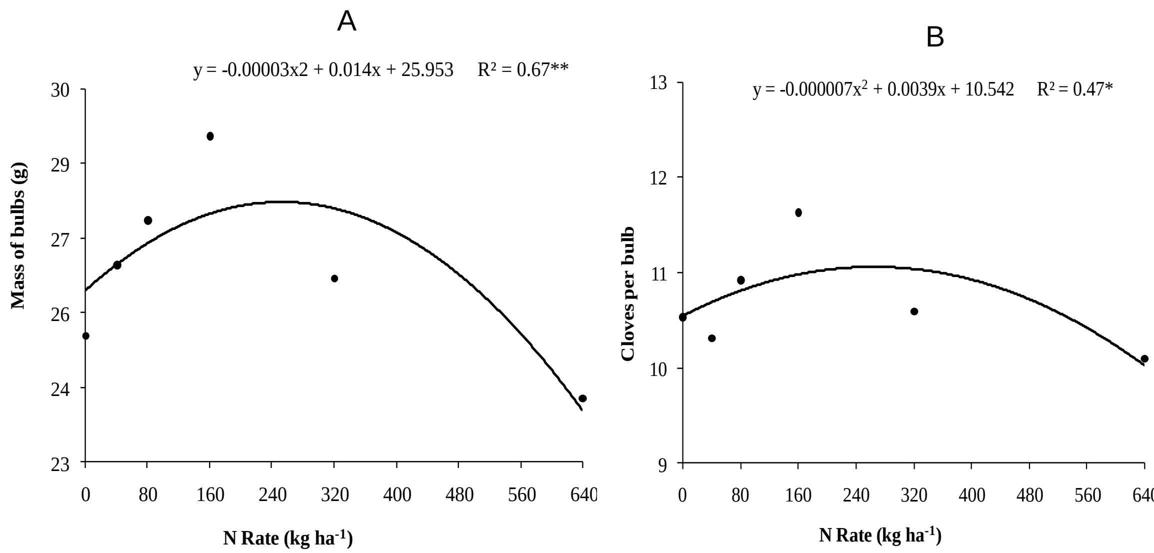

Figure 2. Effect of in-cover Nitrogen fertilization of garlic crop on A) average mass of garlic bulbs; and B) average number of cloves per garlic bulb.

of 32.4 g kg^{-1} of MS at 100 DAP when applying a dose of 360 kg ha^{-1} of N. The production components were affected by the in-cover Nitrogen-based fertilization, except for the clover average mass and the incidence of pseudo-stem tillered bulbs.

The tested N doses did not cause significant pseudo-stem tillering, reaching an average rate of 7.5% of the value considered acceptable according to production patterns. This can be explained by the certainty of the hidric stress, which probably prevented the occurrence of such anomaly. A similar result was recorded by Macêdo et al. (2009), who, in studies of Nitrogen and Molybdenum doses applied to a vernalized garlic crop in Lavras municipality, in southern Minas Gerais state, did not observe any effect of the treatment on that physiological anomaly, with an average rate of 8.7%. However, Lima et al. (2008) observed a linear effect in the occurrence of such anomaly proportional to the application of Nitrogen, as each 100 kg ha^{-1} of N applied caused pseudo-stem tillered bulbs to increase by 3.5%.

Another relevant aspect of the incidence of super sprouting is the level of response of each cultivar to the N supply, particularly in cover. Büll et al. (2002) pointed out that even though pseudo-stem tillering is related to excessive supply of Nitrogen, noble cultivars may react differently to yearly climatic influence, as they are forcefully adapted by vernalization to cultivation in the Cerrado climate conditions.

The average mass of bulbs presented square adjustment to Nitrogen doses, and the estimated dose of 233.3 kg ha^{-1} of N enabled a maximum mass of 27.56 g (Figure 2A). In spite of the difference, a decrease or increase of up to 100 kg ha^{-1} of N related to the estimated maximum dose indicates a variation of only 1.08% in the average mass of bulbs. Backes et al. (2008), working with a Roxo Pérola de Caçador cultivar, observed a square effect of the N doses, which reached a maximum 36 g bulb average with the established dose of 268 kg ha^{-1}. A study accomplished by Resende and Souza (2001a) recorded linear gains in bulb average mass with the application of N doses of up to 120 kg ha^{-1}. However, such result differs from those found by Lima et al. (2008) and Macêdo et al. (2009), which did not find significant differences for that component with doses up to 360 and 180 kg ha^{-1} of N, respectively.

The maximum number of cloves by bulb was 11.08 obtained with the estimated dose of 278.5 kg ha^{-1} of N (Figure 2B). Despite the statistical significance, the effect observed between the minimum and maximum applications of N was only 3.5%, a value corresponding to 0.4 cloves per bulb. This low relation is likely due to the fact that such component is genetic in nature, hence inherent in the cultivar. Resende and Souza (2001a) found a linear increase in the number of cloves per bulb arising from an increase in Nitrogen doses up to 120 kg ha^{-1}. Yet, studies carried out by Resende and Souza (2001b) and Macêdo et al. (2009) did not report on effects of the treatments on the average number of cloves per bulb with the application of N doses up to 160 and 180 kg ha^{-1}, respectively.

Nitrogen fertilization was responsive in bulb classes with respect to the transversal diameter, presenting square adjustments in all of the classes (Figure 3). A directly proportional effect of N is observed through the increased percentage of bulbs ranked in classes 5 and 6, whereas an inversely proportional effect is seen in bulbs from classes 3 and 4. The formation of bulbs with transversal diameter higher than 56 mm is not recorded in class 7 bulbs.

These results are similar to those presented by Macêdo

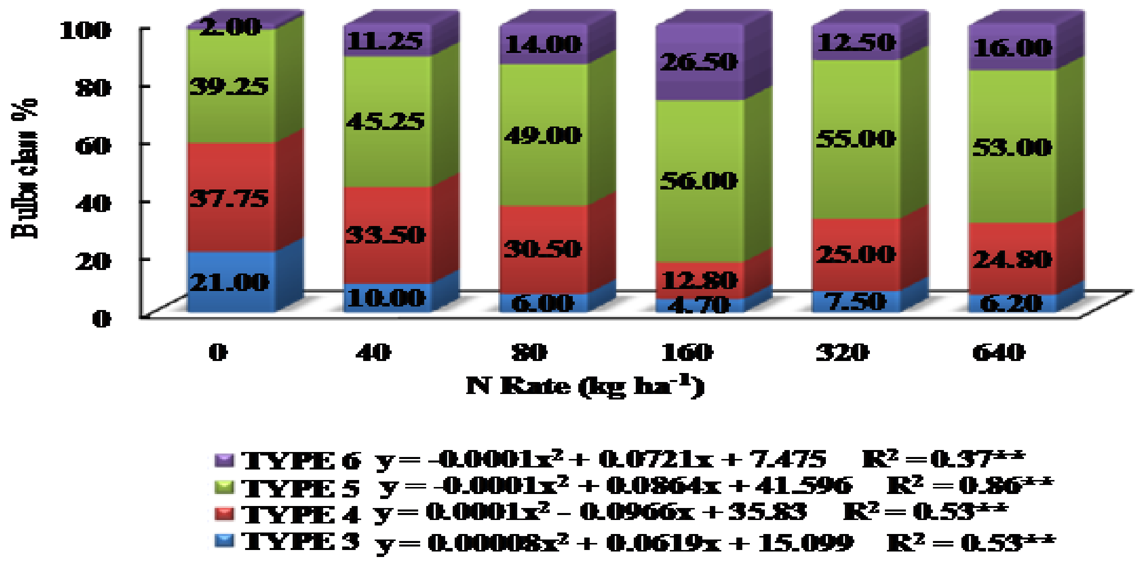

Figure 3. Percentage of garlic bulbs in classes 3 to 6 resulting from in-cover Nitrogen fertilization.

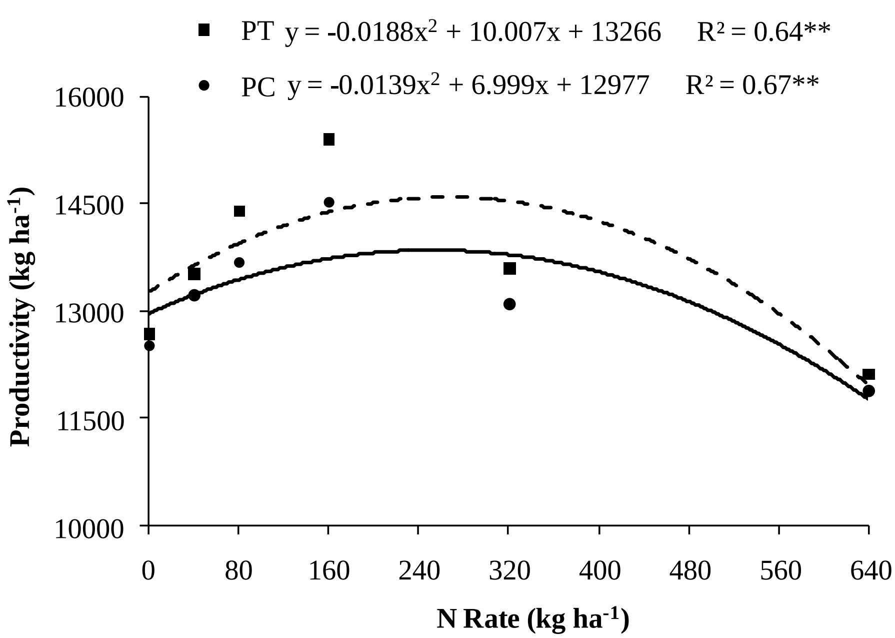

Figure 4. Total and commercial productivity of garlic crop as a result of Nitrogen fertilization.

et al. (2009), where an increase in Nitrogen in cover up to 180 kg ha^{-1} enabled an increase in the percentage of class 6 bulbs, pointing to linear gains in total and commercial productivity. In turn, Backes et al. (2008), observed in similar studies higher concentration of bulbs in classes 5 and 6 with the application of doses up to 160 kg ha^{-1} of N. However, when the dose was increased to 320 kg ha^{-1}, there was a predominance of bulbs from classes 3 and 4, which have lower economic value. The total productivity of bulbs was responsive to the Doses of N applied in cover, expressing square adjustment (Figure 4); the dose of 266.1 kg of N ha^{-1} enabled a maximum estimated productivity of 14,597.6 kg ha^{-1}. Accordingly, the commercial productivity also presented square adjustment, enabling a maximum productivity of 13,858.0 kg ha^{-1} with an estimated dose of 251.7 kg of N ha^{-1}.

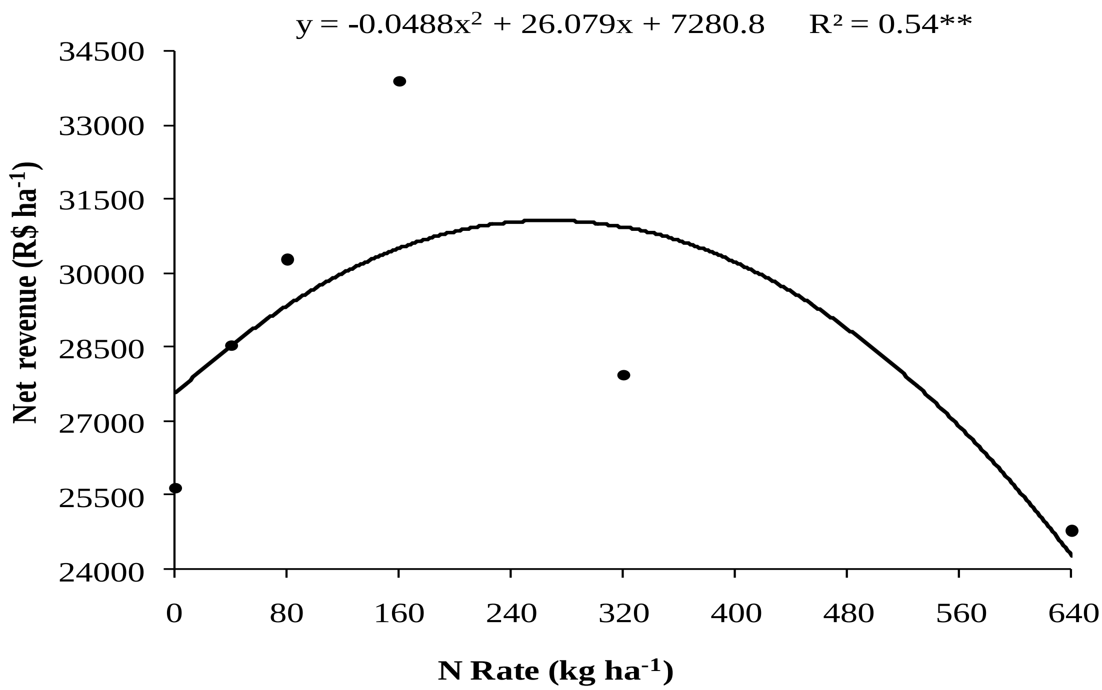

Figure 5. Effect of in-cover N doses on the revenue, free of expenditures on Nitrogen, from the garlic crop.

The results obtained with this study show that the variance, whether an increase or a decrease, by up to 100 kg ha^{-1} of N to the estimated dose, brought about reductions of 1.2 and 2.8%, respectively, in commercial and total productivity. Such results indicate the safety margin for the choice of the Nitrogen dose for in-cover fertilization in view of the excessive sprouting problem. The values observed in this study are higher than those found by Marouelli et al. (2002b), who obtained increases in total productivity up to the 64 kg/ha^{-1} of N dose. In turn, in studies carried out by Backes et al. (2008), total production of bulbs was obtained with the estimated dose of 268 kg ha^{-1} of N, yielding a maximum productivity of 14,250.0 kg ha^{-1}. However, such results differ from those found by Lima et al. (2008), as studies with application of doses up to 360 kg ha^{-1} of N did not obtain responses in the productivity of bulbs from the Roxo Pérola de Caçador cultivar. Now, the cost effectiveness of the garlic crop was indeed affected by Nitrogen-based fertilization. Maximum cost effectiveness was obtained with the estimated dose of 267.2 kg ha^{-1} of N, which provided a net revenue of R$ 31,045.73 (Figure 5). It can be seen that this result comes close to the maximum commercial productivity (251.7 kg ha^{-1} of N), since that difference implies a reduction of only 0.3% to the net revenue (R$31,033.96).

The results found in this analysis, like those about productivity, allow for variance of up to 100 kg ha^{-1} of N in the maximum estimated dose (267.2 kg ha^{-1}) with reduction of only 1.5% in cost effectiveness (R$ 30,557.73). This safety margin of the maximum estimated dose regarding cost effectiveness is likely due to lower concentration of bulbs from classes 3 and 4 in it, since the values paid for smaller bulbs are up to 50% of those of classes 5 and 6 bulbs. The results found differ from those by Lima (2005), who did not observe any interaction of bulb classes with N doses up to 360 kg ha^{-1}, but it did observe higher concentration of classes 6 and 7 bulbs. In turn, Backes et al. (2008), in a work conducted in the municipality of Santa Juliana, Minas Gerais state, a traditional region in the production of noble purple garlic, obtained higher cost effectiveness (R$ 45,623.98) with the application of 237 kg ha^{-1} of N. The authors infer such result by the higher concentration of classes 5 and 6 bulbs, when they apply doses greater than 160 kg ha^{-1} of N.

Conclusions

(1) The agronomic characteristics of the garlic crop were affected by Nitrogen fertilization, in that the average weight of bulbs and the average number of cloves per bulb were components responsible for the increases in productivity, there being a predominance of classes 5 and 6 bulbs.

(2) Maximum agronomic efficiency and cost effectiveness were obtained with the doses of 251.7 and 267.2 kg ha^{-1} of N, respectively, though with a considerable safety margin.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Morphological evaluation of selected sesame (*Sesamum indicum* L.) genotypes from five states in Northern Nigeria

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The morphological characteristics of 12 selected sesame (*Sesamum indicum* L.) genotypes, from five states in northern part of Nigeria (Kaduna, Niger, Nassarawa, Kogi, and Benue), were evaluated during the 2012 cropping season at the Department of Biological Sciences experimental field, Federal University of Technology, Minna, Nigeria using a randomized block design. The objective of the experiment was to assess the performances of all the selected genotypes based on morphological parameters such as plant height, petiole length, number of leaves/plant, number of branches per plant and leaf surface area per plant. While NG01 had the tallest plants 2 weeks after planting, KG01 and NA01 had the shortest plants. Seven genotypes; (KD, NG-01, NG-02, NA-01, BE-01, KG-01 and KG-02 had positive characteristics (such as higher number of leaves and high number of branches) which could bring about high yield. These findings suggest that some of the genotypes could be potential parents for inclusion in future breeding programmes aimed at improving *S. indicum* in northern Nigeria.

Key words: *Sesamum indicum* L., morphological characteristics, genotypes.

INTRODUCTION

Sesame (*Sesamum indicum* L.; Pedaliaceae family) is an annual plant that is considered to be one of the most important and oldest oil crops (Noorka et al., 2011) that has been under cultivation in Asia for over 5000 years (Bisht et al., 1998). The crop originates predominantly from East Africa, with fewer germplasms from India (Nayar and Mehra, 1970; Baydar, 1999; Bedigian, 2003).

Sesame is an important source of high quality oil and protein (IPGRI and NBPGR, 2004). The oil has an excellent stability due to the presence of natural antioxidants such as sesamolin and sesamin (Brar and Ahuja, 1979; Kamal-Eldin, 1993). The fatty acid composition of its oil varies considerably among different cultivars worldwide (Yermanos et al., 1972). After oil

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extraction, the remaining meal contains 35 to 50% protein, and is rich in tryptophan and methionine. Sesame seed coats are rich in calcium (1.3%) and provide a valuable source of minerals (Johnson et al., 1979). The addition of sesame to the high lysine meal of soybean produces a well-balanced animal feed.

India and China are currently the world's largest producers of sesame, followed by Myanmar, Sudan, Uganda, Nigeria, Pakistan, Tanzania, Ethiopia, Guatemala and Turkey. World production of sesame fluctuates due to disturbances in local economies, crop production and weather conditions. Nigeria is the third largest producer of Sesame in Africa, after Sudan and Uganda with about 165.1 ha (harvested area) that produced 83 tons (FAO, 2005) numerous wild relatives occur in Africa (Baydar, 1999). In Nigeria, sesame is often referred to as benniseed and is widely used and very popular in parts of the north, where it is commonly grown. The local names are *riddi* in Hausa, *ishwa* in Tiv, *yamati* or *eeku* in Yoruba, *igorigo* in Igbira, *anufi* in Gbagi, and *esso* in Nupe (Falusi and Salako, 2001). The seeds, which yield half of their weight in oil, are most commonly used in soups while the young leaves are used in a soup vegetable, while the stem and oil extracts are used in making local soups. Traditionally, the seeds are roasted and mixed together with roasted groundnut or used as a soup thickening condiment in Nigeria (Falusi and Salako, 2001). According to Kobayashi et al. (1990), 36 species have been identified of which 22 species have been found in Africa, 5 in Asia, 7 in both Africa and Asia, and one species each in Crete and Brazil.

Variation is a necessary criterion for any selection programme aimed at improving desirable characters. Adeyemo and Ojo (1993) reported some morphological characters such as plant height, height of first capsule, days to flowering, number of Capsule as important characters to be considered for evaluation in sesame. Despite the visible presence of a wide range of variability in morphological characters in sesame, no selection within local genotypes or hybridization has resulted in the improvement of the crop.

The objective of this study was therefore to study such variability in morphological traits that would allow suitable germplasm to be identified as potential parents for future sesame breeding programmes.

MATERIALS AND METHODS

Twelve sesame genotypes used in this study were collected from local farmers in sesame-growing regions in collaboration with Nigeria's Agricultural Development Project (ADP) of the states of the North central zones, namely Kaduna, Niger, Kogi, Benue, and Nassarawa.

A factorial experiment was adopted using a total of 12 combinations in a randomized block design, and each genotype was replicated three times. Two plants were remained in each pot after planting for three weeks with an inter-pot distance of 40 cm. Pots were placed in open sunlight (that is, no shading). The soil type used for the experiment was a sandy-loamy soil (sand, silt, clay = 83.52, 7.28 and 7.20%, respectively) collected from the experimental site with a pH of 6.34. The average temperature in the cropping season was 26.7 to 35.3°C. The experiment was conducted at the Department of Biological Sciences Experimental Garden, Federal University of Technology, Minna, Nigeria. Plants were watered twice daily. The most common pests recorded were *Helicoverpa* sp. caterpillars, which penetrate into the fruit of the sesame plant and destroy them, and fungal attack by *Cercospora sesame*, which usually destroys the plant's leaves. Plants were sprayed with pesticides and insecticides (pyrethroids cypermethrin) at a rate of 10 to 15 L/ha with controlled droplet application using spinning disc sprayers.

The following data was obtained: 1) Plant height at 2 and 4 weeks after planting (WAP) and at maturity, which was measured from the ground level up to the terminal bud on the main axis of each plant using a ruler. 2) Number of branches/plant. 3) Length of petiole (cm) using a ruler. 4) Leaf surface area (cm^2). 5) Survival percentage at 3 WAP.

Data was separated by analysis of variance (ANOVA) and significant differences among the means of morphological and yield parameters were assessed by Duncan's multiple range test. Survival was represented as simple percentages.

RESULTS

Significant differences were detected among the 12 sesame genotypes for seed colour, flower colour and seed length (Table 1). All genotypes showed wide ranges of variation for morphological characters such as plant height, number of leaves per plant, number of branches per plant, petiole length and leaf surface area (Tables 2 and 3). For example, while NG01 had the tallest plants at 2 WAP, KG-01 and NA-01 were shortest (Table 2). NA-01 and KD, on the other hand, had the highest number of branches, while NG-04 had the least. Also, while NA-01 had the highest number of leaves, genotype NG-01 had the longest petioles. KG-02 had the highest leaf surface area while NG-04 had the least. While NG-01 had the highest percentage survival at 3 WAP, NA-02 and NG-04 had the lowest survival percentages (Figure 1). NA-02 did not survive after 3 WAP.

DISCUSSION

The present study indicates that significant genetic variability exists among 12 sesame genotypes from the northern part of Nigeria. These genotypes are available and fundamental for the development of the species in Nigeria. Yahaya et al. (2014) stated that it is common to find similar genotypes with different registrations in germplasm collections. Likewise also it is possible that, in genotypes of distinct origin, genotypes which are the same can be found, even though they are phenotypically different. Alege and Mustapha (2013) reported that morphological attributes such as plant height, number of leaves, stem diameter and number of pods/plant are not under a strong genetic influence.

Nevertheless, the variability that was observed in the

Table 1. Description and sources of the 12 collected sesame genotypes.

Accession number	Local name	Source	Seed colour	Colour of flowers	Seed length (mm)
KD	Riddi	Kafanchan, Kaduna	White	White	3-3.5
NG-01	Anufi	Paiko, Niger	Light brown	White	2-2.5
NG-02	Ishwa	Saminaka, Niger	Light brown	White	3
NG-03	Esso	Katcha, Niger	Light brown	White	2-3
NG-04	Anufi	Mayaki, Niger	Creamy white	White	2-3
NA-01	Riddi	Nassarawa	Black	Purple	2-3
NA-02	Riddi	Nassarawa	Brown	White	2-3
NA-03	Riddi	Nassarawa	White	White	2-3
BE-01	Ishwa	Benue	White	White	2
BE-02	Ishwa	Benue	Creamy white	White	3-3.5
KG-01	Gogori	Kogi	Creamy white	Purple	3
KG-02	Gogorigo	Kogi	Light brown	White	2-3

Table 2. Mean plant height (cm) of the 12 collected sesame genotypes.

Accession number	2 WAP	4 WAP	6 WAP
KD	4.41 ± 1.05^{ab}	17.89 ± 4.75^{a}	59.13 ± 16.34^{cd}
NG-01	4.71 ± 1.49^{a}	16.97 ± 5.44^{ab}	56.16 ± 15.73^{cd}
NG-02	2.50 ± 0.69^{ef}	16.74 ± 4.99^{ab}	63.40 ± 21.84^{bc}
NG-03	4.11 ± 0.77^{ab}	13.76 ± 4.40^{bc}	54.37 ± 16.62^{cd}
NG-04	2.32 ± 0.79^{f}	7.65 ± 3.63^{f}	46.40 ± 13.72^{e}
NA-01	1.94 ± 1.13^{f}	8.30 ± 2.70^{ef}	73.27 ± 4.86^{ab}
NA-03	3.75 ± 0.84^{bc}	11.90 ± 6.68^{cd}	48.90 ± 14.49^{cd}
BE-01	3.13 ± 0.74^{de}	12.67 ± 4.09^{cd}	75.10 ± 9.56^{a}
BE-02	3.49 ± 1.01^{cd}	11.54 ± 3.96^{cd}	48.90 ± 10.94^{de}
KG-01	2.09 ± 0.70^{ef}	11.02 ± 2.79^{de}	61.50 ± 15.36^{c}
KG-02	3.45 ± 0.92^{cd}	14.67 ± 3.41^{ab}	58.27 ± 17.78^{cd}

Values are mean ± SD. Values followed by the same letter(s) within a column do not differ statistically ($P \leq 0.05$) according to DMRT. WAP = weeks after planting.

Table 3. Mean of several morphological characteristics of the 12 collected sesame genotypes.

Accession number	Petiole length (cm)	No. leaves/plant	No. branches/plant	Leaf surface area (cm^2)
KD	1.42 ± 0.56^{ab}	59.00 ± 29.35^{bc}	4.00 ± 1.89^{a}	20.33 ± 6.01^{ab}
NG-01	1.54 ± 0.57^{a}	52.00 ± 16.34^{bc}	3.00 ± 1.16^{ab}	18.77 ± 4.12^{ab}
NG-02	1.32 ± 0.56^{ab}	65.00 ± 31.04^{b}	2.00 ± 0.98^{bc}	19.43 ± 6.42^{ab}
NG-03	1.24 ± 0.33^{ab}	52.00 ± 25.45^{bc}	3.00 ± 1.57^{ab}	17.67 ± 6.42^{ab}
NG-04	1.12 ± 0.27^{b}	34.00 ± 17.95^{d}	1.00 ± 1.26^{d}	13.40 ± 4.97^{d}
NA-01	1.24 ± 0.42^{ab}	96.00 ± 32.88^{a}	4.00 ± 1.38^{a}	16.83 ± 5.39^{ab}
NA-03	1.13 ± 0.40^{b}	40.00 ± 16.45^{cd}	1.47 ± 1.59^{cd}	15.53 ± 8.53^{bc}
BE-01	1.17 ± 0.47^{a}	51.00 ± 16.62^{bc}	2.00 ± 0.79^{bc}	14.40 ± 5.72^{cd}
BE-02	1.48 ± 0.60^{ab}	39.00 ± 15.84^{d}	1.93 ± 1.48^{c}	15.22 ± 6.99^{cd}
KG-01	1.20 ± 0.51^{a}	52.00 ± 26.30^{bc}	2.18 ± 1.19^{bc}	18.17 ± 5.31^{ab}
KG-02	1.21 ± 0.41^{ab}	52.00 ± 17.50^{bc}	2.00 ± 1.00^{bc}	20.67 ± 7.06^{a}

Values are mean ± SD. Values followed by the same letter(s) within a column do not differ statistically ($P \leq 0.05$) according to DMRT.

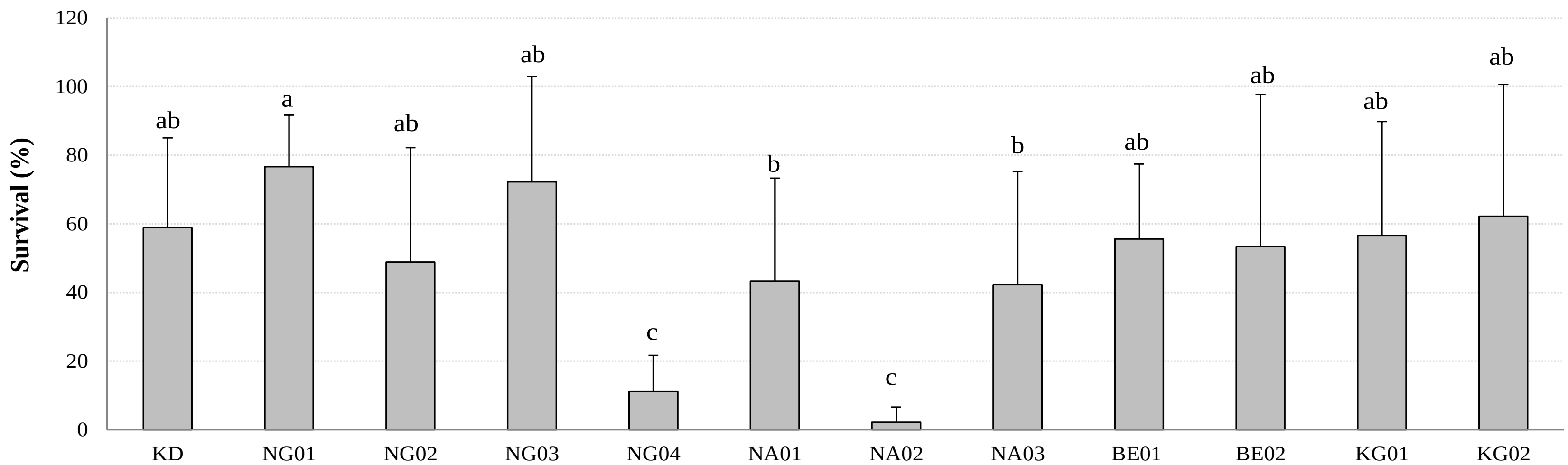

Figure 1. Survival percentages of 12 sesame genotypes collected from the North of Nigeria. Error bars indicate SD. Values followed by the same letter(s) do not differ statistically (*P*≤0.05) according to DMRT.

present study will be further characterized and studied for the identification of duplicates and to select parents for breeding programs. Falusi et al. (2014) characterized Roselle germplasm based on information derived from both morphological and agronomic traits to maximize the germplasm's genetic potential. Plant height, for instance, is one important characteristic that could help to differentiate sesame genotypes into short, medium and tall forms. The high number of branches observed in some of the genotypes, such as KD, NG-01, NG-03, NA-01, may ultimately determine the pod-bearing ability of a plant which in turn may contribute to yield.

Thus, identification and selection of genotypes with more branching ability is necessary. Variation in branch number among sesame varieties has been previously reported (Suhasini, 2006; Seymus and Bulent, 2010). Branching habit is affected by environmental conditions, sowing season, seed rate and spacing (Weiss, 1971). Number of branches in sesame is highly heritable and is influenced by the genetic content of the genotype (Shadakshari et al., 1995; Pham et al., 2010). The number of leaves per plant and leaf surface area also plays important roles in the yield ability as leaves are the site of nutrient synthesis of plants. Several genotypes, such as KD, NG-01, NG-02, NA-01, BE-01, KG-01 and KG-02, which had positive characteristics such as a high number of leaves and number of branches which could bring about high yield, are potential parents for inclusion in future breeding programmes aimed at improving the agronomic aspects of sesame in the north of Nigeria.

Conflict of Interest

The author(s) have not declared any conflicts of interest.

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Performance evaluation of a motorized ginger juice expression machine

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Ginger juice obtained from mechanical expression of fresh ginger rhizomes offers a value-added ginger product which increases market opportunity for farmers. In this study, the performance of a developed motorized ginger juice expression machine was evaluated to determine the effects of moisture content of ginger and screw shaft speed on the expression efficiency, juice yield, expression loss and throughput capacity. Three levels of moisture content (84, 79 and 72%) (wet basis) and three levels of screw shaft speed (420, 472 and 660 rpm) at two replications were used for the study. A 3 × 3 factorial experiment in a completely randomized experimental design was used. Data for the performance evaluation were subjected to analysis of variance for test of significance of the experimental factors and their interactions. The result showed that mean expression efficiency decreased with increase in screw shaft speed and with decrease in moisture content for the speed and moisture content range studied. The highest expression efficiency of 91.62% and juice yield of 61.28% were obtained at screw shaft speed of 420 rpm and at 72% moisture content (wb). The mean juice yield decreased with an increase in screw shaft speed and with a decrease in moisture content of ginger considered. The lowest expression loss of 11.69% was obtained at 472 rpm and 72% moisture content. The machine had highest throughput capacity of 9.47 kg/h at 420 rpm. Analysis of variance (ANOVA) results showed no significant effect of moisture content levels considered, speed and their interactions on all the performance indicators of the machine at P<0.05.

Key words: Expression, moisture content, ginger juice, expression efficiency, expression loss, juice yield.

INTRODUCTION

Ginger (*Zingiber officinale roscoe)* is valued for its essential oils, mainly oleoresin and gingerol, used in the pharmaceutical, bakery and soft drink beverage industries as well as culinary and cosmetics preparation. Percentage composition of volatile oil and non-volatile extract of ginger from Nigeria was given as 2.5 and 6.5%, respectively (Ravindran and Nirmal, 2005). Nigeria's ginger is highly valued for its aroma, pungency, high oil and oleoresin content (Yiljep et al., 2005). However, it has been observed that the quality of its dried ginger has been declining, due to low level of mechanization of ginger production and processing (Onu and Okafor, 2002), with attendant mould growth and loss of some important ginger qualities, as a result of which Nigerian

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ginger attracts the cheapest price in the world market.

Research carried out by Endrais and Asfaw (2011) showed that there is low percentage of oleoresin content per unit volume of ginger as a result of extended harvest, long storage period, over drying and/or re-drying due to dampness. Similarly, Eze and Agbo (2011) reported that drying ginger at a higher temperature appears to denature its protein and alters its organoleptic attributes through loss of its aroma and colour. The deterioration of active ingredients in dried ginger reduces its economic value and utilization in the industries. The bulk of ginger produced in Nigeria is often exported in processed form as split-dried ginger, dried ginger powder and extracts.

Fresh ginger rhizomes can be processed to ginger juice using chemical (extraction) or mechanical (expression) method. The chemical extraction method requires the use of organic solvents to recover oil from products (Ibrahim and Onwualu, 2005). This method of processing ginger is not generally adopted by farmers due to the high cost and complexity of the equipment used in the extraction. The ginger extract obtained from this process usually has some elements of impurity resulting from dissolved chemicals used in the extraction. The wet extraction process otherwise known as hot water or steam extraction used traditionally by women in rural communities for processing varieties of oil-bearing biological materials (Olaniyan, 2010), falls short of standard especially in quality. The traditional method used in expressing ginger juice is usually a manual process and involves pounding with mortar and pestle and hand pressing. This process is inefficient, unhygienic and tedious. These have affected the quality and quantity of ginger extract available in the market in Nigeria. Ginger juice obtained from mechanical expression of pulverized ginger rhizomes offers a value added ginger product which will increase market opportunity for farmers.

Lewis (1990) published that the efficiency of expression processes is determined by the yield and solids content of the liquid obtained. Some of the factors that influence the rate of expression include: Maturity and growth conditions of the raw material, extent of disruption of cell structure, rate of increase in pressure, resistance of the solids to mechanical deformation, time of pressing, the maximum pressure applied, the temperatures of the solids and liquid, and viscosity of the expressed liquid (Fellows, 1990). The effect of particle size, moisture content, heating temperature, heating time, applied pressure, and duration of pressing on the yield and quality of mechanically expressed oil from different crops have been investigated by researchers (Fasina and Ajibola, 1989; Tunde-Akintunde et al., 2001; Olaniyan, 2010). Results showed that these factors had significant influence on the oil yield.

In order to reduce the amount of loss of oleoresin and volatile oil in ginger during processing due to drying and long time storage, a motorized ginger juice expression machine aimed at processing ginger at the shortest possible time after harvest, as well as increasing the retention level of the active ingredients in ginger, was developed. The objective of this work is to evaluate the performance of a developed motorized ginger juice expression machine to determine the effects of moisture content of ginger and screw shaft speed on the expression efficiency, juice yield, expression loss and throughput capacity.

MATERIALS AND METHODS

The study was conducted at the Postharvest Technology Laboratory, Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike. Abia State, Nigeria.

Description of the motorized ginger juice expression machine

The developed motorized ginger juice expression machine (GJEM) consists of the following major components: Feeding unit, pulverizing unit, juice expression unit, juice drainage point (outlet), waste outlet, frame and power transmission system (Figure 1).

Frame

The two design factors considered in determining the material required for the frame are weight and strength. The frame was constructed with 38 mm × 38 mm × 3 mm mild steel angle iron. The frame provides firm support for the entire assembly. Based on anthropometric data of male and female agricultural workers in southern Nigeria reported by Onuoha et al. (2012), the overall dimension of the frame was chosen as 610 mm × 390 mm × 790 mm.

Feeding unit

The hopper is a stationary part mounted onto the machine which forms the feeding chute through which sliced ginger rhizomes are fed into the pulverizing unit by gravity. The passage hole (85 × 55 mm) of the hopper was large enough to prevent choking of the product. The hopper is made of stainless steel and is rectangular pyramid in shape.

Pulverizing unit

The pulverizing unit consists of a shaft with a screw conveyor and two attrition plates. One of the attrition plates is fixed on a stationary horizontally-placed small cylindrical drum, while the other is adjustable to allow the passage of the various sizes of the sliced ginger rhizomes. As the shaft rotates in the drum, it pulverizes the whole ginger rhizomes into smaller sizes and they are conveyed by gravity to the position where it enters the expression unit through the lower hopper. The pulverizer is made of stainless steel to avoid any reaction with the juice.

Ginger juice expression unit

The ginger juice expression unit consists of a tapered cylindrical barrel which covers a perforated tapered cylindrical drum that

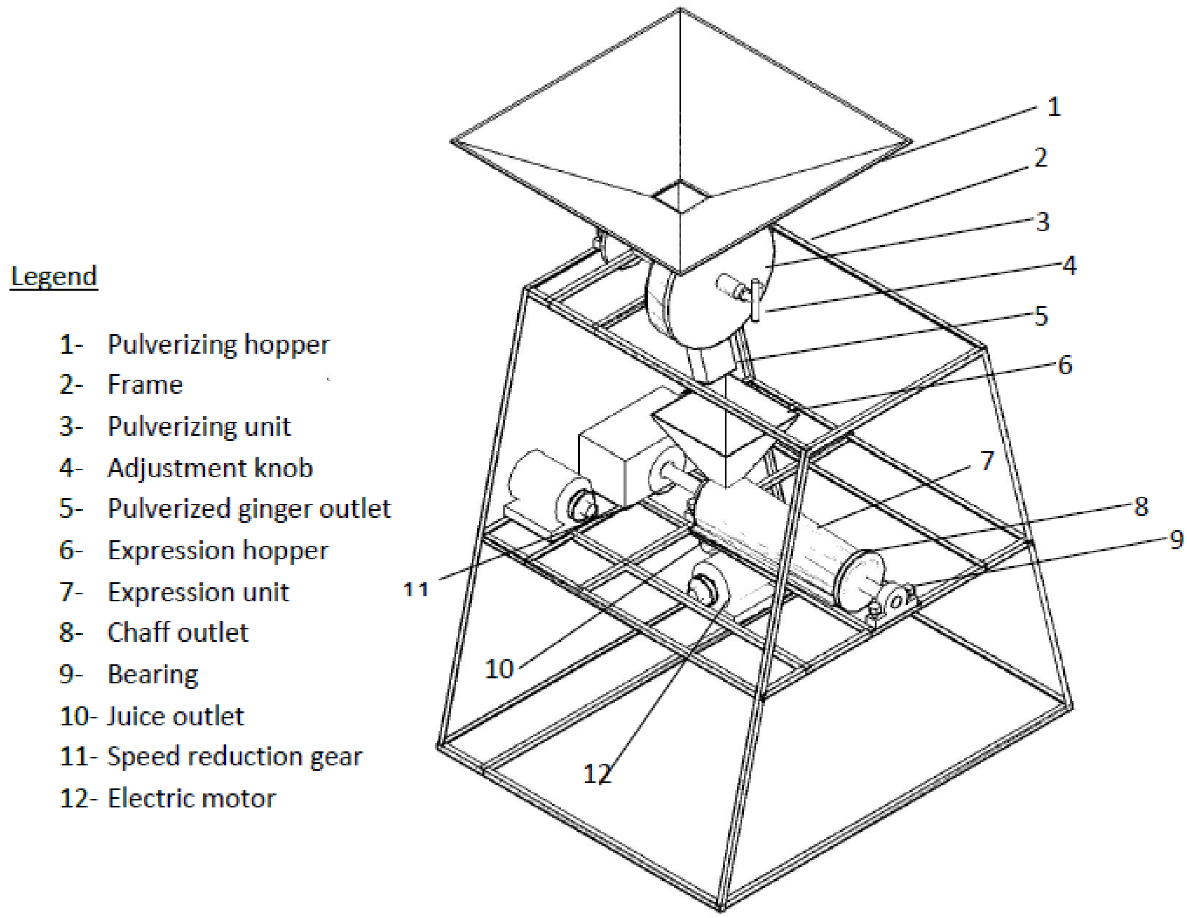

Figure 1. Isometric view of the developed motorized ginger juice expression machine.

houses a screw shaft. The screw shaft is the main component of the juice expression unit. The screw shaft is a stainless shaft with a tapered helical screw of variable pitch. The pitch of the screw flights gradually decreases towards the discharge end, to increase the pressure on the pulverized ginger rhizomes as it is carried through the barrel. The barrel is perforated to allow expressed juice to escape. The diameter of the perforation is about 1 mm. The pressed ginger residue (chaff) passes through the waste discharge point in the barrel outlet.

Power transmission system

The power transmission system comprises the prime mover (electric motor), shaft, speed reduction gear, pulleys and belt. The power was provided by a 2 hp, 1400 rpm and 1 hp, 1430 rpm electric motors. The V-belts and pulley assembly were used to transmit the power to the pulverizing and expression units at a speed of 646 and 240 rpm, respectively. The prime movers were mounted on a slotted plate on the frame to facilitate adjustment of the belt tension.

Working principle of the developed GJEM

The GJEM performs two distinct unit operations simultaneously, size reduction and separation processes. The ginger rhizomes are fed into the pulverizer through the hopper. The ginger rhizomes are comminuted by shearing and rubbing at the pulverizing unit. The screw shaft of the expression unit crushes, presses and conveys the product that comes from the pulverizing unit in such a way that juice is squeezed out of the pulverized rhizomes. The expression is actually achieved by the action of the screw shaft in squeezing the pulverized ginger rhizomes against each other and on the surface of the screw and perforated cylindrical barrel along the line of travel. The juice expressed is drained through the juice channel into the juice outlet from where it is collected while the residual waste is collected at the waste outlet. The picture of the developed GJEM is shown in Figure 2.

Experimental design for performance evaluation

The moisture content and speed of expression were taken as independent parameters for the study. The moisture content of the ginger rhizomes was selected at three levels (84, 79 and 72% wb). The first level was defined after soaking in clean water for two days from the time of purchase. The second level was defined at the period of purchase, while third level was defined after sun drying for one day. The rotational speed of the expression shaft was varied from 420 to 660 rpm at three levels (420, 472 and 660 rpm) using a triple groove pulley of different diameter in order to determine the optimum speed required in expressing ginger juices.

These parameters gave a 3 × 3 factorial experiment fitted into a complete randomized design (CRD). This gave a total of 9 treatments. The experiment was repeated twice giving a total of 18

Figure 2. The developed motorized ginger juice expression machine.

experimental runs.

Experimental procedures

Fresh ginger rhizomes were obtained from a local market in Umuahia, Abia state. Nigeria. Umuahia lies on latitude 5° 32' N and longitude 7° 29' E. The ginger rhizomes were washed, sliced and prepared ready for juice expression. The machine was set into operation and known weights of sliced ginger rhizomes were fed into the pulverizer where they were pulverized and transferred into the expression unit. The feeding time and expression shaft speed were recorded.

The juice expressed and residual waste were collected and weighed separately. The values obtained were used to calculate the juice yield, expression efficiency and expression loss. Also moisture content of the ginger rhizomes was determined. Each of the tests was done at three levels of moisture content and three expression shaft speeds in two replications.

Performance indicators

The performance of the machine was evaluated based on the following performance indicators:

1. Throughput capacity (C_T)
2. Expression efficiency (J_E)
3. Juice yield (J_y)
4. Expression loss (E_L)

Throughput capacity (C_T) was calculated from Equation 1, while J_E, J_y and E_L were calculated using Equations 2, 3 and 4 as given by Olaniyan and Oje (2011).

$$C_T = \frac{Q_o}{t} \quad (1)$$

$$J_E = \frac{100\,W_{JE}}{xW_{fs}}\ \% \quad (2)$$

$$J_y = \frac{100\,W_{JE}}{W_{JE} + W_{RW}}\ \% \quad (3)$$

$$E_L = \frac{100\,[W_{fs} - (W_{JE} + W_{RW})]}{W_{FS}}\ \% \quad (4)$$

Where, Q_o = Total quantity of ginger collected at the outlet (g); t = time taken to complete expression (s); W_{JE} = weight of juice expressed (g); W_{RW}= weight of residual waste (g); W_{fs} = weight of feed sample (g), and x = juice content of ginger in decimal.

RESULTS AND DISCUSSION

Effect of moisture content

The results of effect of moisture content on expression efficiency are presented in Figure 3. The 84% moisture content corresponds to highest mean expression efficiency of 83.12%. This was followed by 79% moisture content with expression efficiency of 78.78%. The lowest mean expression efficiency (76.24%) was however recorded at 72% moisture content. Expression efficiency increases with increasing moisture content between 72 and 84% range studied. From Figure 4, expression efficiency at 84% moisture content increased from 81.32% at 420 rpm to 88.82% at 472 rpm, and then decreased to 79.23% at 660 rpm. At 79% moisture content, the expression efficiency decreased from 88.13% at 420 rpm to 69.19% at 660 rpm. High water content in ginger accounts for high amount of juice yield and increasing expression efficiency. The lowest (47.89%) and highest (57.72%) mean juice yield were obtained at 72 and 84% moisture content respectively as shown in Figure 3 . The result is in conformity with reports of previous studies which recorded that in oil or juice expression using screw press, increase in moisture content leads to increase in juice yield for crambe seed (Singh et al., 2002); and flaked seed of *cuphea* (Evangelista and Cermak, 2007). This may be due to the increase in the water content. It was observed that the highest mean expression loss of 25.5% was at 79% moisture content. Mean expression loss varies directly with moisture content of the ginger rhizomes. Analysis of variance (ANOVA) showed that moisture content and interactions of speed had no significant effect on the performance indicators at P< 0.05 level at the moisture content levels considered (Table 1).

Effect of screw shaft speed

It was observed that expression efficiency generally decreased with increase in screw shaft speed. Figure 5 showed that the expression efficiency was highest (87.0%) at 420 rpm and decreased to 70.47% at 660 rpm. Kolawole et al*.* (2012) observed that the higher the machine speeds, the lower the machine efficiency. Their finding agrees with the relationship between the mean expression efficiency and screw shaft speed recorded in this study. The decrease in expression efficiency with increase in screw shaft speed within the study range can be attributed to the high rate of conveyance of the pulverized ginger by the screw conveyor which results to a short residence time of the pulverized ginger fed in the expression barrel.

The mean juice yield at 420, 472 and 660 rpm were 57.8, 53.1 and 48.47%, respectively (Figure 5). Effect of the interaction of moisture content and screw shaft speed (Figure 6) revealed that speed varies inversely with the juice yield except at 84.03% moisture content. Juice yield at 84% moisture content increased from 55.73% at 420 rpm to 61.25% at 472 rpm, and decreased to 56.18% at 660 rpm. Deli et al. (2011) observed that the percentage of oil yield from *Nigella sativa* L seeds decreased with the increase on the rotational speed of machine, which is in consonance with the result obtained from ginger in this study. The effect of different speeds on the percentage of juice yield is related with the duration of pressing process. Slow speed would probably extend the pressing process and result in increase of temperature during the process (Evangelista and Cermak, 2007).

At 72% moisture content in Figure 7, the mean expression loss decreased with speed from 12.8 to 11.68% and increased rapidly from 11.68 to 19.96% as speed increased from 472 to 660 rpm. This indicates that for minimal loss, the machine is better operated at 472 rpm and lowest moisture content (72%) for the speed range tested. The mean machine losses of sugar cane juice extractor reported by Olaoye and Oyelade (2012) decreased with the speed of operation which was also observed in the ginger juice expression machine within the speed of 420 to 472 rpm. From Figure 8, results showed that the highest mean throughput capacity of 9.47 kg/h was observed at the speed of 420 rpm. This was followed by a mean throughput capacity of 7.81 kg/h at 660 rpm. The minimum throughput capacity of 5.22 kg/h was observed at 472 rpm.

No significant effect of screw shaft speed and interactions of moisture content on the performance indicators recorded in this study (Tables 2 and 3) was due to probably close range of values (72- 84%) of

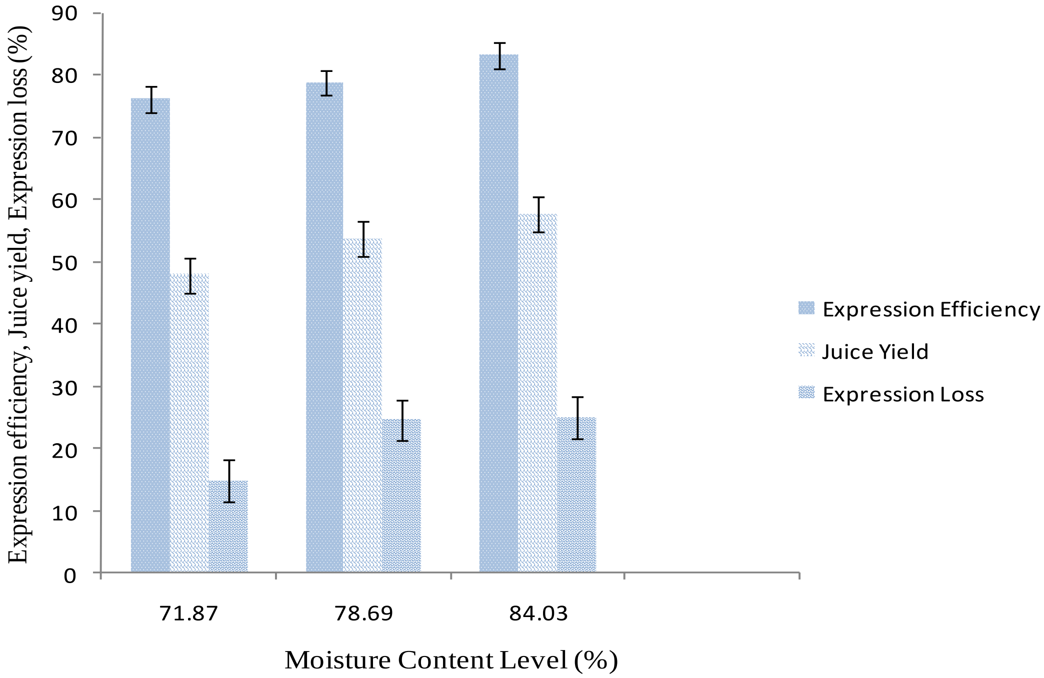

Figure 3. Effect of moisture content on expression efficiency, juice yield and expression loss. Data points are means (±SE) of the replicates.

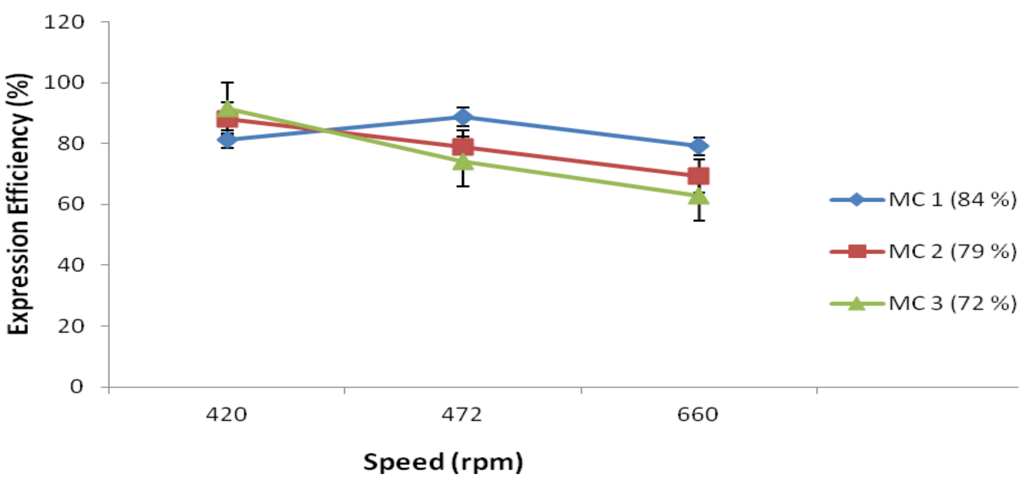

Figure 4. Effect of speed on expression efficiency at different moisture content. MC = moisture content. Data points are means (±SE) of the replicates

Table 1. Analysis of variance (ANOVA) for expression efficiency.

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	145.4	72.7	0.47	0.640*ns
Speed	2	835.8	417.9	2.70	0.121*ns
Moisture speed	4	457.5	114.4	0.74	0.589*ns
Residual	9	1395.5	155.1		
Total	17	2834.1			

*ns = Not Significant at 5% probability level.

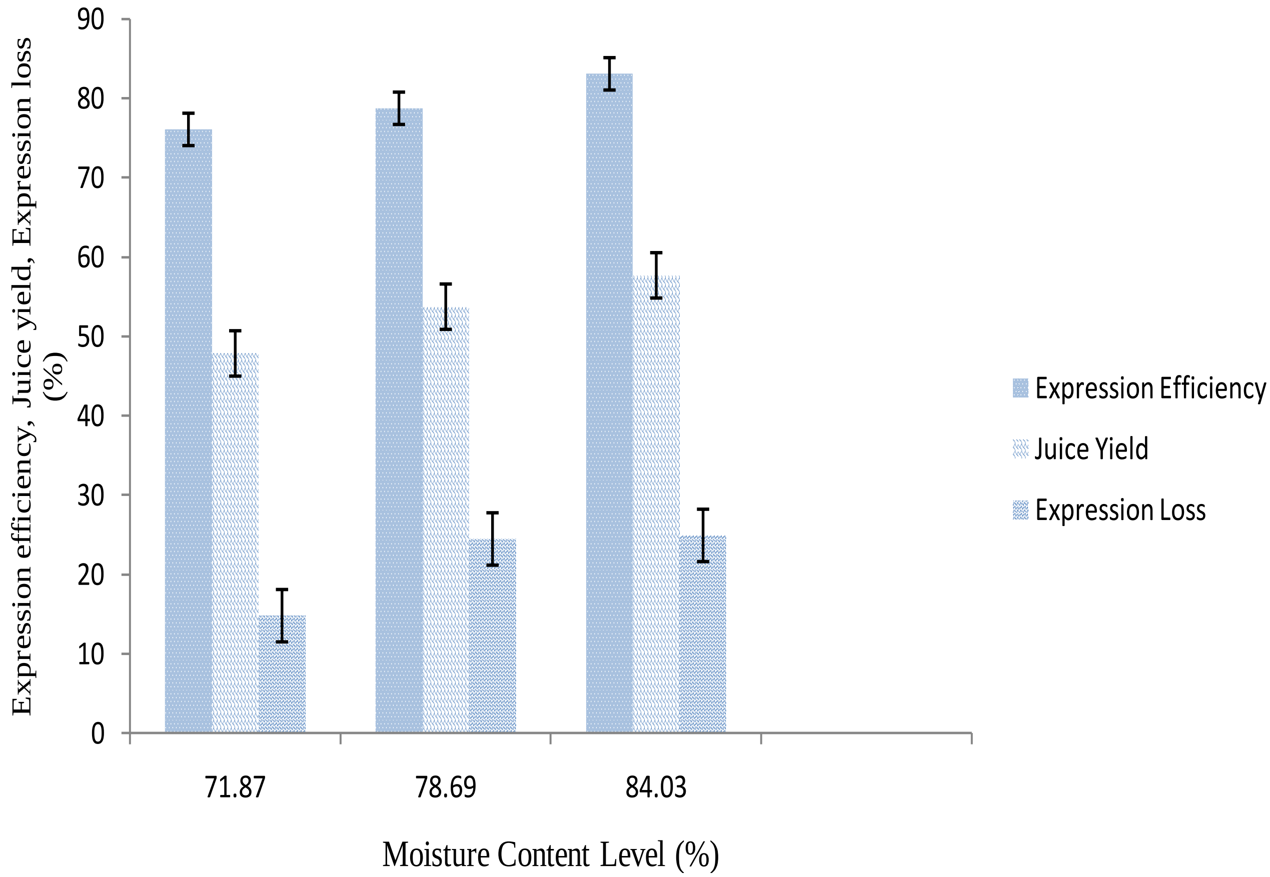

Figure 5. Effect of screw shaft speed on expression efficiency, juice yield and expression loss. Data points are means (±SE) of the replicates.

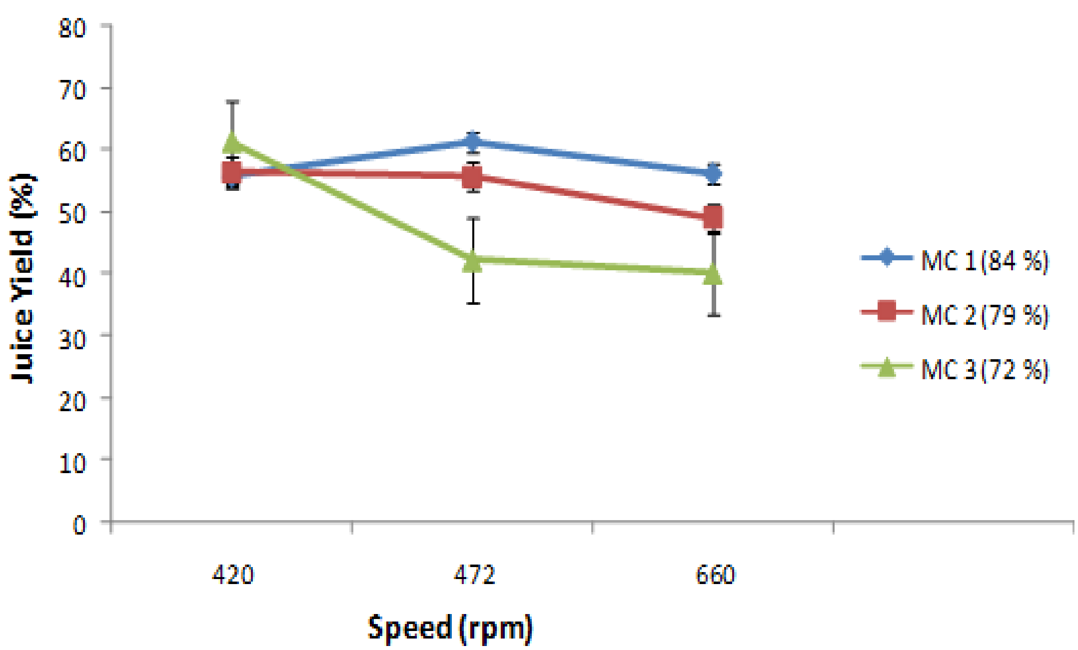

Figure 6. Effect of speed on juice yield at different moisture content. MC = moisture content. Data points are means (± SE) of the replicates.

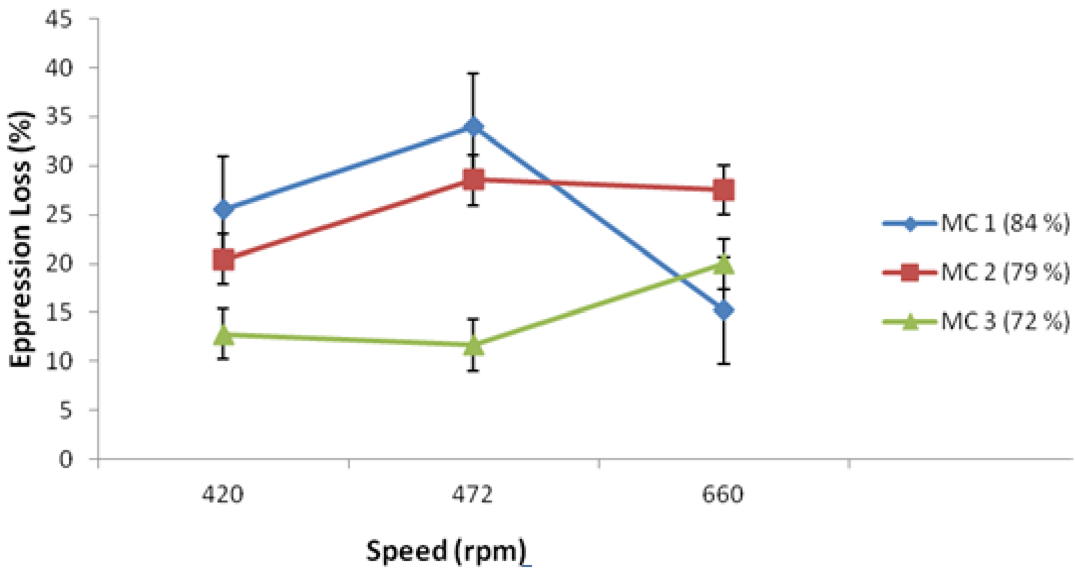

Figure 7. Effect of speed on expression loss at different moisture content**.** MC = moisture content. Data points are means (±SE) of the replicates.

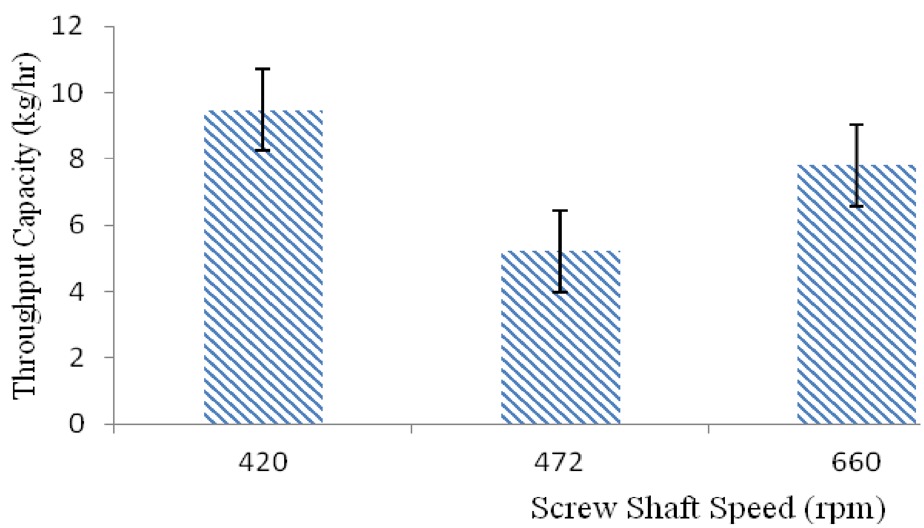

Figure 8. Effect of screw shaft speed on throughput capacity. Data points are means (±SE) of the replicates.

moisture content and speed (420- 660 rpm) used in the test.

Conclusion

The performance of the developed motorized ginger juice expression machine was evaluated, and the following conclusions were drawn:

1. The highest juice yield and expression efficiency of the ginger juice expressing machine can be obtained by operating the machine at lowest possible operational speed and moisture content level. The 420 rpm speed and 72% moisture content level satisfied this condition as was established for the range of speeds and moisture content levels considered in this study.
2. Increase in moisture content level from 72 to 84% led to increase in expression efficiency and juice yield from 76.24 to 83.12% and 47.89 to 57.72%, respectively, while expression loss increased from 14.82 to 25.5% as moisture content level increased from 72 to 79%, and

Table 2. Analysis of variance (ANOVA) for juice yield.

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	293.87	146.94	3.96	0.059*ns
Speed	2	261.14	130.57	3.52	0.074*ns
Moisture .Speed	4	384.87	96.22	2.59	0.108 *ns
Residual	9	334.27	37.14		
Total	17	1274.15			

*ns = Not Significant at 5% probability level.

Table 3. Analysis of variance (ANOVA) for expression loss

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	433.41	216.71	3.55	0.073*ns
Speed	2	85.49	42.75	0.70	0.521*ns
Moisture speed	4	427.71	106.93	1.75	0.222*ns
Residual	9	548.70	60.97		
Total	17	1495.32			

*ns = Not Significant at 5% probability level.

then decreased to 24.94 at 84% moisture content level.

3. The mean expression efficiency and mean juice yield decreased with increase in screw shaft speed from 420 to 660 rpm.

4. Moisture content levels considered, screw shaft speed and their interaction had no significant effect on the performance indicators at 5% probability level.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of inoculating seeds with *Bradyrhizobium japonicum* on the agronomic performance of five varieties of soybean (*Glycine max*) in Côte d'Ivoire

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Recent studies in the Nawa region of Côte d'Ivoire have indicated an acute malnutrition rate of 11.3% among cocoa producers. One of recommended actions from the studies was to diversify agriculture with nutrients rich crops. Introduction of soybean (*Glycine max*) cropping system could go a long way to ensure food and nutritional security in the region. The current study was conducted in two sites (Logboayo and Soubré) in the south-west of Côte d'Ivoire, to evaluate the effect of IRAT-FA3 *Bradyrhizobium japonicum* strain inoculum on the agronomic performance of five varieties of soybean named Doko, Canarana, V3_2013, V6_2013 and IT_235. The experimental design was randomized complete block with a split plot with inoculation as the main factor and variety of soybean as subplot treatment replicated three times. Data were collected on some yield parameters and the grain yield. Results of yield showed a highly significant effect (P<0.0001) of the site and a significant effect (P=0.0316) of the variety x treatment interaction. Highest yield was recorded at Logboayo with 1838 kg ha^{-1} compared to 1220 kg ha^{-1} for Soubré. The variety V6_2013 with a yield of 1931 kg ha^{-1} and good vegetative development could be recommended as elite variety for the farmers in the Nawa region.

Key words: Soybean, Côte d'ivoire, agronomic performance, yield, variety, inoculation.

INTRODUCTION

Soybean (*Glycine max* L. Merrill) is an annual herbaceous plant of the family of Fabaceae and native to eastern Asia. It is a legume cultivated for its seeds which are highly rich in protein and oil (FAO, 1995; Nyabyenda, 2005). Its seeds contain the highest protein content of all food crops. Soybean comes in second position for the amount of oil after peanut for legumes (Gurmu et al., 2009). This richness in fat and vegetable protein allow soybean to be a popular foodstuff in food and feed (FAO, 1995; Pirot, 1998). This crop can use atmospheric nitrogen through biological fixation by establishing a symbiotic relationship with Rhizobium bacteria (Vossen, 2007). Indeed, *Bradyrhizobium japonicum* is a nitrogen-fixing soil bacterium that has a symbiotic relationship with the host legume soybean *Glycine max* (Lee et al., 2012). Such symbiosis makes it less dependent on soil nitrogen

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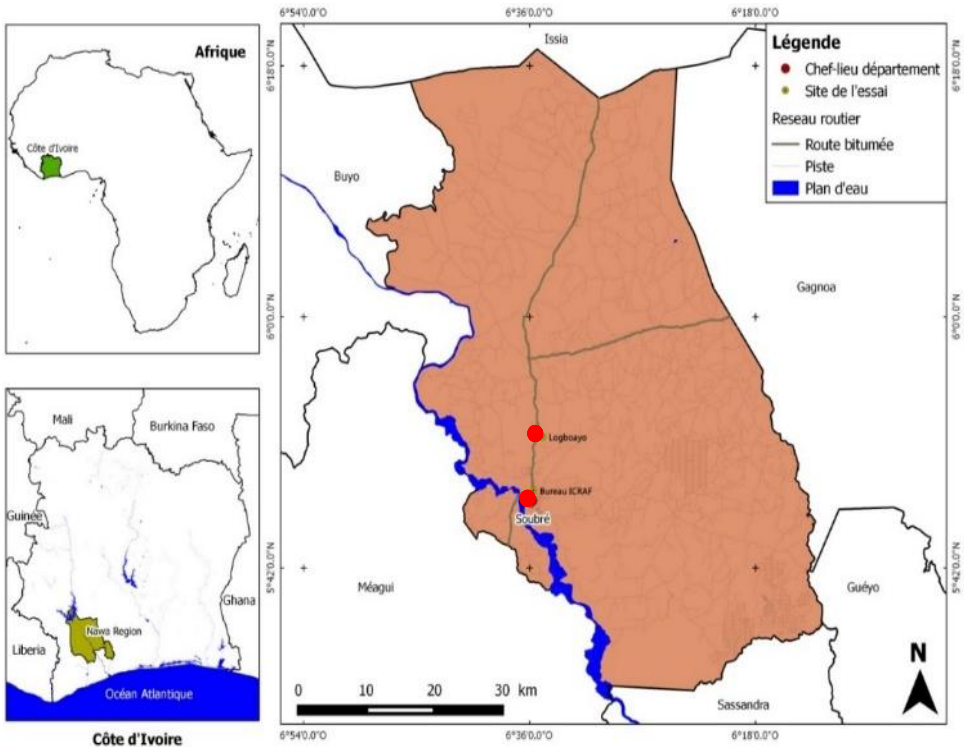

Figure 1. Location of the study area.

particularly in tropical regions of Africa where soils are deficient in nitrogen (FAO, 1995). Given this potential, soybean is considered as a strategic plant for producing countries according CIRAD (2002).

In Côte d'Ivoire, soybean farming was developed in the 1980s by the policy of diversification of food crops in the country (Chaléard, 1996; Beugré et al., 2013). The first results of experiments in the soybean project in the Northwest showed significant potential of soybean (N'gbesso et al., 2013). The national production of this crop is less than 6000 tons, and this quantity is insufficient to satisfy the needs of the Ivorian population estimated at 20 000 tons (CNRA, 2002; N'zoué et al., 2003). In addition, the adoption of the soybean crop is hindered by the lack of suitable variety really adapted to the environmental conditions in the respective areas (N'gbesso et al., 2009; Ama-Abina et al., 2012; Tukamuhabwa et al., 2012). Therefore, the search for varieties adapted to each agro-ecological zone is a precondition for increasing the yield of production and ensure food and nutrition security (Nieuwenhuis and Nieuwelink, 2005).

The region of NAWA contributes to 20% of cocoa production in Côte d'Ivoire (MINAGRI, 2009). The development of cocoa-farming in this region has been at the detriment of food crops which has consequently caused a food crisis in the region, resulting in the shortage of major commodities in the local market. Most households are indeed in a situation of food insecurity and vulnerability with a prevalence of 21.5% (Coulibaly, 2013). In addition, there is limited information available on soybean in this region; despite the opportunities that crop could offer to the people of the Nawa region.

To ensure food and nutrition security in this region, initiatives are being undertaken to diversify crops with the introduction of soybean in the area of the Nawa and, to facilitate its adoption. This work is part of a wider program. It is in this context that this study was conducted to investigate the agronomic performance of five soybean varieties in order to select the most suitable. The objective of this study was to compare the agronomic performance of different varieties of soybean in Soubré and Logboayo in the Nawa region of Côte d'Ivoire.

MATERIALS AND METHODS

Study site

Experiments were performed from September 2014 to February 2015 at the World Agroforestry Centre (ICRAF) Stations in Logboayo and Soubré, located in the Nawa Region; South-West of Côte d'Ivoire, 5°47′08″N, 6° 36′30″W, 276 m a.s.l. (Figure 1).

The vegetation is evergreen with a fraction of dense rainforest semi-deciduous or mesophilic (Kouamé and Zorobi, 2010). The type of sub-equatorial climate is characterized by the existence of two rainy seasons and two dry seasons. The heaviest rains are experienced in June. The mean annual rainfall is 1360 mm and

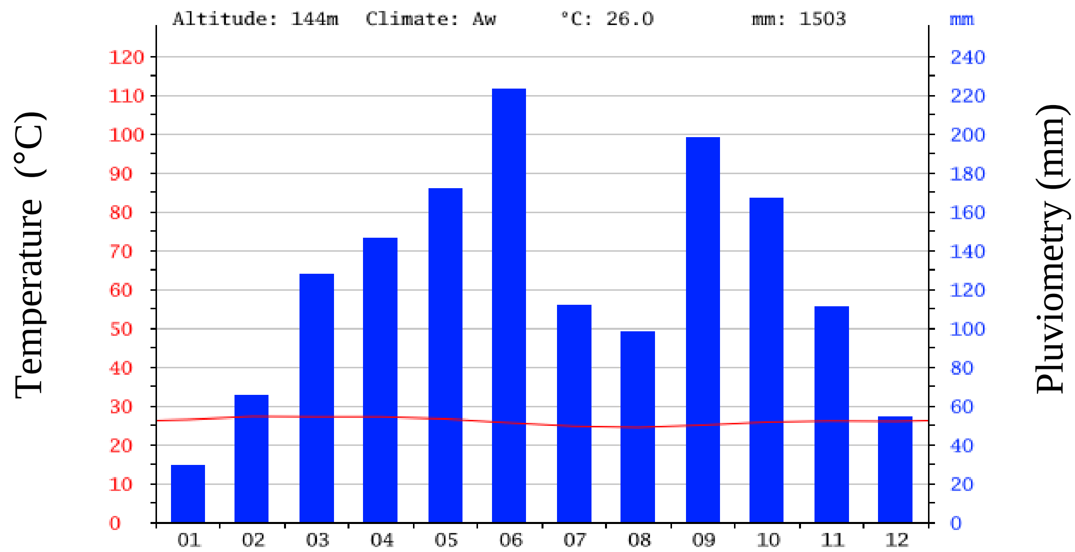

Figure 2. Ombrothermic diagram of the city of Soubré in 2013. Source : http://fr.climate-data.org/location/58795/.

varies from 968 to 1767 mm. The soils are classified as Ferralsols and Gleysols, generally acid, subject to leaching and chemically poor (De Rouw, 1994). The minimum and maximum temperature varies from 23 to 36°C (Figure 2).

The trials were conducted in two sites, one in Soubré and the other at Logboayo Station located 9 km from Soubré. The land in the two sites was previously planted with yams. The experimental plots were located on the top of a slope gradient of 9 and 7%, respectively, for Soubré and Logboayo. The pH of soil at Logboayo was 5.25 and 5.5 for Soubré.

Plant material

Five soybean varieties named Canarana, Doko, V3_2013, V6_2013 and IT_235 were used for the study. They were popularized in Côte d'Ivoire by the Soybean project for over 20 years (N'gbesso et al., 2010). Seeds used in this study were provided by the Research Station on Food Crops of the National Agricultural Research Centre (CNRA) in Bouaké.

Strain of bacterium

The IRAT-FA3 *Bradyrhizobium japonicum* strain was used for inoculum production. The strains of this species, known for a perfect symbiosis with soybean, are insignificant or absent in tropical soils (Cattelan and Hungria, 1995). Peat was used as inoculum substrate. It is described as being very competitive in acid soil and has already been used in Rwanda, Burundi, Madagascar, Cameroon and Côte d'Ivoire (Beugré et al., 2013). The inoculum was produced and provided by the Inoculum Production Unit for Legumes (UPIL) of the CNRA in Bouaké, Côte d'Ivoire.

Experimental design

All experiments were laid out in a randomized complete block design with split plots arrangement replicated three times with two factors in each site. The main factor was the inoculation with two levels: Inoculated treatment and uninoculated treatment or control. The second factor was the soybean variety, with five levels (Canarana, Doko, V3_2013, V6_2013 and IT_235). A block or replicate was divided into two sub-blocks or large plot. Each large plot was assigned with a treatment (Inoculated or uninoculated). Each large plot was divided into as many elementary plots as soybean varieties.

The size of the sub plots was 4 × 3 m giving a total area of 12 m^2. Two consecutive blocks were separated by a space of 2 m wide. Distance between 2 elementary plots of the same block was 1 m. A space of 2.5 m was left between the borders of the field and the blocks. The elementary plot of 12 m^2 was represented by 7 lines of 4 m seedlings, each. Data was collected from 5 lines on the inside of the basic plot 0.5 m from each side, therefore on an area of 6 m^2. There seeds per hole were sowed at 50 cm spacing between the rows and 20 cm between the holes of the lines seed. The experimental plot had a total of 12600 plants.

The site was cleared and this was followed by a manual deep plowing of 30 cm and making ridges. A fertilizer NPK12-24-18 was applied at the rate of 100 kg ha^{-1}. No pesticide treatment was applied throughout the crop cycle. In addition, three manual weeding and tilling were made on the 15th, 30th and 55th days after sowing (DAS) to aerate the soil and reduce competition with weeds. The harvest was done gradually following the period of maturity of the different varieties.

Inoculation of seeds

Seeds were inoculated with the *Bradyrhizobium japonicum* bacterium before being sowed at a depth of 3 cm (Kouamé et al., 2007). The broth method or inoculation by seed coating method was used (Vitosh, 1997). The proportion was 100 g of inoculum for 15 kg of seed. The bacteria density was 10^9 bacteria/g of inoculum (N'gbesso et al., 2010). The control plots were sowed first in order to avoid contamination by bacteria of the inoculum.

Data collection

Data were collected on pod maturation period, plant density at harvest, dehiscence rate at harvest, height of the first pod insertion,

Table 1. Effect of inoculation on pod maturity period, plant density at harvest, number of fruiting nods, insertion height of first pod and height at harvest of the soybean varieties

Variety	Pod maturity period (DAS)	Plant density at harvest (%)	Number of fruiting nods	Insertion height of first pod (cm)	Height at harvest (cm)
Canarana	100.30[d]*	55.81[bc]	10.42[b]	5.77[a]	29.17[c]
Doko	97.40[c]	53.78[bc]	8.25[a]	9.58[c]	37.17[a]
IT_235	95[b]	62.85[a]	11.10[b]	7.83[b]	35.56[a]
V3_2013	88.72[a]	52.68[b]	11.02[b]	6.40[a]	31.42[b]
V6_2013	103.53[e]	23.95[c]	10.56[b]	5.67[a]	31.11[b]
Means	96.94	50.09	10.26	7.19	32.94
CV (%)	5.34	44.16	19.77	44.93	20.16

*Means followed by the same letter are not significantly different at p > 0.05.

plant height at harvest, number of fruiting nodes, pods per plant, seed per plant, and seed per pod, pod filling rate, weight of 100 seeds and grain yield of soybean varieties.

Data analysis

All data were subjected to two way analysis of variance (ANOVA), using the general linear model of Statistical Analysis System (SAS) software (SAS, 2003), and the significance difference between the means were assessed with Duncan method at 5%.

RESULTS AND DISCUSSION

Table 1 shows the results of the most important agronomic characteristics of soybeans. The pod maturation process began about 77 days after sowing (DAS) with V3_2013 variety. A highly significant difference was observed among the soybean varieties (P<0.0001). The pod maturity period for this variety was reached about 88 DAS. V3_2013 was followed by IT_235 and Doko varieties with the pod maturity periods of 95 and 97 DAS, respectively. Varieties Canarana and V6_2013 expressed the longest pod maturity period with 100 and 103 DAS respectively (Table 1).

The varieties being evaluated registered good plant density at the harvest except V6_2013. The highest plant density was shown by the variety IT_235 with about 63 plants. Then, Canarana, Doko and V3_2013 had between 52 and 56 plants. The lowest density was observed with the variety V6_2013 which had 23 plants (Table 1). Analysis of variance showed a highly significant difference among the soybean varieties and the treatment (P<0.0001). The interaction of Treatment x variety was significant (P=0.0132).

The average number of fruiting nodes on the main stem ranged from 8.25 to 11.02. Analysis of variance showed a significant difference among the soybean varieties. Varieties were classified into two groups according to the number of nodes. The first group consists of varieties Canarana, IT_235, V3_2013 and V6_2013. These varieties with 11 nodes had the largest numbers of nodes compared to the variety Doko, of the second group with 8.25 nodes (Table 1).

Concerning the height of insertion of the first pods, 3 groups were distinguished. The highest height was observed in the Doko variety with 9.58 cm. It was followed by the IT_235 variety with 7.53 cm. Canarana, V3_2013 and V6_2013 varieties, the 3rd group, expressed the lowest heights with 5.77, 6.4 and 5.67 cm, respectively (Table 1).

Variance analysis identified a highly significant effect of treatment on dehiscence rate of the seeds. Indeed, the inoculated plants with dehiscent seeds were low compared to non-inoculated plants with averages of 2.37 and 4.99, respectively. In addition, a variety effect was observed in both inoculated plants and the control. Varieties Canarana and V6_2013 had high dehiscence rate for both treatments. The varieties Doko and IT_235 had a very small number of plants with dehiscent pods. No dehiscent pod was observed in the V3_2013 variety (Table 2).

The analysis of variance on the pod filling rate showed no significant effect of the two factors and their interaction and among the soybean varieties. However, the inoculated plants had significantly slightly higher fill rate than non-inoculated plants. These rates ranged from 77.40 to 90.94% for inoculated plants and 52.69 to 88.38% for controls (Table 2).

The results showed a highly significant effect of inoculation, variety and the treatment x variety interaction on the number of pods per plant (P=0.0016 and P<0.0001). Inoculation contributed to a significant increase in the number of pods per plant. The number of pods of Canarana variety increased from 47.85 in the control to 74.74 in the inoculated. For the variety Doko, the number of pods per plant increased from 37.27 to 41.12. In IT_235; this variable ranged from 43.40 to 65.56 and for V6_2013 from 59.48 to 67.79. However, the variety V3_2013 was observed to have a high number of pods per plant in non-inoculated plants than in plants inoculated with 69.10 and 52.80 (Table 2).

The number of seeds per plant of the soybean varieties was improved by the inoculation except for V3_2013.

Table 2. Effect of inoculation on dehiscence rate, pod filling rate and number of pods per plant of 5 soybean varieties.

Variety	Dehiscence rate (%)		Pod filling rate (%)		Number of pod per plant	
	I1	I0	I1	I0	I1	I0
Canarana	9.39[a]*	13.72[a]	77.40[a]	52.69[a]	144.64[a]	92.46[b]
Doko	0[b]	1.99[c]	76.29[a]	67.24[a]	93.66[b]	84.00[b]
IT_235	0.55[b]	0.47[c]	85.44[a]	86.27[a]	137.30[a]	89.36[b]
V3_2013	0[b]	0[c]	90.94[a]	88.38[a]	106.88[b]	136.14[a]
V6_2013	1.64[b]	8.55[b]	77.35[a]	74.57[a]	148.79[a]	128.91[a]
Means	2.37	4.99	79.97	69.58	125.70	106.02
CV (%)	275.16	208.28	14.01	86.17	46.19	53.59

*Means followed by the same letter are not significantly different at p > 0.05.

Table 3. Effect of inoculation on the number of seeds and the weight of 100 seeds of the soybean varieties.

Variety	Number of seeds		Weight of 100 seeds (g)	
	I1	I0	I1	I0
Canarana	1.97[a*]	1.91[a]	11.08[c]	10.06[c]
Doko	2.25[a]	2.26[a]	14.26[a]	13.40[a]
IT_235	2.10[a]	2.05[a]	12.16[bc]	10.80[b]
V3_2013	2.03[a]	1.96[a]	11.74[bc]	11.98[ab]
V6_2013	2.20[a]	2.16[a]	13.68[ab]	12.28[ab]
Means	2.11	2.06	12.58	11.70
CV (%)	10.31	11.42	13.93	14.53

*Means followed by the same letter are not significantly different at p > 0.05.

Canarana, Doko, IT_235 and V6_2013 recorded a respective increase in the number of seed of 52.18, 9.66, 47.91 and 19.88. The control V3_2013 had 136.14 seeds compared to 106.66 for treatment with inoculation. Regarding the number of seeds per pod, inoculated and non-inoculated plants had an average of 2.11 and 2.06 seeds respectively. There was no effect of the treatment and the variety (Table 3).

According to the weight of 100 seeds, it was noted a net improvement by the inoculation with an average of 12.58 g as opposed to 11.70 g for the control. Furthermore, in the same treatment, a highly significant effect of the variety was observed. Doko variety had the highest weight of 100 seeds in both treatments with 14.26 g for inoculated plants and 13.40 for the control. It is followed by V6_2013, IT_235 and V3_2013. Lowest weight was obtained by Canarana variety in each treatment with 11.08 and 10.06 g, respectively in the inoculated and in the control (Table 3).

The pod maturation period revealed that varieties having obtained a good nodulation were early with homogeneity in the maturation of pods. This could mean that the ability to nodulation appearance of varieties did intervene in the maturation process. Indeed, for the varieties IT_235 and V3_2013, harmonious browning pods (Fehr and Caviness, 1977) allowed obtaining a low rate of dehiscence. In contrast, late varieties Canarana and V6_2013 had a heterogeneous maturation manifested by the presence on the same plant of ripe and not ripe pods. This has resulted in a high loss by seeds dropping on feet of these two varieties with losses per basic plot about 69.1 and 26.37%, respectively.

For the number of pods per plant, the pods filling rate, the number of seeds per pod and the weight of 100 seeds, inoculation led generally to the improvement of these characters in the inoculated plots. Indeed, in these plots, plants have the atmospheric nitrogen fixed by symbiotic bacteria in addition to the nitrogen in the soil. These studies concur with those of Ama-Abina et al. (2012) and Ngbesso et al. (2013). According to Gazzoni (1995), atmospheric nitrogen is easily usable by soybean and goes directly into the formation of fruiting bodies, such as pods and seeds in relation to the nitrogen from the soil (Cattelan and Hungria, 1995). These results will allow selecting the best varieties for the locality.

Grain yield

Inoculation improved grain yield of soybean varieties. Highly significant effects of the site and variety x treatment interaction were observed on this parameter

Table 4. Effect of inoculation on grain yield of the soybean varieties

Variety	Logboayo (kg ha^{-1})		Soubré (kg ha^{-1})		Whole study (kg ha^{-1})	
	I0	I1	I0	I1	I0	I1
Canarana	1864.0^{a*}	2250.5^{a}	929.0^{b}	1450.7^{a}	1303.0^{a}	1770.6^{a}
Doko	1912.0^{a}	2231.0^{a}	1023.7^{b}	1334.3^{ab}	1379.0^{a}	1699.0^{a}
IT_235	1626.0^{a}	1821.0^{a}	1448.3^{a}	1196.7^{ab}	1519.4^{a}	1446.4^{ab}
V3_2013	1662.0^{a}	1337.0^{a}	1102.7^{ab}	755.7^{b}	1326.4^{a}	988.2^{b}
V6_2013	1601.5^{a}	2079.0^{a}	1114.7^{ab}	1833.3^{a}	1309.4^{a}	1931.6^{a}
Means	1733.1	1943.7	1124.7	1316.1	1367.4	1567.2
CV (%)	24.30	27.61	18.38	25.20	21.64	26.25

*Means followed by the same letter are not significantly different at p > 0.05.

with P<0.0001 and P=0.0316, respectively. Indeed, the grain yield obtained was higher at Logboayo (1838 kg ha^{-1}) compared to Soubré (1220 kg ha^{-1}) for all the soybean varieties and the treatment (Table 4).

At Logboayo, no significant difference was observed among varieties of inoculated and the control. Grain yield of Canarana ranged from 1864 to 2251 kg ha^{-1} with an increase of 387 kg ha^{-1} due to the inoculation. For Doko, the grain yield oscillated in 1912 to 2231 kg ha^{-1} with an increase of 319 kg ha^{-1}. Variety IT_235 registered 1626 to 1821 kg ha^{-1}, 195 kg ha^{-1} of increase. For V3_2013 the control gave a grain yield of 1662 kg ha^{-1} compared to 1337 kg ha^{-1} for the treatment.

At Soubré, significant effects of the variety and the variety x treatment interaction were observed on the yield with P=0.0356 and P=0.0106, respectively. An improved performance by inoculation was also observed. The three varieties V6_2013, Canarana and Doko recorded a yield increase of 718, 522 and 310 kg ha^{-1}, respectively. However, for varieties IT_235 and V3_2013, the grain yield of the control was higher than that of the inoculated treatment. This could be probably because these varieties did not nodulate with the strain *Bradyryzobium japonicum*.

Regarding the grain yield per hectare, inoculation improved this parameter for the inoculated plants. The best yields were obtained at Logboayo with an estimate of 2251, 2231 and 2079 kg ha^{-1} for varieties Canarana, Doko and V6_2013, respectively. At Soubré, the best variety was V6_2013 with 1833 kg ha^{-1}. It is followed by Canarana and Doko with 1451 and 1344 kg ha^{-1}, respectively. Variety V3_2013 exhibited a decrease of its yield regarding inoculated compared to uninoculated controls in Soubré and Logboayo. This is a good justification of nodulation ability of this variety with indigenous rhizobia. This work confirmed a spontaneous nodulation induced by indigenous strains of bacteria.

During the current study, V6_2013 with a yield of 1932 kg ha^{-1} and an increase of 622 kg ha^{-1} compared to the control, followed by Canarana with a yield of 1770.6 kg ha^{-1} and an increase of 467 kg ha^{-1} and Doko (1699 kg ha^{-1}) with an increase of 320 kg ha^{-1} were the best varieties. The variety V6_2013 got a low grain yield, also in the inoculated treatment than the control. This was certainly due to its low plant density observed in the two tests (N'gbesso et al., 2013). In addition, it was noted an early drying of plant in the maturation phase. This has therefore intensified the dehiscence rate and the loss by dropping of seeds. The best performance obtained in Logboayo could be explained by two successive rains occurred in Logboayo during pod filling when plants in Soubré were manually irrigated during this critical time when they needed water. This irregularity of rainfall was mentioned by Ama-Abina et al. (2012) to justify the low yields obtained in some trials of soybean cultivation in Gagnoa, Côte d'Ivoire. In fact, soybean has two critical periods of water requirement: to plant emergence and timing of pod filling (FAO, 1995).

According to Anthony (2005), a typical inoculation of soybean seeds induces an increase of bacteria in the soil by 256.10^9 bacteria per plant are in the soil. The average yields of 1838 kg ha^{-1} in Logboayo is lower than those obtained by Ngbesso et al. (2010) to 3260.68 kg ha^{-1} in Bouaké and 3560.75 kg ha^{-1} in Touba, but higher than those obtained by Nzabi et al. (2000) with two varieties; Congo Belgium (1720 kg ha^{-1}) and Hill (1430 kg ha^{-1}) in the South-west of Kenya after inoculation. Result of 1220 kg ha^{-1} in Soubré is lower than what these authors obtained. Moreover, the results of this study also showed that the improved performance and other parameters studied after inoculation varied according to the locality and the varieties tested. Indeed, differences between yields of different localities, induced by inoculation were also reported by Yen (2004) in Vietnam. These different behaviors are linked to the ability of each variety to fix nitrogen with the strains of bacteria in presence (Gwata et al., 2003).

In Logboayo and Soubré, inoculation has never been practiced, population densities of bacteria strains were probably weak and insufficient to achieve optimal symbiotic fixation with the varieties tested. Therefore, inoculation with efficient strains of bacteria must be necessary to optimize the yields of the new varieties.

Conclusion

The results of this study showed that inoculating the seeds contributed to the improvement of the performance of the different soybean varieties in both sites. However, there is need to repeat this trial to confirm these first findings and to determine the best time in the year to plant soybean. Evaluation of other promising varieties for the Nawa region of Côte d'Ivoire should be considered in the future work

Conflict of Interest

The authors have not declared any conflict of interest.

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