OPEN ACCESS

African Journal of Agricultural Research

16 August, 2018
ISSN 1991-637X
DOI: 10.5897/AJAR
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

ABOUT AJAR

The African Journal of Agricultural Research (AJAR) is published weekly (one volume per year) by Academic Journals.

African Journal of Agricultural Research (AJAR) is an open access journal that publishes high-quality solicited and unsolicited articles, in English, in all areas of agriculture including arid soil research and rehabilitation, agricultural genomics, stored products research, tree fruit production, pesticide science, postharvest biology and technology, seed science research, irrigation, agricultural engineering, water resources management, marine sciences, agronomy, animal science, physiology and morphology, aquaculture, crop science, dairy science, entomology, fish and fisheries, forestry, freshwater science, horticulture, poultry science, soil science, systematic biology, veterinary, virology, viticulture, weed biology, agricultural economics and agribusiness. All articles published in AJAR are peer- reviewed.

Contact Us

Editorial Office: ajar@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJAR

Submit manuscript online http://ms.academicjournals.me/

Editors

Editorial Board

African Journal of Agricultural Research

Table of Contents: Volume 13 Number 33, 16 August, 2018

ARTICLES

Vol. 13(33), pp. 1674-1688, 16 August, 2018
DOI: 10.5897/AJAR2018.13278
Article Number: B6962E658108
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Farmers' synergistic selection criteria and practices for livelihood security through the sustainable uses of on-farm Sorghum landrace diversity, Ethiopia

Awegechew Teshome[1*], Kenneth Torrance[2] and Laura Breuer[1]

[1]Seeds of Trust Consultancy, 1750 Ainsley Dr., Ottawa, ON, K2C 0T2, Canada.
[2]Geography and Environmental Studies, Carleton University, Ottawa, ON, K1S 5B6, Canada.

Received 28 May, 2018; Accepted 25 July, 2018

The relationships among the multiple criteria that farmers in this study area, the north Shewa and south Wollo regions of Ethiopia, use to select which sorghum landraces to grow were examined in order to assess the extent of synergistic relatedness among them as they fulfilled their roles in meeting the farmers' goals. Surveys were conducted on 300 randomly selected farmers' fields during the 2011/2012 cropping season. In each field, the farmers identified the sorghum landraces encountered at 5m intervals along transect lines, spaced 10 m apart; they were also asked to specify the reasons (selection criteria) for growing each landrace. Pearson correlation, t-Tests and Linear Regression analyses were conducted on the twelve most common selection criteria identified. These statistical analyses demonstrated that the individual selection criteria exhibited various degrees of independent functionality while also exhibiting various and significant magnitudes of relatedness (Biomass and Market – r=0.72, R^2 =0.52, P<0.00001; Grain Yield and Market- r=0.73, R^2 =0.54, P<0.00001; and Biomass and Grain Yield- r=0.79, R^2 =0.63, P<0.00001). These results indicate that the farmers' selection criteria reflect farmers' needs, knowledge and practices; and also that the heterogeneous adaptive responses of both the genetic resources and the agroclimatic conditions provide for livelihood and environmental benefits. These correlations among the selection criteria will have value when designing and redesigning participatory varietal selection and breeding practices for future development of crop varieties with the adaptive capacities to respond to biophysical variations and sociocultural preferences. It is thus crucial to appropriately recognize and to incorporate the continuing roles of these traditional farmers and their selection criteria in crop enhancement programmes and policies for food and livelihood security.

Key words: Adaptive capacity, agroclimatic variations, diversity, Ethiopia, farmers' selection criteria, livelihoods, sorghum bicolor landraces, synergism.

INTRODUCTION

Since agriculture began, farmers have been domesticators, users and managers of diversification and expansion of the cultivated crop genetic resources that they manage and own. "Traditional farmers", as used in this paper, are identified as 'farmers who grow a diversity of crops on highly heterogeneous agroclimatic environments using dynamic time-tested knowledge and practices developed by their predecessors, along with their own ingenuity, to meet their varied livelihoods. Their farm sizes tend to be small and the farmers use animal and human power, inherited approaches and strategies, and ingenuity to meet the challenges presented by natural factors (biotic and abiotic stresses). On-farm, diversity-based practices that have evolved over the ages are essential components. Among the most important are the selection practices, exchange mechanisms and diverse seed systems that have been practiced over many generations. These 'traditional farmers' in their diverse agricultural landscapes, and especially in the world's centers of crop origin and diversity, have generated and maintained a wealth of crops and crop varieties that continue to have local, national, regional and global importance (Meyer et al., 2012).

In contrast, the high-input, mechanized, commercial agriculture currently practiced on large farms in more prosperous settings is geared to produce surpluses for national and global markets through the cultivation of genetically-uniform, high-yielding, hybrid crop varieties. It relies annually on off-farm commercially produced hybrid seeds and manufactured fertilizers and pesticides. The dominant selection criteria for modern commercial agriculture relate to yield and profit. These have been reported to lead to reduced crop diversity with negative consequences for crop nutrient density (Davis et al., 2014). According to Kuhnlein (2014), these commercially grown crops besides lacking nutrient density and cultural meanings, are also directly linked to losses of the local knowledge of ecosystem management for food and nutrition practiced by indigenous and traditional farmers and subsistence oriented people.

Survival in the traditional systems requires that both individual farmers and communities must be self-insured. The only insurance available at both levels is diversity; in both the range of crops grown on individual farms and in the range of landraces of crops and crop varieties grown across communities.

"Survival" does not mean just having 'enough food to eat'; they must also have ''income security'' to meet a whole range of other needs. These are basic and immediate issues of health, survival and more that offer multiple livelihood benefits on a dynamic basis. The traditional farmers have learned by experience that they must imitate nature through the practices of maintaining variability and taking advantage of opportunities to maintain and enhance food and livelihood security. Sunderland (2011) argues that smallholder farmers must maintain and practice biodiversity within the cropping system for livelihood and environmental security while managing agricultural landscapes on multifunctional basis by combining food production, biodiversity conservation and maintenance of ecosystem services. The crop genetic resources of traditional agricultural systems that have been domesticated, diversified, conserved and managed across non-uniform agricultural landscapes and over climatic seasons are, and will remain, the sources of genetic variations and the associated knowledge and practices to maintain/enhance humanity's food supply systems (including high-input, mechanized, commercial agriculture). Note: the term "landraces" is used to designate "variable plant populations adapted to local agroclimatic conditions which are named, selected and maintained by the traditional farmers to meet their social, economic, cultural and ecological needs" (Teshome et al., 2001).

Numerous examples exist on agricultural, medical and pharmacological scientists, seed companies and others having exploited the range of features that the farmers' selection criteria and time-tested knowledge and practices have preserved and long utilized. These include pest resistance (Arnason et al., 1993; Adams, 1977; Dogget, 1958; Teshome et al., 1999b), sorghum classification, phytochemical and pharmacological uses (Farnsworth et al., 1985), medicinal plant studies (Leaman et al., 1995), and to evaluate crop genetic erosion risks (Mekbib, 2009; Tsegaye et al., 2007). Farmers' varietal names of crops and crop varieties also are used as *de facto* sources of information to identify quality nutritional traits in sorghum landrace diversity (Singh et al., 1973; ICRISAT, 1985; National Academy of Sciences, 1996).

Although traditional farmers have made immense critical contributions to human livelihood and environmental security through crop selections and diversifications, their knowledge and practices have not received the attention they deserve (Zeven, 2000). While Cleveland et al. (1994) noted that little scientific data was available on the selection and maintenance of landraces by farmers, Derbie et al. (2002), Abdi and Asfaw (2005) and Mekbib (2008) recognized the dynamic on-farm relationships between farmers' selection criteria and sorghum diversity. Geleta et al. (2002) analyzed the critical role of farmers' selections and practices in the cultivation and uses of oil crops that are integrated with sorghum and teff (*Eragrostis teff*) cereal crops. Elsewhere, Zurita et al. (2016) have established that plant diversity increased with time through the management practices of the Waorani people in Ecuadorian Amazon. Also, Cruz-Garcia and Struik (2015) demonstrated the uses and variations of wild food plants through farmers' management practices over climatic seasons and across various structural aspects of home-gardens in northeast Thailand. Nabhan (2014)

*Corresponding author. E-mail: seedsoftrust@gmail.com.

documented a diversity of heirloom and landraces of various food plant varieties that have increased through the practices of selection as well as seed saving and exchanges; providing healthy locally-produced food options to commoditized foodstuffs of industrial agriculture in the US and Canada.

Farmers' selection criteria are derived from the complementary and competing socioeconomic, cultural, agronomic, ecological, biological, dietary and nutritional needs each farm family desires to satisfy from the diversity of crops and crop varieties the family cultivates. In short, selection criteria reflect the multiple functional values of the crops (Campbell, 2014) farm families cultivate to meet their multiple livelihoods (Sander and Vandebroek, 2016; Teshome et al., 2016b). Farmers employ multiple selection criteria per crop and per field and across the variable agricultural landscape and over climatic seasons based on the recognition that multiple crops and crop varieties are essential to meet their livelihood requirements. A single landrace does not possess all the attributes needed to meet the requirements of individual farmers, and hence all farmers plant more than one landrace and use a range of the selection criteria appropriate to their requirements when deciding which landrace to grow.

We contextualize farmers' selection criteria with growing concern on livelihood insecurity and their adaptive enabling capacity to managing resilient multifunctional landrace diversity for sustainable livelihoods. As the number of farmers' selection criteria increases, the diversity on-farm increases, and the fields in which farmers used more selection criteria were more diverse. The study hypothesize that there must be a degree of synergism acting among the farmers' selection criteria that functions to increase livelihood security. Synergism in this study is used to demonstrate the collaborative effects of multiple selection criteria to meet multiple farmers' livelihoods, which is greater than the sum of their separate effects. This paper examines the differences and magnitudes of relatedness among the selection criteria that farmers use to generate and maintain the sorghum landrace diversity that produces livelihood and environmental benefits.

Study area

The north Shewa and south Wollo study area is located in the central highlands of north-eastern Ethiopia adjacent to the western escarpment of the great east African Rift Valley that bisects the country (Figure 1). Its diverse agroclimatic resources (Table 1) of soils, climate and topography influence the generation, diversification, selection and maintenance of crop genetic resources. The farmers apply their knowledge of agroclimatic variations and adaptive responses of genetic diversity to variable growing conditions and cultural preferences to grow a range of staple and companion crops and crop varieties across the agricultural landscapes and over cropping seasons.

Sorghum [*Sorghum bicolor (L.)* Moench], a staple grain crop in many countries of Asia and Africa, is widely cultivated in the study area for food, income, animal feed, building material, and to improve soil fertility on-farm. Ethiopia is an important centre of origin and diversity for sorghum and a number of other crops (Vavilov, 1926, 1951; Dogget, 1991; Harlan, 1969). Sorghum is the second most important cereal crop in production and acreage in Ethiopia (CSA, 2012). Besides Sorghum, there are numerous complementary, key and companion crops (grain, pulses, oil, fiber, fruits, vegetables, trees and shrubs) that provide resilient livelihood and environmental benefits to the farming communities in the study area (Geleta et al., 2002).

The agricultural system is predominantly a rain-fed seed farming complex (Westphal 1975). Home-saved seeds are the single most important seed source used for seasonal planting and replanting purposes. The seed systems are centred on the diversity of landraces and the time-tested farmers' selection criteria, knowledge and practices. Their landraces constitute heterogeneous populations with adaptations to the heterogeneous economic, socio-cultural, agroclimatic environments and production systems. Resiliency in this study refers to the adaptive capacity of sorghum landraces to rebound back from unfavourable agroclimatic conditions through adaptable farmers' managerial skills for livelihood and environmental security. Mixtures of landraces cultivated through farmers' selection practices offer the farming communities resilience or buffer from climate induced events or other shocks (Nabhan, 2014).

Parts of the study area are moderately vulnerable to high unpredictable droughts and dry-spells that influence the diversity, productivity and productive capacity of the agricultural system, and may result in severe shortfalls in grain and biomass production (Dyer et al., 1992, 1993). The farmers' strategy to reduce such losses is to maintain diverse seed network exchange mechanisms as a sustainable buffer, along with the broad base of on-farm genetic diversity. Sustainability is used in the context of the adaptive capacity of landrace diversity for continuous cultivation through farmers' conscientious selection practices for livelihood and environmental benefits. Multiple functionality of landrace ensures human sustenance and agroclimatic resource base revitalization.

METHODOLOGY

Surveys were conducted on 300 randomly selected farmers' fields in north Shewa and south Wollo during the 2011/2012 cropping season. During the surveys, sorghum landrace samples were collected along transect lines that were 10 m apart. At 5 m intervals along each transect line, the farmers were asked to identify the landrace and to provide the reasons (selection criteria) why she/he had decided to grow each sorghum landrace. Significantly, the farmers' names for the sorghum landraces were consistent across

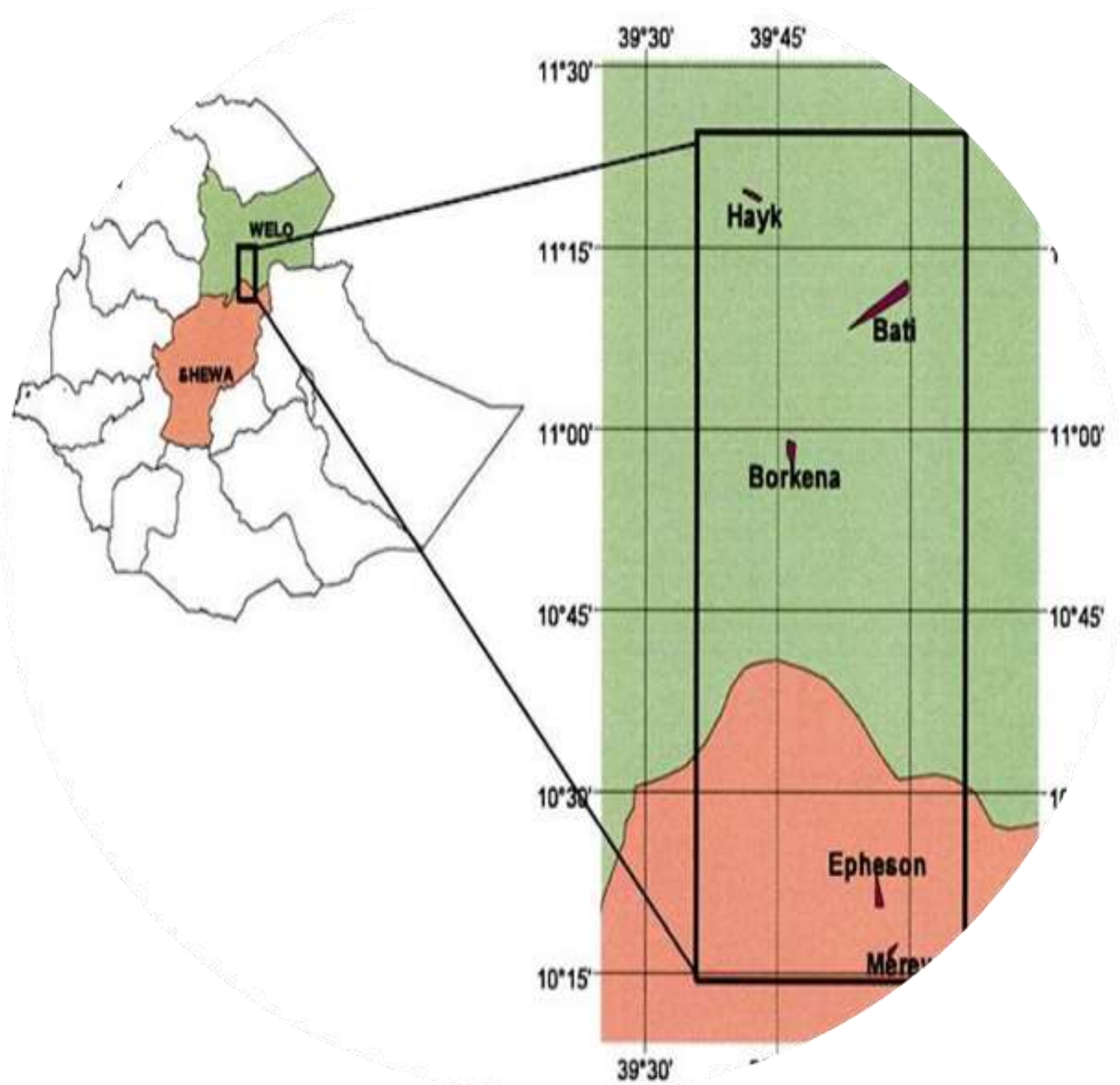

Figure 1. North Shewa and South Wollo Study Area, Ethiopia.
(Adapted from Teshome et al. 2007).

the study area and consistent with scientific numerical taxonomy. The individual landrace names have been chosen on the basis of distinctive agromorphological characteristics, use values, and other criteria; which help to provide information on how the landrace is adapted to environmental variations and cultural preferences.

The twelve selection criteria most commonly identified cluster into three major groupings: Agronomic values *(*Grain yield production, Biomass production, Market values, and Threshability); Home-Uses (Milling quality, Beverage quality, Sweet-stalk, and Fresh green immature-grains); and Resistance to Biotic and Abiotic stresses (*Bird resistant, Insect resistant, Disease resistant, and Drought resistant*). The clustering was done by collaborating female and male farmers with the involvement of researchers while gathering agricultural biodiversity information for the study. These groupings were subjected to correlation, t-Tests, and Linear Regression analyses in order to examine the magnitudes of differences and relatedness among the selection criteria used by the farmers. Microsoft Excel 2013 was used for all the statistical analyses. An alpha value of 0.05 was set for all statistical tests. Readers are reminded that although the data for this study were gathered from 300 randomly selected fields in 5 distinct agricultural communities, the analysis, results and discussion will be presented at the geographical scale of the whole study area. Such approach was employed to facilitate discussion on multiple selection criteria and their relationships as farmers employed them to meet multiple livelihoods through the cultivation of sorghum landraces while responding to agroclimatic variations, policy, political and institutional opportunities and challenges (Manel et al., 2010; Schoville et al., 2012; Teshome et al., 2016b).

RESULTS

The 12 common selection criteria identified and described by participating farmers are presented in Table 2. The descriptions in Table 2 represent the multiple functionality of landrace cultivated through farmers' selection practices

Table 1. Agroclimatic variations in north Shewa and south Wollo study area.

Agroclimatic factors	Descriptions
Landforms	Dominated by ranges of mountains and hills, broken and undulating landscapes with variable sizes of valley bottoms
Slope (%)	Ranges from zero in the flat valley bottoms to in excess of 30% in the steep slopes of mountainous and hilly agricultural landscapes
Altitude (m.a.s.l)	900 to 3000 m/a/s/l
Soil resources (major soil orders)	Highly heterogeneous and variable encompassing the dominant major soil orders of *Alfisols, Inceptisols, Vertisols,* and to some extent *Aridisols* in the drier and *Histosols* in the wetter parts of the study area, support a diversity of cultivated crops and natural vegetation across the altitudinal gradients of the study area
Temperatures (in °C)	monthly minimums = 2- 11°C monthly maximum = 22- 33°C
Rainfall (mm)	Annual minimum = 300 to 500 mm Annual maximum = 750 to 1700 mm Some part of the study area experience bimodal rainfall regime involving short and long rain periods within a year
Natural vegetation	Highly variable and contrasting along the altitudinal gradients of the study area, reflecting the agroclimatic variations from coniferous forest in the highlands to deciduous savannah woodlands and savannah grasslands along the mountain sides and on the valley bottoms to semi-arid and arid scrublands dominating along the rangeland of the Afar escarpment.
Risks to droughts and dry spells	Vary greatly from highly vulnerable in Bati and Merewa to moderately vulnerable communities of Epheson and Borkena and to not vulnerable of the highlands of Hayk agricultural landscape.

for livelihoods. The Pearson correlations among the selection criteria in Table 3 were the outcome of their relationships at the landscape level of the study area. Selection criteria for biomass production and grain yield production are among the highly correlated farmers' selection criteria (r=0.79), benefiting farmers sufficiently in biomass and grain products.

The selection criteria are statistically independent with no cause-effect, and dependent–independent relationship as demonstrated by significant t-Tests for mean differences among the selection criteria and group of selection criteria (Table 4), as employed by collaborating farmers in 2011/2012 cropping season. The frequency distributions for the individual selection criteria (Figure 2) showed the occurrence and relative importance of each selection criterion as employed by farmers for livelihood and environmental benefits. Selection criteria frequency occurrence further demonstrates the influences of each selection criterion in seed selection, planting and harvesting of multiple landrace composition and products. As a result, a range of sorghum landraces were predominantly selected for biomass production, grain yield, milling quality, beverage quality, and market value, in descending order of importance in 2011/2012 cropping season.

In the linear regression and correlation analyses, the t-Tests demonstrated that farmers' selection criteria were different and independent, they functioned with strongly variable degrees of relatedness, as practised in the 2011/2012 cropping season. The linear regression analyses between independent variables of the selection criteria (grain yield production; biomass production, and market values) showed significant relationships (Figures 3, 4 and 5). The significant positive relationship (r=0.73; R^2 = 0.54; P<0.000001) between the selection criteria for grain yield production and market values (Figure 3) indicates that as yield increases, the revenue from marketing surplus grains also increases; contributing to household consumption and income security. The positive correlation (r=0.73) and the huge variation explained (R^2 =54%) between yield and market selection criteria establish that, as the demand for their products increases, farmers are incentivized to produce more.

The positive strong relationship between the selection criteria for biomass production and grain yield (Figure 4 - r=0.79; R^2 =0.63; P<0.000001) demonstrates the photosynthetic and physiological efficiency of sorghum landraces in generating both biomass, (which, to the farmer, includes all non-reproductive parts of the sorghum crop – roots, leaves, peduncles, nodes and internodes) and grain (including all the reproductive parts of male and female sorghum flowers), without compromising the values of one at the expense of the other. Farmers use both the selection criteria of biomass production and grain production to derive benefits from these landraces in a balanced manner. The relationship between landrace selection criteria for market and biomass production is significantly strong (Figure 5 - r=0.72; R^2 =0.52; P<0.00001). From such relationship, farmers cultivate a range of landraces with the capacity to generate

Table 2. Farmers' Selection Criteria for sorghum landraces as practised and described by farmers.

Selection Criteria	Descriptions
Biomass	Includes all plant parts, except the grain, from the root to the flag leaf of a sorghum landrace plant. The cane/stem is used for fuel, construction and fencing. Livestock feed upon leaves and stems. All parts are good sources of organic materials to improve soil fertility. Solid canes of sorghum landraces are sold in the market for income generation.
Grain yield	Seeds and grains harvested from peduncled sorghum heads for home consumption and for sale in the local markets.
Drought resistant	Resistance to climatic and soil constraints causing crop failure
Pest resistance	Resistance to biotic stress causing losses of diversity and production. *Striga* is a notorious plant pest affecting susceptible crops and crop varieties
Disease resistant	Resistance to pathogens causing diseases which decimate diversity and production, example includes *fusarium* a disease caused by fungi.
Insect resistant	Resistance to a variety of insect pests, such as weevils, causing diversity and production losses of many grain crops and crop varieties.
Beverage quality	Sorghum grains rich in secondary metabolites such as phenolic and tannins are fermented and distilled into beverages of variable alcoholic contents for home consumption or for income generation
Sweet-Stalk	Sorghum varieties rich in chewable sugar-rich stem/cane cultivated sparingly either for home consumption or for income generation
Fresh Green Immature-Grains	Quick maturing sorghum landraces cultivated for their nutritious soft-grains for consumption during food scarcity period until harvest.
Milling Quality	Dry-grain landraces free from tannins are selected for human consumption for their high palatability, digestibility and absorbability in human digestion systems.
Marketability	Dry-grain sorghum landraces are selected and cultivated primarily for income generation by selling them in the local market.
Threshability	Sorghum landraces of naked grains with less glume and awn covers are easily threshable. They do not demand too much labor and do not cause itchiness while threshing
Bird Resistant	Landraces with big grains, total glume cover and with long awns are bird resistant. Usually, what is palatable to humans is highly susceptible to bird attacks.

marketable biomass products for income security to improve family purchasing power for household essentials.

The groups of independent selection criteria of agronomic values, home-uses, and resistances to abiotic and biotic stresses, also showed significant relationships between them in the linear regression statistical analyses (Figures 6, 7, and 8). The highly significant strong relationships ($r=0.83$; $R^2=0.69$; $P<0.0.000001$) between the selection criteria farmers used for agronomic quality and for home uses (Figure 6) testify to the fact that traditional farmers select, cultivate, conserve and use sorghum products on a sustainable basis, primarily to provide adequate food at home and to save and resave a diversity of seeds to ensure their livelihood security through the cultivation of agricultural biodiversity on-farm. The selection criteria used to select landraces for home-uses and for their resistance to biotic and abiotic stresses (Figure 7) exhibit positive but relatively weak relationships ($r=0.61$; $R^2=0.37$; $P< 0.001$). Such a relatively lower percentage of variations explained ($R^2 = 37\%$) by the relationship (compared to the relationship between home-uses and resistances to biotic and abiotic stresses, Figure 8), between selection criteria for home-uses and for resistances to biotic and abiotic stresses should not be taken as threat in a knowledge-based traditional agricultural systems such as the north Shewa and south Wollo study area. The farmers know the inherent vulnerability of their crops to soil and climatic constraints (abiotic stresses) and to the biotic stresses of insects, pests and diseases; they take appropriate measures to reduce losses. On the other hand, the magnitude of the relatedness between the selection criteria farmers used to select landraces for agronomic quality (threshability, grain yield, biomass production and marketability) and for resistance to biotic and abiotic stresses (Figure 8) is strong with significant positive correlation

Table 3. Pearson Correlations among the selection criteria.

Variable	Grain yield	Biomass	Threshability	Bird resistance	Insect resistance	Disease resistance	Drought resistance	Milling quality	Beverage quality	Fresh green grains	Sweet stalk	Market value
Grain Yield	1											
Biomass	0.79	1										
Threshability	0.39**	0.42	1									
Bird resistance	0.43	0.43	0.38	1								
Insect resistance	0.47**	0.55	0.54	0.71	1							
Disease resistance	0.35**	0.41**	0.58	0.56**	0.74	1						
Drought resistance	0.63	0.67	0.68	0.58	0.69	0.62	1					
Milling quality	0.78	0.68	0.29**	0.33**	0.37**	0.23	0.54	1				
Beverage quality	0.63	0.76	0.37**	0.61	0.60	0.44	0.66	0.61	1			
Fresh green grains	0.60	0.57	0.21**	0.27**	0.24**	0.13	0.41**	0.59	0.52	1		
Sweet stalk	0.56	0.63	0.21	0.34**	0.43	0.23	0.50	0.43	0.55	0.37	1	
Market value	0.74	0.72	0.36**	0.34	0.43**	0.27	0.60	0.70	0.66	0.54	0.44	1

**=Not significant @ P≤0.05.

(r=0.73; R^2 =0.54; P<0.00001). Such relationship demonstrates farmers' selection capacity to cultivate landraces that are threshable, marketable and high grain and biomass yielding that are resistant to biotic and abiotic stresses.

The various farmers' selection criteria that were conscientiously chosen by farmers reflect the multiple functional values of sorghum landraces cultivated in the 2011/2012 cropping season are discussed below for the purpose of emphasizing (demonstrating) their synergistic role in obtaining multiple livelihood and environmental benefits for the practising farming communities.

DISCUSSION

The statistical analyses undertaken, and other information in Tables 2 and 3; and Figures 2, 3, 4, 5, 6, 7 and 8 have demonstrated that the farmers' selection criteria are significantly different from one another. Table 4 indicates that there is no statistical cause-effect or independent-dependent relationships associated with the farmers' selection criteria synergistic relationships to achieve livelihood security through on-farm landrace diversification.

The frequency of statement by the individual farmers that specific selection criteria were applicable to specific sorghum landraces shows the relative importance of each selection criterion and its influences in the selection, planting and harvesting of the range of sorghum landraces in the 2011/2012 cropping season. The first five frequent selection criteria were employed to meet primarily household consumption (grain yield, milling and beverage quality), income security (market value) and animal feed, fuel and construction needs (biomass) of farming communities. Such strategic synergistic selection practices demonstrate the desires of the farming communities to the production of adequate and nutritious food to feed their family, and to secured household income by selling any surplus grain (and other products that they make from the grain) in the local market to meet their household's essential requirements and to purchase assets for future use. The relatively less frequent selection criteria for sweet-stalk and fresh-green-grains were used to cultivate landraces for non-grain products also are used for home consumptions and income generation during the bridging months between flowering and harvesting periods. The selection criteria for drought, insect, disease, and bird resistances are used to grow a range of landraces for their attributes to defy biotic and abiotic stresses, ensuring production and diversity of landraces for livelihood and environmental benefits. Thus, the selection criteria frequency occurrences affirm the egalitarian and inclusive

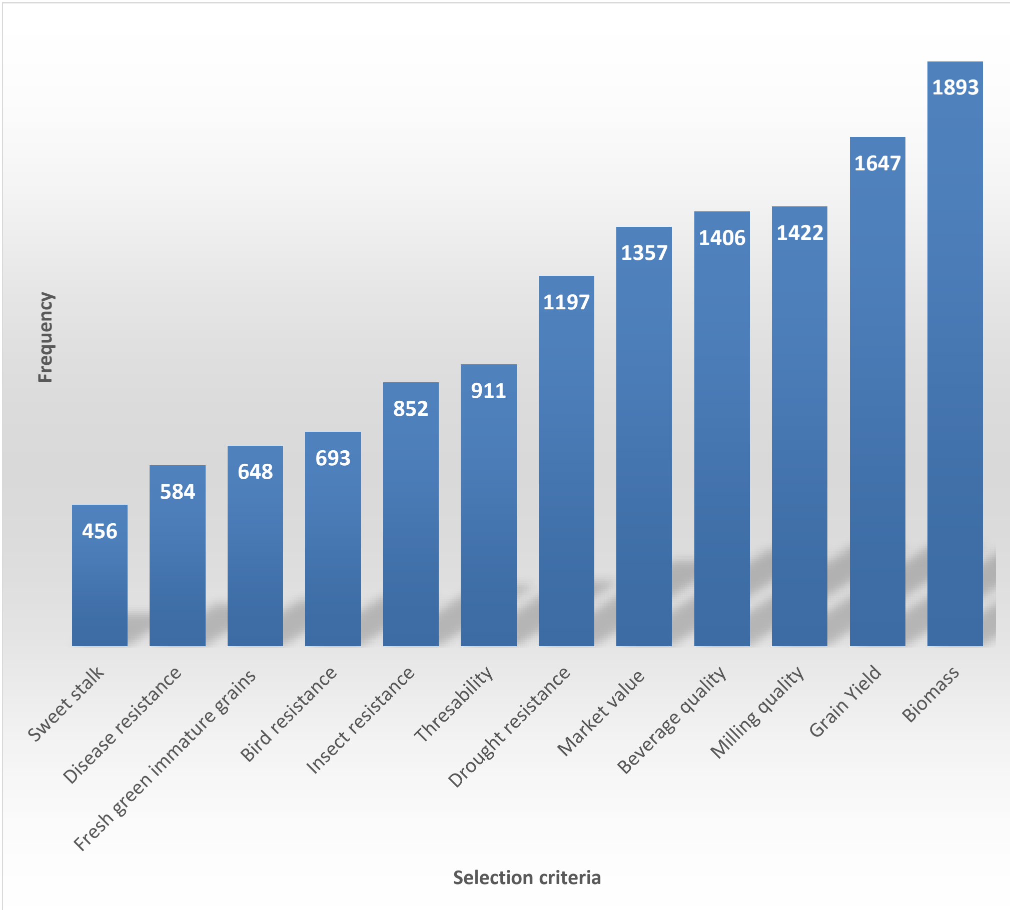

Figure 2. Farmers' selection criteria frequency, 2011/2012 cropping season.

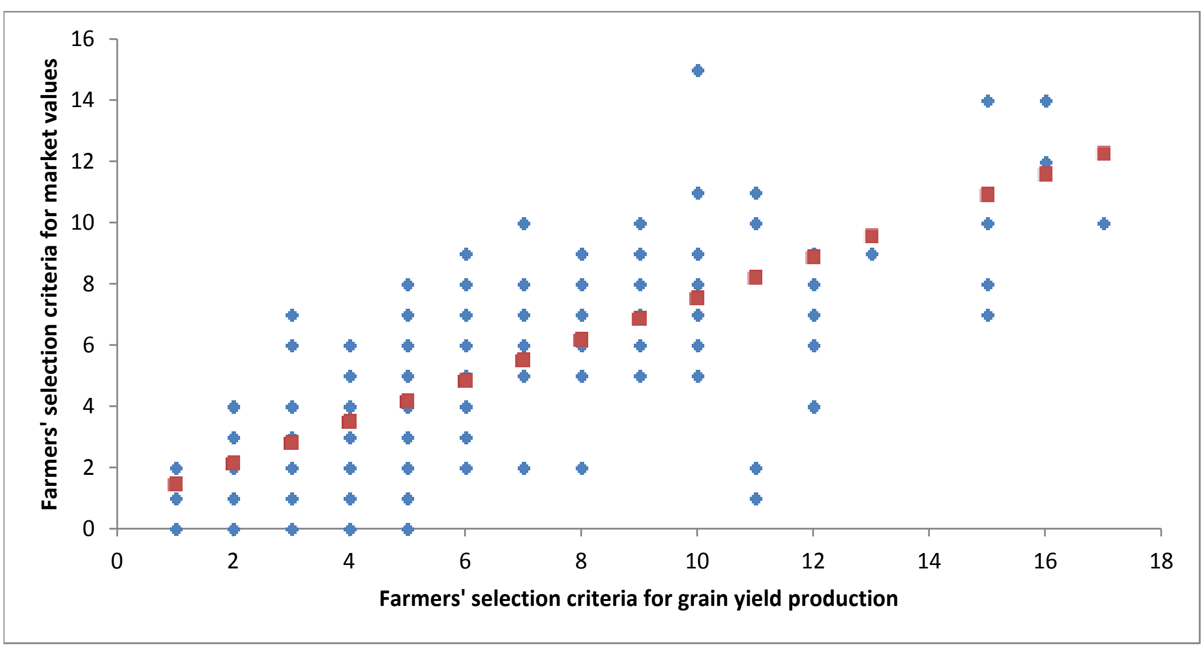

Figure 3. Relationship between farmers' selection criteria for market values and grain yield production based on linear regression analysis (r=0.73; R^2 = 0.54; P < 0.0000001).

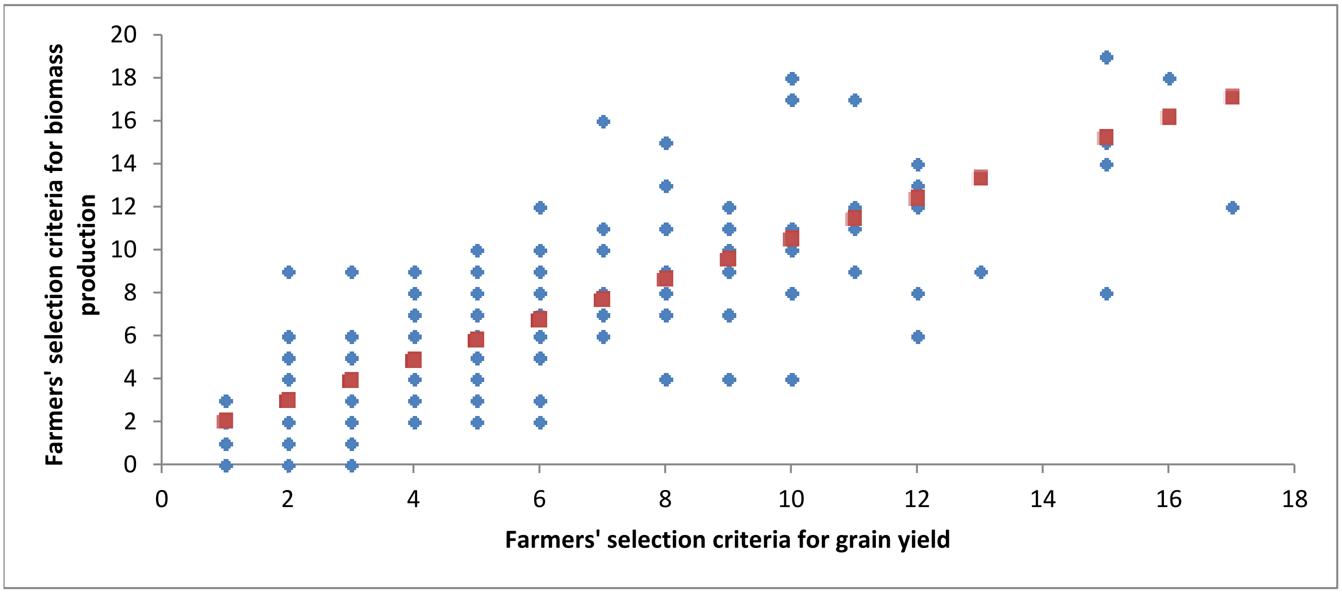

Figure 4. Relationship between farmers' selection criteria for biomass production & grain yield production based on linear regression analysis (r=0.79; $R^2 = 0.63$; P < 0.0000001).

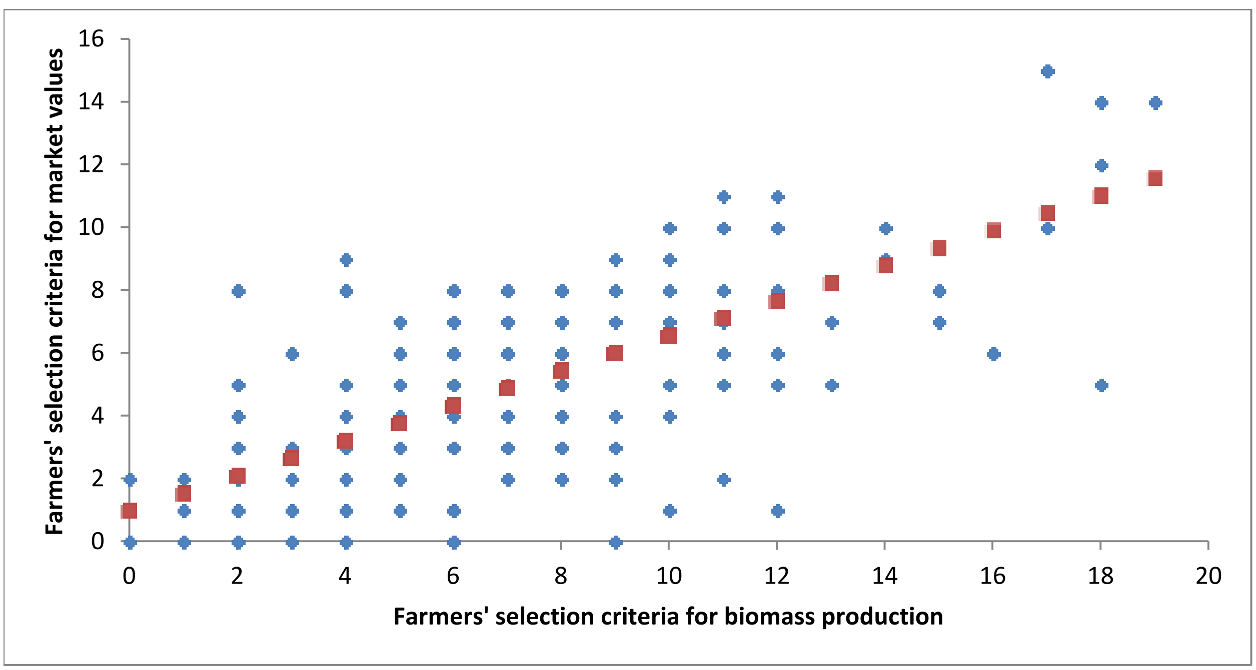

Figure 5. Relationship between Farmers' selection criteria for Biomass Production & Market Values Based on Linear Regression Analysis (r=0.72; $R^2 = 0.52$; P < 0.0000001).

approaches of farming communities to the generation and maintenance of landraces for livelihood through the seasonal practices of multiple selection criteria on-farm over climatic seasons and across the agricultural landscape of the study area.

Sorghum landraces selected for market values, grain yield and biomass production contributes hugely to food and income security for farming communities. The landraces that produce both grain and biomass represent a bonanza for the farmers as they can meet family food

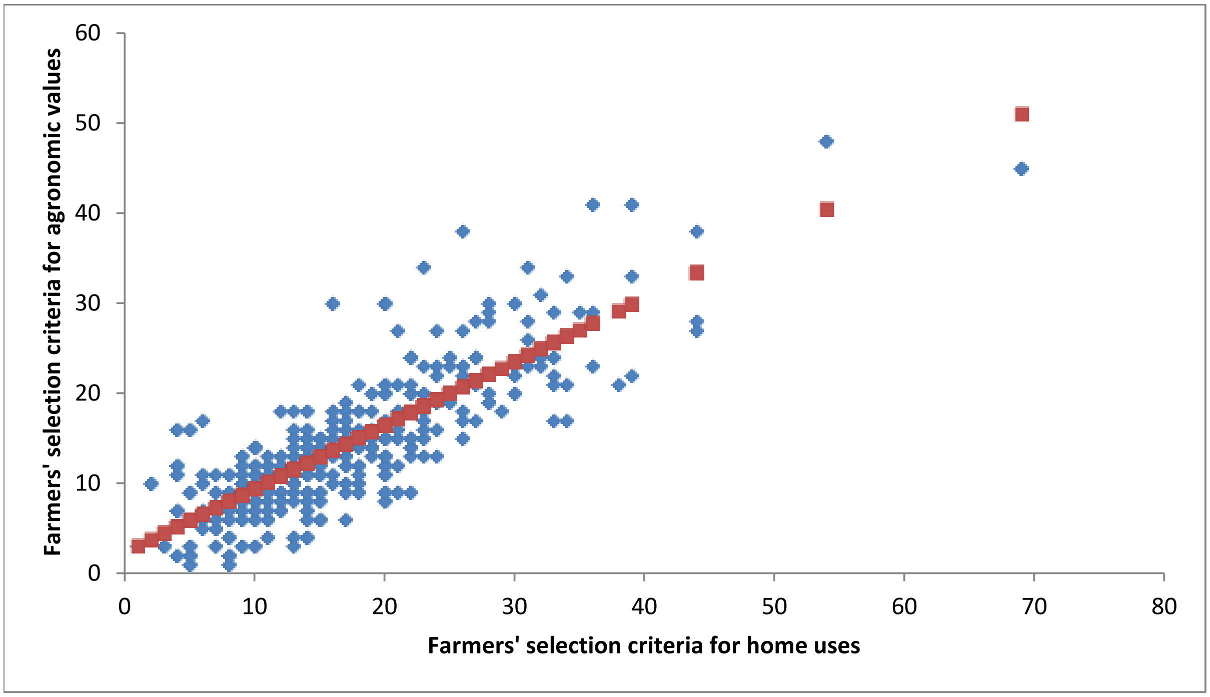

Figure 6. Relationship between farmers' selection criteria for agronomic values & home-uses based on linear regression analysis (r=0.83; $R^2 = 0.69$; $P < 0.0000001$).

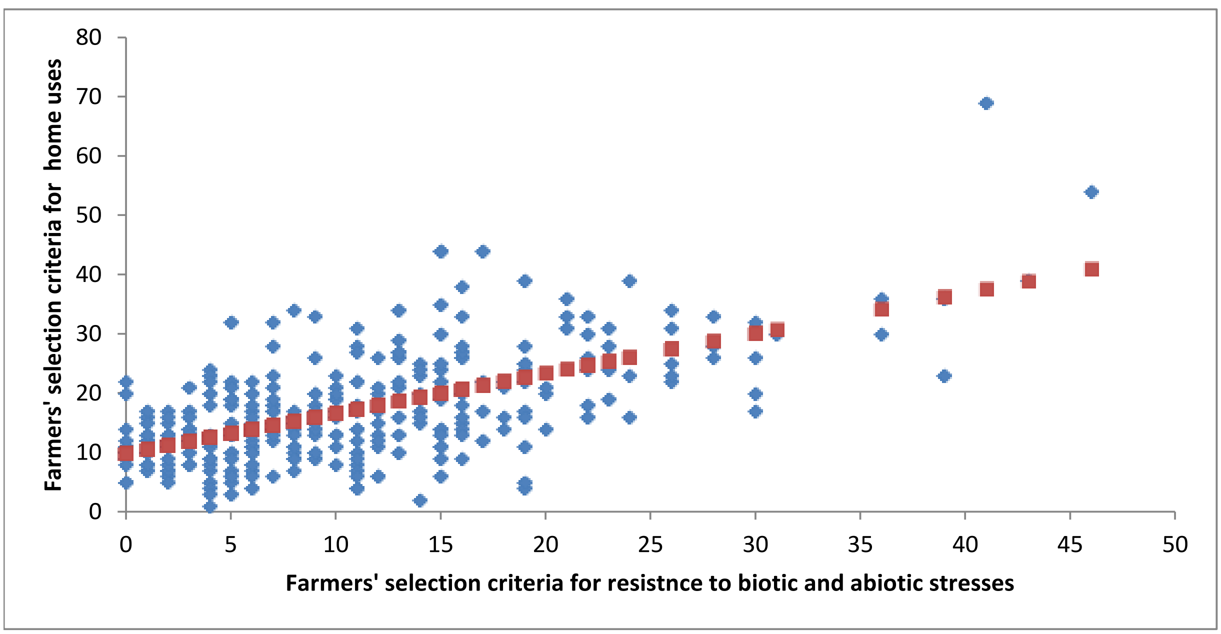

Figure 7. Relationship between farmers' selection criteria for home-uses and resistance to biotic and abiotic stresses based on linear regression analysis (r=0.61; $R^2 = 0.37$; $P < 0.01$).

demand and basic income security from the grain yield; while using the abundant, non-grain sorghum products for livestock feed, firewood, fencing, and other construction purposes. The synergistic outcome between yield and biomass selection criteria in sorghum cropping systems is the opposite to that of commercial agriculture crop selection and breeding paradigm for surplus grain yield production by greatly limiting diversity and the potential of non-grain producing vegetative parts of the crop for biomass production.

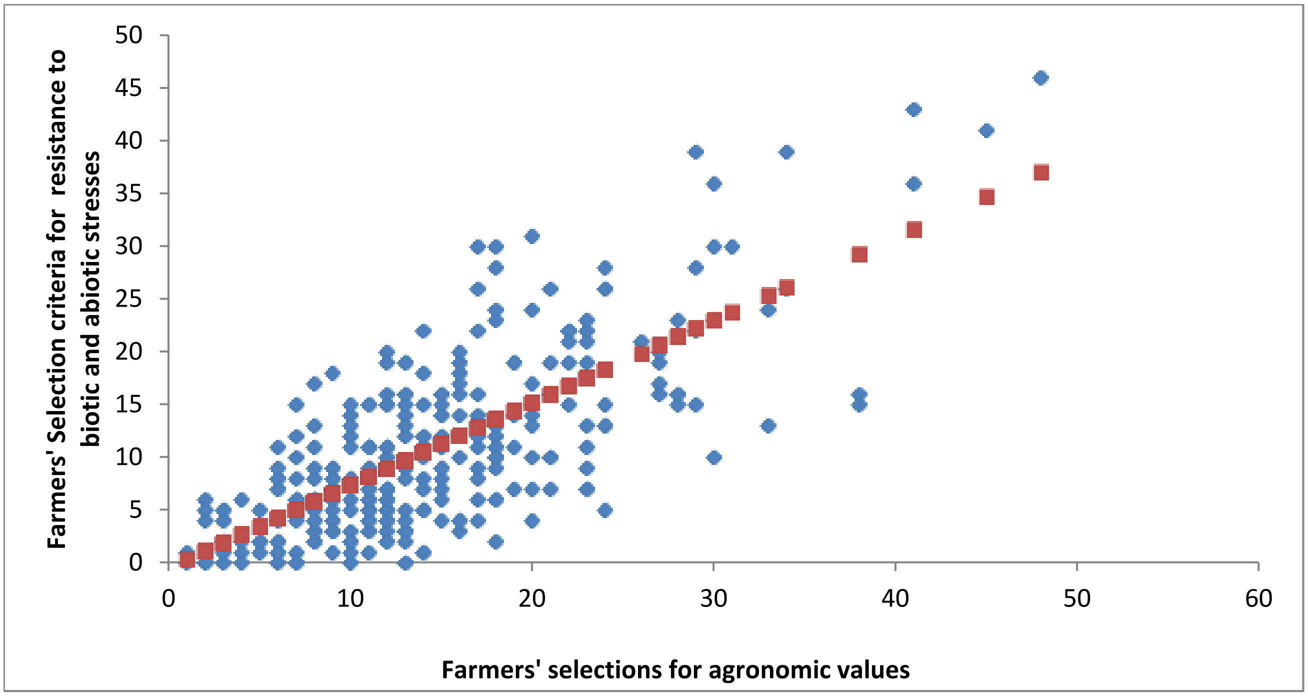

Figure 8. Relationship between farmers' selection criteria for agronomic values and resistance to biotic and abiotic stresses based on linear regression analysis (r=0.73; $r^2 = 0.54$; $p < 0.00001$).

Non-grain sorghum landrace production of biomass includes all the plant materials of cane/stems, leaves and roots of sorghum crops cultivated by the farmers. As the demand for sorghum biomass increases farmers produce more non-grain materials to earn more income by selling more biomass in the local market. The farmers generate income by selling solid sorghum canes for firewood, fencing and construction materials.

Fences are erected and shades are constructed using solid sorghum canes/stems. They are also efficient sources of firewood for cooking in the house. Sometimes farmers burn sorghum biomass materials remaining in the field to improve soil fertility by tilling it into the residual ashes. Also, the roots of the sorghum crops are ploughed into the soil to increase the organic matter content of the soil resources. The leaves are mostly fed to livestock that either free graze in the agricultural fields or to stall-fed livestock in pens. The strong positive relationships clearly demonstrate that, as farmers produce more biomass they earn more income; and as the market demand for biomass (non-grain plant parts) produce increases farmers are incentivized to produce more biomass for more income.

Some landraces in the study area are, however, neither cultivated for grain nor for biomass production, but for specialty products of sweet-stalks and fresh-immature-soft-grains. Sweet-stalk sorghum landraces are popular for their chewable, green, sugar-rich stems. The fresh-immature-soft-grain producing landraces are selected for their soft-grains that are free from phenolic compounds affecting the palatability of most sorghum grains. The two specialty sorghum landraces are harvested as bridging crops for human consumption between grain-filling and harvesting months. They are also sold in the local market to augment family income.

The basis for the sustainable production of food and seed in the study area is the extant adaptive capacity of mixture of landraces that farmers own and manage through conscientious selection practices across variable agricultural landscapes and over climatic seasons. Consequently, as farmers increase sorghum landrace selection criteria for the agronomic quality of threshability, and of biomass production, and of grain yield, and of marketability, the selection criteria for the in-home uses of milling quality, sweet-stalks, fresh-green-soft-immature-grains, and beverage quality increase. Through this strong significant relationship, digestible and palatable dry-grain sorghums free from phenolic compounds are selected, cultivated and harvested for home consumption and income generation. Landraces endowed with phenolic compounds are set aside for brewing and distillation either for home consumptions or marketing purposes. The landraces selected for beverage quality, sweet-stalk, and fresh-green-soft-grains are available for home consumption as well as for selling in the local markets.

The strong relationship between selection criteria for agronomic quality and home-use affirms that as individual landraces are actively brought into a diversity of uses in

Table 4. Summary of t-Tests of significance of differences and relationships between groups of Farmers' selection criteria, 2011/2012 cropping season.

Selection criteria	Mean	Variance	Pearson correlation	t-Stat	P-value
Market values and Biomass production	4.39 6.13	7.26 12.19	0.72	-12.60	0.00000
Market values and Grain yield production	4.39 5.33	7.26 8.66	0.73	8.01	0.000000
Biomass production and Grain yield production	6.13 5.33	12.19 8.66	0.79	-6.57	0.000000
Agronomic values and Resistance to abiotic and biotic stresses	14.40 10.76	61.37 69.49	0.73	10.83	0.000000
Agronomic values and Home-Uses	14.40 17.12	61.37 85.03	0.83	-9.28	0.000000
Resistance to biotic and abiotic stresses and Home-Uses	10.76 17.12	69.49 85.03	0.61	-14.35	0.000000

the farm community, their continuing presence in the livelihoods of farming communities is enhanced through the resilient practice of farmers in continuing to use multiple selection criteria in choosing landraces of crops and crop varieties to be grown on their farm. This is enhanced by the sharing of seeds through market mechanisms within the communities. The mixtures of landraces farmers cultivate offer farming communities and their selection practices resiliency or buffer them from climate extremes or human or nature-induced events.

Sorghum landraces selected for home consumption, by and large, are susceptible to biotic and abiotic stresses, including storage pests, and are consumed quickly or sold in the local markets, with precautionary and mitigating strategies and practices being taken to protect quantity, quality and variation for planting the next year. Cleaning, drying and short-and long-term storage practices, that guarantee the grain will remain safe for consumption and viable as seed materials, are well established. Such knowledge-based management strategies increase the diversity and productivity of the landraces cultivated for livelihood security in times when situations conducive to pest proliferation occur, whether caused by climatic variations or human mismanagement.

If farmers increase the selection criteria of landrace for resistance to biotic and abiotic stresses, the agronomic value and quality of the selected landraces for biomass production, grain yield production, threshability, as well as their marketability increases. From these landraces with high agronomic quality, farmers' incomes increase through the sale of quality grains and seeds; the quality of seeds for saving and exchanging increase; and the amount and diversity of seeds and grains stored for future uses increase. Such magnitude of relatedness between selection criteria for agronomic quality and resistances to biotic and abiotic stresses is a good omen for the continued sustainable conservation and uses of sorghum landrace diversity on-farm and for the improvement of farmers' livelihood security in light of the recognizable climate and other variations and extremes.

IMPLICATION AND CONCLUSIONS

The analyses reported demonstrate that farmers' selection criteria in the study area are wide-ranging, with statistical independence of cause-effect and dependent-independent relationships (Table 4). Nevertheless, there are synergistic functions among the farmers' selection criteria that operate in variable degrees of relatedness to achieve multiple livelihood and environmental benefits for the farmers through the generation and management of on-farm sorghum landrace diversity (Table 3; Figures 3, 4, 5, 6, 7 and 8).

Farmers' selection criteria are not only forces of diversification (Meyer et al., 2012; Teshome et al., 1999b) but are also means of deriving multiple benefits for human and environmental security. Selection criteria compositions (Table 2) and their frequency distributions (Figure 2) show the synergistic contributions of each selection criterion to the collective farmers' seed, food and livelihood security through the on-farm cultivation and uses of a range of sorghum landrace diversity in the

2011/12 cropping season. The selection frequency further demonstrates that the resulting diversity of crops and crop varieties on-farm were selected for their adaptive capacity and responses to the agroclimatic variations and sociocultural preferences in that cropping season.

More selection criteria means that more sorghum landrace diversity is cultivated over the diverse growing seasons and across the various agroclimatic agricultural landscapes (Teshome et al., 2016b). The synergistic practices of multiple selection criteria for multiple livelihoods establishes that farmers have an intimate knowledge of their own varied needs, the requirements of the agroclimatic variations and the heterogeneity of the crops they domesticate, select, manage, exchange, and use (Meyer et al., 2012; Samberg et al., 2013) and that the inherent adaptive capacity of the landraces depends on soil and climatic factors (Ayana et al., 2002) as well as societal needs and preferences. Such intimate knowledge that selection of agricultural biodiversity has such positive impacts on their livelihoods encompasses all ages, classes and gender segments of the traditional farming systems.

Having selection criteria, mean decisions must be made. The farmers make their selection criteria decisions by consultation with immediate family members and the community at large. Selections are based on their knowledge of their livelihoods and landrace diversity management and conservation. The decisions are made at various stages of the cropping season. The decisions are especially important at harvest time when each farmer must decide how much of each landrace to harvest for seed, grain and biomass; how much is available for consumption; how much to save for planting and exchange, and how much to sell in the local market. While farmers' selection criteria practices contribute to the livelihood security of the farming family, they also increase the adaptive capacity and responses of the selected landrace and its breeding population to natural pressures of soil and climatic variations. Farmers' selection criteria also reduce the risks of genetic erosion (Mekbib, 2012; Tunstall et al., 2001) by actively involving all the landraces in the seasonal production and use decisions.

The farmers have a wealth of time-tested information on the genetic, physiological, and morphological attributes of the landraces that are particularly responsive to their needs, preferences, selections and farming practices over climatic seasons and across agricultural landscapes. The mixture of traits associated with sorghum breeding systems, grain quality and storability (Ramputh et al., 1999), agromorphological variations (Abdi et al., 2002; Ayana and Bekele, 2000), growing seasons, physiological and ecological adaptations and photoperiod sensitivity offer choices to the farmers to develop multiple, synergistic, selection criteria that will lead to multiple, synergistic livelihoods through the cultivations of the desired diversity of crops and crop varieties according to the season and the agricultural landscape.

Farmers in the study area select late maturing landraces (Mamo et al., 2007) for infertile soils to make use of the limited availability of soil moisture and soil nutrients during long maturing period. The short maturing landraces with the capacity to escape drought and dry spells were selected for immediate harvest and uses. Farmers select over the ages sorghum landraces that are sensitive to photoperiod so that harvest is not hampered by climatic vagaries of untimely prolonged destructive rains and proliferation of pest and diseases.

Sorghum landraces, in variable proportions, are composed of outcrossing and self-pollinating populations. Farmers know the breeding characteristics of their landraces and use them to their advantage in the contexts of retaining desirable landraces and of seeking to develop new landraces.

The farmers generate variations through the selections and cultivations of outcrossing sorghum landraces from cropping season to cropping season across the agricultural landscapes; allowing them to select and capture adaptable, responsive and desirable and novel populations. When they desire to retain distinct stable novel qualities, farmers select self-pollinating sorghum landrace populations. Farmers in north Shewa and south Wollo study area have been observed, cultivating 50 self-pollinating sorghum landraces continuously year-after-year over a twenty year period (1992/1993-2011/2012) for their distinctive and stable morphological characteristics that made selections, harvest, exchange, marketing and processing much easier for the farmers and other end users (Teshome et al., 2016b).

Farmers select sorghum landraces rich in phenolic compounds for fermentations and distillations into beverages of variable alcoholic contents. Fermentation unlocks essential nutrients which are made unavailable to absorptions due to phenolic compounds present in some sorghum landraces (National Academy of Sciences 1996). White and yellow dry- grain producing sorghum landraces are selected for human consumptions as they are free from phenolic compounds affecting the palatability, digestibility and absorptions of essential nutrients by the human digestive system. Yellow grain sorghum landraces *(*such as *Tenglaye)* are rich in vitamin A and other bioactive nutrients. Landraces rich in tannins are selected for their resistance to a host of biotic stresses including storage and field pests (Ramputh et al., 1999). Farmers select their landraces according to use values they attach-dry-grain producing landraces are selected for the superior quality of grains for human consumptions; sweet-stalk landraces for their chewable stem/cane; and fresh- green landraces for their soft and nutritious immature-grains for consumptions between flowering and harvesting months.

Elastic landraces are selected by farmers for their capacity to bounce back from variable intensity and frequency of biotic and abiotic stresses that may affect the diversity and productivity of the cropping system. Farmers use agromorphological plasticity as selection criterion to harness resilient and adaptable landrace populations by cultivating highly plastic landraces over large heterogeneous climatic and soil environments. Generalist landraces are selected by farmers for cultivation across a vast agroecological and sociocultural gradients for multiple uses, while niche-specific specialist landraces are selected and cultivated in restricted agroclimatic and sociocultural environments for specialized uses (Teshome et al., 2007).

Farmers' selection criteria are dynamic and vary by individual farmer's desire and by the desirable crop, and by community, field, landscape, cropping seasons and agroclimatic conditions under which the selected landraces are cultivated for the purposes of attaining the desired selection criteria. Over the 20-year research period (1992/1993-2011/2012) in north Shewa and south Wollo study area, 72% of the farmers increased the number of selection criteria, 11.5% decreased and 16.5% maintained the same number of selection criteria. In the same research period, the number of intraspecific sorghum landraces increased from 60 in 1992/1993 to 68 in 2000/2001 and to 77 in 2011/2012 cropping season.

Farmers' selection criteria and practices have been in dynamic interactions over the ages with the spatio-temporal variations of the agroclimatic resources to respond to farmers' own needs and to societal sociocultural preferences, at large; through the sustainable conservation and uses of agricultural biodiversity farmers domesticate, own, and manage them. This study has established the intimate knowledge and synergistic selection practices of farmers to meet their varied needs through the cultivation of sorghum landrace diversity over climatic seasons and across heterogeneous agroclimatic resources. However, demographic changes, and risks of losses of knowledge and crop diversity through the influences of climate extremes, and inadaptable policies, programs and institutions are threats to cropping systems in the study area and elsewhere in the world (Campbell, 2014; Kuhnlein, 2014; Nabhan, 2014; Shewayrga et al., 2008; Sunderland, 2011; and Teshome et al., 2016b). To mitigate such threats, favourable policies need to be redesigned and developed to ensure ownership and protection of farmers' selection practices for sustainable and resilient livelihood security (Kuhnlein and Erasmus, 2013a), through the cultivation and uses of adaptable diversity of crops and crop varieties (Nabhan, 2014 and Sunderland, 2011).

The study further suggests the establishment and strengthening of programs, policies and institutions to advance/improve food and nutrition security and health at local and community levels (Kuhnlein, 2014) by incorporating farmers' time-tested selection criteria and practices through farmer-led participatory varietal selections and breeding to reflect farmers' varied needs and diverse cropping systems (Mekbib, 2008; Teshome et al., 2016b).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEGEMENT

The authors sincerely appreciate the farmers of North Shewa and South Wollo for their faithful collaboration. They also appreciate the Seeds of Trust (SoT) consultancy for the financial support. The authors are grateful to IDRC, IPGRI and USC Canada as well as EOSA, Wollo University, Institute of Biodiversity Conservation, Addis Abeba University, Agriculture Canada, University of Ottawa and Carleton University for their support and contributions. This paper is dedicated to the memory of Professor John Lambert for his commitment to traditional farmers and agroecosystems and to biodiversity conservation and uses.

REFERENCES

Abdi A, Bekele E, Asfaw Z, Teshome A (2002). Patterns of morphological variations of sorghum [*Sorghum bicolor* (L.) Moench] landraces in qualitative characters in north Shewa and south Wollo, Ethiopia. Hereditas 137(3):161-172.

Abdi A, Asfaw Z (2005). *In Situ* (on-farm) conservation dynamics and the patterns of uses of sorghum (*Sorghum bicolor (L.)*Moench) landraces in north Shewa and south Wollo, Central Highlands of Ethiopia. Ethiopian Journal of Biological Sciences 4(2):161-184.

Adams JM (1977). The evaluation of losses in maize stored on a selection of small farms in Zambia, with particular reference to methodology. Tropical Stored Products Information 34:23-30.

Arnason JT, Lambert JD, Gale J, Mihan J, Bjarnason M, Jewell D, Serrratos JA, Fregeau-Reid J, Pietrazak L (1993). Is "quality protein" maize more susceptible than normal cultivars to attack by the maize weevil *Sitophilus zeamais?* Post harvest Biology and Technology 2:349-358.

Ayana A, Bekele E (2000). Geographic patterns of morphological variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Ethiopia and Eritrea: Quantitative characters. Euphytica 115(2):91-1014.

Ayana A, Bryngelsson T, Bekele E (2002). Geographic and Altitudinal allozyme variation in sorghum (*Sorghum bicolor* (L.) Moench) landraces from Ethiopia and Eritrea. Hereditas 135 (1):1-12.

Campbell BC (2014). Just eat peas and dance: field peas (*Vigna unguiculata*) and food security in the Ozark highlands, U.S. Journal of Ethnobiology 34(1): 14-122.

Central Statistical Agency (CSA) (2012). Agricultural sample survey, report on area and production of major crops (private peasant holdings, Meher season), Statistical Bulletin, Vol 1, September – December, Addis Abeba, Ethiopia.

Cleveland DA, Soleri D, Smith SE (1994). Do folk crop varieties have a role in sustainable agriculture? BioScience 44:740-751.

Cruz-Garcia SG, Struik CP (2015). Spatial and Seasonal Diversity of Wild Food Plants in Home Gardens of Northeast Thailand. Economic Botany 69(2):99-113

Davis D, Epp M, Riordan H (2004). Changes in USDA food composition data for 43 garden crops, 1950-1999. Journal of Ethnobiology 11(1):23-49

Derbie S, Asfaw Z, Teshome A, Demissew S (2002) .Management of agrobiodiversity in the Borkena watershed, South Wollo, Ethiopia:

Farmers allocate crops/landraces to farm types. Ethiopian Journal of Biological Sciences 1(1):13-36.
Dogget H (1958). The breeding of sorghum in East Africa: The breeding of weevil-resistant varieties. The Empire of Journal of Experimental Agriculture 26:37-46.
Dogget H (1991). Sorghum History in Relation to Ethiopia. In: Plant Genetic Resources of Ethiopia (eds. J. M. Engels, J. G. Hawks and M. Worede), Cambridge University Press, and Cambridge.
Dyer JA, Teshome A, Torrance JK (1993). Agroclimatic profiles for Uniform Productivity Areas in Ethiopia. Water International 18(4):189-199
Dyer JA, Teshome A, Torrance JK (1992). A climate analysis package for land use planning in Ethiopia. Canadian Water Resources Journal 17(4):311-322
Farnsworth NR, Akarele O, Bengel AS, Soejarto DD, Guo Z (1985). Medicinal Plants in Therapy. Bulletin of the World Health Organization 63:965-981.
Geleta M, Asfaw Z, Bekele E, Teshome A (2002). Edible oil crops and their integration with the major cereals in North Shewa and south Wollo, Central Highlands of Ethiopia: an ethnobotanical perspective. Hereditas 137:29-40.
Harlan JR (1969). Ethiopia: A center of diversity. Economic Botany 23:309-314
International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) (1985). ICRISAT research highlights 1984. ICRISAT, Patancheru, India.
Kuhnlein HV (2014). How Ethnobiology can contribute to food security. Journal of Ethnobiology 34(1):12-27.
Kuhnlein HV, Erasmus B, Spigelski D, Burlingame B (2013a). Indigenous People's Food Systems (Commentary). World Nutrition 4:488-513
Leaman DJ, Arnason JT, Razali Y, Sangat-Romantyo H, Soedjito C, Angerhoffer HS, Pezzuto JM (1995). Malaria remedies of the Kenyah of the Apo Khayan, E. Kalimantan, Indonesian Borneo: a quantitative assessment of local consensus as an indicator of biological activity. Journal of Ethnopharmacology 49:1-16.
Mamo S, Ayana A, Tesso T (2007). RAPD variation of late-maturing sorghum [*Sorghum bicolor* (L.) Moench] landraces from Ethiopia. Acta Agronomica Hungarica 55(3):375-382.
Manel S, Joost S, Eperson BS, Holderegger R, Storfer A, Rosenberg MS, Scribner KT, Bonins A, Fortin MJ (2010). Perspectives on the use of landscape genetics to detect genetic adaptive variation in the field. Molecular Ecology 19:3760-3772.
Mekbib F (2008). Farmers' Breeding of Sorghum [*Sorghum bicolor* (L.) Moench] in the Centre of Diversity, Ethiopia: II. Selection Process, Criteria and Methods. Journal of New Seeds 9(3):234-265.
Mekbib F (2009). Farmers as treasure chest of biodiversity: the case of sorghum [*Sorghum bicolor* (L.) Moench] in Ethiopia – a five decade analysis. Maydica 54(1):11-23.
Mekbib F (2012). Genetic enrichment, a new concept in genetic resource management: the case of sorghum [*Sorghum bicolor* (L.) Moench] in Ethiopia. Biodiversity 13(1):2-15.
Meyer SR, DuVal, EA, Jensen RH (2012). Patterns and processes in crop domestication: and historical review and quantitative analysis of 203 global food crops. New Phytologist 196:29-48.
Nabhan GP (2014). Food Security, Biodiversity and Human Health: Ethnobiology as a Predictive Science. Journal of Ethnobiology 34(1):7-11
National Academy of Sciences (1996). Lost Crops of Africa. Grains. National Academy of Sciences. Washington, D.C. P 1.
Ramputh A, Teshome A, Bergvinson DJ, Nozzolillo C, Arnason JT (1999). Soluble phenolic content as an indicator of sorghum grain resistance to *Sitophilus oryzae* (Coleoptera: Curculionidae). Journal of Stored Products Research 35:57-64.
Samberg HL, Fishman L, Allendorf WF (2013). Population genetic structure in a social landscape: barley in a traditional Ethiopian agricultural system. Evolutionary Applications ISSN 1752-4571. 1-13.
Sander L, Vandebroek L (2016). Small-scale Farmers as Stewards of useful plants Diversity: A case study in Portland Parish, Jamaica. Economic Botany 70(3):303-319.
Schoville SD, Bonin A, Francois O, Lobreaux S, Melodelima C, Manel S (2012). Adaptive Genetic Variation on the Landscape: Methods and Cases. Annual Review of Ecology, Evolution, and Systematics 43:23-43.
Shewayrga H, Jordan DR, Godwin ID (2008). Genetic erosion and changes in distribution of sorghum [*Sorghum bicolor* L. (Moench)] landraces in North-eastern Ethiopia. Genetic Resources, Characterization and Utilization 6(1):1-10.
Singh R, Axtell JD (1973). High Lysine mutant gene (h1) that improves protein quality and biological value of grain sorghum. Crop Science 13:535.
Sunderland TCH (2011). Food Security: Why is Biodiversity Important? International Forestry Review 13:265-274
Teshome A, Fahrig L, Torrance JK, Lambert JD, Arnason TJ, Baum B (1999b). Maintenance of Sorghum [*Sorghum bicolor* (L.) Moench] landrace diversity by farmers' selection in Ethiopia. Economic Botany 53:79-88
Teshome A, Brown ADH, Hodgkin T (2001). Diversity in Landraces of Cereal and Legume Crops. Plant Breeding Review 21:221-261.
Teshome A, Patterson D, Asfaw Z, Torrance JK, Arnason JT (2007). Changes in Sorghum bicolor landrace diversity and farmers' selection criteria over space and time, Ethiopia. Genetic Resources and Crop Evolution 54:1219-1233
Teshome A, Patterson D, Worede M, Martin J, Torrance JK (2016b). Sorghum bicolor landraces: Selection criteria and diversity management in Ethiopia's East-Central Highlands, 1992-2012. International Journal of Biodiversity and Conservation 8(11):278-290
Tsegaye B, Berg T (2007). Genetic erosion of Ethiopian tetraploid wheat landraces in Eastern Shewa, Central Ethiopia. Genetic Resources and Crop Evolution 54:715-726.
Tunstall V, Teshome A, Torrance JK (2001). Distribution, abundance and risk of loss of sorghum landraces in four communities in North Shewa and South Wollo, Ethiopia. Genetic Resources and Crop Evolution 48:131-142.
Vavilov NI (1926). Studies on the origin of cultivated plants. State Press, Leningrad.
Vavilov NI (1951). The origin, variation, immunity, and breeding of cultivated plants. In: Selected Writings of N.I. Vavilov. Chronica Botanica.
Westphal E (1975). Agricultural systems in Ethiopia. Centre for Agricultural Publishing and Documentation, Wageningen.
Zeven AC (2000). Traditional maintenance of breeding of landraces: 1. Data by crop. Euphytica 116:65-85.
Zurita-Benavides GM, Jarrín–V P, Rios M (2016). Oral History Reveals Landscape Ecology in Ecuadorian Amazonia: Time Categories and Ethnobotany among Waorani People. Economic Botany 70(1):1-14.

Vol. 13(33), pp. 1689-1697, 16 August, 2018
DOI: 10.5897/AJAR2017.12292
Article Number: AE331A758110
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Physiological quality of seeds of shepherd's purse (*Zeyheria montana* M. Bignoniaceae) as a function of substrate temperature and storage

Sara Dousseau Arantes[1*], Izabel de Souza Chaves[1], Lúcio de Oliveira Arantes[3], Amauri Alves de Alvarenga[4], Rafael Costa de Sant'Ana[3], Dayane Littig Barker[2], Daniele Freisleben Lavanhole[3] and Sheila Cristina Prucoli Posse[1]

[1]Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural, Centro Regional de Desenvolvimento Rural Rodovia BR-101 Norte, Km 151, Linhares - ES, CEP 29.915-140, Brasil.
[2]Centro Universitário Norte do Espírito Santo (CEUNES), Universidade Federal do Espírito Santo (UFES). Rodovia BR 101 Norte, Km 60, Bairro Litorâneo - São Mateus - ES, CEP 29.932-540, Brasil.
[3]Universidade Federal de Viçosa, Avenida Peter Henry Rolfs s/n, Campus Universitário, Viçosa –MG, CEP 36.570-900, Brasil.
[4]Universidade Federal de Lavras, Campus Universitário, departamento de biologia/dbi –Lavras - Minas Gerais - Caixa Postal 3037, Lavras - MG, CEP 37.200-000, Brasil.

Received 7 March, 2017; Accepted 2 January, 2018

The present study aimed to investigate the influence of different substrates, temperatures and storage conditions on shepherd's purse seed quality. It was evaluated in germination paper substrates Germitest®, vermiculite, sand and Plantmax®, and roller temperatures of 25, 30, 15-25 and 20-30°C. Longevity was measured by the temporal response to different packaging (paper, plastic and aluminum) and storage environments (laboratory and freezer). Germination percentage, germination rate index, percentage of normal, abnormal and dead seedlings were evaluated. The paper roll at 25°C provides an optimal condition for maximum germination potential and vigor. The storage for three months in freezer provides an increase in vigor in the seed without storing. The laboratory promoted reduction in germination potential from nine months of storage, with total loss of germination at 24 months. The combination of freezer and plastic packaging provide maintenance of seed longevity after two years of preparation.

Key words: Germination, vigor, longevity.

INTRODUCTION

Zeyheria montana Mart. (Bignoniaceae), commonly known as "shepherd's purse", is a plant species native to the Brazilian Cerrado. The extracts of leaves and roots of *Z. montana* are conventionally used in Brazilian popular medicine for the treatment of ulcers, cutaneous tumors and inflammatory diseases (Bertoni et al., 2007). Phytochemical analysis of *Z. montana* leaf extract showed the presence of terpenoids and flavonoids, whereas root and stem extracts are particularly rich in lapachol (Machado et al., 2006).

Despite the medicinal and commercial importance of shepherd's purse seeds, there are few studies regarding their germination process (Dousseau et al., 2007). When the germination process is considered, it is necessary to take into account the factors that affect this process, being temperature and the substrate which are the basic environmental factors of the germination test (Carvalho and Nakagawa, 2012; Stockman et al., 2007).

Several authors report the importance of temperature in germination, controlling the intensity and velocity (Orzari et al., 2013), regulating imbibition rates, electrolyte release (Kader and Jutzi, 2002), reserve mobilization (Ataíde et al., 2013), affecting the growth and vigor of seedlings (Alves et al., 2013, Pacheco Junior et al., 2013) and regulating the transcription of genes associated with germination (Chiu et al., 2012), since the substrate exerts influence on the development of the root system and provides nutrients for plants (Nogueira et al., 2012). The substrate exerts a great influence on the development of the root system and nutrient supply to the plants (Nogueira et al., 2012). In addition, several materials can be used in the original composition of a substrate or its compounds (Delarmina et al., 2015), contributing to germinability (% G) and germination rate (IVG).

However, maximum values of germination and germination velocity index also depend on post-harvest conservation of seeds, adequate storage of seeds is a fundamental condition for maintaining their viability and longevity, regardless of whether they are orthodox or recalcitrant (Yamanishi et al., 2005).

Another factor that need to be highlighted is the type of packaging used, which directly interferes with the conservation of seed vigor when they are stored in packages through which gas exchange with the atmosphere occurs. Here, the seeds can gain or lose moisture which may influence its viability (Batista et al., 2011).

Seed Analysis Rules (Brazil, 2009) establish instructions for conducting the germination test, including; basically, the type of substrate and the requirements for the availability of water, light and temperature (Carvalho and Nakagawa, 2012). However, information on many species is scarce, even in the Instructions for Analysis of Seeds of Forest Species (Brazil, 2013), and it is necessary to expand the work in the area of seed propagation and production, mainly due to the growing demand for propagation and conservation of medicinal Cerrado species.

In this context, the objective was to evaluate the influence of different substrates and temperatures on germination of shepherd's bag seeds, as well as to evaluate the temporal response to packaging in different packaging and storage environments in longevity for a period of two years.

MATERIALS AND METHODS

Fruits were collected from 30 plants located in the municipality of Ijaci - MG (21º 10 '12 "S latitude, 44º 55' 31" W longitude and 832 m altitude), in a private Cerrado reserve during the September / November harvest of 2006, at the time of dispersion. After collection, the fruits remained for 12 h, under laboratory conditions, for complete dehiscence and seed collection, after which the seeds were manually carved; the winged and disinfested expansion were removed by immersion for 5 min in 0.1% (w/v) Benomyl® solution (Dousseau et al., 2007). All experiments were conducted in germination chambers of type B.O.D., with photoperiod of 12 h and 58% relative humidity.

Three different experiments were conducted. In the first one, the influence of different substrates in the germination percentage (% G) and on the germination velocity index (IVG) of the shepherd's bag seeds was evaluated at 25°C; in the second, the response to different temperatures in the germination of germinated seeds in the best substrate chosen from the previous experiment and, in the third, storage conditions for maintenance of longevity under the predefined conditions of substrate and temperature.

The substrates were paper roll Germitest®, vermiculite, organic substrate Plantmax® and washed sand media. The roller system was conducted according to Dousseau et al. (2007). The other substrates were autoclaved and distributed in each Gerbox® polyethylene box. The sowing was done 1 cm deep, covering them with the respective substrate, the temperatures tested were the constants of 25 and 30°C and alternates of 15-25 and 20-30°C, in the roll of Germitest® paper.

For the storage study, the seeds with the winged expansion were treated with Captan ® 2% and packaged in 3 individual packages, made of materials of different permeabilities: paper bags, transparent plastic and aluminum. They were maintained in laboratory and cold chamber environments. The cold chamber was maintained at 10°C and 50% relative humidity, while in the laboratory the temperature ranged from 20 to 30°C. Stored seeds were evaluated for 0 (control), 3, 6, 9, 12 and 24 months. The analysis of the storage experiment was carried out in a 3 x 2 x 5 factorial scheme, corresponding respectively to the 3 types of packages, 2 storage environments and 5 storage periods.

In all trials, a completely randomized experimental design was used, with 4 replicates of 25 seeds per treatment. Germination, IVG, percentage of normal seedlings (% Pn), percentage of abnormal seedlings (% Pa) and percentage of dead seeds (% M) were evaluated. The percent G and IVG were calculated as described in Dousseau et al. (2007), where% G was obtained by calculating the germination percentage and IVG, according to Maguire (1962); after data collection was performed statistical analysis by means of the statistical program SISVAR (Ferreira, 2014) was done. The variance analysis was performed and the averages for germination in the substrates and at the temperatures were compared by the Tukey test ($p < 0.05$), while the storage averages were compared to the standard error of the mean,

*Corresponding author. E-mail: sara.arantes@incaper.es.gov.br.

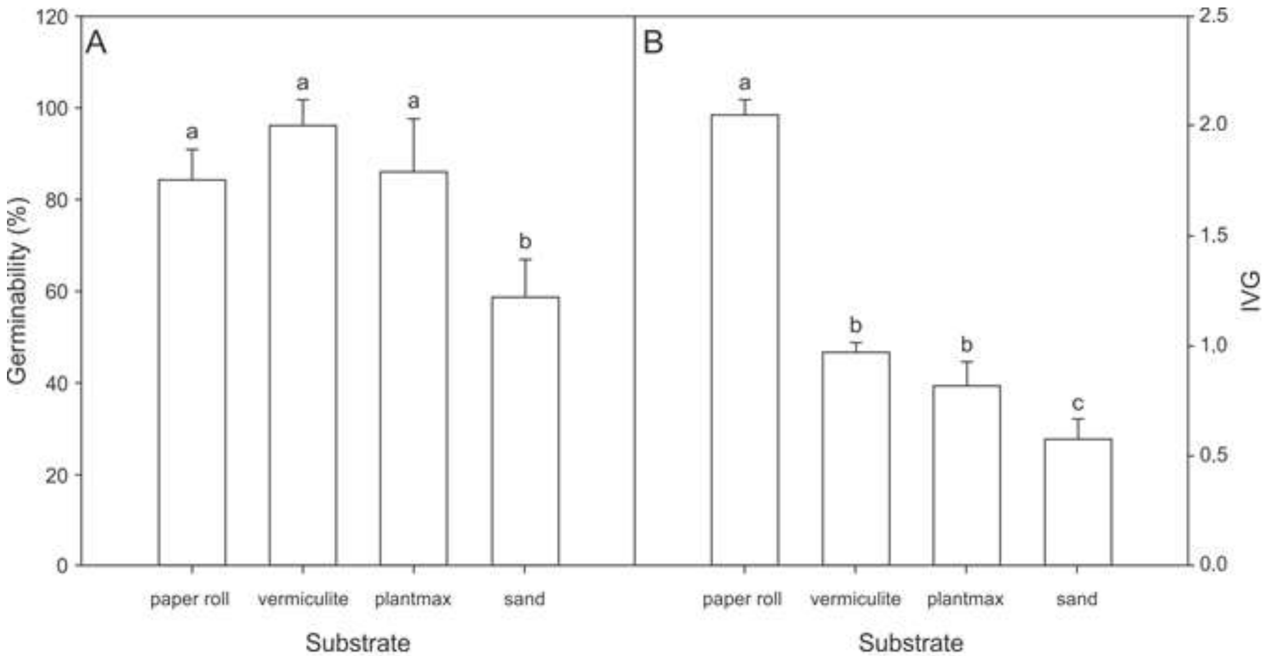

Figure 1. Germination of shepherd's bag seeds as a function of different substrates. A, Germinability (%); B, germination velocity index (IVG). Means followed by the same letter do not differ by Tukey test at 5% probability.

represented by the bars of error.

RESULTS AND DISCUSSION

The analysis of the best substrate for the germination of shepherd's pouch revealed that there was no statistical difference in the % G when compared with the paper roll, vermiculite and Plantmax® substrates, while the sand provided lower % G (Figure 1A). However, there were differences in the IVG for these substrates, where the paper roll provided higher IVG values when compared to vermiculite, Plantmax® and sand, respectively (Figure 1B).

Seeds germination of other species of Bignoniaceae showed that the response to the substrate is very variable, with no pattern. The substrate paper blotter is the most recommended condition for the germination tests of *Handroanthus serratifolius* seeds (Leão et al., 2015). The paper and sand substrate was more adequate for the evaluation of the physiological quality of the seeds of *Tabebuia aurea* (Silva Manso) Benth. & Hook f. S. Moore (Pacheco et al., 2008). For *Tabebuia roseo-alba* (Ridl.), sand was the ideal substrate, both on paper and paper roll, and between vermiculite, the lowest germination and vigor was observed (Stockman et al., 2007).

The effect of different temperatures on seeds germination was evaluated by the paper roll, which allowed the highest values of IVG and high germinability. The results show that % G values at temperatures of 25, 30 and 20-30°C did not differ from each other, while the temperature of 15-25°C provided lower % G (Figure 2A). However, when the IVG is analyzed, it is observed that the highest index occur at 25°C, followed by temperatures of 30, 20-30 and 15-25°C (Figure 2B). Both for the evaluation of the best temperature and for the best substrate in the germination process, all germinated seeds developed normal seedlings and no dead seeds were observed.

For some species, seed germination performance is favored by constant temperatures (Machado et al., 2016), by temperature alternation (Pereira et al., 2013) and by indifference to the temperature regime used (Martins et al., 2008).

Tests carried out with seeds from other forest species recorded that the thermal range suitable for seed germination of these species are between 20 and 30°C (Pascuali et al., 2012). However, variations can occur even among populations of the same species due to environmental conditions and adaptive and ecological characteristics (Mattana et al., 2012); for example, for other species of the family, Bignoniaceae at 35°C is the most recommended for germination of *T. aurea* (Pacheco et al., 2008) and *Pyrostegia venusta* (Ker Gawl.) Miers (Rossatto and Kolb, 2010).

Alternating temperatures also reduced seed germination and vigor of *T. serratifolia* and *T. impetiginosa* (Oliveira et al., 2005). According to Brancalion et al. (2010), alternation of temperatures is more common in pioneer

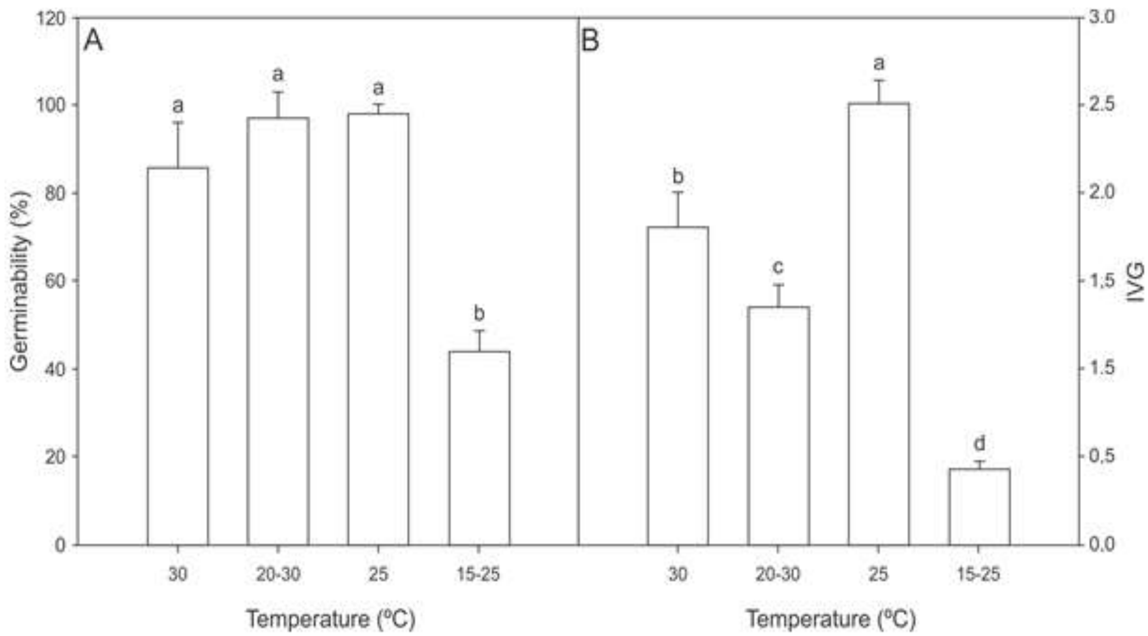

Figure 2. Germination of shepherd's bag seeds according to different temperatures. A. Germinability (%). B. Germination velocity index (IVG). Means followed by the same letter do not differ by Tukey test at 5% probability.

species, where alternating temperature regimes may be essential for overcoming dormancy, both physical and physiological, although the seeds of later species of succession may also benefit.

Shepherd's purse seeds were able to germinate under all the evaluated thermal regimes (Figure 2), showing the importance of this genus, which can be characterized by its ability to change its physiology according to environmental conditions, a feature that is a priority for the reforestation projects, mainly in the recovery of degraded areas and areas of permanent preservation (Martins et al., 2012, Sampaio et al., 2012).

For the storage experiments, the seeds that were placed to germinate in paper roll conditions at 25 °C provided the best IVG and% G, showing that there was no significant difference in seed moisture content of 7 to 8% in the laboratory environment (Figure 3A) and 7 to 10% in the cold chamber (Figure 4A).

However, for the other variables, there was a triple interaction between the studied factors (packaging, environment and storage time) (Table 1).

The longevity of shepherd's purse seeds differed from laboratory and cold storage. In the laboratory environment, a reduction was observed in the % G (Figure 3B) and in the normal seedlings (% Pl) (Figure 3C) from the 3 months of storage in aluminum, not differing in the other packages. At 9 months of storage, it was observed that expressive decrease in the % G and % Pn in all packages with the maximum value of dead seeds (Figure 3 E). The Pa appeared after 6 months of storage (Figure 3D). The vigor, expressed by the IVG value, was higher than 3 months of storage, then decreased (Figure 3F).

In the cold chamber environment, the % G (Figure 4B), % Pn (Figure 4C) and IVG (Figure 4F) also increased at 3 months, however, it was maintained until 12 months, with reduction only at 2 years. Pa remained at low values throughout storage (Figure 4D). The dead seeds were expressive only in the last evaluation (Figure 4E).

Seed longevity varies according to the genotype, but the period of conservation of the physiological potential depends to a large extent on the degree of moisture and storage environment conditions (Marcos Filho, 2005). Shepherd's purse seeds can be considered orthodox, similar to most species of Bignoniaceae (Carvalho et al., 2006) and storage at low temperatures is essential for the conservation of this class of seeds, once they guarantee the reduction of metabolism (Carvalho et al., 2006). Thus, since the values of water content did not reach harmful limits to the physiological quality of the seeds, the loss of viability when kept in the laboratory is related to the temperatures recorded in this environment, which varied from 20 to 30°C. High temperatures accelerate the degeneration processes of biological systems, where intense respiration occurs, consuming their reserve material, so that under these conditions the seeds lose their vigor and ability to germinate (Delouche and Potts, 1974). Seeds of *T. chrysotricha* stored at a water content of 21.1 and 15.9% at 20°C underwent an intense deterioration process, whereas the temperature and

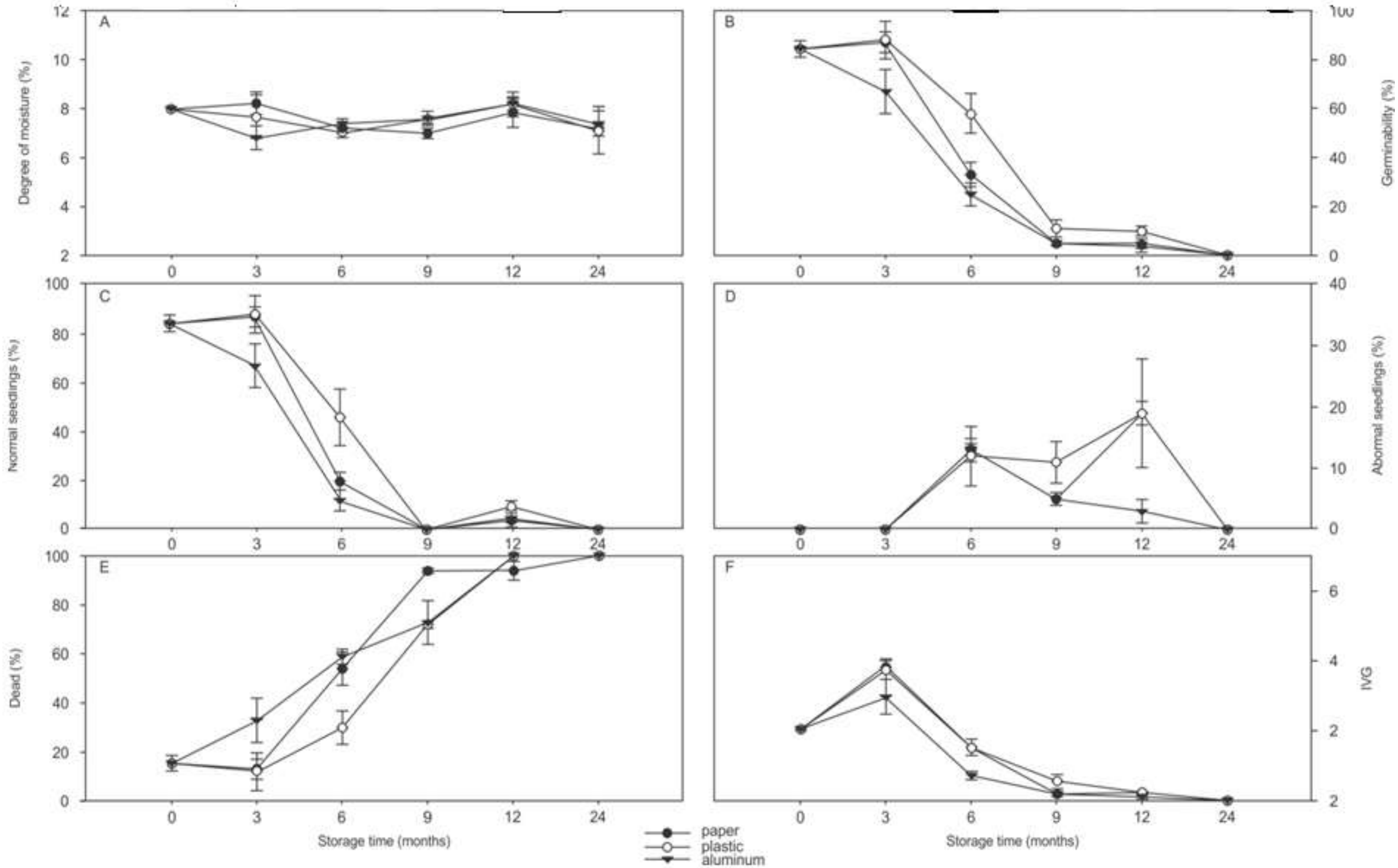

Figure 3. Time response of germination due to packaging in different packages under laboratory conditions. A. Degree of seed moisture; B. % of germination, considering root protrusion (% G); C. % of normal seedlings (% Pn); D. % of abnormal seedlings (% Pa); E. % of dead seeds (% M); F. germination velocity index (IVG).

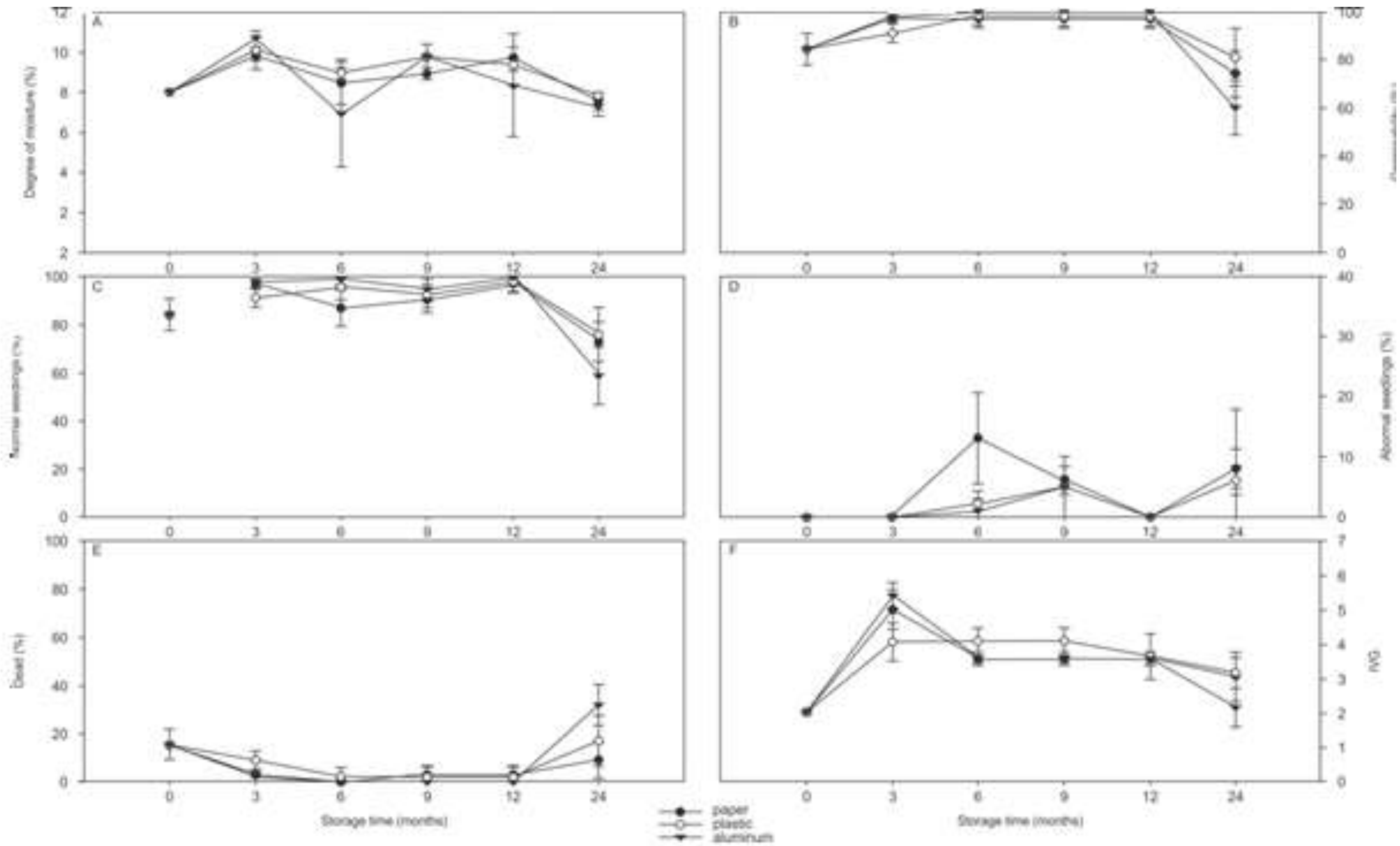

Figure 4. Time response of germination as a function of packaging in different packages under cold chamber conditions. A. Degree of seed moisture; B. % of germination, considering root protrusion (% G); C. % of normal seedlings (% Pn); D. % of abnormal seedlings (% Pa); E. % of dead seeds (% M); F. rate of germination (IVG).

water content combinations of 11.9% at 10°C; 11.9% at 12°C and 13.6% at -12°C favored seed conservation (Martins et al., 2009).

Analyzing the different packages, there were also differences between storage environments over time (Table 1). In the cold chamber, where % G and % Pn differed only at 24 months (Figure 5), the highest values of % G (Figure 5A, E) and % Pn were found in plastic and paper packages,

Table 1. Deployment of triple interaction between packing containers, environments (Laboratory and Cold Chamber) and months of storage of shepherd's bag seeds.

Packing	Time (months) and environments									
	3		6		9		12		24	
	LAB	CF	LAB	CF	LAB	CF	LAB	CF	LAB	CF
%G										
Paper	87 ^{Ba}	97 ^{Aa}	33^{Bb}	97 ^{Aa}	5 ^{Ba}	97 ^{Aa}	4 ^{Ba}	97 ^{Aa}	0 ^{Ba}	74 ^{Aa}
Plastic	88 ^{Aa}	91 ^{Aa}	58 ^{Ba}	98 ^{Aa}	11 ^{Ba}	98 ^{Aa}	10 ^{Ba}	98 ^{Aa}	0 ^{Ba}	81 ^{Aa}
Aluminum	67 ^{Bb}	98 ^{Aa}	25^{Bb}	100 ^{Aa}	5 ^{Ba}	100 ^{Aa}	5 ^{Ba}	100 ^{Aa}	0 ^{Ba}	60 ^{Ab}
IVG										
Paper	3.8 ^{Ba}	4.7^{Ab}	1.5 ^{Ba}	4.1 ^{Aa}	0.6 ^{Ba}	4.1 ^{Aa}	0.2 ^{Ba}	3.6 ^{Aa}	0 ^{Ba}	3.2 ^{Aa}
Plastic	3.8 ^{Ba}	5.0 ^{Aa}	1.5 ^{Ba}	3.6 ^{Aa}	0.2 ^{Ba}	3.6 ^{aa}	0.2 ^{Ba}	3.6 ^{Aa}	0 ^{Ba}	3.1 ^{Aa}
Aluminum	2.9^{Bb}	5.4 ^{Aa}	0.7 ^{Bb}	3.6 ^{Aa}	0.2 ^{Ba}	3.6 ^{Aa}	0.1 ^{Ba}	3.6 ^{Aa}	0 ^{Ba}	2.2 ^{Ab}
%PI										
Paper	87 ^{Ba}	97 ^{Aa}	20 ^{Bb}	87 ^{Aa}	0 ^{Ba}	91 ^{Aa}	4 ^{Ba}	97 ^{Aa}	0 ^{Ba}	73 ^{Aa}
Plastic	88 ^{Aa}	91 ^{Aa}	46 ^{Ba}	96 ^{aa}	0 ^{ba}	93^{Aa}	10 ^{Ba}	98 ^{Aa}	0 ^{Ba}	76 ^{Aa}
Aluminum	67 ^{Bb}	98 ^{Aa}	12 ^{Bb}	99 ^{Aa}	0 ^{Ba}	95 ^{Aa}	5 ^{Ba}	100 ^{Aa}	0 ^{Ba}	59 ^{Ab}
%Pa										
Paper	0 ^{Aa}	0 ^{Aa}	13 ^{Aa}	13 ^{Aa}	5 ^{Aa}	6^{Aa}	13 ^{Ab}	0 ^{Ba}	8 ^{Aa}	0 ^{Ba}
Plastic	0 ^{Aa}	0 ^{Aa}	12 ^{Aa}	2 ^{Bb}	11 ^{aa}	5 ^{Aa}	26 ^{Aa}	0 ^{Ba}	0 ^{Aa}	6 ^{Aa}
Aluminum	0 ^{Aa}	0 ^{Aa}	13 ^{Aa}	1 ^{Bb}	5 ^{Aa}	5 ^{Aa}	5 ^{A}c	0 ^{Aa}	0 ^{Ba}	8 ^{Aa}
%M										
Paper	13 ^{Ab}	3 ^{Aa}	54 ^{Aa}	0 ^{Ba}	94 ^{Aa}	3 ^{Ba}	82 ^{Aa}	3 ^{Ba}	100 ^{Aa}	9 ^{Bb}
Plastic	12 ^{Ab}	9 ^{Ba}	30 ^{Ab}	2 ^{Ba}	89 ^{Aa}	2 ^{Aa}	64 ^{Ab}	2 ^{Ba}	100 ^{aa}	17 ^{Bb}
Aluminum	33 ^{Aa}	2 ^{Ba}	59 ^{Aa}	0 ^{Ba}	95 ^{Aa}	0 ^{Ba}	88 ^{Aa}	0 ^{Ba}	100 ^{Aa}	32 ^{Ba}

Means followed by the same letter do not differ by Tukey test at 5% probability. On the line, uppercase letters compare environments in each packaging and month of storage, while in the column, lower case letters compare packages in each environment and month of storage. LAB, Laboratory environment; CF, cold environment.

which did not differ between them (Figure 5D), and aluminum packaging provided lower results. Regarding IVG, at 3 months, plastic and aluminum provided higher IVG in relation to paper, while in the other months no difference was observed between the packages, differing only in the last evaluation, with lower aluminum vigor. Abnormal seedlings (% Pa) appeared from the six months of evaluation (Figure 5C), while Pm at 24 months (Figure 5F).

In the laboratory environment, the values of % G, % Pn and IVG were higher on the paper and plastic packages compared to aluminum at 3 months of storage, not differing in the other times. However, in this environment, the germination capacity decreased at 6 months, with a drastic reduction at nine months of storage. Pa was obtained at 6 months of evaluation, as occurred in the cold chamber environment, but the presence of Pm was observed after 6 months (Figure 5B). The characteristics of the containers that store seeds influence the deterioration of seeds, depending on the greater or lesser ease of water vapor exchange between the seeds, the atmosphere and the environmental conditions in which the seeds are stored.

Paper, for example, is considered a porous packaging, which does not obstruct such exchanges. However, the plastic is resistant to the movement of water vapor between the seeds and the outside air while the aluminum packaging is considered impermeable because it does not allow the exchange of water vapor (Marcos Filho, 2005).

Thus, although no statistical difference was observed in the water content of the seeds in the tested different packages, it is speculated that the lower values of % G and IVG of the seeds conditioned in aluminum foil at 3 and 6 months storage in laboratory and At 24 months in cold chamber conditions, are due to the absence of water vapor exchange between the seeds and the media. According to Carvalho and Nakagawa (2000), changes in

Figure 5. Seed germination at 24 months storage in plastic packaging. A. Cold room environment; B. Laboratory environment. C. Detail of an abnormal seedling of a seed stored in a cold chamber; D. Detail of a normal seedling of a seed stored in a cold chamber; E. Radicular protrusion of a normal seed stored in a cold chamber; F. Dead seed stored in a cold room.

temperature and relative humidity of the air cause constant adjustments in the water content of the seeds stored in water vapor permeable packages until they reach an equilibrium moisture content. In the case of aluminum packaging, these variations in seed water content did not occur and provided the lowest values of % G and IVG in relation to paper and plastic.

Conclusion

The Germitest® roll paper substrate at a constant temperature of 25°C provided the highest values of germination and rate of germination. The period of three months in the cold chamber provides maintenance on the vigor in relation to the seeds without storing. The laboratory environment promotes reduction in germination potential from nine months of storage, with total germinability loss at 24 months. The combination of cold compartment and plastic packaging ensures the longevity of the seed after two years of packaging.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors thank the Federal University of Lavras, the Foundation for Research and Innovation of Espírito Santo (Fapes), the National Council for Scientific and Technological Development (CNPq) and the Capixaba Institute of Research from Espirito Santo, Technical Assistance and Rural Extension (INCAPER), by the physical structure for the development of the proposed project activities and by the financial support.

REFERENCES

Alves EU, Alves MM, Bruno RLA, Silva KRG, Barrozo LM, Santos-Moura SS, Cardoso EA (2013). Germinação e vigor de sementes de *Clitoria fairchildiana* Howard (Fabaceae) em função da coloração do tegumento e temperaturas. Bioscience Journal 29(1):216-223.

Ataíde GM, Borges EEL, Gonçalves JFC, Guimarães VM, Flores AV, Bicalho EM (2013). Alterations in seed reserves of *Dalbergia nigra* ((Vell.) Fr All. ex Benth.) during hydration. Journal of Seed Science 35(1):56-63.

Batista IMP, Figueiredo AF, Silva AM, Silva TAF (2011). Efeito de embalagens, ambientes e períodos de armazenamento na germinação e no vigor das sementes de cedro (C*edrela odorata*) em Manaus. Rev. Florest. Curitiba 41(4):809-818.

Bertoni BW, Astolfi Filho S, Martins ER, Damião Filho CF, França SC, Pereira MAS, Telles MPC, Diniz Filho JF (2007). Genetic variability in natural populations of *Zeyheria montana* Mart. from the Brazilian Cerrado. Scientia Agricola 64(1):409-415.

Brancalion PHS, Novembre ADLC, Rodrigues RR (2010). Temperatura ótima de germinação de sementes de espécies arbóreas brasileiras. Rev. Bras. Sement. 32(4):15-21.

Brazil (2009). Ministério da Agricultura, Pecuária e Abastecimento. Regras para análise de sementes. Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. Brasília: MAPA/ACS. 399 p.

Brazil (2013). Ministério da Agricultura e Reforma Agrária. Instruções para análise de sementes de espécies florestais. Brasília: SNDA/CGAL. 97 p.

Carvalho LR, Silva EAA, Davide AC (2006). Classificação de sementes florestais quanto ao comportamento no armazenamento. Revista Brasileira de Sementes 28(2):15-25.

Carvalho N, Nakagawa J (2012). Sementes: Ciência, tecnologia e produção. 5. ed. Jaboticabal: FUNEP. 590 p.

Chiu T, Christiansen K, Moreno I, Lao J, Loqué D, Orellana A, Heazlewood JL, Clark G, Roux SJ (2012). AtAPY1 and AtAPY2 Function as Golgi-Localized Nucleoside Diphosphatases in Arabidopsis thaliana. Plant and Cell Physiology 53(11):1913-1925.

Delarmina WM, Caldeira MVW, Faria JCT, Lacerda LC (2015). Uso de resíduo orgânico em substrato para produção de *Chamaecrista desvauxii* (Collad.) Killip var. latistipula (Benth.). Rev. Cerne

21(3):429-437.
Delouche JC, Potts HC (1974). Programa de sementes: Planejamento e implantação. 2. ed. Brasília: Agiplan.
Dousseau S, Alvarenga AA, Castro EMC, Arantes LO, Nery FC (2007). Superação de dormência em sementes de *Zeyheria montana* Mart. Ciência e Agrotecnologia 3(6):1744-1748.
Ferreira DF (2014). Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. Ciência e agrotecnologia 38(2):109-112.
Kader MA, Jutzi SC (2002). Temperature, osmotic pressure and seed treatments influence imbibition rates in sorghum seeds. Journal of Agronomy and Crop Science 188(1):286-290.
Leão NVM, Felipe, SHS, Shimizu ESC, Santos Filho BG, Kato OR, Benchimol RL (2015). Biometria e diversidade de temperaturas e substratos para a viabilidade de sementes de ipê amarelo Embrapa. Amazônia Oriental-Artigo em periódico indexado 2015.
Machado SR, Gregorio EA, Guimarães E (2006). Ovary peltate trichomes of *Zeyheria montana* (Bignoniaceae): Developmental ultrastructure and secretion in relation to function. Annals of Botany 97(1):357-369.
Machado DF, Bortolin GS, Paranhos JT, Silva AC (2016). Temperatura, luz e desinfecção na germinação das sementes de Gochnatia polymorpha (Less.) Cabrera. Revista de Ciências Agrárias 39(1):144-152.
Maguire JD (1962). Speed of germination-aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2(1):176-177.
Marcos Filho J (2005). Fisiologia de sementes de plantas cultivadas. Piracicaba: Fealq 495 p.
Martins CC, Machado CG, Nakagawa J (2008). Temperatura e substrato para o teste de germinação de sementes de barbatimão (*Stryphnodendron adstringens* (Mart.) Coville (Leguminosae)). Revista Arvore 32(4):633-639.
Martins CC, Machado CG, Santana DG, Zucareli C (2012). Vermiculita como substrato para o teste de germinação de sementes de ipê-amarelo. Semina: Ciênc. Agrár. Londrina 33(2):533-540.
Martins L, Lago AA, Andrade ACS (2009). Armazenamento de sementes de ipê-branco: Teor de água e temperatura do ambiente. Bragantia 68(3):775-780.
Mattana E, Daws MI, Fenu G, Bacchetta G (2012). Adaptation to habitat in Aquilegia species endemic to Sardinia (Italy): Seed dispersal, germination and persistence in the soil. Plant Biosystems 146(1):374-383.
Nogueira NW, Ribeiro MCC, Freitas RMO, Matuoka MY, Sousa VFL (2012). Emergência e desenvolvimento inicial de plântulas de *Mimosa caesalpiniifolia* Benth. em função de diferentes substratos. Revista Agroambient 6(1):17-24.
Oliveira LM, Carvalho MLM, Silva TTA, Borges DI (2005). Temperatura e regime de luz na germinação de sementes de *Tabebuia impetiginosa* (Martiusex A. P. de Candolle) Standley e *Tabebuia serratifolia* VahlNich. – Bignoniaceae. Ciênc. Agrotec. 29(3):438-443.
Orzari I, Monquero PA, Reis FC, Sabbag RS, Hirata ACS (2013). Germinação de espécies da família Convolvulaceae sob diferentes condições de luz, temperatura e profundidade de semeadura. Planta Daninha 31(1):53-61.
Pacheco MV, Matos VP, Feliciano ALP, Ferreira RLC (2008). Germinação de sementes e crescimento inicial de plântulas de *Tabebuia aurea* (Silva Manso) Benth. and Hook f. ex S. Moore. Ciência Florestal 18(2):143-150.
Pacheco Junior F, Silva JB, Negreiros JRS, Silva MRG, Farias SB (2013). Germinação e vigor de sementes de pimenta-longa (*Piper hispidinervum*) em função da temperatura e da luz. Revista Ciência Agronômica 44(2):325-333.
Pascuali LC, Silva FS, Porto AG, Silva Filho A, Meneghello GE (2012). Germinação de sementes de pinhão manso em diferentes temperaturas, luz e substratos. Semina: Ciências Agrárias 33(1):1435-1440.
Pereira SR, Kalife C, Rodrigues APDC, Laura VA (2013). Influência da temperatura na germinação de sementes de *Peltophorum dubium* (Spreng.) Taub. Informativo Abrates 23(3):52-55.
Rossatto DR, Kolb RM (2010). Germinação de *Pyrostegiavenusta* (Bignoniaceae), viabilidade de sementes e desenvolvimento pós-seminal. Brazilian Journal of Botany 33(1):51-60.
Sampaio MTF, Polo M, Barbosa W (2012). Estudo do crescimento de espécies de árvores semidecíduas em uma área ciliar revegetada. Revista Árvore, Viçosa 36(5):879-885.
Socolowski F, Vieira DCM, Takaki M (2008). Interaction of temperature and light on seed germination in *Tecomastans* L. Juss. ex Kunth (Bignoniaceae). Brazilian Archives of Biology and Technology 51(4):723-730.
Stockman AL, Brancalion PHS, Novembre ADLC, Chamma HMCP (2007). Sementes de ipê-branco (*Tabebuia roseo-alba* (Ridl.) Sand. – Bignoniaceae): temperatura e substrato para o teste de germinação. Revista Brasileira de Sementes 29(3):121-125.
Yamanishi OK, Fagundes GR, Filho JAM, Sacramento ERS (2005). Conservação das sementes de lichia (*Litchichinensis*). Revista Brasileira de Fruticultura 27(1):161-162.

Vol. 13(33), pp. 1698-1707, 16 August, 2018
DOI: 10.5897/AJAR2018.13304
Article Number: 7E9E9CA58112
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Agricultural mechanization in small rural properties in the State of Piauí, Brazil

Antônio Veimar da Silva[1*], Carla Michelle da Silva[1], Wagner Rogério Leocádio Soares Pessoa[2], Milena Almeida Vaz[2], Karine Matos de Oliveira[3] and Francisco Sérgio Ribeiro dos Santos[2]

[1]Department of Plant Science, Federal University of Viçosa, Viçosa, Minas Gerais, Brazil.
[2]Department of Agronomy, State University of Piauí, Piauí, Brazil.
[3]Department of Agronomy, Federal University of Piauí, Piauí, Brazil.

Received 7 June, 2018; Accepted 24 July, 2018

The use of machines in the rural sector increases crop productivity in the field, making it essential to use these technologies for a successful rural enterprise in the market. In this way, this study aimed to analyze the current situation of agricultural mechanization in farms of small producers. The study was conducted in State of Piauí, in Brazil with 30 farmers in the region. This was a quantitative and qualitative research, developed as a questionnaire applied by direct interview. Data were analyzed and represented in graphs using SigmaPlot® 12.0. It was concluded that the use of agricultural machinery for cultivation by small producers in the region studied is almost non-existent due to low purchasing power and also because they are small areas. Thus, the own family comprises most of the hand labor, working with crops in the field primarily by hand, leaving only more difficult services to be performed, such as disking, land clearing and threshing for agricultural machinery.

Key words: Mechanization, family farming, production, Brazil.

INTRODUCTION

The planning and rational use of natural resources requires efficient and effective management, since efficient management will promote the preservation and conservation of the environment, benefiting sustainable development, and assisting farmers in decision making (Francisco et al., 2012). Based on this, the industrial revolution favored the advancement of technology in agriculture, using the necessary tools to expand the acreage, thus inserting agricultural mechanization as a strategic form of rural development and consequently increasing productivity (Francisco, 2010).

These tools (agricultural mechanization) have taken on a large share in agriculture and contribute significantly to the Brazilian gross domestic product (GDP) with steady growth, since it carries out work in a timely manner in relation to the work done manually by the farmers. Thus,

*Corresponding author. E-mail: veimar26@hotmail.com. Tel: +5589999223050.

it is essential and necessary to investment in agricultural mechanization, but it is necessary before that, to make a correct and precise diagnosis as to its use in order to reduce costs in the labor (production) and thereby maximize profit (Pacheco, 2000).

For any producer, whether small, medium or large, its main activity is production with profit maximization and for this the producer must unite the resources that can help the agricultural work with the work in the field thus searching, through the use of machines and inputs, to decrease the cost of production and increase profits (Mochon and Troster, 1994). Caution is required in decision-making with regard to machines because the expense with them may exceed 20% of the cost of the crops, depending on the productive system, thus, the knowledge of these machines and inputs and their correct use is necessary in order to reduce their production costs (Rezende, 2003).

Agricultural mechanization is essential in agriculture, because in addition to raising labor productivity, it reduces labor costs and increases production, yet allows the farmer to carry out planned tasks in a timely manner and according to the demands of quality of services, in the different forms of work (Embrapa, 2006).

The use of agricultural machinery and implements in planting and managing a field crop presents great efficiency and financial return to the producer, besides promoting the reduction of soil compaction, reduction of rural operations and optimization of efficacy through the control of skating (Duarte Júnior et al., 2008). Thus, the use of machines in rural areas is directly related to the improvement of management systems, and better utilization of the productive resources of agriculture, as a consequence of the modernization and technological evolution of agriculture (Santos and Vale, 2012).

Peloia and Milan (2010) point out that in Brazil, expenditures on agricultural mechanization are high, generally being in second larger in spending on agricultural activities, being the first place to land ownership. However, when well applied and organized, mechanization in the medium and long term has a good potential for reducing production costs. The authors also point out that in order to reduce costs with mechanization, it is necessary and urgent to use administrative techniques, focusing on time, movements, mechanization systems, aiming at productivity increase and costs decrease, operations quality, motivation, environment and strategic alignment as a whole.

In this sense, Artuso et al. (2015) emphasize that mechanization must be planned within agriculture, where the correct sizing can be a factor of cost reduction, since rationalization of resources can lead to increased profitability of the activity.

Despite the benefits proposed by agricultural mechanization, the Northeast region has scarce study material in this area and this is a negative point, since the inadequate use and management of the soil has intensified the erosion process, especially in the northeastern semi-arid region where the climate and soil properties already favor this event (Chaves et al., 2010).

Inserted in this reality is the State of Piauí, which also has little research on the use of machines and agricultural implements by small farmers. The goal of this study was to analyze the use of agricultural mechanization in agricultural properties in the State of Piauí.

METHODOLOGY

This study was developed from a field and bibliographical survey, seeking the interaction, understanding and importance of the same to society. It presents a qualitative nature, where the interpretation and translation of the written text occurs, in a thorough way, with cleverness and scientific competences (Chizzotti, 2003). The objective was to understand the reality of the farmers and the motivation in the use of agricultural machinery that can contribute in a significant economical way and in the production of their crops. In quantitative terms, it was sought to quantify the use of these machines and to make an accurate estimate of their use by the farmers, demonstrating objectivity and emphasizing the reality (Gerhardt and Silveira, 2009).

The study region is located in the semi-arid Piauí, located between the geographical coordinates latitude 07° 04’ 37” S, longitude 41° 28’ 01” O and altitude of 206 m. According to the climatic classification of Köppen, the climate is semi-arid, very hot, with an annual average air temperature of 27.2°C. The average annual precipitation for the period (1960-2016) is of 684.2 mm concentrated in the months of December to April (PIAUÍ, 2010).

The daily pluviographic records of the Meteorological Station of the municipality of Picos, PI, were used in the archives of the National Institute of Meteorology (INMET; 3° DISME), in Recife, PE, which were grouped by chronological order, month and years. The mean monthly and annual precipitation of the municipality of Picos, PI corresponding to the 2006 to 2016 (the years 2009, 2010, 2011, and 2015 were excluded) are shown in Table 1. The rainfall index ranged from 311,90 mm in 2012 to 911,2 mm in the year 2006. This interannual variation is the very characteristic of the semi-arid state of Piauí. The temperature varies annually with averages of the minimum 21°C, average of 26.3°C and maximum of 32.5°C. Heat stroke with 3.000 h/year and average evapotranspiration of 2.000 mm/year (IBGE, 2010).

The producers of the region under study produce a great diversity of agricultural and livestock products, however, the most cultivated products are: cashew, mango, coconut, guava, banana, pumpkin, cassava, vegetables, beans, corn, watermelon, and rice, with respect to animal part stands out the raising of hens, cattles, goats, sheeps and pigs.

The field research was carried out in the State of Piauí, in August 2016. A questionnaire of 20 questions was prepared and applied through a direct interview to 30 small producers, which represented a sample of more than 13% of the region’s farmers.

For the sample, the statistical method of systematic sampling (Crespo, 2009) was used. Initially, a draw was made using the amount of property (approximately 220) for the sample that was 30 producers, resulting in 220/30 = 7.33, that is, chose by random draw a number between 1 and 7 (inclusive) that would indicate the first farm; the others would be periodically considered 7 in 7 uniformly. This was done to obtain the smallest possible error in the final representation of the probabilities in this work.

For the interview with farmers in the study region, the questionnaire comprised 6 multiple choice questions and 14 subjective questions (Appendix A). The questions were structured in the identification of personal data of the producer; characteristics of the production system used; human resources used in

Table 1. Monthly and annual precipitations of Picos, PI from 2006 to 2016.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
						mm							
2006	65.10	221.80	193.60	190.80	41.20	0.00	0.00	000	10.80	19.80	14.50	153.70	911.30
2007	95.10	202.40	94.90	63.80	46.20	0.00	0.00	0.00	0.00	3.20	32.90	30.10	568.60
2008	88.90	75.00	287.80	138.40	14.20	0.00	0.00	1.10	2.40	0.90	2.90	141.80	753.40
2012	49.50	75.10	47.40	12.70	7.10	1.80	0.00	0.00	0.00	0.60	103.90	13.80	311.90
2013	73.90	8.80	69.90	68.50	67.00	8.60	1.00	0.00	0.00	1.30	16.20	0.00	315.20
2014	28.40	109.60	99.70	64.10	11.20	0.20	23.80	0.00	0.00	43.80	35.60	0.00	416.40
2016	319.30	86.30	97.00	5.90	32.60	0.00	0.00	0.00	7.70	8.80	10.30	0.00	567.90
Media	102.89	111.29	127.19	77.74	31.36	1.51	3.54	0.16	2.99	11.20	30.90	48.49	549.24
CV	0.95	0.68	0.66	0.85	0.70	2.11	2.52	2.65	1.49	1.42	1.11	1.42	0.41

CV: Coefficient of variation.

production; and the mechanized resources for planting and managing the crops in the field. These interviews are objective (concrete facts) and subjective, obtained by the involvement of the actors aiming at a social contribution (Szymanski, 2010). In this regard, the author also emphasizes that the analysis of the interviews (contained in the results and discussion) conventionally implies the way in which the phenomenon under study is inserted in the context of which it is part. The author also emphasizes that when analyzing the interviews, one must remain focused on the objectives of the study.

Data collected in the interview were quantified, analyzed and represented in graphs elaborated in SigmaPlot® 12.0 and later discussed.

RESULTS AND DISCUSSION

The results analyzed showed that 90% of the interviewees were male and only 10% were female, showing that the majority of the producers in the State of Piauí are men. The participation of women in agriculture in the present times has taken positive courses because they have and/or had their work as domestic activities or helping men in various activities. The other study was found that, in family farming, men are responsible for 87.32% of the total and women account for 12.68% of the total (IBGE, 2009).

From the farms surveyed, all are from family farmers and their families actively participate in rural activities, including women. Family farmers are those who are in accordance with the law no. 11.326 of 24 of July 2006, that in his article, 3° stands out: "the family farmer is one who practices activities in rural areas, simultaneously meeting the following requirements: (I) does not hold, in any capacity, an area greater than 4 fiscal modules; (II) predominantly use the labor force of the family itself in the economic activities of its establishment or enterprise; (III) have family income predominantly from economic activities linked to the establishment or enterprise; (IV) direct your establishment or venture with your family" (Oliveira, 2018).

All farmers have the aptitude statement to pronaf (ASP). Therefore, studies on the use of mechanization are of the utmost importance, since these farmers can acquire agricultural machines and implements through Pronaf. The Pronaf is a government program to help family farmers acquire machinery, implements, irrigation, greenhouses for the production of food products with a credit line of up to 100,000 reais to be paid in up to 10 years, with three years of grace and interest below the market at 2% per year (Revista Rural, 2018).

Thus, it is evident that all of the family work in the production either with planting of crops or with breeding and rearing of animals. In this respect, it is well known in this research that women perform activities related to production (crops) and reproduction (animals) contributing financially, albeit indirectly, to family farming (Mesquita and Mendes, 2012).

Another important factor to be discussed is the schooling of these farmers, since the techniques for a good development in agriculture require a minimum of knowledge or at least the search for it. Thus, according to the collected samples, it can be seen that the level of education of rural owners is quite diverse, as shown in Figure 1.

The educational level of most of the farmers is concentrated in the completion of High School and Elementary Education II, which means that most of them have basic knowledge of the study, and this is positive, since access to scientific and technological knowledge benefits in the management of field crops (Abebe et al., 2013).

As far as farmer income is concerned, almost all respondents stated that they earn about 600 reais per month (Figure 2), which is considered a very low value, mainly because 50% of families have 6 to 10 people in the same family and 47% below 6 people. This is mainly due to the climatic disparity, such as low rainfall, excessive heat, and low fertility soils, which raises poverty in the Northeast, especially in the Brazilian semi-arid region (Buainain and Garcia, 2013).

Much of what is planted by these farmers are consumed

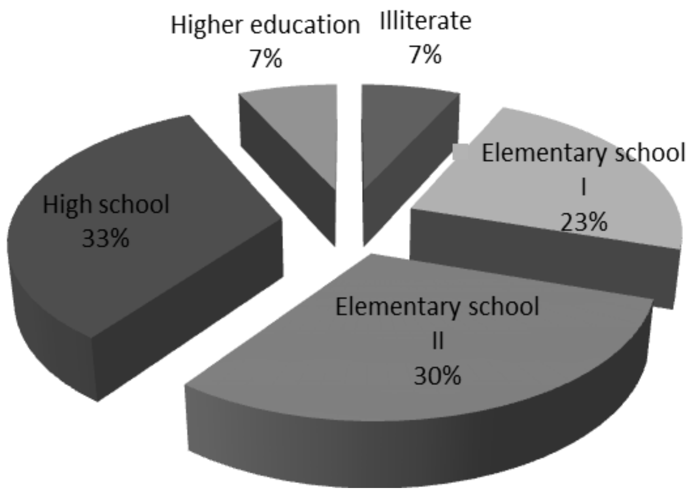

Figure 1. Schooling of the agricultural producers surveyed.

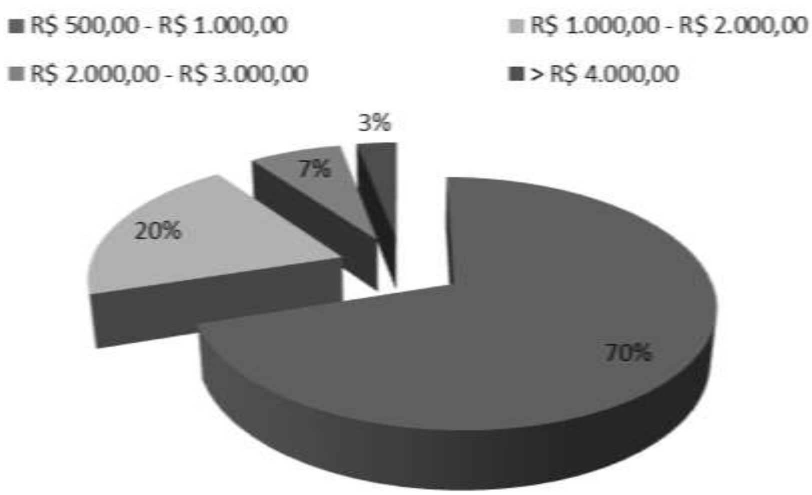

Figure 2. Monthly income of the interviewees.

by them, since their families are large, marketing only what is left from their subsistence. In this context, Lima et al. (2015) highlight that gross monthly income ranges from less than a minimum wage up to two wages, evidencing rural poverty and the consequent history of rural exodus in Brazil.

Another important factor is that due to the small areas that they have (Figure 3), together with the low income, which has been a limiting factor in the acquisition of agricultural machines and/or implements, since it has a high value.

The knowledge of these family farmers about Pronaf is important since they can improve their production and consequently their quality of life. Farmers should know that they are important in the production chain, since they are, according to IBGE, responsible for 38% of Brazil's gross value of production (GVP) (IBGE, 2009).

Since the largest number of farmers has little area for cultivation, the amount of labor employed is small and usually hired in the rainy season, which lasts around 3 to 4 months. They are used for cleaning, planting and harvesting the product. However, a large part of the workforce is owned by the family members who live in the property, because since the income is low, there is not much money available to pay the daily employment services, since these costs about R$ 35.00 to R$ 50.00. This context is justified because family agriculture is characterized precisely by the family's participation in agriculture and must be understood from studies and research focused on its socioeconomic specificities and differentiation (Silva, 2015).

Nevertheless, even the area being small is still necessary to hire people for the most important operations of the crop, because there are cultures that

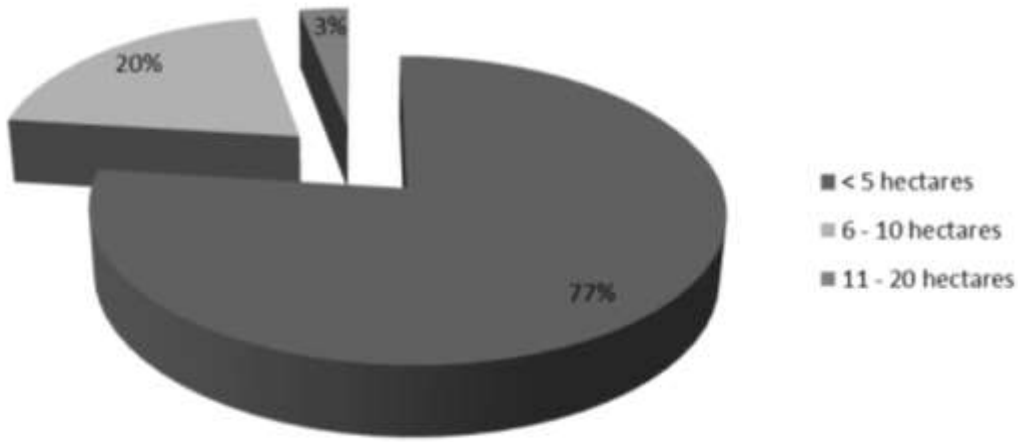

Figure 3. Acreage of small farmers.

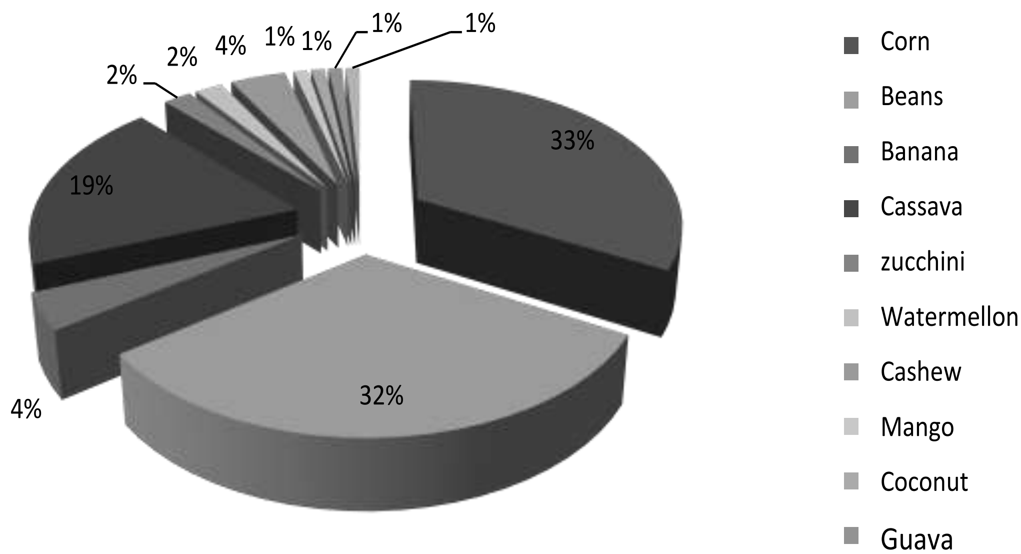

Figure 4. Cultures grown in the properties of small producers.

are exhausting to be accompanied, so that there is a good production. According to the results of this study, of the plants cultivated in the semiarid region of Piauí, the ones that stand out most in the production of these farmers are as shown in Figure 4.

Corn and beans are the most cultivated crops in the region, followed by cassava. In the Northeastern region of Brazil, crop cultivations stand out per region, being beans in the North-Center regions of Piauí, Agreste and Northeastern of Paraíba, South of Ceará, Agreste of Rio Grande do Norte, Agreste of Pernambuco and backwoods of Sergipe. Corn stands out in the South and Center South of Ceará, backwoods of Ceará, backwoods of Pernambuco, and cassava is concentrated in north and east of Maranhão, Agreste of Rio Grande do Norte and Sergipe (Buainain et al., 2016).

As for the temporary crops per agricultural mesoregions (average participation in planted area (2011-2014)), Freitas and Maciente (2016) pointed out that, in the Southwest of the State of Piauí, corn (20.73% grain) and beans (8.67% grain) are in the 2nd and 3rd place, respectively, losing only to the soybean crop (60.38% grains) considered the leading crop in production.

An important point to consider is that family farming is responsible for 70% of the beans we eat, 60% of the cheeses we consume, among others and that are produced in up to four fiscal modules, placing food on the table of Brazilians (Oliveira, 2018). Oliveira also points out that the majority of family farmers are located in the Northeastern region of Brazil, which justifies the need for more research for this region as well as the dissemination of the results in electronic media and with the farmers

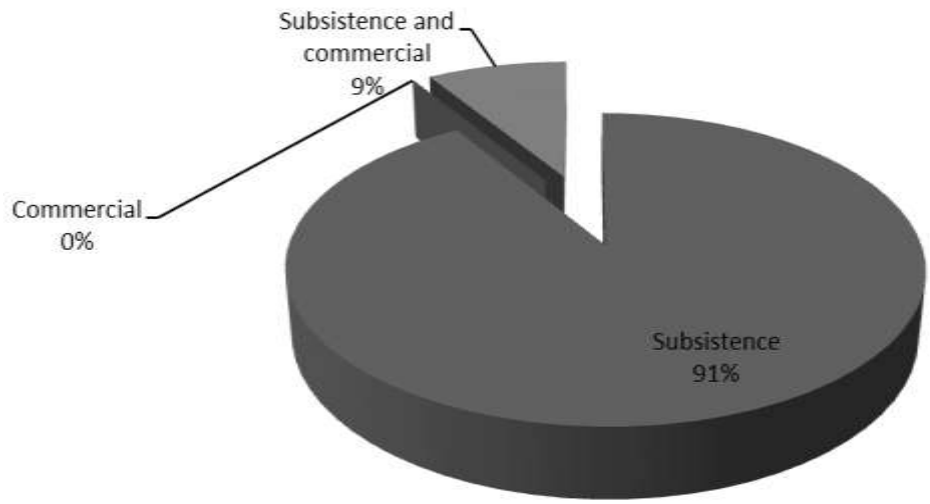

Figure 5. Purpose of the production of small farmers.

themselves so that they will value themselves and seek to use modern equipment on their properties and thus improve their quality of life.

With the constant growth of the population, the look at family agriculture has changed course by two important characteristics. On one hand, is the quality of the food, since family farmers take care of their lands with the minimum use of pesticides seeking environmental sustainability and socioeconomic development (FAO, 2014; Smith and Haddad, 2015); on the other hand, family farmers are no longer seen as problems by the elite class, placing the responsibility of hunger on small producers, and in the current context the solution to world hunger (McIntyre et al., 2009; Silva, 2014)

Almost all production of farmers in the State of Piauí is used for subsistence (Figure 5) and many of these are retirees not depending entirely on agriculture to survive. On the other hand, 9% of the mentioned farmers sell part of their production (small, by the way) for the acquisition of belongings they need like clothes, shoes, etc. and to pay the daily labor costs, which they will need during the plantation. Thus, sales of fruits, vegetables, flours, gums among others in fairs in the region where they live are justified (Menezes et al., 2016).

Of the 30 interviewees in this survey, only one person claimed the use of tractor. Its use was in soil preparation, with plowing and spraying, stating that the tractor was rented. None farmer used tractor for sowing or harvesting. Almost all of them pointed out that they use other types of manual equipment and animal traction, which shows the need to use the family labor force due to low purchasing power (Figure 6).

However, only 10% of the interviewees are aware of the operation of agricultural machinery and this is because 100% of producers do not have such equipment. In addition, the tractors used for cultivation aid are rented from third parties that are often not trained and have not

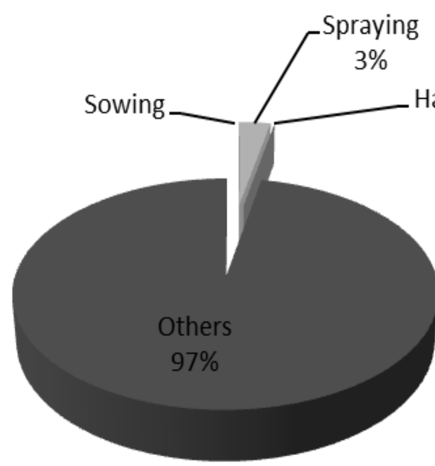

Figure 6. Operations carried out with the use of agricultural machinery during the work with the crop in the field.

undergone any training to use the machines. This is a cause of great concern, since the tractor is a machine that is among the main causes of accidents occurring in the rural context, reaching about 65% of reported incidents (Monteiro, 2010).

The values of the rent of tractors vary according to the purpose and number of hours that will be used. According to the interviewees, prices can vary from R$ 50.00 to R$ 120.00, the most common being R$ 100.00 and R$ 120.00 and are used in the most difficult operations to be performed (Figure 7).

Thus, the agricultural tractor must be able to do as many operations as possible in the rural property (Machado et al., 2010). However, it should be handled by trained personnel so that there is no poor management of the activity, harming people, the environment or even the

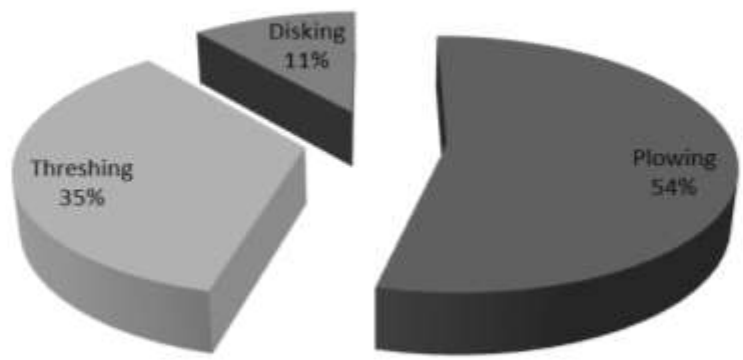

Figure 7. Operations carried out with the use of agricultural machinery.

product itself. For this, it is necessary that the tasks are executed in a rational and planned way, thus promoting the time and financial savings for the small farmers (Silva, 2009).

Conclusion

The use of agricultural machinery for cultivation in farms in the region studied is almost non-existent due to the low purchasing power and also because they are small areas. In this way, the family comprises most of the labor force, working with crops in the field primarily by hand.

More research is recommended in the different regions of Brazil, regarding the use or not of agricultural machinery, inputs, equipment, etc., in order to obtain more information about the real situation of the production of small and medium farmers and their participation in agribusiness .

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abebe GK, Bijman J, Pascucci S, Omta O (2013). Adoption of improved potato varieties in Ethiopia: The role of agricultural knowledge and innovation system and smallholder farmers' quality assessment. Agricultural Systems 122(1):22-32.

Buainain AM, Jardim A, Alves E, Mendonça de Barros JR, Neto O, Navarro Z (2016). A economia agropecuária brasileira. O que fazer? Avaliable in: http://economia.estadao.com.br/noticias/geral,a-economia-agropecuaria-brasileira-o-que-fazer,10000051278.

Buainain AM, Garcia JR (2013). "Capítulo V: Pobreza Rural e Desenvolvimento do Semiárido Nordestino: Resistência, Reprodução e Transformação". In: Buainain AM, Dedecca C (orgs.). A nova cara da pobreza rural: desenvolvimento e a questão regional, Brasília IICA 536 p.

Chaves IB, Francisco PRM, Lima ERV (2010). Classificação das terras para mecanização agrícola e sua aplicação para o estado da Paraíba. In: XVIII Reunião Brasileira de Manejo e Conservação do Solo e da Água, Teresina. Anais...Teresina: SBCS. http://dx.doi.org/10.12722/0101-756X.v28n01a05

Chizzotti A (2003). A pesquisa qualitativa em ciências humanas e sociais: evolução e desafios. Revista Portuguesa de Educação 16(2):221-236.

Crespo AA (2009). Estatística fácil. 19ª ed. São Paulo: Saraiva 224 p.

Duarte Júnior JB, Garcia RF, Coelho FC, Amim RT (2008). Desempenho de trator-implemento na cana-de-açúcar em sistemas de plantio direto e convencional. Revista Brasileira de Engenharia Agrícola e Ambiental 12(6):653-658.

Embrapa (2006). Sistema brasileiro de classificação de solos. Rio de Janeiro: EMBRAPA Solos 412 p.

Food and Agriculture Organization (FAO) (2014). The state of food and agriculture 2014: Innovation in family agriculture. Roma (2014). Avaliable in: < http://agenciabrasil.ebc.com.br/geral/noticia/2014-10/paises-devem-investir-em-inovacao-para-agricultura-familiar-alerta-fao>.

Francisco PRM (2010). Classificação e mapeamento das terras para mecanização do Estado da Paraíba utilizando sistemas de informações geográficas. Dissertação (Mestrado em Manejo de Solo e Água). Centro de Ciências Agrárias. Universidade Federal da Paraíba, Areia 122f.

Francisco PRM, Chaves IB, Lima ERV (2012). Mapeamento das terras para mecanização agrícola - Estado da Paraíba. Revista Brasileira de Geografia Física 5(2):233-249.

Freitas RE, Maciente AN (2016). Culturas Agrícolas Líderes nas Mesorregiões mais Dinâmicas. Repositório do conhecimento do IPEA. Avaliable in: http://repositorio.ipea.gov.br/handle/11058/6055.

Gerhardt TE, Silveira DT (2009). Métodos de pesquisa, planejamento e gestão para o desenvolvimento rural da SEAD/UFRGS. 1 ed. Porto Alegre: UFRGS, 120 p.

Instituto Brasileiro de Geografi a e Estatística (IBGE) (2009). Censo Agropecuário 2006. Agricultura Familiar. Brasil, Grandes Regiões e Unidades da Federação. Brasília/Rio de Janeiro: MDA/MPOG.

Instituto Brasileiro de Geografi a e Estatística (IBGE) (2010). Censo de 2010. Avaliable in:< https://censo2010.ibge.gov.br/>.

Lima GTC, Silva JA, Reis AS, Albuquerque Júnior JE, Silva IC (2015). Análise do perfil social, econômico, ambiental e físico conservacionista do assentamento Logradouro Campina Grande – PB. Cadernos de Agroecologia 10:3.

Machado ALT, Reis AVR, Machado RLT (2010). Tratores para a agricultura familiar: guia de referência. Pelotas: Ed. Universitária UFPEL 124 p.

McIntyre BD, Herren HR, Wakhungu J, Watson R (2009). International assessment of agricultural Science knowledge, and technology for development (IAASTD): global report. Washington, DC: Island Press. Avaliable in: <http://www.unep.org/dewa/assessments/ecosystems/iaastd/tabid/105853/default.aspx>.

Menezes LJM, Zanon JS, David C (2016). A agricultura familiar em meio às transformações recentes no distrito de Santa Flora, Santa Maria, RS. Ambiência 12(1):71-86.

Mesquita LAP, Mendes EPP (2012). Mulheres na agricultura familiar: A Comunidade Rancharia, Campo Alegre de Goiás (GO). XXI Encontro

Nacional de Geografia Agrícola. UFU. Avaliable in: http://www.lagea.ig.ufu.br/xx1enga/anais_enga_2012/eixos/1104_1.pdf.

Mochon F, Troster RL (1994). Introdução à Economia. São Paulo: Makron Books 391 p.

Monteiro LA (2010). Prevenção de Acidentes com Tratores Agrícolas e Florestais. Botucatu, SP: Editora Diagrama 105 p.

Oliveira MLR (2018). Learn what it takes to be part of Family Agriculture. Revista Agropecuária. Avaliable in:<http://www.revistaagropecuaria.com.br/2011/09/26/saiba-o-que-e-preciso-para-fazer-parte-da-agricultura-familiar/>.

Pacheco EP (2000). Seleção e custo operacional de máquinas agrícolas. Rio Branco: Embrapa Acre 21 p. (Embrapa Acre. Documentos, 58).

Peloia P, Milan M (2010). Proposal of a Performance Measurement System Applied to mechanization. Engenharia Agrícola 30(4):681-691.

Piauí (2010). Secretaria de Meio Ambiente e Recursos Hídricos. Plano Estadual de Recursos Hídricos. Diagnóstico e Prognóstico das Disponibilidades Hídricas das Bacias Hidrográficas - RTP-6. Diagnóstico referencial consolidado sobre os Recursos Hídricos no Estado do Piauí. Teresina: SEMAR 333 p.

Revista Rural (2018). Crédito Rural – Mecanização no caminho da produção. Avaliable in: <http://www.revistarural.com.br/edicoes/item/5588-credito-rural-mecanizacao-no-caminho-da-producao>.

Rezende GC (2003). Estado, macroeconomia e agricultura no Brasil. Porto Alegre: UFRGS/ IPEA 246 p.

Santos HF, Vale AR (2012). Modernização da agricultura e novas relações campo-cidade no atual período da globalização: algumas análises a partir do agronegócio cafeeiro no município de Alfenas-MG. In: Jornada Científica de Geografia, 3, 2012, Alfenas. Anais eletrônicos... Alfenas: UNIFAL, v. 1. Avaliable in: http://www.unifal-mg.edu.br/jornadageografia/files/MODERNIZA%C3%87%C3%83O%20DA%20AGRICULTURA%20E%20NOVAS%20RELA%C3%87%C3%95ES%20CAMPO-CIDADE%20NO%20ATUAL%20PER%C3%8DODO%20DA%20GLOBALIZA%C3%87%C3%83O-%20ALGUMAS%20AN%C3%81LISES%20A%20PARTIR%20DO%20~1_0.pdf

Silva JM (2015). Estratégias de Reprodução Social na Agricultura Familiar: as comunidades rurais do município de Catalão (GO). Espaço em Revista 17(1):31-41.

Silva GF (2009). Análise de custos operacionais e eficiência gerencial para conjuntos trator implemento em operações agrícolas. Piracicaba: Universidade de São Paulo. Avaliable in: http://www.ler.esalq.usp.br/download/gmap/estagio/Gustavo.pdf.

Silva JG (2014). The family farming revolution. An opinion piece from the Director-General of FAO. Avaliable in: <http://www.fao.org/about/who-we-are/director-gen/faodg-opinionarticles/detail/en/c/212364/>.

Smith LC, Haddad L (2015). Reducing child malnutrition: drivers and priorities from the past to the post-MDG era**.** World Development 68 (2015):180-204.

Szymanski H (2011). A entrevista na pesquisa em educação: a prática reflexiva**.** Brasília: Liber Livro Editora. 4ª Ed. 157 p.

APPENDIX A

DIAGNOSIS OF AGRICULTURAL MECHANIZATION
FORM FOR DATA COLLECTION

Who should respond to this interview?

Person responsible for the administration of the property, owner or person having knowledge of the production system and the equipment used in the place.

Restrictions

Data should not be collected from properties where the focus is not on agriculture.

1. IDENTIFICATION

1.1 SEX: ________________

1.2 SCHOOLING LEVEL: ____________________________________

1.3 MONTHLY INCOME: ( ) 500-1000 ( ) 1000-2000 ( ) 2000-3000 ( ) 3000 – 4000
( ) 4000 – 5000

1.4 PURPOSE OF AGRICULTURAL PRODUCTION
SUBSISTENCE ( ) COMMERCIALIZATION ( )

1.5 CULTIVATION AREA__________ha
OWN______________ha
LEASED___________ha

THIS QUESTION CAN BE SUMMARIZED, IF NECESSARY, IN: WHAT IS THE SIZE OF YOUR AREA AND WHAT IS THE SIZE OF THE CULTIVATED AREA?

2. HUMAN RESOURCES

2.1 TOTAL NUMBER OF PEOPLE (FAMILY MEMBERS, EMPLOYEES...)
2.2 NUMBER OF PEOPLE OPERATING AGRICULTURAL MACHINES
2.3 MAXIMUM NUMBER OF TEMPORARY JOBS IN THE YEAR
2.4 INTENSITY OF USE OF TEMPORARY WORKFORCE
2.5 IN WHICH OPERATION IS THE TEMPORARY WORKFORCE USED IN? AND WHAT IS THE COST PER HOUR WORKED?
2.6 ARE THE PEOPLE OPERATING AGRICULTURAL MACHINES SPECIALIZED, THAT IS, THIS TYPE OF OPERATION IS ALWAYS WORKED BY THEM?

PULVERIZATION YES ( ) NO ( )
SOWING YES ( ) NO ( )
HARVEST YES ( ) NO ( )

2.7 DO PEOPLE OPERATING AGRICULTURAL MACHINES RECEIVE TRAINING FOR THE OPERATION? HOW OFTEN? WHAT TYPE OF TRAINING? WHAT IS THE TRAINING APPROACH?

3. CHARACTERISTICS OF THE PRODUCTION SYSTEM

3.1 CULTIVATION PERFORMED (CROPS PLANTED ON THE PROPERTY)
3.2 AVERAGE PRODUCTIVITY (IDENTIFY THE AVERAGE PRODUCTIVITY OF EACH CROP PLANTED ON THE PROPERTY IN t/ha)
3.3 CULTURE PARTICIPATION IN THE AREA (%)
3.4 AGRICULTURAL OPERATIONS MADE WITH MACHINERY

3.4.1 SOWING ( )
3.4.2 PULVERIZATION ( )
3.4.3 HARVST ( )
3.4.4 OTHERS ( ) ____

4. MECHANIZED RESOURCES

RELATE THE TRACTORS USED IN THE PROPERTY WITH THE CHARACTERISTICS USED

4.1 NEW PURCHASE ON RESALE ( )
PURCHASE USED IN THE RESALE ( ) RENTED ( )
4.2 IF RENTED, WHAT THE VALUE COLLECTED BY THE RENT (PER HOUR):
4.3 IF THE HOROMETER WORKS, WHAT IS THE NUMBER OF HOURS WORKED:

4.4 THE TRACTOR IS INTENDED TO PERFORM WHICH OPERATIONS? RELATE IN ORDER OF IMPORTANCE:
1) ______________________________
2) ______________________________
3) ______________________________
4) ______________________________
5) ALL ( )

Vol. 13(33), pp. 1708-1718, 16 August, 2018
DOI: 10.5897/AJAR2018.13311
Article Number: 698894958114
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Evaluation of chemical and non-chemical weed control practices on weed communities and maize yield in two agroecological zones of Swaziland

T. L. Mncube and H. R. Mloza Banda*

Department of Crop Production, Faculty of Agriculture, University of Swaziland. P. O. Luyengo M205, Luyengo, Swaziland.

Received 11 June, 2018; Accepted 3 July, 2018

Manual weeding, maize-cowpea intercropping, pre-emergence (PRE) and early post-emergence (EPOST) herbicide applications comprised ten weed control practices evaluated in the 2015-16 cropping season on weed species structure and maize (*Zea mays* L.) yield in the Middleveld and Highveld of Swaziland. The herbicides used were Harness (acetochlor) and Dual Gold (S-metolachlor) as pre-emergence applications and Micro-Tech (alachlor) and Callisto (mesotrione) as early post-emergence applications. PRE and EPOST herbicides were used as once-off or combined applications besides manual weeding or intercropping practices. Results indicated that the combination of PRE and EPOST herbicides reduced both species richness (number) and evenness (dominance) but weed species composition (types) were not distinguished amongst treatments. Manual weeding in combination with PRE herbicides or maize-cowpea intercropping resulted in significantly lower weed density and biomass as compared to singular or combinations of PRE or EPOST herbicides in both locations. The effects of weed control practices on grain yield of maize were not significantly distinguished among weed control practices between the two sites. The study reaffirmed that herbicides may need to be supplemented with other weed control strategies to obtain acceptable weed control.

Key words: Herbicides, maize, Shannon-Wiener diversity index, Simpson's dominance index, Steinhaus coefficient index, weeds.

INTRODUCTION

Despite benefits that have been reported from chemical weed control practices in small scale crop production, effective control of weeds remains a major impediment to productivity as weed infestations continue to cause debilitating effects on crop health and human welfare under subsistence production (Gianessi and Williams, 2011). Although, awareness and use of herbicides for weed control in Swaziland has been increasing over the

*Corresponding author. E-mail: mbanda@uniswa.sz

last decade, few smallholder farmers use herbicides and generally perform one manual-weeding operation (Mncube et al., 2017). The narrow range of herbicides available in the country and lack of knowledge on their correct use remains a big challenge for many farmers (Dlamini et al., 2016). In addition, most herbicide applications are limited to post-emergence (Mncube et al., 2017) and farmers do not practice soil cultivation practices to reduce weed escapes.

Sustainable agriculture calls for limiting use of herbicides either by reducing application rates (Zhang et al., 2013), herbicide rotations, use of selective narrow-spectrum products, containing the most ecologically detrimental range of products (Norsworthy et al, 2012) or using alternative soil and crop management methods (Pacanoski et al., 2015; Saudy, 2015). However, development of effective strategic combinations of weed control techniques, where herbicides are a part, remains a major limitation to farmers and their agents in emerging agriculture already beset with poor adoption of herbicide technology.

Armengot et al. (2012) reported that increasing intensity of various agricultural measures has led to strong changes in the structure of weed communities in developed agriculture. These changes have especially been attributed to altered standards of crop rotation and higher efforts in fertilizing and crop protection measures that include herbicides. In contrast, the present work suggests that intensive monoculture practices and lower efforts in weed control measures practiced by small scale farmers may have influenced weed community diversity, for instance, by altering the variation in both the numbers and kinds of species present. There remains inadequate information on weed community structure and abundance based on singular and combinations of manual, cultural and chemical weed control as a prelude to possible and potential approaches to practical weed management for small scale farmers. Arable fields in Swaziland are dominated by continuous maize production that occurs on 80% of 80,000 ha of total rain-fed cultivable land (Swaziland Government, 2016) where weeds are marginally controlled. A clear understanding of how the timing and longevity of different weed control practices condition weed communities is a key component in the development of integrated weed management programs to maintain low and consistent weed abundance and enhance yields of staple crops (Romero et al., 2008).

Ryan et al. (2010) suggested that weed management practices may filter specific characteristics that determine the trajectory of community change even in the short term. Most changes in biological community structure are reflected by distinct parameters of diversity which may be expressed by means of various measures and indices (Booth et al., 2003). The use of ecological indicators such as Shannon-Wiener Diversity index and Simpsons Dominance Index have been cited to provide information on species richness, evenness and dominance of weeds in croplands while measure of similarity or distinctiveness between communities within the landscape have been described by indices such as the Sørensen and Steinhaus Coefficient Indices (Nkoa et al., 2015). These indices have aided identification of floristic composition and characterization of weed populations of crops under varying management practices (Izquierdo et al., 2009; Concenço et al., 2011; Ramirez et al., 2014). The study hypothesized weed species diversity and abundance to be higher where manual and cultural methods were applied because of the lack of herbicide treatment and where singular methods were used because of weed escapes.

MATERIALS AND METHODS

Experimental sites

Experiments were conducted on experimental farms between November 2016 and March 2017 at Luve (26.32°S, 31.47°E, elevation 400-800 m.a.s.l.) and Mangcongco (26.58°S, 30.99°E, elevation 1200-1800 m.a.s.l.) in the Middleveld and Highveld of Swaziland, respectively. The total rainfall during the experimental period at Luve was 332 mm whose distribution was 76, 20, 54, 72.9, 108.8 mm and a total of 871.2 mm at Mangcongco with a distribution of 236.5, 165.4, 198.3, 152.9 and 118.1 mm for the months of November through March, respectively. The soil type at Luve was determined as sandy-loam with clay content of 19.3% while at Mangcongco, soils were characterized as sandy clay loams with clay content of 30%.

Experimental procedures

The experiment was designed as a randomized complete block design with four replications. The weed control practices shown in Table 1 were included in the study. The tillage method used in both locations was mouldboard ploughing to a depth of 20 cm followed by disc-harrowing. Maize, variety SC403 (Seed-Co®, Zimbabwe), was planted at a spacing of 0.9 m × 0.25 m. In plots with cowpeas, the variety IT18 was planted two seeds per hill in two hills at 0.10 m from maize planting hills. Basal fertilizer [N: P: K, 2: 3:2 (22)] was applied two weeks after planting maize at the rate of 400 kg ha^{-1} for Luve and 500 kg ha^{-1} at Mangcongco. Five weeks after emergence, the crop was side-dressed with LAN (28% N) at a rate of 100 kg ha^{-1} for Luve and 115 kg ha^{-1} at Mangcongco.

Pre-emergence (PRE) herbicide plots were planted as previously described and then sprayed with herbicides one day after sowing with rates of application adjusted based on soil clay content. Early post-emergence (EPOST) herbicides were applied when the crop had reached four- to five-leaf stage. Herbicides were applied using a hand-pumped CP-3 knapsack sprayer with Defy 3D angled nozzles calibrated to deliver 250 l ha^{-1} at 210 kPa. Manual weeding in particular plots was done once at five weeks after planting. This simulated the smallholder farmer practice in Swaziland of planting into a clean seedbed after mouldboard ploughing and then manual weeding 40 or more days after planting.

Crop yield and weed observations

In each sampling row for grain yield of maize, the crop was cut at the soil surface and yield at a predetermined moisture content of

Table 1. Weed control practices, time of application and expected efficacy

Treatment	Active ingredient	Time of application*	Expected efficacy
T1: Maize-cowpea + manual weeding	-	5 WAP	General
T2: Manual weeding (control)	-	5 WAP	General
T3: Harness	900 g/l Acetochlor	PRE	Annual grasses and broadleaf weeds; not effective for control of emerged seedlings
T4: Dual gold	960 g/l S-metolachlor	PRE	Control of several annual grasses; not effective for control of most broadleaves
T5: Micro-Tech	384 g/l Alachlor	EPOST	Control of several annual grasses; not effective for control of most broadleaves
T6: Callisto	Mesotrione	EPOST	Control of broadleaves; not effective for control of most grass weeds
T7: Harness + Micro-Tech	Acetochlor + Alachlor	PRE + EPOST	Annual grasses and broadleaf weeds;
T8: Dual gold + Callisto	s-Metolachlor + mesotrione	PRE + EPOST	Control of several annual grasses and broadleaves
T9: Harness + Manual weeding	Acetochlor	PRE + 5 WAP	General
T10: Dual gold + Manual weeding	s-Metolachlor	PRE + 5 WAP	General

*PRE = Preemergence, EPOST = early postemergence, 5 WAP = weeding 5 weeks after planting.

12.5% was determined. Weed samples were collected at physiological maturity (R6 growth stage) of the maize crop. Each sampling row for weeds was divided into three sub-units of equal length, and one sample quadrat of 0.5 m^2 was placed in line in each sub-unit. Thus, three samples were taken from each replication. All weed individuals of up to 5 cm in height were cut at the soil surface and taken to the laboratory for sorting and counting. Weed density was the number of plants rooted within each quadrat. Counted weeds were oven-dried at 80°C for 48 h and weighed to obtain weed biomass. Both weed biomass and density per quadrat were extrapolated to a square metre. Following observation of preponderance of *Cynodon dactylon*, density and biomass of *C. dactylon* was similarly and simultaneously assessed. The nomenclature of plant species followed that of botanical keys supported by regional field identification guides (Lightfoot, 1970; Vernon, 1983).

Rank-abundance was used to display species relative abundance data to provide a complete description of the community diversity and simultaneously show both components of species diversity, species number, and evenness under each weed control treatment (Ramírez, 2015). The relative abundance of a species indicates its degree of dominance or subordination in the weed community (that is, the lower the number, the greater the relative abundance of a species in the weed community and the higher its dominance).

The amount of diversity of weeds within weed control practices, termed alpha diversity, was determined by the Shannon-Wiener index (H') and the Simpson dominance index (D). The Shannon-Wiener index is based on the proportional abundance of each species and specifies both species richness (number of species in a given area) and evenness (how relative abundance is distributed among species). However, the method is considered moderately sensitive to sample size. The Simpson index is based on the probability that two individuals in a community sample will be of the same species. The method does not provide an assessment of species richness but measures the state of dominance within the community which is useful in describing evenness. This method is considered less sensitive to sample size. Weed species diversity between weed control practices was based on determining similarity of the composition of weed communities through the calculation of the Steinhaus Coefficient Index (S_A). The index estimates the smallest abundance for each species established in different communities as a proportion of the average community abundance (Booth et al., 2003). The ten weed control practices were compared pairwise and a matrix of values of index of similarity of weeds between treatments established. The indices were computed in accordance with the equations below cited by Booth et al. (2003):

$$H' = -\sum p_i \times \ln p_i$$

$$D = \Sigma\{[ni\ (ni - 1)] / [N(N - 1)]\}$$

$$S_A = W/[(A + B)/2] = 2W/(A + B)$$

Where, ln = natural logarithm; ni = number individuals per species; N = total number of all species in the community; pi = proportional abundance of each species (n_i/N); W = sum of the lower of the two abundances of each species in the community; A = total number of individuals in population A; B = total number of individuals in population B.

Statistical analysis

Prior to statistical analysis, weed density and biomass data were square root transformed ($\sqrt{x + 0.5}$) to homogenize variances (Palaniswamy and Palaniswamy, 2006). All data (weed density, weed biomass and crop yield) were subjected to analysis of variance using GenStat Release 9.1. The means of the treatments were separated by least significant difference (LSD) at 5% level of significance. Data are presented as untransformed means.

RESULTS

Weed species composition and diversity

Five common weed species from each of the weed control practices obtained from ranking of the frequency of the occurrence of the species are presented in Table 2. Except for *Tigetus minuta* at Luve and *Cleome monophylla* at Mangcongco, the two locations shared the same most abundant weed species*. Cyanodon dactylon* was the only species that was observed to exist in all the

Table 2. Rank of abundance of five most prevalent weed species existing in each of the weed control practices at Luve and Mangcongco.

Location/species name	Weed control practice*									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Luve (*S* = 10)[†]										
Tigetus minuta	-	2	-	-	4	3	-	-	-	3
Cynodon datylon	2	1	1	1	1	1	1	1	1	1
Acanthospermum hispidum	-	-	2	2	3	-	-	-	2	-
Richardia scabra	1	3	-	-	2	2	2	-	3	2
Xanthium strumonium	-	3	3	3	4	3	3	-	-	-
Number of species	*2*	*4*	*4*	*4*	*5*	*5*	*3*	*1*	*6*	*5*
Mangcongco (*S* = 8)										
Cleome monophylla	-	-	-	-	2	2	-	-	-	-
Cynodon datylon	2	1	1	1	1	1	2	1	1	1
Acanthospermum hispidum	1	3	4	3	-	4	-	-	-	-
Richardia scabra	2	2	3	-	3	3	1	-	2	2
Xanthium strumonium	2	2	2	-	4	-	3	-	-	-
Number of species	*4*	*4*	*5*	*4*	*4*	*4*	*3*	*1*	*2*	*2*

*T1: Maize-cowpea + manual weeding; T2: Manual weeding only; T3, Harness (PRE); T4: Dual gold (PRE); T5: Micro-Tech (EPOST); T6: Callisto (EPOST); T7: Harness (PRE)+ Micro-Tech (EPOST); T8: Dual gold (PRE)+ Callisto (EPOST); T9: Harness (PRE) + manual weeding; T10: Dual gold (PRE) + manual weeding; †*S* = total number of species or species richness in research area.

Table 3. Weed species diversity based on Simpson's Dominance Index (*D*) and Shannon-Wiener Diversity Index (*H'*) at Luve and Mangcongco.

Treatment	Simpson Index (*D*)		Shannon–Wiener Index (*H'*)	
	Mangcongco	Luve	Mangcongco	Luve
T1: Maize-cowpea + manual weeding[a]	4.7	2.0	0.60	0.29
T2: Manual weeding only	4.4	3.8	0.60	0.56
T3: Harness (PRE)	5.2	3.7	0.68	0.57
T4: Dual gold (PRE)	3.4	3.6	0.55	0.47
T5: Micro-Tech (EPOST)	4.1	3.4	0.60	0.59
T6: Callisto (EPOST)	4.4	3.6	0.60	0.61
T7: Harness (PRE)+ Micro-Tech (EPOST)	2.7	2.2	0.44	0.38
T8: Dual gold (PRE)+ Callisto (EPOST)	1.0	1.0	0.00	0.00
T9: Harness (PRE) + manual weeding	2.0	5.5	0.30	0.73
T10: Dual gold (PRE) + manual weeding	2.1	4.5	0.30	0.64

weed control practices and was predominantly ranked first in terms of abundance at both locations. *Richardia scabra* was the second-most prevalent in either location. There was residual presence of *C. monophylla*, an important edible plant in Swaziland, in two EPOST weed control practices at Mangcongco.

The Shannon-Wiener Diversity Index (*H'*), and the Simpson's Dominance Index (*D*) were computed as an estimate of weed species diversity within weed control practices (alpha-diversity) (Table 3). At both Mangcongco and Luve, the lowest values of evenness (*D*) and species richness (*H'*) were evident with combination of Dual gold (PRE) + Callisto (EPOST) (T8). In addition, at Mangcongco, Harness (PRE) + Micro-Tech (EPOST) (T7), and manual weeding in combination with pre-emergence herbicides (T9 and T10) also showed lower species evenness and richness. At Luve, manual weeding and intercropping (T1) and Harness (PRE) + Micro-Tech (EPOST) (T7), additionally showed lower species evenness (*D*) and the same treatments with the addition of Dual gold (PRE) (T4) showed lower species richness (*H'*).

The measure of similarity or distinctiveness of weed species composition between weed control treatments (beta diversity) using the Steinhaus Coefficient Index (S_A) is given in Table 4 for Luve. The combination of manual

Table 4. Similarity matrix of weed species based on Steinhaus Coefficient Index (S_A) at Luve.

Treatment	Treatments								
	T2	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
T1*	0.49	0.54	0.56	0.49	0.39	0.37	0.26	0.59	0.44
T2		0.74	0.51	0.69	0.50	0.52	0.28	0.71	0.73
T3			0.78	0.85	0.54	0.67	0.41	0.60	0.57
T4				0.77	0.49	0.85	0.56	0.51	0.52
T5					0.58	0.69	0.49	0.69	0.63
T6						0.50	0.11	0.64	0.58
T7							0.57	0.44	0.53
T8								0.21	0.28
T9									0.78

*T1: Maize-cowpea + manual weeding; T2: manual weeding only; T3, Harness (PRE); T4: Dual gold (PRE); T5: Micro-Tech (EPOST); T6: Callisto (EPOST); T7: Harness (PRE)+ Micro-Tech (EPOST); T8: Dual gold (PRE)+ Callisto (EPOST); T9: Harness (PRE) + manual weeding; T10: Dual gold (PRE) + manual weeding.

Table 5. Similarity matrix of weed species based on Steinhaus Coefficient Index (S_A) at Mangcongco

Treatments	Treatments								
	T2	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
T1*	0.87	0.74	0.69	0.69	0.72	0.62	0.21	0.42	0.50
T2		0.66	0.74	0.77	0.77	0.61	0.31	0.46	0.54
T3			0.71	0.82	0.77	0.63	0.32	0.57	0.64
T4				0.83	0.73	0.68	0.52	0.65	0.60
T5					0.83	0.68	0.39	0.68	0.73
T6						0.74	0.22	0.47	0.53
T7							0.21	0.48	0.56
T8								0.63	0.53
T9									0.85

*T1: Maize-cowpea + manual weeding; T2: manual weeding only; T3, Harness (PRE); T4: Dual gold (PRE); T5: Micro-Tech (EPOST); T6: Callisto (EPOST); T7: Harness (PRE)+ Micro-Tech (EPOST); T8: Dual gold (PRE)+ Callisto (EPOST); T9: Harness (PRE) + manual weeding; T10: Dual gold (PRE) + manual weeding.

weeding with maize-cowpea intercropping (T1) showed lower similarity of weed community contrasted with six other weed control practices using S_A values ranging from 0.26 to 0.49. Similar results were obtained with the combination of Dual gold (PRE) and Callisto (EPOST) (T8) against five weed control practices using S_A values between 0.11 and 0.49. Based on S_A values >0.5, 71% of the treatment pairs showed similarities between weed communities at Luve. At Mangcongco (Table 5), S_A values of the combination of Dual gold (PRE) and Callisto (EPOST) versus other weed control practices were similar to that at Luve. Similarities between weed communities at Mangcongco accounted for 78% treatment pairs that subtended S_A values >0.5.

Weed density and biomass

Manual weeding in combination with pre-emergence herbicides or maize-cowpea intercropping resulted in significantly lower weed density as compared to pre- or post-emergence herbicide weed control in both locations (Table 6). There were no significant differences in weed density amongst pre- and post-emergence herbicides or their combined applications. There were no significant differences in efficacy of weed control practices on weed density between the two locations except with the combination of Dual gold (PRE) + Callisto (EPOST) which resulted in significantly lower weed density at Mangcongco when compared with Luve.

The effect of weed control practices on weed biomass is similar to that of weed density at Luve where manual weeding in combination with pre-emergence herbicides or maize-cowpea intercropping resulted in significantly lower weed biomass as compared to pre- or post-emergence herbicide weed control. At Mangcongco, Harness (PRE), Dual gold (PRE) and Micro-Tech (EPOST) were similarly and significantly less efficacious than other weed control practices. Using combined applications of PRE and EPOST herbicides (T7 and T8)

Table 6. Density and biomass of weeds at Luve and Mangcongco.

Treatment	Weed density (No. m^{-2})		Weed biomass (g m^{-2})	
	Luve	Mangcongco	Luve	Mangcongco
T1: Maize-cowpea + manual weeding	16.2^{b}	20.9^{d}	22.3^{c}	22.7^{b}
T2: Manual weeding only	20.7^{b}	24.9^{cd}	26.3^{c}	30.8^{b}
T3: Harness (PRE)	35.8^{a}	35.9^{abc}	46.9^{ab}	44.5^{a}
T4: Dual gold (PRE)	37.8^{a}	42.5^{a}	55.8^{a}	50.7^{a}
T5: Micro-Tech (EPOST)	37.3^{a}	39.6^{a}	43.4^{ab}	49.3^{a}
T6: Callisto (EPOST)	35.5^{a}	36.7^{ab}	41.6^{bA}	27.2^{bB}
T7: Harness (PRE) + Micro-Tech (EPOST)	32.9^{a}	25.6^{bcd}	44.4^{abA}	24.4^{bB}
T8: Dual gold (PRE) + Callisto (EPOST)	37.3^{aA}	26.2^{bcdB}	47.3^{abA}	27.1^{bB}
T9: Harness (PRE) + manual weeding	19.7^{b}	25.2^{cd}	26.8^{c}	26.9^{b}
T10: Dual gold (PRE) + manual weeding	21.7^{b}	23.3^{d}	28.9^{c}	22.1^{b}
SE (between treatments)	4.84	5.47	6.01	7.91
LSD (between treatments)	9.90	11.17	12.27	16.15
SE (between locations)	3.66		4.97	
LSD (between locations)	7.31		9.93	

*Different lower case letters in each column indicate a difference between treatments according to Fisher protected LSD test at α = 0.05; †Different uppercase letters between columns indicate a difference between locations for each variable and respective treatment according to Fisher protected LSD test at α = 0.05; ‡Data were square root transformed before analysis.

Table 7. Density and biomass of *Cynodon dactylon* at Luve and Mangcongco.

Treatment	***C. dactylon*** **density (No. m^{-2})**		***C. dactylon*** **biomass (g m^{-2})**	
	Luve	Mangcongco	Luve	Mangcongco
T1: Maize-cowpea + manual weeding	7.0^{d}	9.7^{c}	13.3^{c}	18.1^{c}
T2: Manual weeding only	13.3^{c}	13.4^{c}	18.7^{c}	19.2^{c}
T3: Harness (PRE)	29.3^{b}	30.9^{a}	34.3^{ab}	35.6^{b}
T4: Dual gold (PRE)	30.0^{ab}	29.6^{ab}	35.5^{a}	38.5^{b}
T5: Micro-Tech (EPOST)	27.5^{b}	28.3^{ab}	32.3^{b}	35.6^{b}
T6: Callisto (EPOST)	24.8^{Bb}	32.4^{aA}	37.7^{b}	32.4^{b}
T7: Harness (PRE) + Micro-Tech (EPOST)	29.9^{b}	23.5^{b}	27.3^{b}	40.2^{ab}
T8: Dual gold (PRE) + Callisto (EPOST)	37.8^{aA}	27.5^{abB}	31.0^{aA}	51.1^{aB}
T9: Harness (PRE) + manual weeding	9.9^{cd}	13.3^{c}	15.8^{c}	16.3^{c}
T10: Dual gold (PRE) + manual weeding	12.3^{c}	13.4^{c}	14.6^{cA}	18.8^{cB}
SE (between treatments)	3.07	3.49	4.29	3.86
LSD (between treatments)	6.27	7.12	8.76	7.88
SE (between locations)	2.32		2.88	
LSD (between locations)	4.64		5.77	

*Different lower case letters in each column indicate a difference between treatments according to Fisher protected LSD test at α = 0.05; †Different uppercase letters between columns indicate a difference between locations for each variable and respective treatment according to Fisher protected LSD test at α = 0.05; ‡Data were square root transformed before analysis.

resulted in significantly lower weed biomass at Mangcongco when compared with Luve.

The efficacy of weed control practices on density and biomass of *C. dactylon* is similar to that of the weed complex (Table 7). Manual weeding in combination with pre-emergence herbicides or maize-cowpea intercropping resulted in significantly lower weed density and biomass as compared to performance of pre- or post-emergence herbicides or their combinations on *C. dactylon* at both locations. Dual gold (PRE) in combination with either Callisto (EPOST) or manual weeding, significantly resulted in lower biomass of *C. dactylon* in Mangcongco when compared with Luve. Contrasting results were obtained for weed density where Callisto (EPOST)

Table 8. Effect of weed control practices on grain yield of maize at Luve and Mangcongco.

Treatment	Yield (kg ha^{-1})	
	Luve	Mangcongco
T1: Maize-cowpea + manual weeding	2903.1^{abcdB}	4348.9^{aA}
T2: Manual weeding only	2625.2^{abcd}	3023.1^{bc}
T3: Harness (PRE)	2763.2^{abcd}	2358.5^{c}
T4: Dual gold (PRE)	3814.1^{abc}	3300.4^{abc}
T5: Micro-Tech (EPOST)	1624.5^{d}	2646.4^{c}
T6: Callisto (EPOST)	2152.9^{cd}	3455.7^{abc}
T7: Harness (PRE) + Micro-Tech (EPOST)	4244.2^{a}	4055.7^{ab}
T8: Dual gold (PRE) + Callisto (EPOST)	2733.2^{abcd}	3235.4^{abc}
T9: Harness (PRE) + manual weeding	3921.0^{ab}	3990.8^{ab}
T10: Dual gold (PRE) + manual weeding	2474.5^{bcdB}	4146.3^{abA}
SE (between treatments)	839.34	564.56
LSD (between treatments)	1714	1153
SE (between locations)	505.77	
LSD (between locations)	1400.99	

*Different lower case letters in each column indicate a difference between treatments according to Fisher protected LSD test at α = 0.05; †Different uppercase letters between columns indicate a difference between locations for each variable and respective treatment according to Fisher protected LSD test at α = 0.05.

significantly reduced weed density in Luve as compared to Mangcongco but the reverse was observed where Dual gold (PRE) in combination with Callisto (EPOST) showed greater suppression of weed numbers in Mangcongco than Luve. The effects of the remaining weed control practices on density and biomass of *C. dactylon* were not significantly distinguished between the two sites.

Crop yield

There were no significant differences in grain yield amongst weed control practices at Luve although the highest yield (4244.2 kg ha^{-1}) was obtained with the combination of Harness (PRE) + Micro-Tech (EPOST) application (T7) (Table 8). Similarly, the highest kernel yield (4348.9 kg ha^{-1}) obtained with maize-cowpea + manual weeding at Mangcongco was not significantly different from yields obtained with other weed control practices. The lowest yield (1624.5 kg ha^{-1}) was obtained with Micro-Tech (EPOST) at Luve, while Harness (PRE) gave the lowest kernel yield (2358.5 kg ha^{-1}) at Mangcongco. The effects of weed control practices on grain yield were not significantly distinguished between the two sites with the exception of manual weeding in combination with either maize-cowpea intercropping or Dual gold (PRE) that respectively performed 30-40% better at Mangcongco than Luve.

The relationship between maize yield and weed biomass for each of the weed control practice are indicated in Figures 1 and 2. At Luve, weed control practices that were combined with manual weeding (T1, T2, T9, T10) reduced weed biomass to less than 30 g m^{-2} where Harness (PRE) plus manual weeding (T9) showed the highest yield, 3,921 kg ha^{-1}, amongst the treatments (Figure 1). The combination of Harness and Micro-Tech (T7) and pre-emergence application of Dual Gold (T4), respectively, showed higher yields amongst the herbicide-based treatments. At Mangcongco (Figure 2), the performance of manual weeding combined with pre-emergence herbicides (T9, T10) or with maize-cowpea intercropping (T1) is similar at Luve. Amongst the herbicide treatments, the combination of Harness (PRE) and Micro-Tech (EPOST) (T7) showed higher yield (4,056 kg ha^{-1}) and weed suppression with biomass of less than 30 g m^{-2}.

DISCUSSION

Weed diversity

The present study considered that knowledge on distribution of weed diversity amongst weed control treatments may be useful for identifying variety of weed management practices. Derksen et al. (1995) reported that although herbicides may affect species richness because of their selectivity patterns, they generally affect relative abundance more than species composition. Gaba et al. (2016) however suggested a reappraisal of how herbicides affect yields of major crops following use and efficacy on weed infestations. They argued that herbicides affected rare species (species at low abundance in absence of herbicide application) rather than common weed species and non-targeted species rather than

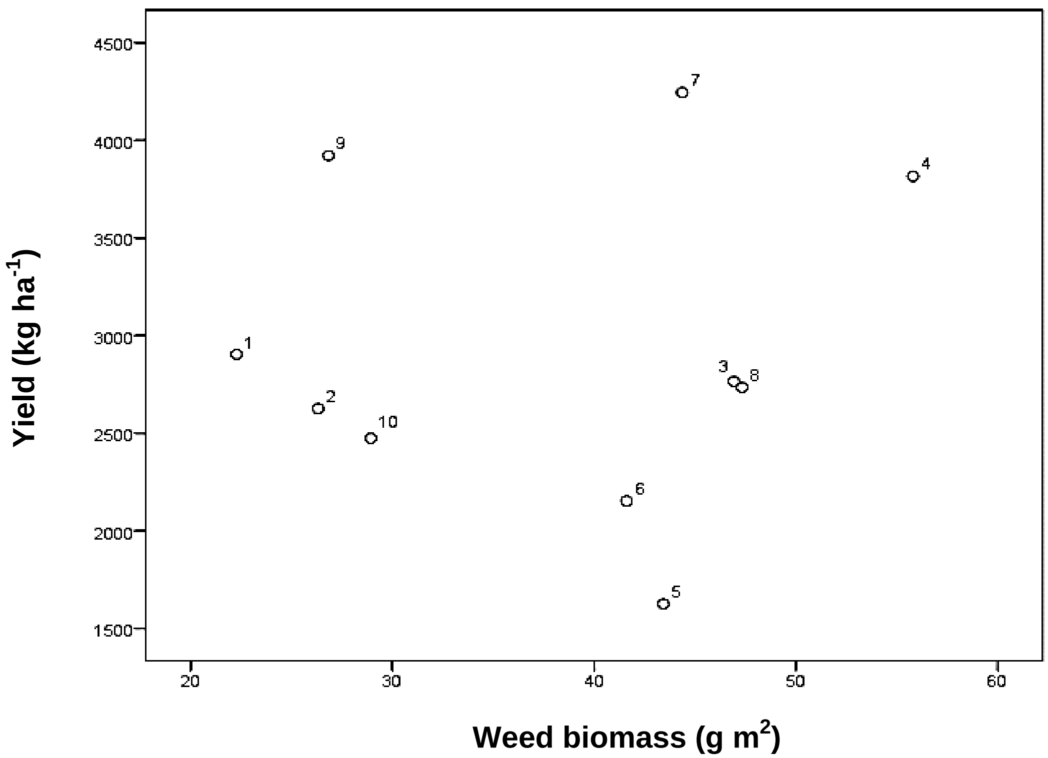

Figure 1. Box-plot of maize yield and weed biomass at Luve. Individual weed control treatments are identified by a number corresponding to their description given in Table 1.

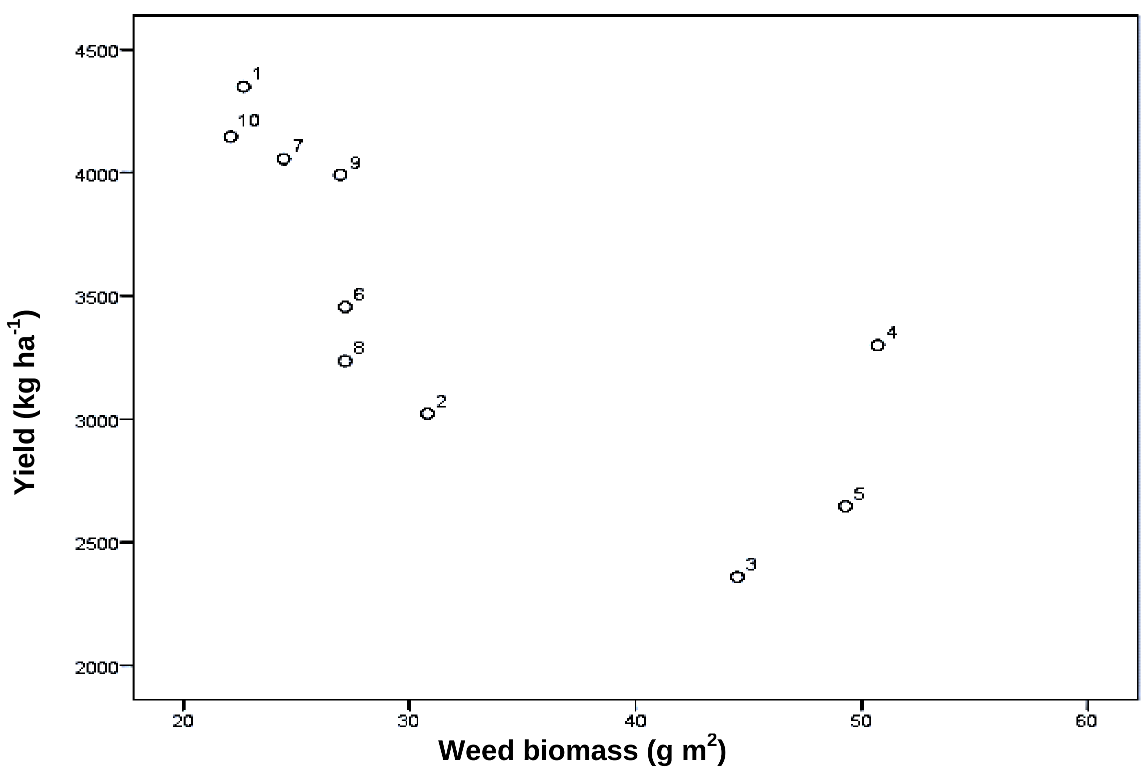

Figure 2. Box-plot of maize yield and weed biomass at Mangcongco. Individual weed control treatments are identified by a number corresponding to their description given in Table 1.

noxious species. The study expected that weed communities would differ between weed control treatments because of the timing and efficacy of control measures. The Steinhaus Coefficient Index showed that only 29 and 22% of paired comparisons of weed control treatments at Luve and Mangcongco, respectively, exhibited distinctiveness of weed species composition. The rank of abundance of five most prevalent weed species existing in each of the weed control treatments as well the Steinhaus Coefficient Index showed that the combination of Dual Gold (PRE) with Callisto (EPOST) was most effective against existing weed spectrum at either sites. In addition, at Luve, the combination of intercropping and manual weeding also showed differences in weed species composition versus other weed control treatments. It is considered that PRE applications which have residual activity through the soil may provide control of most common weed species. However, the application of PRE or EPOST herbicides alone, represent 'one shot' tool for the control of weeds. In this study, the Steinhaus Coefficient Index showed similarity in weed species composition amongst these treatments.

Weed density and biomass

Change in susceptibility of weed species associated with different weed control practices provides only part of the picture of the weed flora in arable fields. Weed density and biomass were significantly reduced by manual weeding and its combination with PRE herbicides or maize-cowpea intercropping at Luve. At Mangcongco, similar but insignificant trends were observed for weed density while greater weed biomass was obtained with singular applications of PRE or POST herbicides. Tesfay et al. (2014) showed lowest weed density recorded in plot treated with hand weeding and hoeing, while Kebede and Anbasa (2017) found statistically similar minimum weed density in plots hand weeded twice when compared with evaluated herbicides. Typically weed infestations are not uniform within and amongst agricultural fields with some areas within fields and across farmers' fields having higher weed densities than others. However weed management practices tend to be applied uniformly across fields. Weed density and biomass (and diversity) data may allow development of recommendations that adjust rates of soil or foliar applied herbicides based on experiences of probable weed vegetation in addition to other factors at different agronomic landscape scales.

The study showed that *T. minuta*, *C. dactylon*, *Acanthospermum hispidum*, *R. scabra*, *Xanthium strumonium* and *C. monophylla* were species that occurred with rather high abundance in the researched areas. However, only manual weeding and its combination with PRE herbicides or maize-cowpea intercropping significantly reduced both density and biomass of *C. dactylon.* Despite 500 mm difference in rainfall during the cropping season between Luve and Mangcongco, only three treatments showed significant difference in weed density and biomass between them. The former location, with a lower rainfall regime, subtended higher weed biomass in those treatments. While environmental and other factors can result in sub-optimal performance from herbicide treatments (Izquierdo et al., 2009), the results showed that none of the herbicide treatments were efficacious against *C. dactylon* which prevailed in all treatments. Many farmers struggle to achieve effective weed control, largely due to lack of knowledge in selecting appropriate herbicides. In the present case, materials available at retail outlets appeared ineffective in the diminution of *C. dactylon* infestation.

Crop yield

There were no significant differences in grain yield amongst weed control practices at Luve although the highest yield (4244.2 kg ha^{-1}) was obtained with the combination of Harness (PRE) + Micro-Tech (EPOST) application. Similarly, the highest kernel yield (4348.9 kg ha^{-1}) obtained with maize-cowpea intercropping + manual weeding at Mangcongco was not significantly different from yields obtained with other weed control practices. In the current study, the box plots of weed biomass and maize yield showed that at Luve, manual weeding and its combination with PRE herbicides or maize-cowpea intercropping resulted in a reduction in weed biomass to below 30 plants m^{-2}. The highest crop yield amongst these treatments was where manual weeding was combined with application of Harness (PRE). Additionally, Dual Gold (PRE) and the combination of Harness (PRE) + Microtech (EPOST) also produced higher yields with the latter treatment showing better reduction in weed biomass. Similar trends in maize yield and weed biomass reduction under manual weeding and its combination with PRE herbicides or maize-cowpea intercropping practices were evident at Mangcongco.

While these results relate to other recent work in the region (Tesfay et al., 2014; Kebede and Anbasa, 2017), effects of crop yield-herbicides-weeds relationships will tend to be inconsistent experimentally amongst researchers and in practice versus farmers' experiences based on an interplay of herbicide use, weeds and environment. While numerous studies have experimentally shown a relationship between herbicide use and crop yield, Gaba et al. (2016) suggested a reappraisal of how herbicides affect yields of major crops by taking into account, farmers' decisions and adaptive practices. These attributes are considered to influence effectiveness of treatment through elements such as herbicide application mode (timing and dose), choice of active ingredient, depending on the observed or expected weed species, and the agricultural techniques used.

Earlier work has shown that weeds that emerge together with the crop or shortly thereafter cause greater yield reduction than weeds emerging later in the growth cycle of the crop (Swanton et al., 1999). Appropriate timing of control whether by application of PRE and POST herbicide combinations or by other means was shown to represent a significant opportunity to introduce control at the optimum time (Janak and Grichar, 2016). However, the efficacy of some PRE herbicides requires incorporation which is either machine- or rain-dependent. In the present study, Luve showed higher weed density and biomass due to lower rainfall to facilitate incorporation. On the other hand, post-emergence manual or chemical weed control practices are often compromised by continuous wet conditions post-planting which is characteristic of the beginning of the growing season in the region (Mashingaidze, 2004). There is still need for rigorous farmer support in the timely use of appropriate techniques for suitable PRE or POST herbicides in combination with recommended agronomic practices.

Implication of findings

The efficacy of weed control practices on simultaneous weed biomass reduction, lower weed diversity and high yield were evident for Harness (PRE) + Micro-Tech (EPOST) and for the combination of manual weeding with Harness (PRE). At Mangcongco, this was evident for manual weeding in combination with Dual Gold (PRE) or intercropping practice. This study argues that the employment of herbicides to reduce weed populations as an innovation in technology-deprived low-input systems is not enough; rather, the introduced technology should be evaluated together with rigorous reassessment of prevailing cropping systems and patterns. For instance, the prevailing annual cycle of tractor tillage and manual weeding allows *C. dactylon* (and other weeds) to survive in field headlands and crop edges or its stolons and rhizomes incorporated into the soil through soil inversion. The weed species is known to be a poor competitor for light but adaptively adjusts patch extension rate enabling it to grow in empty gaps and sustain field colonization (Guglielmini and Satorre, 2002). Santín-Montanyá et al. (2013) suggested that some factors (tillage and crop rotation), which have a species-specific effect on plant composition, may provide quicker and more detailed data on weed competitiveness processes occurring in an arable field. Thus, it may be necessary to explore the changes on weed communities according to species. Invariably, according to the present study, strategic tillage operations, competitive cropping practices and herbicide technologies should synergistically be evaluated as pillars of crop intensification to improve weed management and yields of staple crops.

Conclusion

The study showed that the combination of PRE and EPOST herbicides reduced both species richness and evenness like the combinations of manual weeding and PRE herbicides at Mangcongco or manual weeding and intercropping at Luve. Further, the study expected that weed communities would differ between weed control practices because of the timing and efficacy of control measures. Results showed that only 29 and 22% of paired comparisons of weed control treatments at Luve and Mangcongco, respectively, exhibited distinctiveness of weed species composition. The rank of abundance of five most prevalent weed species existing in each of the weed control treatments and dissimilarity index showed that the combination of Dual Gold (PRE) with Callisto (EPOST) was most efficacious against existing weed species composition at either sites. There were no significant differences in grain yield amongst weed control practices at Luve although the highest yield (4244.2 kg ha^{-1}) was obtained with the combination of Harness (PRE) + Micro-Tech (EPOST) application. Similarly, the highest kernel yield (4348.9 kg ha^{-1}) obtained with maize-cowpea intercropping + manual weeding at Mangcongco was not significantly different from yields obtained with other weed control practices.

The results suggest that weed control may move from being a predominantly post-emergence activity as practiced by small scale farmers to one split between controlling weeds pre- and early post-emergence, to impact weed management that is often considered for current season infestation than long-term diminution of the weed problem. In addition, there is potential for reducing weed infestation where manual weed control, which often occurs a month after planting, follows suitable pre-emergence herbicides rather than post-emergence herbicide application alone. Maize-legume intercropping significantly suppressed weed density and biomass of the intractable weed *C. dactylon* signifying potential for incorporating crop intensification techniques to address weed problems. The weed species was not controlled by any of the herbicide treatments suggesting need for integrative research insight into this problem that include strategic tillage practices and diversifying the range and weed spectrum of herbicides available at retail outlets for farmers' use.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Armengot L, Sans FX, Fischer C, Flohre A, Jose´-Maria L, Tscharntke L, Thies C (2012). The β-diversity of arable weed communities on organic and conventional cereal farms in two contrasting regions. Applied Vegetation Science 15:571-579.

Booth DB, Murphy SD, Swanton CJ (2003). Weed ecology in natural and agricultural systems. Editorial CABI Publishing, Wallingford, UK. doi: 10.1079/9780851995281.0000.

Concenço G, Salton JC, Secretti ML, Mendes PB, Brevilieri RC, Galon L (2011). Effect of long-term agricultural management systems on occurrence and composition of weed species. Planta Daninha. 29:515-522.

Derksen DA, Thomas AG, Lafond GP, Loeppky HA, Swanton CJ (1995). Impact of postemergence herbicides on weed community diversity within conservation-tillage systems. Weed Research 35:311-320.

Dlamini TM, Mloza-Banda HR, Edje OT (2016). Evaluation of the efficacy of selected herbicides on weed biomass control and maize [*Zea mays* (L.)] yield production in two agro-ecological zones in Swaziland. American Journal of Agriculture and Forestry 4(4):75-85.

Gaba S, Gabriel E, Chadoeuf J, Bonneu F, Bretagnolle V (2016). Herbicides do not ensure for higher wheat yield, but eliminate rare plant species. Scientific Reports 6:30112.

Gianessi L, Williams A (2011). Overlooking the obvious: the opportunity for herbicides in Africa. Outlooks on Pest Management pp. 211-215.

Guglielmini AC, Satorre EH (2002). Shading effects on spatial growth and biomass partitioning of *Cynodon dactylon*. Weed Research 42:123-134.

Izquierdo J, Blanco-Moreno JM, Chamorro L, Gonz´alez-And´ujar JL, Sans FX (2009). Spatial distribution of weed diversity within a cereal field. Agronomy of Sustainable Development 29:491-496.

Janak TW, Grichar WJ (2016). Weed control in corn (*Zea mays* L.) as influenced by preemergence herbicides. International Journal of Agronomy 2016:1-9.

Kebede M, Anbasa F (2017). Efficacy of pre-emergence herbicides for the control of major weeds in maize (*Zea mays L.*) at Bako, Western Oromia, Ethiopia. American Journal of Agriculture and Forestry 5(5):173-180.

Lightfoot C (1970). Common veld grasses of Rhodesia. Natural Resources Board of Rhodesia. Government Printer, Salisbury, Rhodesia 131 p.

Mashingaidze AB (2004). Improving weed management and crop productivity in maize systems in Zimbabwe. PhD thesis. Wageningen University.

Mncube TL Mloza-Banda HR, Kibirige D, Khumalo MM, Mukabwe WO, Dlamini BP (2017). Composition and management of weed flora in smallholder farmers' fields in Swaziland. African Journal of Rural Development 2(3):441-453.

Nkoa R, Owen MDK, Swanton CJ (2015). Weed abundance, distribution, diversity, and community analyses. Weed Science 63:64-90.

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Wittand WW, Barrett M (2012). Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations. Weed Science 60:31-62.

Pacanoski Z, Svečnjak Z, Saliji A (2015). Herbicides impact on weed control and injury of maize and climbing bean grown in an intercropping system. Herbologia 15(2):2.

Palaniswamy UN, Palaniswamy KM (2006). Handbook of Statistics for Teaching and Research in Plant and Crop Science. Haworth Pres Inc., New York: Binghamton 624 p.

Ramírez JS, Hoyos VC, Plaza GT (2015). Phytosociology of weeds associated with rice crops in the department of Tolima, Colombia. Agronomía Colombiana 33(1):64-73.

Romero A, Chamorro L, Sans FX (2008). Weed diversity in crop edges and inner fields of organic and conventional dryland winter cereal crops in NE Spain. Agriculture, Ecosystems and Environment 124:97-104.

Ryan MR, Mortensen DA, Bastiaans L, Teasdale JR, Mirsky SB, Curran WS, Seidel R, Wilson DO, Hepperly PR (2010). Elucidating the apparent maize tolerance to weed competition in long-term organically managed systems. Weed Research 50:25-36.

Santín-Montanyá MI, Martín-Lammerding D, Walter I, Zambrana E, Tenorio JL (2013). Effects of tillage, crop systems and fertilization on weed abundance and diversity in 4-year dry land winter wheat. European Journal of Agronomy 48:43-49.

Saudy HS (2015). Maize–cowpea intercropping as an ecological approach for nitrogen-use rationalization and weed suppression. Archives of Agronomy and Soil Science 61(1):1-14

Swanton CJ, Weaver S, Cowan P, Van Acker R, Deen W, Shreshta A (1999). Weed thresholds: theory and applicability. Journal of Crop Production 2:9-29.

Swaziland Government (2016). Ministry of Agriculture. Mbabane, Swaziland. http://www.gov.sz/index.php/ministries-departments/ministry-of-agriculture

Tesfay A, Amin M, Mulugeta N (2014). Management of weeds in maize (*Zea mays* L.) through various pre and post emergency herbicides. Advances in Crop Science and Technology 2:151.

Vernon R (1983). Field Guide to Important Arable Weeds of Zambia. Department of Agriculture, Mount Makulu Central Research Station, Chilanga, Zambia 151 p.

Zhang J, Zheng L, Jäck O, Yana D, Zhang Z, Gerhards R, Ni H (2013). Efficacy of four post-emergence herbicides applied at reduced doses on weeds in summer maize (*Zea mays* L.) fields in North China Plain. Crop Protection 52:26-32.

Vol. 13(33), pp. 1719-1729, 16 August, 2018
DOI: 10.5897/AJAR2018.13322
Article Number: ED888F358116
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Public policy on the family farming sector in Brazil: Towards a model of sustainable agriculture

Flaviana Cavalcanti da Silva[1], Antonio Lázaro Sant'Ana[2] and Ana Heloisa Maia[3*]

[1]Department of Agronomy, Faculty of, Agrarian Science, Federal University of Mato Grosso – UFMT, Av. Alexandre Ferronato, 1200, St. Industrial, Sinop –MT, Brazil.
[2] Department of Phytotechnology, Food Technology and Socio Economy, Faculty of Engineering, Júlio de Mesquita Filho" São Paulo State University – UNESP, Av. Brazil, 56, Centro, Ilha Solteira – SP, Brazil.
[3] Department of Agronomy, Faculty of Agrarian Sciences, Mato Grosso State University – UNEMAT, Av. Prof. Dr. Figueiro Varella, Cx postal 08, Nova Xavantina –MT, Brazil.

Received 13 June, 2018; Accepted 30 July, 2018

This study is based on a review of the literature that analyses the repercussions of the principal public policies established for the promotion of the family farming sector in Brazil. In this review, the processes that have contributed to the establishment of these policies are assessed critically, together with their mechanisms and the connections for the evaluation of their contributions to the promotion of sustainable production systems. The review was based on a wide range of sources, including books, journals, and other scientific papers, in particular those published by the principal authors in this field, in addition to the databases of Brazilian governmental institutions. The analysis focuses primarily on the National Program for Strengthening Family Farming (PRONAF), the baseline for all other policies, as well as the recently-established Technical Assistance and Rural Extension Policy (PNATER), and the government food purchasing programmes. Despite advances, a number of important limitations were found, in particular in relation to credit programmes and the Technical Assistance and Rural Extension, for the development of models of sustainable agriculture. Overall, many of the mechanisms found in the policies analyzed are oriented towards conventional production systems, which cause socio-environmental impacts that contradict the goals of sustainable rural development.

Key words: Agro-ecology, rural development, agricultural policy.

INTRODUCTION

From an agro-ecological perspective, the objective of sustainable farming is to generate long-lasting income for the farmer through the application of ecologically appropriate ecological management technologies (Altieri, 2004, 1989). The broader aim is to maintain agricultural productivity through the achievement of economic returns compatible with the reduction of poverty, in response to the social needs of rural populations, with the minimum

*Corresponding author. E-mail: anaheloisamaia@unemat.br. Tel: +55 66 99680-4761.

possible environmental impact. Moura et al. (2017, n.p) understand agro-ecology as “a contemporary approach inserted in the construction of public policies that are concerned with rural development, food sovereignty, and the human right to adequate food”. However, Caporal and Petersen (2012) concluded that conservative values tend to persist and dominate societies and their governments, impeding the effective adoption of paradigmatic changes in official policies on farming and rural development. This has left the science of Agro-ecology at the margins of the decision-making process and, as a consequence, it plays only a minor role in the development of public policy on agricultural issues. As one of the principal perspectives of the Agro-ecological field is to promote change in the existing paradigm of development, it is important to re-evaluate the theoretical and practical guidelines that contribute to the establishment of official public policies (Claudino et al., 2012).

Weid (2006) concluded that the principal limitation of the capacity of the “agro-ecological field” to influence public policy is related to the institutional perspective and its approach to the implementation of these policies, which are characterized by considerable structural dispersion. Each policy is geared to its own intrinsic logic, creating specific, differentiated mechanisms that form barriers to efforts to support development, even from the policy makers themselves. The development of effective public policies based on agro-ecological principles and directed towards family-owned properties will require a revision of the technical framework, a new approach to rural extension, and incentives for the provision of rural credit, resulting in a differentiated set of policies directed specifically at the family farming sector (Carmo, 1998). This agro-ecological transition (as observed in the implantation of the Green Revolution) should be supported by adequate financial and technical resources, to guarantee the integration of family farming practices in this process (Caporal, 2008a).

The present study, based on a systematic review of the literature, provides a panorama of the principal public policies on family farming in Brazil established since the mid-1990s, and highlights their principal repercussions for the potential development of sustainable farming practices from an agro-ecological viewpoint. Based on this review, the principal questions involved in the establishment of these policies will be evaluated from a critical perspective, focusing on their mechanisms and links, with emphasis on their implications for the development of effective models of sustainable agriculture in the country.

MATERIALS AND METHODS

The present study was based on a literature review (Silva, 2016), which provided the data for the systematic discussion of theoretical questions, focusing on the development and implementation of Brazilian public policy in the sphere of the family farming sector, in particular actions that support sustainable rural development. A broad body of publications was consulted, including books, journals, papers published in periodicals, and other public documents, in particular those written by the principal authors working in this specific field of research. The compilation of data for the establishment of the theoretical basis of the present study was also supported by the consultation of the databases of the principal government institutions related to this theme, including the Brazilian Institute for Geography and Statistics (IBGE), the National Institute for Colonisation and Agrarian Reform (INCRA), the Ministry for Agricultural Development (MDA), and the Ministry of Social Development (MDS).

The concept of *public policy,* which is the central theme of this study, refers to any “programme of governmental action that proposes to coordinate the means available to the state with private activities, for the development of socially relevant and politically determined objectives” (Bucci, 2006).

RESULTS AND DISCUSSION

The first step in this review was to revisit the three historical events that characterize the trajectory of public policies on family farming in Brazil, based on Grisa and Schneider (2014), followed by an overview of the National Program for Strengthening Family Farming (PRONAF: *Programa Nacional de Fortalecimento da Agricultura Familiar*), which is considered to be the principal initiative on the part of the Brazilian government in support of family farming, and the fundamental event that brought visibility to this sector in the eyes of both the State and Brazilian society in general. The next step in the review is to explain the National Policy on Technical Assistance and Rural Extension (PNATER: Política National de Technical assistance and Extensão Rural), followed by comments on the two principal government purchasing programmes related to the family farming sector, the Food Acquisition Programme (PAA: *Programa de Aquisição de Alimentos*) and the National School Meals Programme (PNAE: *Programa National de Alimentação Escolar*). The review highlights specific points related to the development of policies that support sustainable agriculture, based on questions raised by the principal actors that have contributed to the compilation of this complex sociopolitical sphere.

Three generations of Brazilian public policy on family farming

Based on the Agricultural Census 2006 (IBGE, 2017), it is worth mentioning that family agriculture accounts for 84.4% of all real estate in the agricultural sector and occupies only 24.3% of the total area allocated to the agricultural sector in the country. However, the family farmer is responsible for 38% of gross value of production and accounts for 74.4% of the employed staff in the agricultural sector. Regarding the importance of family farming in Brazil, about 70% of the food consumed by the Brazilian people is made by family farmers. Family farming produces 87% of manioc, 70% of beans, 46% of corn and 38% of coffee in Brazil. Family farming also stands out in the livestock sector, accounting for 60% of milk production, and accounts for 59% of pork production and 50% of poultry in the country. There is an interest in supporting family farming so that it becomes more competitive sector, as a strategy for poverty reduction, food security and economic growth (Medina et al., 2015); for this the construction and implementation of public policies is indispensable.

Grisa and Schneider (2014) defined three generations of Brazilian public policy in the family farming sector, in distinct periods and contexts. The first generation was initiated in 1994, with the creation of the PRONAF, the National Program for Strengthening Family Farming, which established specific policies on rural credit, and guarantees of pricing and production, and also refers to the creation of projects of agrarian reform and rural settlement. In the second generation, the focus was once again on social and assistantialist measures, which were increasingly prioritised in the family farming agenda from 1997–98 onwards. Initiatives during this period included the PRONAF Infrastructure and Municipal Services, the Guaranteed Harvest, the National Rural Housing Programme (PNHR: *Programa National de Habitação Rural*), and the School Grant Programme.

The third generation is marked by the implementation of an increasing diversity of public policy on family farming, culminating in the establishment of a new market focused on food security and sustainability. While the rural social movements had been proposing measures of this type since the beginning of the 1990s, it was only after a shift of policy, in 2003, that any real, institutional changes were implemented. The principal measures that combined the questions of food security and sustainability were the creation of the Food Acquisition Programme (PAA) and a change in the National School Meals Programme (PNAE), which was obliged to reserve a minimum percentage of its resources for the purchase of the produce of family farms (Grisa and Schneider, 2014).

Brazilian national programme for the strengthening of family farming (pronaf)

Up until the mid 1990s, there was no specific national policy in Brazil that provided financial support for the family farming sector (Aquino and Schneider, 2015). Prior to this period, the high costs and lack of credit were seen as the principal problems facing Brazilian farmers, and in particular, family-based operations (Guanziroli, 2007).

In 1996, the Brazilian government established the National Program for Strengthening Family Farming (PRONAF) through decree 1946 of June 28th. This programme was the country's first public policy directed specifically at the family farming sector, and was the result of consolidated pressures from social movements and rural workers' unions (Denardi, 2001). The establishment of the PRONAF represents a fundamental event in the intervention of the Brazilian State in the national agricultural sector, through the effective incorporation of family farming in rural policies (Gazolla and Schneider, 2013).

Between 2001 and 2009, PRONAF contributed to an increase in Brazilian *per capita* income and a reduction in economic inequalities, as measured by the Gini coefficient. Mattei (2006) identified a certain consensus in the analyses of the PRONAF with regard to the conclusion that, given the fundamental vulnerability of the family farming sector, its social and economic conditions would be even more precarious if the PRONAF had not existed. The principal criticisms of the programme include the focus on certain activities for the concession of credit, in particular, the production of grain and commodities, such as soybean, corn, and wheat (Grisa et al., 2014).

Based on this perspective, Aquino and Schneider (2015) concluded that the intimate relationship between the PRONAF and the conventional model of production and traditional market forces restricted considerably its capacity to contribute to real changes in the sector. In this case, the model of family farming actually benefitted by the PRONAF credit policy is not the model that prioritises the diversification of productive activities and sources of income, but rather the "small family business" model, specialised in the production of export commodities.

Caporal and Petersen (2012); Grisa et al. (2014); Sambuichi et al. (2012) and Weid (2006) have criticized this feature of the PRONAF, and its limitations with regard to the development of models of sustainable agriculture. Despite this, subsidised credit is the principal economic mechanism currently available to the agro-environmental sector (Sambuichi et al., 2012), and a number of lines of credit have been created specifically to support more sustainable farming practices, including the PRONAF Forests, Semi-arid, Agro-ecology, and Eco agendas. Together, these lines of credit form the "Green PRONAF" (Sambuichi, 2012) and are described in Table 1.

Sambuichi et al. (2012) found that only 0.7% of the credit conceded by the PRONAF for the harvests between 2004–2005 and 2010–2011 was applied to the Green Programme, representing only 0.5% of the total number of PRONAF contracts emitted during this period (including only costing and investments, without the special lines of credit). In other words, the conventional production systems continued to receive a much larger proportion of the available PRONAF resources than the agro-ecological, organic, agroforestry, and other more sustainable systems (Sambuichi and Oliveira, 2011).

While the creation of the Green PRONAF lines of credit represents an important advance, then, these innovative financial mechanisms, designed specifically to provide incentives for the agro-ecological transition, have been used only rarely (Weid, 2006). The limited scope of these lines of credit does in fact restrict their applicability for

Table 1. Lines and objectives of the "Green Pronaf".

CREDIT LINE	OBJECTIVES
Pronaf Agro-ecology *Pronaf Agroecologia*	Line for the financing of investments of the production systems of agroecological or organic products, including the costs of implantation and maintenance of the systems.
Pronaf Eco	It is the financing of investments that minimizes the impact of rural activity on the environment and that is more favorable to the conviviality with the biome that its property is inserted.
Pronaf Forests *Pronaf Floresta*	Financing investments in agroforestry systems projects; ecologically sustainable extractive exploitation, forest management plan, restoration and maintenance of permanent preservation areas and legal reserve and degraded areas.
Pronaf Semi-arid *Pronaf Semiárido*	Line for the financing of investments in projects related to the semi-arid region, focusing on the sustainability of agroecosystems, prioritizing water infrastructure and the implantation, expansion, recovery or modernization of other infrastructures, including those related to agricultural and non-agricultural production and services projects, according to the reality of families

Fonte: MDA/Brasil (2016).

ecologically-oriented producers or those interested in initiating an agro-ecological approach in their production systems. In addition to these considerations, considerable difficulties are also encountered for the implementation of this credit (Weid, 2006).

Caporal and Petersen (2012) are critical of the Green PRONAF initiatives (PRONAF Agro-ecology, Forests, Semi-arid and Eco) due to the lack of specific resources, which results in the marginal status of these lines of credit, which has persisted since their creation. In addition, some of the measures adopted by the ministries for Agricultural Development (MDA), and Agriculture and Provisioning (MAPA) as incentives for the development of organic agriculture have been implemented following a conventional perspective. Furthermore, Caporal and Petersen (2012) point out that these measures are generally restricted to the technical-agronomical sphere, impeding significant changes in the use of inputs, such as artificial fertilisers and pesticides, which limits any consistent advances towards sustainability.

Sambuichi et al. (2012) concluded that the Agro-ecological line of credit is the least effective of the Green PRONAF initiatives, with a negligible number of contracts being signed each harvest. A number of factors contribute to this situation, including the difficulty of obtaining credit from banking institutions, the lack of knowledge on the part of the farmers with regard to the characteristics of this line of credit, and the lack of the technical assistance necessary for the preparation of projects. Ferrari and Abraão (2008) and Weid (2006) recommend greater flexibility in the current requirements of the PRONAF Agro-ecology programme in order to guarantee that more farmers have access to this support. These authors also highlight limiting factors, such as the general lack of information on the opportunities available to the farmers, and the reduced capacity of support institutions to facilitate the access of these farmers to this line of credit.

To stimulate the demand for credit from the Green PRONAF, a number of specific advantages were added to these specific lines of credit, in comparison with the general PRONAF, especially in recent years (Sambuichi et al., 2012). In addition to the advantages in terms of the interest charged on loans, deadlines, and credit limits, however, a number of changes are still necessary to guarantee an effective increase in the implementation of the Green PRONAF lines of credit, such as changes in the banking mechanisms responsible for the concession of credit, and the provision of technical assistance more appropriate for sustainable farming systems. Other forms of support, in particular credit for investments, will be important to guarantee the transition to more sustainable models of farming (Weid, 2006). As mentioned previously by a number of authors, the credit available for investment is still restricted to a small portion of family farmers. Even in the small number of cases that the farmer obtains this type of credit, the qualitative aspects are debatable, from an agro-ecological perspective.

Technical assistance and rural extension (ATER) service in Brazil and the changes necessary for the development of measures consistent with the agro-ecological perspective

Following the establishment of the first credit programme aimed specifically at family farmers (the PRONAF), in 1996, the perspectives for the development of effective government policies for the family farming sector expanded considerably. In particular, the consolidation of the PRONAF intensified the demands from social movements for a more effective public Technical Assistance and Rural Extension (ATER: *Assistência Técnica e Extensão Rural*) service for family farmers (Dias, 2008; Peixoto, 2009).

In 2003, the ATER service came under the control of the Ministry of Agricultural Development (MDA). In this same year, with the aim of establishing a new Technical Assistance and Rural Extension Policy (PNATER: *Política de Technical assistance and Extensão Rural*), the government conducted a thorough public consultation, based on seminars, meetings, and hearings, which involved non-governmental ATER organisations and the general public, with the extensive participation of representatives of the family farming sector, social movements, and the entities that work in the ATER services. These debates resulted in a number of important consensuses and a set of agreements that were summarised in the PNATER. It is important to note here, that this policy is supervised by the National Programme of Technical Assistance and Rural Extension (PRONATER: *Programa National de Assistência Técnica e Extensão Rural*) and that its implementation established a range of categories and activities contemplated by the Brazilian family farming sector, which take a number of questions into account, including gender, ethnicity, and generation, as well as the role of the non-governmental organizations (Caporal, 2005; Brasil, 2015).

Pettan (2010) points out that the PNATER also resulted from a process of reconsideration of the consequences of the Green Revolution, which matured over the course of the 1990s. While there have been considerable efforts to implement this proposal, the process has been marked by intense disputes on the character of the ATER and its institutional format (Diesel et al., 2015). Contradicting the strategies adopted for the modernization of Brazilian agriculture, underpinned by the principles of the so-called Green Revolution, the PNATER designated rural families (and other beneficiaries of the MDA/SAF programmes) as the only sector to be benefitted by the ATER services. In this case, the operational strategies of the ATER were directed specifically at the needs and idiosyncrasies of the family farming sector, providing a new perspective on rural development, underpinned by agro-ecological principles.

As Caporal (2011) explains, the PNATER was the first federal public policy in Brazil to include an agro-ecological perspective, integrated with the recommendations on the measures necessary to support rural and agricultural development on a national scale. In 2009, however, new discussions on the ATER format, with a reduced involvement of the general public, culminated in the approval of federal law 12,188, which was sanctioned in 2010. This law established the PNATER and, in contrast with the document published in 2004, it did not mention the word *agro-ecology*, and no longer referred to the principles of this field of knowledge as a basis for the development of the measures contemplated by this policy. The law only mentions that the principles of this public policy should include the "adoption of the principles of ecology-oriented agriculture as the preferential focus for the development of sustainable production systems" (Brasil, 2015).

Caporal and Petersen (2012) concluded that the methodological proposals included in the ATER legislation of 2010 are fundamentally opposed to the basic principles of the agro-ecological perspective, in particular by reinforcing the diffusionist approach in the activities of its technicians. The lack of involvement of the sectors most interested in the reformulation of this policy led to the dilution of the demands defined previously as priorities, by a faction of social actors (Caporal and Petersen, 2012).

The debates and reflections that occurred during the 1st National Conference of Technical Assistance and Rural Extension (CNATER), in 2012, which involved an ample range of representatives of the family farming and agrarian reform sectors, recognized the advances attained by the restructuring of the public ATER, initiated in 2003, and the institutionalisation of the PNATER and PRONATER through federal law 12,188 of 2010. A number of challenges to the achievement of sustainable rural development by the ATER were also highlighted. In particular, while the PNATER would no longer necessarily adopt agro-ecological principles in the development of its measures, the Conference highlighted questions on the defense of actions taken by the ATER, based on methods and practices derived from agro-ecological themes, in addition to the training of ATER professionals to consolidate their capacity to implement these agro-ecological principles.

The challenges presented at the 1st CNATER indicated that certain social actors involved in rural development opted for an ATER consistent with agro-ecological principles, and support this perspective. A process of rural extension based on an agro-ecological perspective should reinforce the potential for endogenous development through the maximization of the use of the available resources, within the different spheres, including the historical, cultural, social, and political spheres, as well as existing economic mechanisms, which are considered to be essential for the sustainable use of local natural resources (Caporal and Costabeber, 2004).

Caporal (2008b), in turn, emphasizes that any shift in the extensionist paradigm must be accompanied by institutional changes, followed by a revised structure, and new management strategies. In this context, it is important to emphasize changes in the pyramidal model of supervision, which existed previously in the structure of the ATER, and is common in the strategies of the Green

Revolution, but is incompatible with participative management mechanisms. This author emphasizes the need for models that stimulate the dialogue between the different social actors and institutions involved in the sphere of action of the ATER, in order to consolidate cooperative and democratic forms of management that are reflected in the planning, monitoring, and evaluation of the measures implemented.

Brazil has invested in the training of professionals expected to follow the precepts of the Green Revolution, as part of a general strategy for the modernisation of its agricultural sector. To guarantee sustainability, however, it will be necessary to invest heavily in the training of the ATER agents, to guarantee the capacity of these professionals to develop new technological and human approaches for the intensification of the country's agricultural sector (Sambuichi et al., 2012).

The institutional market for the produce of family farming and incentives for sustainability: The food acquisition programme and the national school meals programme

The "institutional market" is defined here, as in Grisa (2010), where it refers to:

A specific configuration of the market in which the network of exchange has a particular structure, determined by predefined norms and convention negotiated by a set of actors and organisations, where [sic] the State generally assumes a central role, in particular through public buying. (Grisa, 2010: 103)

In Brazil, the sale of the products of family farming in the institutional market is a relatively recent phenomenon, which began through initiatives of state and municipal governments, interested in stimulating family farming and the local production of foodstuffs, but they tended to be restricted in scope and mostly intermittent. In 2003, the creation of the Food Acquisition Programme (PAA: *Programa de Aquisição de Alimentos*), resulted in a series of important changes in this field (Schmitt and Guimarães, 2008).

The PAA was established through federal law number 10,696 of July 10th, 2003, and regulated by decree number 7775 of July 4th, 2012 (Brasil, 2012). This important programme was established through the efforts of the National Council for Food and Nutritional Security (CONSEA), which, together with the federal government, stimulated debates on the creation of effective strategies for the resolution of the problems of poverty and hunger, leading to the establishment of the PAA as one of the principal structural components of the Zero Hunger Programme (*Programa Fome Zero*).

Grisa et al. (2011) conclude that, since the 1990s, with the establishment of the dialogue between the different spheres of criticism of the hegemonic models of agricultural and rural development in Brazil, as well as the establishment of a broader understanding of food security, not restricted to the simple access to food, it was possible to integrate the need to transform the productive matrix of family farming with the process that gave rise to the PAA. Mattei (2006) suggests that this contributed to the development of mechanisms that benefitted not only the family farmer, but also the consumer, by integrating policies supporting food and nutritional security with the policies that aimed to support the family farming sector.

The exemption of the PAA from the public bidding process required by law reduces bureaucracy and facilitates the access of farmers, and is one of the principal innovative advances in the programme. While experiencing some setbacks, this exemption is a key factor for the effective socio-productive inclusion of family farmers on a national scale. One other characteristic that differentiates the PAA, as public policy, is its double fundamental objective, that is, to both support family farming and guarantee access to food, which allows it to benefit not only farming families, but also other populations in a position of social vulnerability, marked by risks to their food and nutritional security (MDA, 2012).

These objectives are achieved through the purchase of the produce of family farmers, who are exempted from the public bidding process, and the distribution of this produce to the population at risk of nutritional insecurity, as well as to entities of social assistance and through public food and nutrition organisations. The programme also aims to contribute to the formation of public food stocks derived from family farming (MDA, 2012), which permit the farmers to stockpile their produce until it can be sold for a fair price (Souza-Esquerdo and Bergamasco, 2014).

The impacts of the PAA can be best understood through the comprehension of its implicit objectives, as defined by Becker and Anjos (2010), which include the redistribution of income, the circulation of financial resources in local economies, the more logical exploitation of rural environments, the promotion of agro-biodiversity, and the preservation of regional culinary traditions. The PAA represents a new phase in the development of policies directed at the strengthening of the family farming sector, in particular through the establishment of specific, differentiated market mechanisms for this social stratum, by guaranteeing the purchase of its produce by the State. The guarantee of the purchase of a fixed quota of the produce of this sector provides family farmers with new incentives, allowing them to exploit their specific, local practices and values to negotiate with a range of public purchasers (Grisa et al., 2011).

Currently, the PAA operates through six different schemes: Direct Purchasing, Purchasing with Simultaneous Donation, Support for the Formation of Stocks, PAA-Milk (Support for the Production and

Consumption of Milk), Institutional Purchasing, and the Acquisition of Seed (Brasil, 2016). Hespanhol (2013) points out that government purchasing programmes, such as the PAA, not only support the production of food by family farms, but also contribute to the strengthening of social assistance networks on local or even regional scales, as well as promoting local culture and values, supporting cooperatives, and contributing to the self-esteem of producers. The establishment of new marketing mechanisms can also contribute to the improvement of the conditions of social reproduction for the family farmers.

However, Schimitt and Guimarães (2008) recognise a number of operational limitations that are yet to be resolved by the government organs responsible for the PAA, such as the delays in the implementation of financial resources, the bureaucracy faced by the farmers, and the lack of integration of the different mechanisms of public policy that support the programme. These authors also mention that the fragility of the organisation and management structure must be overcome by the local entities that implement these measures, to guarantee the more effective monitoring of the supply chain and the qualification of the mechanisms of access of the beneficiaries to the food. It would also be important to reinforce the access of producers to alternative sales channels, in order to reduce their dependence on the institutional market.

Hespanhol (2013) found that, while there was a nationwide increase in the volume of resources made available, and the numbers of both producers and persons receiving the produce, between 2003 and 2011, the scope of the PAA is still limited at the macro-regional and state levels. In addition to these limitations, the programme suffers from a lack of articulation among the different mechanisms, such as access to rural credit (PRONAF) and technical assistance. The National School Meals Programme (PNAE), also known simply as "School Meals", is managed by the Ministry of Education, and aims primarily to "supplement the diet of the students, contribute to school attendance, and guarantee the performance of the students and the development of healthy eating habits" (Brasil, 2010: 6).

The National Fund for Education Development (FNDE: *Fundo National de Development da Educação*) is responsible for the transfer of PNAE funding to creches, kindergartens, federal schools, municipal councils, and the education secretariats of the states and the federal district. These institutions and organs are responsible for the implementation of the programme through the purchase of the produce for the preparation of the school meals, as well as accounting, which is overseen by the School Meals Council, the CAE (Brasil, 2010).

The origin of the PNAE can be found in the 1950s, when the National Food Commission (CNA: *Comissão Nacional de Alimentação*) was created. The CNA was linked to the Public Health sector of the Ministry of Health. It was originally called the National School Meals Programme, and was intended to reduce nutritional deficiencies in needy Brazilian schoolchildren. The Campaign for School Meals (CME: *Campanha de Merenda Escolar*) was established by federal decree 37,106, which came into effect on March 31st, 1955, under the control of the Ministry of Education. This programme was initially linked to international food subsidy organisations created following World War II and, while it originally had a specific focus, this perspective was amplified progressively. The PNAE was consolidated primarily by the Constitution of 1988, which established school meals as a guaranteed right of the citizens (Triches and Grisa, 2015). The PNAE is the world's largest and oldest school meals programme, although it was only integrated with family farming policies in 2009, with federal law 11,947, published on June the 16th. This law aligned the school meals programme with the development of family farming by determining that: At least 30% (thirty percent) of the financial resources provided to the PNAE by the FNDE must be used for the acquisition of foodstuffs directly from family farming and rural family operations or their cooperatives, prioritising agrarian reform settlements, and traditional indigenous and quilombola communities (Brasil, 2009).

Prior to this law, all purchases made by the PNAE were obliged to adhere to the principles of isonomy and competition. The new law meant that producers from family farms were no longer required to participate in the public bidding process (Triches and Grisa, 2015). The PNAE originally had close links to the food industry, when the distribution of processed, ready-to-eat foods was prioritised, although the change in policy contributed to the establishment of the institutional markets for the produce of family farming and, simultaneously, the promotion of food and nutritional security throughout Brazil (Triches and Grisa, 2015; Schmitt and Grisa, 2013). Mossmann et al. (2017) conclude that public policies as PNAE can provide benefits for farmers and the students, with positive effects in both rural and urban settings in relation to food and nutritional security. One year after the implementation of federal law 11,947, which obliged educational authorities to purchase produce from family farms, Saraiva et al. (2013) found that only 47.4% of Brazilian municipalities were purchasing the produce of family farms for school meals, with these municipalities devoting an average of 22.7% of their spending on this item to family farm produce. The Brazilian Southern region presented the highest rates of adherence to the policy, whereas the Midwest returned the lowest percentage. Saraiva et al. (2013) found that the principal reason given by the municipalities for not adopting the official PNAE quotas was the incapacity of family farmers to provide constant and regular supplies of their produce.

Despite their legal obligation, then, less than half of Brazilian municipalities have applied PNAE resources to the purchase of the produce of family farmers, given the many practical limitations, which have only been overcome effectively in some areas (Real and Schneider, 2011). In this case, one of the principal challenges that must be overcome is the structure of the public purchasing mechanisms that supply the programme, which have, historically, been under the control of the food sector's principal companies.

Souza-Esquerdo and Bergamasco (2014) noted that, in the municipalities of the region of the Brazilian State of São Paulo known as the "Fruit Circuit" (*Circuito das Frutas*), the purchase of the produce of family farming for school meals has increased gradually, although the majority of the municipalities surveyed were yet to apply the full quota of FDE resources defined by the programme. This is despite the predominance of family farming in this region of São Paulo. It is important to note here, that this new model of public purchasing is still at the trial stage, which is also related to the barriers that have always existed in the participation of family farming operations in formal markets (Triches and Grisa, 2015).

While environmental conservation is not a central concern of the PAA, the federal government has used this purchasing mechanism to stimulate more sustainable practices by family producers, a perspective now included in the PNAE (Sambuichi et al., 2014). Caporal (2008b) believes that government purchasing programmes, such as the PAA and PNAE, should focus exclusively on farming based on ecological principles, and the acquisition of foodstuffs produced without the application of pesticides. While these programmes have not yet adopted a strict policy on this question, they are supporting incentives for the use of more sustainable practices by their suppliers.

When discussing the ampler effects of the policies associated with the institutional market, Schmitt (2010) mentions that the initiatives of the PAA and the School Meals Law may contribute to the development of the principles of sustainability, not only through regulatory measures, but also by implementing incentives for a more sustainable lifestyle. The efforts of the institutional market to promote sustainable food production can also be seen in the incentives to ecologically-based farming practices incorporated into the PAA and the PNAE. This can be observed, for example, in federal decree number 7775, of July 4th 2012, which regulates the law that established the PAA, and determines that the objectives of this programme are to "promote and valorize biodiversity, and the organic and agro-ecological production of food, and provide incentives for the adoption of healthy eating habits at local and regional levels" (Brasil, 2012).

In the specific case of the PNAE, priority is given to the "suppliers of foodstuffs certified as organic or agro-ecological, according to federal law 10,831, of December 23rd, 2003" (Brasil, 2015). These government initiatives are also intended to support the production of healthier foods and the sustainable exploitation of agro-ecosystems, established by judicial mechanisms, which reveal that "the government can use market forces as an incentive for the development of more socially and environmentally sustainable strategies of production, as observed in the case of these two programmes" (Sambuichi et al., 2014: 99).

A number of studies have referred to the stimuli provided by the PAA and PNAE for ecologically-based production, including the fact that they permit an increase of up to 30% in the purchase price of products derived from organic farms or agro-ecological production systems (Grisa et al., 2011; Sambuich et al., 2012; Triches and Grisa, 2015; Sambuich et al., 2014; Schmitt and Grisa, 2013). Sambuichi et al. (2012) highlight the incentives of the PAA and PNAE for organic production, given this explicit priority (differentiated pricing) for the acquisition of this type of food. Their analysis of the data provided by National Supply Company (CONAB: *Companhia Nacional de Abastecimento*) revealed the evolution of the purchase of this type of produce between 2009 and 2011 through the PAA. Overall, however, only a relatively small amount of resources is allocated to the acquisition of these foods, reflecting the many difficulties of this type of agriculture, in particular in certain specific regions (Sambuichi et al., 2012).

Santos et al. (2014) analysed the use of organic foods in the school meals of the rural municipalities of the state of Rio Grande do Sul, and found that the inclusion of these foodstuffs in the school menu does not depend solely on the motivation and commitment of the municipal administrators of the PNAE to this objective, but also on a range of other factors, including local production, certification, and costs. This reinforces the need for more effective incentives and support for the farming operations to ensure an increase in the proportion of organic products included in the school meals programme.

In many cases, while the produce supplied to the PAA (and the PNAE) is free of pesticides, it is not sold as organic (Siliprandi and Cintrão, 2011), due to either a lack of information or the bureaucratic difficulties of obtaining certification. Grisa et al. (2011) describe a number of challenges faced by the PAA for the stimulation of sustainable production by ecologically-sound farming operations, which also converge on the question of certification.

In this context, there is a clear need for the establishment of more flexible mechanisms of evaluation for the certification of the organic quality of farm produce, adapted to the specific characteristics of each Brazilian region. Marques et al. (2014) analysed the impacts of the PAA on rural settlements in the state of São Paulo, and observed that the programme contributes to the debate on the development of alternative models of agriculture, based on an agro-ecological transition, and the diversification of farming methods, in particular the production of more healthy foods. The PAA has in fact encouraged family farmers to adopt models of production more closely aligned with the agro-ecological perspective.

One of the principal advantages of the PAA, revealed by the studies that have analysed in detail the impacts of this public policy, is the increase in the diversity of the produce grown by the family operations that participate in the programme (Gonzaga, 2015; Sambuich et al., 2014; Hespanhol, 2013; Schmitt and Grisa, 2013; Grisa et al., 2011). The programme's support for this process of diversification is an important strategy for the strengthening of family-based production systems, given that it provides greater security in terms of income, in addition to contributing to the conservation of the environment. This is a fundamental strategy to guarantee the environmental and economic sustainability of the family farming sector (Sambuichi et al., 2014).

Caporal (2008b) supports the strengthening of institutional purchasing and local markets through the establishment of programmes that contribute to the reduction of the distance between the areas in which the food is produced and consumed, as emphasized by the results of both the PAA and the PNAE. This reduction in the marketing cycle is one of the fundamental elements in the development of sustainable systems. The PAA and the PNAE also make the family-farming sector more viable by providing local markets, as well as providing incentives for the exploitation of other marketing strategies, such as the sale of produce in local farmer's markets, which reinforces the short cycle, and provides the family farmers with more equitable opportunities. The establishment of government purchasing programmes, such as the PAA and PNAE, which also promote family farming, has generated a number of opportunities for the improvement of the conditions for the socio-economic reproduction of this sector through marketing mechanisms that are more appropriate to the specific characteristics of the sector, and are more equitable, when compared with the conventional marketing system. This process has also contributed to the amplification of the perspectives for the sustainability of the family farming sector, which makes this type of market an important ally in the transition to more sustainable farming models. However, this transition to more sustainable production systems still faces a number of challenges, involving both programmes.

FINAL CONSIDERATIONS

In recent years, sustainability has become an increasingly important aspect of the public policies established by the Brazilian government for the family farming sector. However, while the PRONAF, the government's principal programme in this sector, is supported by legislation that prioritises the sustainable development of the family-farming sector, it has continued to support primarily the more conventional production systems, perpetuating the adoption of less sustainable models of production. Despite the fact that certain components of the programme are directed specifically at the promotion of sustainable agriculture, the results of these efforts have been negligible, up to now.

Contradicting its original 2004 proposal, the law that established the PNATER no longer bases its strategies of technical assistance and rural extension on agro-ecological principles, hampering the implementation of proposals that integrate the multiples dimensions of sustainability, which underpin the agro-ecological perspective. While the scope of the PNATER encompasses the promotion of sustainable rural development, it is yet to achieve more tangible results. For these objectives of this programme to be achieved, it will be imperative to increase the resources invested in personnel training and the agro-ecological scope of the ATER, to overcome the productive paradigm inherited from the Green Revolution. This will require changes that include the process of training the ATER agents, and the strengthening of the institutions involved in its activities.

From the current perspective of the PAA and the PNAE, the institutional market is an important ally for the production of healthier foods, and supports the transition towards more sustainable models of farming. This emphasizes the importance of these policies for the implementation and reproduction of ongoing advances within an agro-ecological framework. Given this, any further consolidation of these programmes will represent a commitment to both the family farming sector and sustainability. It is nevertheless important to emphasize the need for the inclusion of specific strategies to amplify the production and acquisition of the produce of the sustainable farming systems, which remains a challenge for both programmes.

While the present review has shown that the public policies implemented in recent years in support of the Brazilian family farming sector have achieved a number of important advances, it has also highlighted a number of limitations, in particular in the concession of credit and technical support (ATER) necessary for the promotion of sustainable models of farming. This is because many of the measures adopted by the programmes are aligned with the conventional systems of production adopted during the modernisation of Brazilian agriculture, which have socio-environmental impacts that contradict the goals of sustainable rural development.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Altieri MA (1989). Agroecology: the scientific basis of alternative agriculture. Boulder: Westview Press 84 p.

Altieri M (2004). Agroecologia: a dinâmica produtiva da Agricultura Sustentável. 4. ed. UFRGS: Rio Grande do Sul. 110 p.

Aquino JR, Scheneider S (2015). O Pronaf e o desenvolvimento rural brasileiro: avanços, contradições e desafios para o futuro. Porto Alegre: Editora da UFRGS 1:53-82.
Becker C, Sacco dos Anjos F (2010). Segurança alimentar e desenvolvimento rural: limites e possibilidades do Programa de Aquisição de Alimentos da agricultura familiar, em municípios do Sul gaúcho. Segmente Alimentation e Nutrition 17(1):61-72.
Brasil (2016). Companhia Nacional de Abastecimento - CONAB. Agricultura Familiar. http://www.conab.gov.br/conteudos.php?a=1125
Brasil (2012). Decreto Nº 7.775, de 4 de julho de 2012. Regulamenta o art. 19 da Lei nº 10.696, de 2 de julho de 2003, que institui o Programa de Aquisição de Alimentos, e o Capítulo III da Lei no12.512, de 14 de outubro de 2011. Diário Oficial [da] República Federativa do Brasil. http://www6.senado.gov.br/legislação
Brasil (2009). Lei nº 11.947, de 16 de junho de 2009. Dispõe sobre o atendimento da alimentação escolar e do Programa Dinheiro Direto na Escola aos alunos da educação básica; altera as Leis nos 10.880, de 9 de junho de 2004, 11.273, de 6 de fevereiro de 2006, 11.507, de 20 de julho de 2007; revoga dispositivos da Medida Provisória no 2.178-36, de 24 de agosto de 2001, e a Lei no 8.913, de 12 de julho de 1994; e dá outras providências. Diário Oficial [da] República Federativa do Brasil. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l11947.htm
Brasil (2016). Ministério de Desenvolvimento Agrário - MDA. Linhas de crédito: conheça as linhas de crédito do Pronaf. http://www.mda.gov.br/sitemda/secretaria/saf-creditorural/linhas-de-cr%C3%A9dito
Brasil (2015). Ministério do Desenvolvimento Agrário - MDA. Política Nacional de Assistência Técnica e Extensão Rural (Pnater). http://www.mda.gov.br/sitemda/secretaria/saf-captec/pol%C3%ADtica-nacional-de-assist%C3%AAncia-t%C3%A9cnica-e-extens%C3% A3o-rural-pnater
Brasil (2009). Ministério do Desenvolvimento Agrário - MDA. Secretaria de Desenvolvimento Territorial - SDT. Sistema de Informações Territoriais – SIT. Imagens/mapas.http://sit.mda.gov.br/mapa.php?opcaomapa=TR&modo=0
Brasil (2010). Cartilha par os Conselheiros do Programa Nacional de Alimentação Escolar. https:// portal. tcu. gov. br/ lumis/ portal/ file/ fileDownload. jsp? fileId =8ª 8182A24D6E86A4014D72AC812A5383&inline=1
Bucci MPD (2006). O conceito de política pública em direito. In: BUCCI, Maria Paula Dallari (org.). Políticas públicas: reflexões sobre o conceito jurídico. São Paulo: Saraiva. 241p.
Caporal FR (2008a). Agroecologia: uma nova ciência para apoiar a transição a agriculturas mais sustentáveis. In: Faleiro FG, Farias Neto AL (Eds). Savanas: desafios e estratégias para o equilíbrio entre sociedade, agronegócio e recursos naturais. Planaltina: Embrapa Cerrados 1:895-929.
Caporal FR (2011). Lei de ATER: exclusão da Agroecologia e outras armadilhas. Agroecologia e Desenvolvimento Rural Sustentável 4(1):23-33.
Caporal FR (2005). Política Nacional de ATER: primeiros passos de sua implementação e alguns obstáculos e desafios a serem enfrentados. Temporalis 2(28):243-273.
Caporal FR, Costabeber JA (2004). Agroecologia: alguns conceitos e princípios. Brasília: MDA/SAF 24 p.
Caporal FR, Petersen P (2012). Agroecologia e políticas públicas na América Latina: o caso do Brasil. Reviews for Agroecology 6:63-74.
Caporal F (2008b). Em defesa de um Plano Nacional de Transição Agroecológica: compromisso com as atuais e nosso legado para as futuras gerações. Brasília: Embrapa 20 p.
Carmo MS (1998). A Produção familiar como locus ideal da agricultura sustentável. Agricult. em São Paulo 45(1):1-15.
Claudino LSD, Lemos W, Darnet L (2012). Fatores capazes de interferir na transição agroecológica externa e mudança social. Agroecologia e Desenvolvimento Rural Sustentável 5(1):56-62.
Denardi RA (2001). Agricultura familiar e políticas públicas: alguns dilemas e desafios para o desenvolvimento rural sustentável. Agroecologia e Desenvolvimento Rural Sustentável 2(3):56-62.
Diesel V, Dias M, Neumann OS (2015). Pnater (2004-2014): da concepção à materialização. In: Grissa C, Schneider S (Eds.). Políticas públicas de desenvolvimento rural no Brasil. Porto Alegre: Editora da UFRGS, 1:107-128.
Ferrari EA, Abraao SS (2008). Pronaf Agroecología: sistematización de una experiencia llevada a cabo en la Zona da Mata de Minas Gerais. In: Scotto G (Ed.). Aun hay tiempo para el sol. Pobrezas rurales y programas sociales: Brasil, Venezuela, Guatemala. Una mirada desde lo local. Rio de Janeiro: Action Aid - Oficina Regional Américas 1:65-89.
Gazolla M, Schneider S (2013). Qual “fortalecimento” da agricultura familiar? Uma análise do Pronaf crédito de custeio e investimento no Rio Grande do Sul. Revista de Economia e Sociologia Rural 51:45-68.
Gonzaga DA (2015). Resultados e significados do programa de aquisição de alimentos (PAA) para os agricultores familiares de Pereira Barreto (SP). http://hdl.handle.net/11449/128068
Grisa C, Schmidt CJ, Mattei LF, Maluf RF, Leite SP (2011). O Programa de Aquisição de Alimentos (PAA) em perspectiva: apontamentos e questões para o debate. In: Romano JO, Heringer R. (Eds.). A política vivida: olhar crítico sobre monitoramento de políticas públicas. Rio de Janeiro: Actionaid/Ford Foundation 1:321-342.
Grisa C, Schneider S (2014). Três gerações de políticas públicas para a agricultura familiar e formas de interação entre sociedade e estado no Brasil. Revista de Economia e Sociologia Rural 52(1):125-146, 2014.
Grisa C, Wesz Junior VJ, Buchweitz VD (2014). Revisitando o Pronaf: velhos questionamentos, novas interpretações. Revista de Economia e Sociologia Rural 52(2):323-346.
Grisa C (2010). Diferentes olhares na análise de políticas públicas: considerações sobre o papel do Estado, das Instituições, das ideias e dos atores sociais. Sociedade e Desenvolvimento Rural 4(1):96-116.
Guanziroli CE (2007). PRONAF dez anos depois: resultados e perspectivas para o desenvolvimento rural. Revista de Economia e Sociologia Rural 45(2):301-328.
Hespanhol RAM (2013). Programa de Aquisição de Alimentos: limites e potencialidades de políticas de segurança alimentar para a agricultura familiar. The Sociedade and Natureza 25(3):469-483.
Marques PEM, Moal MFL, Andrade AGF (2014). Programa de Aquisição de Alimentos (PAA) no Estado de São Paulo. Ruris, 8(1):63-89.
Mattei L (2006). Pronaf 10 anos: mapa da produção acadêmica. Ministério do Desenvolvimento Agrário, Núcleo de Estudos Agrários e Desenvolvimento Rural. Brasília: MDA, 2006. http://nead.mda.gov.br/download.php? file= publicacoes/ estudos/pronaf_10_anos_mapa_da_producao_academica.pdf
Medina G, Almeida C, Novaes E, Godar J, Pokorny B (2015). Development Conditions for Family Farming: Lessons From Brazil. World Development 74:386-396.
Mossmann MP, Teo CRPA, Busato MA, Triches RM (2017). Interface Between Family Farming and School Feeding: barriers and coping mechanisms from the perspective of different social actors in Southern Brazil. Revista de Economia e Sociologia Rural 55(2):325-342.
Moura IF, Guedes CAM, Assis RL (2017). Agroecology in the Brazilian Government Agenda: Developments between 2011 and 2014. Cuadernos de Desarrollo Rural 14(79):1-15.
Peixoto M (2009). A extensão privada e a privatização da extensão: *uma* análise da indústria de defensivos agrícolas. r1. ufrrj. br/

cpda/ wp -content/ uploads/ 2011/ 08/ tese_ marcus_ peixoto.pdf
Pettan KB (2010). A Política Nacional de Assistência Técnica e Extensão Rural: percepções e tendências. repositorio.unicamp.br/handle/REPOSIP/256920
Sambuichi RHR, Silva APM, Oliveira CMA, Savian M (2014). Compras públicas sustentáveis e agricultura familiar: a experiência do Programa de Aquisição de Alimentos (PAA) e do Programa Nacional de Alimentação Escolar (PNAE). In: Sambuichi RHR, Silva APM, Oliveira MAC, Savian M. (Eds.). Políticas agroambientais e sustentabilidade: desafios, oportunidades e lições apreendidas. Brasília: IPEA 1:75-104.
Sambuichi RHR, Oliveira MAC (2011). Análise das linhas de crédito do PRONAF para o desenvolvimento sustentável da agricultura familiar. Cadernos de Agroecology 6:1-6.
Sambuichi RHR, Oliveira MAC, Silva APM, Luedemann GA (2012). Sustentabilidade ambiental da agropecuária brasileira: impactos, políticas públicas e desafios. Texto para Discectomy 1782:1-47.
Santos ROC (2014). Reforma Agrária em questão: a propriedade privada como fator de desterritorialização camponesa no Assentamento Fazenda Primavera (Andradina-SP). http://hdl.handle.net/11449/121923
Saraiva EB, Silva APF, Sousa AA, Cerqueira GF, Chagas CMF, Toral N (2013). Panorama da compra de alimentos da agricultura familiar para o Programa Nacional de Alimentação Escolar. Revista Ciência and Saúde Coletiva 18(4):27-42.
Schimitt CJ, Guimarães LA (2008). O mercado institucional como instrumento para o fortalecimento da agricultura familiar de base ecológica. Review of Agricultural 5(2):7-13.
Schmitt CJ, Grisa C (2013). Agroecologia, mercados e políticas públicas: uma análise a partir dos instrumentos de ação governamental. In: Niederle PA, Almeida L, Vezzani FM (Eds.). Agroecologia: práticas, mercados e políticas para uma nova agricultura. Curitiba: Kairós 1:215-265. http:/ /ideias namesa. unb. br/ upload/ bibliotecaIdeias/ 1405627337 AGROECO OGIA-praticas-mercados-e-politicas.pdf
Siliprandi E, Cintrão R (2011). O progresso das mulheres rurais. In: BARSTED, Leila Linhares; PITANGUY, Jaqueline. O progresso das mulheres no Brasil 2003-2010. Rio de Janeiro: Cepia; Brasília: ONU Mulheres 92 p.
Silva FC (2016). Tecnologia social PAIS (Produção Agroecológica Integrada e Sustentável): uma alternativa para a promoção de avanços dentro da perspectiva da agroecologia? as experiências vivenciadas no território rural Prof. Cory/Andradina (SP). http://hdl.handle.net/11449/144500
Souza-Esquerdo VF, Bergamasco SMPP (2014). Análise sobre o acesso aos programas de políticas públicas da agricultura familiar nos municípios do circuito das frutas (SP). Revista de Economia e Sociologia Rural 52(1):205-222.
Triches RM, Grisa C (2015). Entre mudanças e conservadorismos: uma análise dos programas de aquisição de alimentos (PAA e PNAE) a partir da retórica da intransigência. Review NERA 18:10-27.
Weid JM (2006). A transição agroecológica das políticas de crédito voltadas para a agricultura familiar. Agriculturas 3(1):18-20.

Vol. 13(33), pp. 1730-1746, 16 August, 2018
DOI: 10.5897/AJAR2018.13349
Article Number: 1F0A9B458118
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Moisture content, moisture-related properties and agricultural management strategies of the Benue floodplain vertisols in North Cameroon

Primus Azinwi Tamfuh[1,2*], Emmanuel Djoufac Woumfo[3], Emile Temgoua[1], Alexis Boukong[1] and Dieudonné Bitom[1]

[1]Department of Soil Science, Faculty of Agronomy and Agricultural Sciences, University of Dschang, BP 222 Dschang, Cameroon.
[2]Department of Mining and Mineral Engineering, National Higher Polytechnic Institute, University of Bamenda, P.O. Box 812, Cameroon.
[3]Department of Inorganic chemistry, Faculty of Science, University of Yaoundé I, P.O. Box 812 Yaoundé, Cameroon.

Received 26 June, 2018; Accepted 19 July, 2018

Vertisols are widespread in North Cameroon, but are undercultivated due to difficulties linked to their shrink-swell behaviour under different moisture conditions. Eighteen vertisol samples from five profiles representative of the studied area (Benue floodplain in North Cameroon) were studied to establish a relationship between moisture and physico-chemical characteristics and supplement data for planning sustainable agricultural management. The main results revealed that the soils are deep, dark grey, heavy clayey, with high coefficients of linear extensivity, low organic matter and low electrical conductivity. At field capacity, they showed a very low bulk density, high porosity and a high void ratio. Oven-dry soils exhibited very high bulk density, very low porosity and very low void ratio. This high reversibility of properties with changing moisture content is related to high smectitic mineralogy. The moisture properties revealed very high water-holding capacity, very high available water and very high readily available water. Most of the physico-chemical characteristics correlated well with the moisture parameters. The principal component analysis revealed a reduction of 17 initial variables to two principal components (PC1 and PC2) explaining over 70% of the total variance. The PC1 clustered 12 soil and soil moisture variables indicating strong correlation between moisture and physicochemical properties. Management practices for crop production must be primarily directed at moisture control.

Key words: Vertisols, soil moisture, soil suction, land evaluation, Benue floodplain.

INTRODUCTION

Soil and water are the basic natural resources for agricultural production (Duchaufour, 1997; Chow et al., 2012). Soil water is indispensable in ecosystem's productivity: it intervenes directly in plant nutrition as a transporter of dissolved plant nutrients, and indirectly as a principal pedogenetic factor controlling the majority of soil forming processes (Western et al., 2004; Yerima et al., 2013; Wubie 2015; Bhattacharyya et al., 2016). Soil moisture is a key variable in the water and energy cycles and its accurate representation and measurement is required for estimation and prediction of infiltration, evaporation, runoff, ground heat fluxes, etc (Liu et al., 2010). Soil water is thus essential for adequate development of crops and is dependent on soil properties

(Reichert et al., 2010; Chow et al., 2012). Vertisols are heavy clay soils that occur mainly in the intertropical zone with contrasting wet and humid seasons (Eswaran and Cook, 1988; Chow et al., 2012). They constitute a considerable agricultural potential but adapted management is a precondition for sustained production (Seini-Bouker et al., 1992; Fassil, 2009; Fassil and Yamoah, 2009; Azinwi Tamfuh et al., 2012). The key agricultural potentials of vertisols are their extremely rich chemical fertility and occurrence in extensive plains where reclamation and mechanical cultivation can be envisaged (Azinwi Tamfuh et al., 2016). However, their physical features and their difficult water management problems constitute a limitation to their agricultural exploitation (Yerima et al., 2013). The heavy clay texture and dominance of expansive clays of smectitic type result in a narrow soil moisture range between moisture stress in the dry season and water excess in the rainy season (Ambassa-Kiki et al., 1996; Özsoy and Aksoy, 2007). The susceptibility of vertisols to waterlogging is the most important factor that reduces the actual growing period (Azinwi et al., 2012). Water, thus, greatly affect the exploitability of vertisols during tillage, weeding and harvest (Astatke et al., 1995). In North Cameroon, vertisols cover a total surface area of 1100 ha, specifically in the Benue floodplain and the Chad basin (Brabant and Gavaud, 1985; Jones et al., 2013; Djoufac Woumfo et al., 2006). They are chemically very fertile soils (Ambassa Kiki et al., 1996; Azinwi Tamfuh et al., 2005). However, due to their vertic properties under different moisture conditions, they remain undercultivated. Although interest in estimating vertisol moisture content has been strong, the relationship between moisture content and other vertisol characteristics that affect agricultural management is still not fully understood. The aim of the present work was: (1) to study the main vertisol physico-chemical properties; (2) to determine the soil moisture content and moisture tension; and (3) to highlight the influence of soil properties on moisture storage and agricultural management strategies. The study's interest is both fundamental (to supplement the available database on vertisols) and applied (for better management and protection/conservation of these soils). Besides, it would be possible to provide soil information to use especially for agricultural purposes, farm planning and other engineering practices.

MATERIALS AND METHODS

Study site description

The study site is the Benue River floodplain at the centre of the Benue trough in North Cameroon, between latitude 08°30´ to 09°40´ N and longitude 12°25´ to 016°00´ N (Figure 1). This seasonally flooded plain is rich in alluvial deposits, about 35 m thick, composed mainly of sands, gravels and clays (Ngounouno, 1993). It is under a tropical climate with two contrasted seasons: a humid season from May to October and a dry season from November to April (Figure 2). The total annual precipitation is 1033 mm and the mean monthly temperature is 28.2°C, typical of a classical sudanian climate (Etia, 1980). The total annual evapotranspiration, insolation and average relative humidity range are 1920 mm, 2974 h and 42-71%, respectively (Olivry, 1986). The Benue River, principal collector, with its numerous tributaries constitutes a dense and dendritic pattern (Olivry, 1986). Most of the streams are seasonal (except the Benue River) taking their rise either on the Mandara Mountains in the north of the Benue trough or the Adamawa highlands in the south (Olivry, 1986). The relief is diversified on both sides of the Benue trough, typified by irregular and uneven landforms with the highest point at Tchabal Mbabo (2460 m) and the lowest one in the Benue floodplain (<200 m altitude). The Benue trough is a rift formed within the Meso-to-Neoproterozoic granitic-gneissic basement and is entirely filled with continental sediments, precisely sandstones of the Middle to Upper Cretaceous (Ngounouno et al., 1997). The natural vegetation, which is the Sudanian savannah, has been strongly replaced by crops (notably sorghum) and human settlement (Letouzey, 1980). The major soils are raw mineral, lightly evolved, hydromorphic, ferrallitic, vertisolic, halomorphic, ferruginous and fersiallitic soils (Gavaud et al., 1976; Brabant and Gavaud, 1985). In the Benue trough, a ground water underlies the alluvial deposits, the sandstones and the weathered basement (Brabant and Gavaud, 1985; Njitchoua et al., 1995). At the beginning of the dry season, this water is less than 4 m deep (Brabant and Gavaud, 1985). Its lateral extension is variable from one stream to another and along the same stream. It is less than 3 km wide on either sides of streams and becomes shallower with increasing distance away from the stream bed.

METHODOLOGY

Five profiles (P_1, P_2, P_3, P_4 and P_5) were dug on vertisols along the Benue floodplain and described; horizon per horizon and profile per profile. These five profiles, representative of the studied site, were selected on different land use systems which include sorghum cultivation (Garoua, Bounguel and Poumpoumre), Badoudi (grassed savannah, previously under sorghum) and Karewa (rice cultivation)
The soil samples were collected for each horizon, packed in air-tied plastic bags and taken to the laboratory for further description and analysis. The soil analyses where done in the "Laboratoire d'Analyses des Sols et de Chimie d'Environnement" (for the physicochemical analyses) and the Soil Physics Laboratory (for the moisture contents), both in the Faculty of Agronomy and Agricultural Sciences (University of Dschang). So, for the physico-chemical properties, electrical conductivity was measured by conductimetry in a supernatant suspension of 1:5 soil: water ratio (FAO, 2006). Cation exchange capacity was determined by sodium saturation method (Rhoades, 1982). For the physical properties, bulk density (Db) was determined in reference to Archimedes' principle and particle density (Dp) was measured by pycnometer method (FAO, 2006). The organic carbon (OC) was measured by Walkley-Black procedure (Nelson and Sommers 1982).'

*Corresponding author. E-mail: aprimus20@yahoo.co.uk.

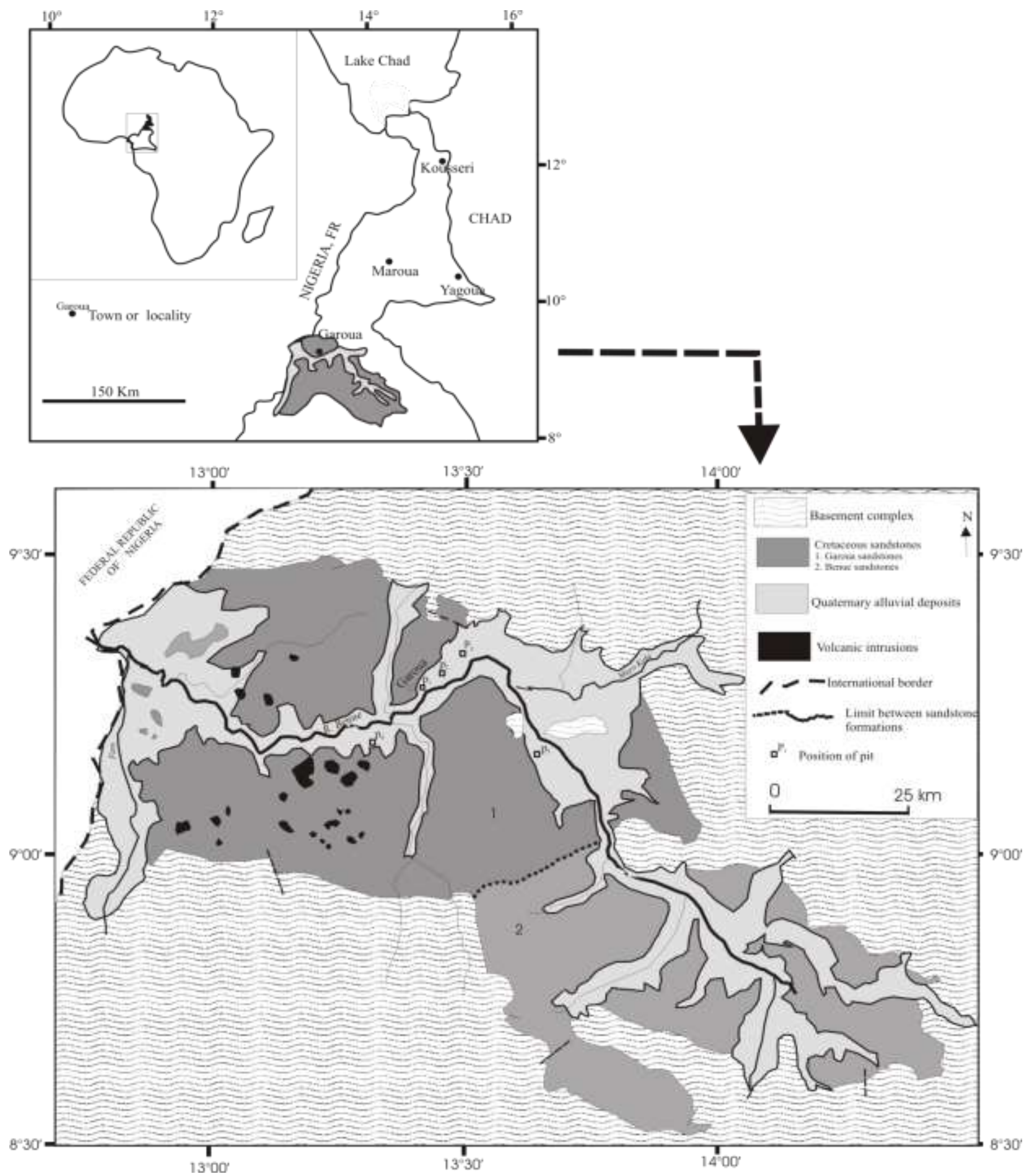

Figure 1. Benue trough in North Cameroon: geology and position of sampled pits in the alluvial floodplain (modified from Ngounouno, 1997).

Porosity (P) and void ratio (e) were deduced from the particle (Dp) and bulk densities (Db):

$$P = \left(\frac{Dp - Db}{Dp}\right) x100 \text{ (Duchaufour, 1997)} \quad (1)$$

$$e = \left(\frac{Dp}{Db}\right) - 1 \text{ (Oicha et al., 2010)} \quad (2)$$

The particle size distribution was measured by Robinson's pipette method (FAO, 2006), organic carbon by Walkley-Black method

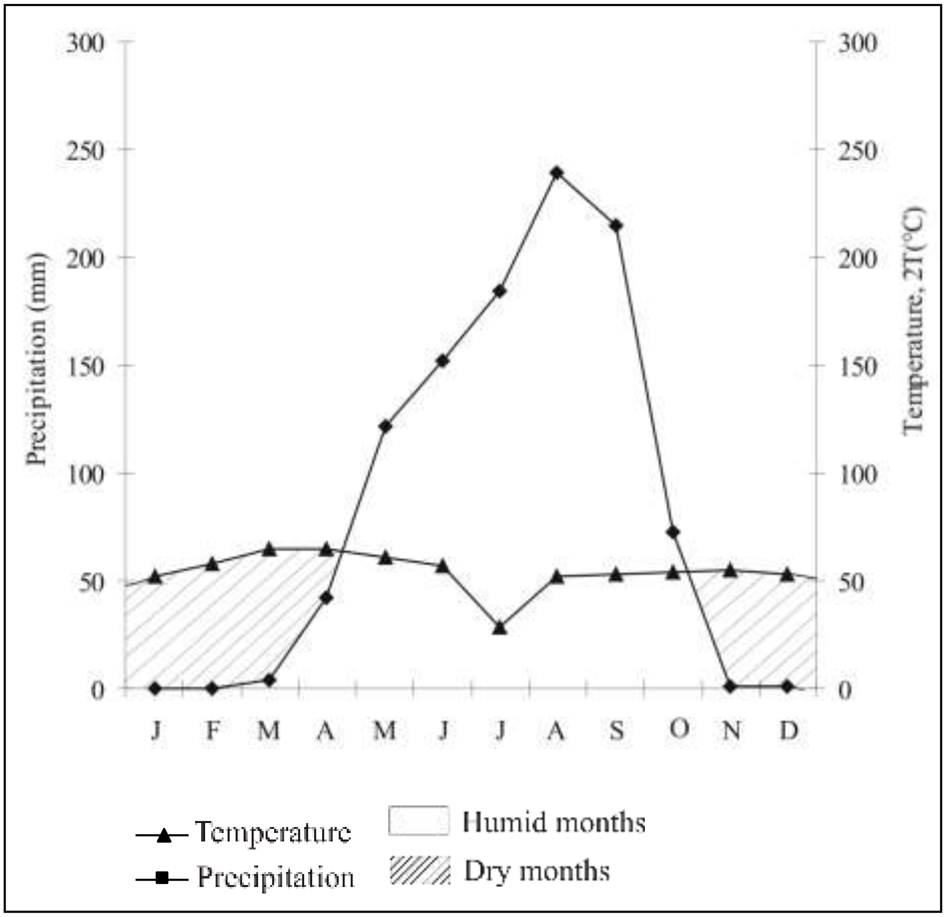

Figure 2. Bagnouls and Gaussen's rainfall-temperature curves for the study region (data from Garoua Meteorological Station from 1970 to 2000).

(Nelson and Sommers, 1982). The air-filled porosity (air capacity) was calculated as the difference between total porosity and field capacity (Duchaufour, 1997). The coefficient of linear extensivity (COLE) was calculated as the difference in bulk density at field capacity (Dbfc) and bulk density at oven-dry (Dbod) stated as follows (Grossman et al., 1968):

$$COLE = \left(\frac{Dbod - Dbfc}{Db}\right)^{1/3} - 1. \qquad (3)$$

The linear extensivity (LE) of each soil horizon was calculated as the product of its thickness (in cm), multiplied by its COLE (FAO, 2006). The LE of each soil profile was obtained as the sum of products for all soil horizons (FAO, 2006). The permeability of individual soil horizons was estimated from permeability-related soil properties and matching them with standard charts (Van Gool et al., 2005).

Concerning the soil moisture characteristics, hygroscopic water content was determined by noting the weight-loss of an air-dried sample, after subjecting it to an oven temperature of 105°C for 24 h (FAO, 2006). The field capacity was measured by centrifugation at 1000 *g* (1 bar) for 30 minusing a crushed soil sample previously water-saturated (Jabiol, 2001). The permanent wilting point (PWP) was measured using a pressure membrane apparatus (Duchaufour, 1997). The capillary water (CW) was calculated as the difference between the hygroscopic water and the field capacity water content (Vilain, 1997). The unavailable water content (UW) was obtained as the difference between the capillary water and permanent wilting point water content (Baize and Jabiol, 1995). The available water reserve (AWR), water-holding capacity (WHC), available water capacity (AWC) and the readily available water capacity (RAW) were calculated as follows:

$AWR = FC - PWP$ (Baize and Jabiol, 1995; Lozet and Mathieu, 1986) (4)

$AWC = \left(\frac{Db \times E \times (FC - PWP)}{100}\right)$ (Duchaufour, 1997) (5)

$RAW = MAD \times AWC$ (Lozet and Mathieu, 1986; Bruand and Duval, 1996) (6)

$WHC = 2 \times AWC$ (GEPPA, 1981) (7)

Where, AWR is the available water reserve (%); AWC is the available water capacity (mm/m); FC is the moisture content at field capacity (%); PWP is the moisture content at permanent wilting point (%); RAW is the readily available water capacity (mm/m); MAD is the management allowed deficiency (about 2/3 for the studied soils); WHC is the water- holding capacity (mm/m); Db is the bulk density (g/cm^3); E is the thickness of horizon (dm).

Before calculating the wetting depth (D) of water in each soil layer, the volumetric water content was previously deduced as follows:

$$Vw = FC.\frac{Db}{Dw} \quad (8)$$

Where, V_w is the volumetric water content (at field capacity), FC is the gravimetric water content (at field capacity), Db is the soil bulk density, and Dw is the density of water (1 g cm^{-3}). The wetting depth was then given as:

$$D = Vw \ \text{x} \ E \quad (9)$$

Where, D is the wetting depth of a soil layer (in cm), E is the depth of the horizon (in cm).

The PWP-to-clay ratio was used to indicate the significance of the particle-size distribution. The CEC-to-clay ratio enabled to estimate clay mineralogy and clay dispersion of each layer (FAO, 2006).

Statistical analysis

The data were subjected to statistical analysis using Microsoft Excel 2010 and SPSS 16.0. Analysis of correlation coefficients and coefficient of variations were used to identify soil variables that correlate significantly and or not, respectively. The principal component analysis (PCA), by varimax rotation, enabled to do away with the problem of autocorrelation and to reduce the contributing soil factors to orthogonal principal components.

RESULTS

Morphology

The studied profiles showed the following morphological characteristics: Profile P_1 was dug at the east of Garoua Brasseries on latitude 9°15´N, longitude 13°24´E and an elevation of 175 m. Slope gradient was 0.6%, current land use was for counter-season sorghum cultivation. This pit was 2.5 m thick above the water table and presented four main horizons including, from surface to bottom (Figure 1); (a) the A1 (0-30 cm), grey (10YR5/1) horizon, which presented yellowish red patches (10 %) and voids (20 %). The presence of numerous deep (30-35 cm) and wide-opened (1-5 cm) cracks separating polygonal blocks (20 to 40 cm diameter) define a strongly expressed polyhedral macrostructure. Few dark brown dry leaves and roots were present, completely mixed up with the clayey matrix. Transition with the underlying horizon was gradual, marked by the disappearance of cracks, appearance of slickensides and light darkening of colour; (b) the B1 (30-100 cm), dark grey (10YR4/1) horizon was characterised by numerous smooth and shiny surfaces called slickensides that separated different blocks; their thicknesses varied between 5 and 10 cm. Transition to the next horizon was very gradual, marked by the disappearance of slickensides; (c) the B21 (100-150 cm), dark grey (10YR4/1) horizon, with clayey texture and massive and compact structure; reddish yellow (7.5YR6/8) patches (5%) were still present. Transition with the underlying horizon was gradual, marked by an intensification of dark colour; (d) the B3g (150-250 cm), very dark grey (10YR3/1) horizon, clayey and compact, with a massive blocky structure, 5% reddish yellow (7.5YR6/8) patches.

Profile P_2 (2.1 m above the water table) was implanted at Poumpoumré (latitude 9°20´N, longitude 13°28´E, altitude of 180 m) on a flat plain surface (0.3% slope). It showed three horizons above the water table which were morphologically very similar to those of profile P1. The land use was for sorghum cultivation without irrigation.

Profile P_3 (2.3 m above water table) was dug at Bounguel (latitude 9°24˝ N, longitude 13°31´ E and altitude 178 m). Slope gradient was about 1%; land use was for sorghum cultivation. This pit was morphologically very similar to the previous one.

Profiles P_4 at Badoudi (latitude 10°13´36˝ N, longitude 13°34´28˝ E and altitude 173.6 m) was implanted on a four-year old fallow with grassed savannah, previously under sorghum. This profile was 2.15 m above the water table and presented four horizons.

Pit P_5 (2.0 m above water table) was dug on a vertisol plot at Karewa (latitude 09°11´34˝ N, longitude 13°20´59˝ E and altitude 191 m) 40 km at SE Garoua. This pit shows four horizons which are morphologically similar to the previously described ones. The land is used for rice cultivation.

All the vertisol materials showed a clay texture, a massive blocky structure and became very hard when dry.

Physico-chemical characteristics

The bulk density at field capacity was low, ranging globally from 1.15 to 1.30 g cm^{-3} (Table 1). There was a slight decrease with depth in all profiles except P5 where values are maintained at 1.29-1.30 g cm^{-3} although increasing slightly with depth. At oven-dry state, the bulk density values were comparatively very high (1.80-2.20 g cm^{-3}) increasing slightly with depth. The particle density was constant at 2.60 g cm^{-3} except for the surface horizons of P_1, P_2 and P_3 which showed slightly lower values (Table 1). The coefficients of linear extensivity values were very high, ranging from 0.11 to 0.27 cm/cm (Table 1). They increased with depth for all the profiles, except for P_1 where values decreased slightly. The void ratio (e) values at field capacity were very high (1.05 to 1.26). These values increased with depth for all profiles except P_5 where they were almost constant increasing only slightly from 1.02 to 1.00 (Table 1). The void ratio values after oven-drying were relatively very low (0.18 to 0.44), increasing with depth for all the profiles (Table 1).

The total porosity at field capacity ranged between 48.80 % and 55.80 % (Table 1). All the vertisols profiles showed lower porosity values (at FC) at the surface than at depth. At oven-dry state, the porosity values dropped to 15.40-30.76 %. Contrary to porosity values at FC, the porosity at oven-dry state increased with depth of all the profiles (Table 1).

The particle size distribution analysis revealed that clay was the most abundant fraction in all the soil profiles, increasing gradually with depth. The clay contents were higher and comparable in P_1 and P_2 ranging from 62.50 to 75.00 % (Table 1). In all the studied profiles, the highest silt contents appeared at the surface, and then gradually decreased with depth; sand presented a reverse trend to those of clay and silt. The highest sand contents were observed in Bounguel (Table 1). Silt showed an inverse relationship with clay, marked by a silt-to-clay ratio which decreases with depth in all profiles (Table 1). The representation of the various particle size fractions on a textural triangle in reference to USDA (Robitale and Tremblay, 1997) revealed a clayey to heavy clayey texture for all the vertisol horizons (Figure 3).

The permeability rates of the studied vertisols varied from <0.06 to 0.20 cm/hour (Table 1). These intervals correspond to very slow to slow permeability soil classes according to Van Gool et al. (2005). The organic carbon was low to moderate for all the soils, but higher at the surface than in the sub-surface horizons (Table 1). The highest values were observed in Garoua (4.50%) and the lowest ones in Bounguel (Table 1). The bottom horizons revealed the lowest organic carbon contents. The CEC at pH7 was high and ranged from 26 to 46 me/100 g (Table 1). The values globally increased with depth in all the studied sites. The CEC-to-clay ratio ranged from 0.53 to 0.71 for all the profiles (Table 1). The lowest value appeared for A1 of P_3 and the highest one by B21 of P_2.

The electrical conductivity of the different vertisol profiles was very low, ranging from 0.46 to 1.84 mmhos per cm. Those values increased slightly with depth for all the profiles (Table 1). The highest values were recorded for P_4 while the lowest ones were shown by P_5. Nevertheless, electrical conductivity values did not vary much from one profile to the other.

Moisture characteristics

The hygroscopic water content ranged from 6.70 to 13.42% (Table 2). The values were quite comparable for all sites and showed a slight increase with depth for all the profiles (Table 2). The water-holding capacity increased with depth for all the profiles, except for P_1 which showed a zigzag trend. The values were globally moderate to very high for all horizons, ranging between 268.10 to 855.80 mm/m. The general observed trend was the appearance of lower values at the surface and higher ones at depth (Table 2). The readily available water ranged between 89.40 and 271.33 mm/m (Table 2). The available water capacity ranged between 134.04 and 407.00 mm/m (Table 2). Both parameters follow the same trend as the water-holding capacity (Table 2).

Globally, the sums of the water-holding capacity (1318.70 to 1901.50 mm), available water (659.40 to 950.75 mm) and readily available water (439.60 to 633.83 mm) are very high for all the profiles (Figure 4; Table 3) placing those vertisols under class 7 in reference to GEPPA (Table 4).

The moisture contents at field capacity (FC) generally ranged between 36.52 and 55.70%. The values of P_3 and P_4 were clearly lower than those of the other profiles (Table 2).

The water content at permanent wilting point (PWP) ranged between 22.70 and 35.17% (Table 2). For all the profiles, water content at PWP varied irregularly with depth. The lowest values appeared in the P_3 and P_4, just as for the field capacity values.

The soil-water characteristic curve (Figure 5) revealed an almost uniform mean water contents for all profiles, apart from P1 with slightly higher hygroscopic water content. Under moist and wet conditions, the different profiles presented different behaviours. But again, at saturation point (zero porosity), all the vertisol profiles behaved almost similarly; their maximum water capacity, that is when all pores are filled (pF=0), ranged between 52 and 60%.

The capillary water content was high for all the horizons and globally ranged from 27.26 to 46.00% (Table 2). The values for P_1 and P_2 were slightly higher than those of the rest of the profiles.

The air-filled porosity varied between 1.02 and 15.58 % (Table 2). The highest values were observed in P_3 and P_4 with maximum values of 15.48 and 11.38 %, respectively. The rest of the profiles did not attain 6.00%.

The PWP-to-clay ratio ranged between 0.46 and 0.59 (Table 2). All ratio values were of the same order of magnitude and decreased slightly with profile depth in the studied sites.

Correlation and factor analysis of the soil characteristics

The Pearson correlation test showed that most of the vertisol physico-chemical characteristics were correlated with the soil moisture properties, either negatively or positively (Table 5). The Clay content correlated best with the moisture properties than any other physico-chemical characteristic. Bulk density at oven-dry state also correlated negatively well with the moisture characteristics while porosity at field capacity instead correlated positively with those properties. The air capacity showed

Table 1. Physico-chemical properties the Benue floodplain vertisols.

Soil properties Horizon (Depth)	Dbfc ($g\ cm^{-3}$)	Dbod ($g\ cm^{-3}$)	Dp ($g\ cm^{3}$)	COLE (cm/cm)	LE	VRfc	VRod	Pfc (%)	Pod (%)	Particle size distribution (%)				Textural indices		Permeability		OC (%)	CEC7 (me/100 g)	CEC_A	CEC:clay ratio	ECse	SS (%)
										Sand	Silt	Clay	USDA class	TDI_{h0}	Silt:clay	Rate (cm/hr)	Class						
Profile P_1 (Garoua)																							
A_1(0-30 cm)	1.26	1.80	2.50	0.14	4.2	1.05	0.38	55.18	28.0	10.84	26.66	62.50	H	1	0.43	<0.06	VS	4.5	35.00	41.6	0.56	0.44	0.03
B_1 (30-100 cm)	1.17	2.10	2.60	0.22	15.4	1.22	0.24	55.0	19.00	6.3	25	70.00	H	1.12	0.36	<0.06	VS	0.48	37.00	51.5	0.53	0.50	0.03
B_{21} (100-150 cm)	1.15	2.10	2.60	0.22	11	1.26	0.24	55.70	19.0	6.5	17	72.50	H	1.16	0.23	<0.06	VS	0.51	40.00	53.8	0.55	0.59	0.03
B_{3g} (150-250 cm)	1.15	2.20	2.60	0.24	24	1.26	0.18	55.70	15.4	7.5	18.86	75.00	H	1.2	0.25	<0.06	VS	0.53	42.00	54.6	0.56	0.61	0.04
Profile P_2 (Poumpoumré)																							
A_1(0-40 cm)	1.18	1.90	2.50	0.27	10.8	1.11	0.32	52.80	24.0	10.7	22.5	68.00	H	1	0..33	<0.06	VS	2.82	39.00	49.06	0.57	0.46	0.03
B_1 (40-110 cm)	1.15	2.10	2.60	0.22	15.4	1.26	0.24	55.80	19.0	11.95	16.03	72.00	H	1.05	0.22	<0.06	VS	1.01	42.00	55.53	0.58	0.46	0.03
B_{21} (110-210 cm)	1.15	2.10	2.60	0.22	22	1.26	0.24	55.80	19.0	6.4	20	75.00	H	1.1	0.27	<0.06	VS	0.71	46.00	59.44	0.61	0.73	0.05
Profile P_3 (Bounguel)																							
A_1(0-60cm)	1.28	1.80	2.50	0.12	7.2	0.95	0.38	48.80	28.0	24.96	31.68	45.00	C	1	0.70	0.06-0.20	S	1.76	26.00	49.96	0.57	0.52	0.03
B_1(60-150cm)	1.25	20	2.60	0.17	15.3	1.08	0.30	52.00	23.10	29.46	23.96	47.50	C	1.05	0.50	0.06-0.20	S	0.66	28.10	56.38	0.59	0.54	0.03
B_{21}(150-230 cm)	1.24	2.20	2.60	0.21	16.8	1.10	0.18	52.30	15.40	22.89	26.38	53.50	C	1.18	0.49	0.06-0.20	S	0.88	34.00	60.26	0.64	0.55	0.03
Profile P_4 (Badoudi)																							
A_1(0-30 cm)	1.3	1.80	2.60	0.11	3.3	1.00	0.44	50.00	30.76	20.01	34.3	46.60	C	1	0.74	0.06-0..20	S	2.17	33.10	61.72	0.71	1.12	0.07
B_1 (30- 110 cm)	1.26	2.00	2.60	0.17	5.1	1.06	0.33	51.50	23.10	16.83	29.4	54.20	C	1.16	0.54	0.06-0.20	S	1.67	35.40	59.15	0.65	1.60	0.10
B_{21} (110-160 cm)	1.16	2.20	2.60	0.23	13.8	1.24	0.18	55.40	15.40	14.63	18.33	68.00	H	1.45	0.27	<0.06	VS	0.98	37.06	51.62	0.55	1.80	0.11
B_{3g} (160-215 cm)	1.25	2.20	2.60	0.21	19.95	1.08	0.18	51.90	15.40	13.37	27.37	58.26	C	1.25	0.47	0.06-0.20	S	0.70	39.00	64.54	0.67	1.84	0.12
Profile P_5 (Karewa)																							
A_1(0-20 cm)	1.29	2.00	2.60	0.16	3.2	1.02	0.33	50.40	23.10	17.14	24.09	59.50	C	1	0.40	0.06-0.20	V	2.78	29.00	39.39	0.49	0.52	0.07
B_1(20-45 cm)	1.29	2.00	2.60	0.16	6.4	1.02	0.33	50.40	23.10	23.01	18.1	60.50	H	1.01	0.30	<0.06	VS	1.20	32.30	49.42	0.53	0.49	0.10
B_{21} (45-140 cm)	1.3	2.20	2.60	0.19	11.4	1.00	0.18	50.00	15.40	13.53	21.7	66.75	H	1.12	0.33	<0.06	VS	0.87	35.92	51.21	0.54	1.08	0.12
B3g (140-200 cm)	1.3	2.20	2.60	0.19	11.4	1.00	0.18	52.52	15.40	12.7	16.11	72.50	H	1.21	0.22	<0.06	VS	0.91	38.54	50.65	0.53	1.44	0.12

Dbfc, bulk density at field capacity; Db_{OD}, bulk density at oven-dry state; Dp, particle density ; COLE, coefficient of linear extensivity (cm/cm); LE, linear extensivity; VRfc, void ratio at field capacity; VRpwp, void ratio at permanent wilting point; Pfc, Porosity at field capacity; P_{OD}, porosity at oven-dry state; C, clayey texture; H, Heavy clayey texture; TDI_{ho}, textural differentiation index of horizon ; OC, organic carbon; ECse, electrical conductivity in mmmhos/cm; in/h, cm per hour; S, slow; VS, very slow; CEC7, cation exchange capacity by ammonium acetate at pH7; CEC_A , apparent cation exchange capacity; SS, total water soluble salt.

a very strong negative correlation with permanent wilting point and field capacity (Table 5). Although a good number of the soil properties were correlated, the explanation and interpretations of some patterns were difficult due to existence of redundancies thus justifying the use of the principal component analysis.

The results of the principal component analysis enabled to observe a reduction of 17 original variables studied to only two components explaining 72.28% of the total variance expressed (Table 6). Component 1 alone explained 52.42% and had significant loadings on all the soil variables, except particle density, electrical conductivity, organic carbon, permanent wilting point and air capacity (Table 6). Component 2 had a significant loading of PWP explaining 19.86% of the total variance (Table 6). The graphical

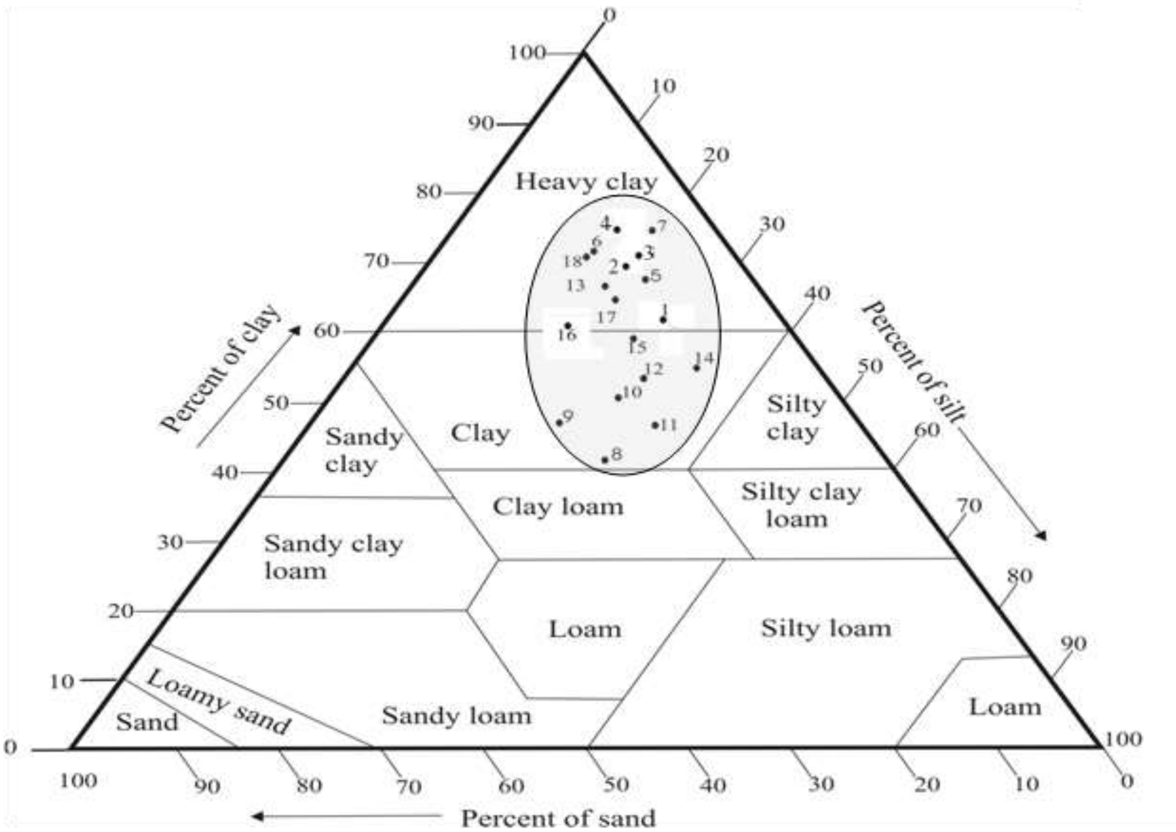

Figure 3. Textural classes of the vertisol samples in reference to the United States Department of Agriculture (Robitale and Tremblay, 1997). P1: **1**. A1 (0-30 cm); **2**. B1 (30-100 cm); **3**. B21 (100-150 cm); **4**. B3g (150-250 cm); P2: **5**. A1 (0-150 cm); **6**. B1 (40-110 cm); **7**. B21 (110-210 cm); P3: **8**. A1 (0-60 cm); **9**. B1 (60-150 cm); **10**. B21 (150-230 cm); P4: **11**. A1 (0-30 cm); **12**. B1 (30-110 cm); **13**. B21 (110-160 cm); **14**. B3g (160-215 cm); P5: **15**. A1 (0-20 cm); **16**. B1 (20-45 cm); **17**. B21 (45-140 cm); **18**. B3g (140-200 cm).

representation of the first two principal components on a factorial plane enables to note the dispersion of the soil variables based on their influence on one another (Figure 6).

DISCUSSION

Specificities of the studied vertisols

The Benue floodplain vertisols showed deep profiles, below the rooting zone which greatly increased the moisture retention capacity. In these vertisols, depth appears to be a very favourable factor enhancing the water-holding capacity and hence plant available water retention which is in agreement with the report of Laroche (1996) and Duchaufour (1997).

The heavy clayey texture was related to the flat topography, the highly contrasted climate and the alluvial parent material rich in fine clays derived from erosion, transportation and deposition of material from the upper parts of the landscape (Gavaud et al., 1976; Azinwi Tamfuh et al., 2012; Azinwi Tamfuh et al., 2016). The heavy clayey texture is favourable for a high water retention capacity (Laroche, 1996). According to Reichert et al. (2010), the vertisols with higher silt-to-clay ratios are probably less weathered, hence likely have higher smectite contents.

The bulk density was high at oven-dry state and low at field capacity and probably played a role in controlling pore space responsible for retaining water and air in the soil (Eswaran and Cook, 1988; Coulombe et al., 1996). Reports elsewhere reveal high bulk densities of about 1.30 to 1.80 g cm^{-3}, a times attaining 2.05 to 2.50 g cm^{-3} (Azinwi Tamfuh, 2012).

The very high COLE is an indication of the presence of high expansive smectite clays (Eswaran and Cook, 1988). The COLE denotes a fractional change in the clod dimension from a dry to a moist state (FAO, 2006). Hence, vertisols with relatively high smectite clays have the capacity to swell significantly when moist as well as to shrink and crack when dry (FAO, 2006; Gidigasu and Gawu, 2013; Azinwi Tamfuh et al., 2016; Diaz et al., 2016). This pedoturbation is vital in explaining some soil

Table 2. Moisture characteristics of the different vertisols profiles.

Soil properties horizon (Depth)	E (cm)	HW (%)	FC (%)	PWP (%)	AWR (%)	AWC (mm/m)	UW (%)	RAW (mm/m)	WHC (mm/m)	CW (%)	AC (%)	D (in/m)	PWP:clay ratio
Profile P_1 (Garoua)													
A_1(0-30 cm)	30	6.70	48.90	37.30	12.60	325.00	11.20	216.70	650.00	42.20	6.28	7.38	0.59
B_1 (30-100 cm)	70	8.10	49.72	32.22	17.50	367.50	9.40	245.00	735.00	41.62	5.28	6.98	0.46
B_{21} (100-150 cm)	50	9.70	55.70	33.60	22.10	378.00	12.40	252.00	756.00	46.00	3.90	7.69	0.46
B_{3g} (150-250 cm)	100	10.30	52.28	34.78	17.50	407.00	7.20	271.33	814.00	41.98	3.42	7.21	0.46
Profile P_2 (Poumpoumré)													
A_1(0-150 cm)	40	7.90	54.55	36.30	18.25	346.75	10.35	231.17	693.50	46.65	1.75	7.72	0.53
B_1 (40-110 cm)	70	8.80	52.52	34.42	18.10	380.00	9.91	253.33	760.00	43.72	3.28	7.25	0.48
B_{21} (110-210 cm)	100	9.30	53.62	35.17	18.45	387.50	9.15	258.33	775.00	44.32	2.18	7.40	0.47
Profile P_3 (Bounguel)													
A_1(0-60cm)	60	7.70	37.62	23.77	13.85	249.33	6.15	166.22	498.70	29.92	11.18	5.78	0.53
B_1(60-150cm)	90	7.90	36.52	22.76	13.80	275.00	5.86	183.33	550.00	28.62	15.48	5.48	0.48
B_{21}(150-230 cm)	80	10.80	38.06	25.86	12.20	327.88	15.06	218.58	655.80	27.26	14.24	5.66	0.48
Profile P_4 (Badoudi)													
A_1(0-30 cm)	30	11.10	38.64	25.34	13.30	343.00	2.20	228.67	686.00	27.54	11.36	6.03	0.54
B_1 (30- 110 cm)	30	12.30	41.09	27.74	13.35	307.00	1.05	204.67	614.00	28.79	10.41	6.21	0.51
B_{21} (110-160 cm)	60	11.80	52.01	32.56	19.45	427.92	7.65	285.25	855.80	40.21	3.39	7.24	0.48
B_{3g} (160-215 cm)	95	13.25	43.20	27.60	15.60	343.26	2.35	228.84	686.50	29.95	8.00	6.48	0.47
Profile P_5 (Karewa)													
A_1(0-20 cm)	20	11.10	49.16	32.36	16.80	134.04	5.70	89.36	268.10	38.06	0.80	7.61	0.54
B_1(20-45 cm)	40	10.30	45.80	29.60	16.20	324.50	5.90	216.33	649.00	35.50	4.60	7.09	0.49
B_{21} (45-140 cm)	60	11.80	48.98	31.86	17.14	377.00	5.30	251.33	754.00	37.18	1.02	7.64	0.48
B3g (140-200 cm)	60	13.42	50.00	34.42	15.58	399.00	2.16	266.00	798.00	36.58	2.52	7.80	0.47

E, thickness of horizon; UW, Unavailable water; HW, hygroscopic water (pF_7); FC, Moisture content at Field capacity (pF_3); PWP, Moisture content at permanent wilting point (pF4.2); AWR, Available water reserve; AWC, Available water capacity; RAW, Readily available water; WHC, water-holding capacity; AC, soil air capacity; CW, capillary water (pF_5); D, Water depth at field capacity (inch/metre).

physical features (wide-opened cracks in the dry season, surface ponding in the rainy season, slickensides) and pedogenic processes (Kovda et al., 2017).

The void ratios, high at field capacity and low at oven-dry state, are within the limits of 0.30 (moist) and 1.50 (dry) typical of expansive clays, but much higher than values reported for organic horizons (Jones and Holtz, 1973; Sridharan and

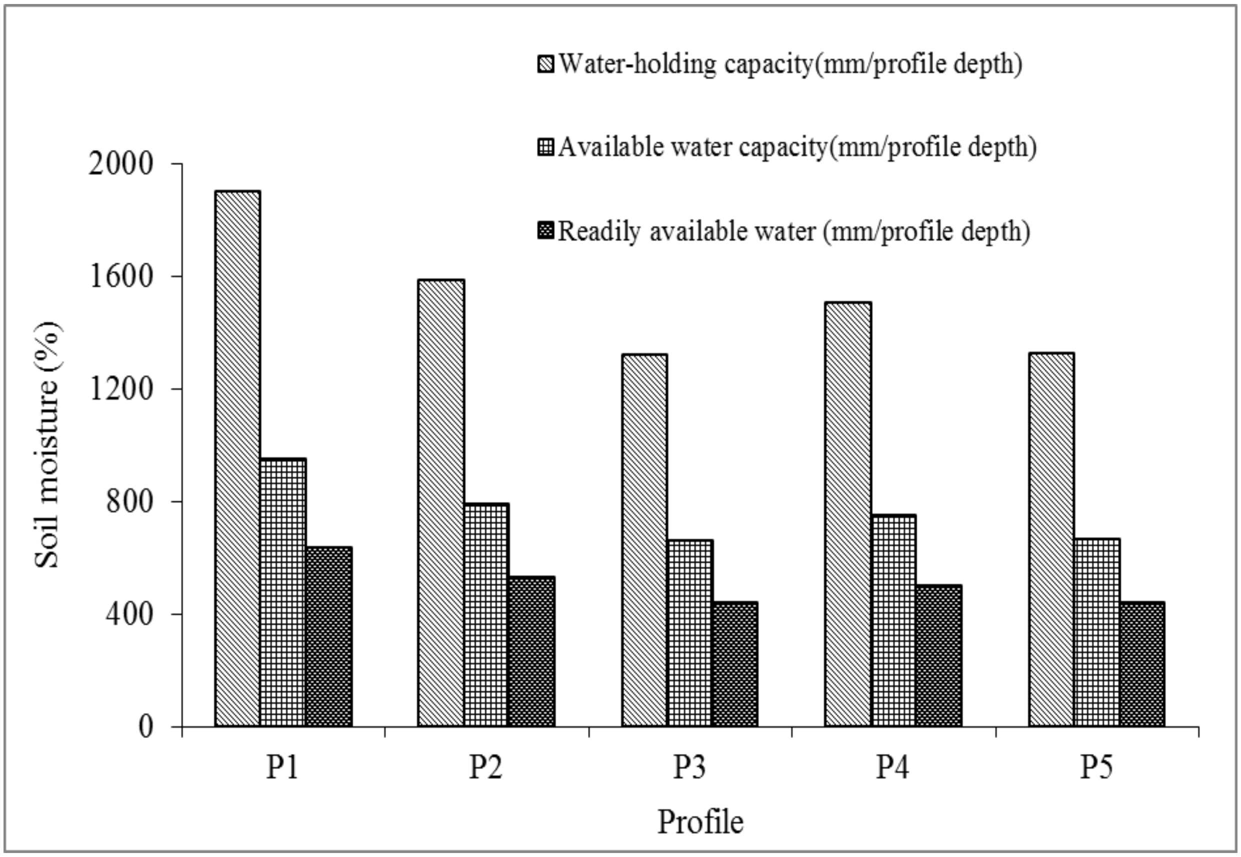

Figure 4. Global soil water retention capacities of the different vertisols profiles at different suction pressures.

Table 3. Global soil moisture properties, textural differentiation index and linear extensivity of the vertisol profiles.

Properties thickness (meters)	Moisture content (mm/profile depth)				TDI_p	LE_P
	WHC	TAWC	RAW	Class (GEPPA, 1981)		
P1 (2.5)	1901.50	950.75	633.83	Very high	1.21	54.60
P2(2.1)	1584.40	792.20	528.13	Very high	1.10	48.20
P3(2.3)	1318.70	659.40	439.60	Very high	1.24	39.30
P4(2.15)	1504.20	752.10	501.40	Very high	1.46	42.15
P5(2.0)	1324.98	662.50	441.67	Very high	1.22	32.50

WHC, Water-holding capacity; TAWC, total available water capacity; RAW, Readily available water; TDI_p, textural differentiation index of profile; LE_p, linear extensivity of profile.

Nagaraj, 2010). In the field, low void ratio values for vertisols are common in the dry season and higher ones in the rainy season in agreement with the shrink-swelling movements with moisture variation. The higher void ratios indicate possible reduction in permeability (Holtz and Kovacs, 1981). This phenomenon is related to the presence of smectite which has the capacity to absorb water molecules and free ions, and by so doing, limits pore space (Shainberg et al., 1988).

The air capacity was generally low for most horizons compared to the optimum root aeration value of 10.00% and the critical value of 5.00% required for optimum plant performance (Gidigasu and Bawu, 2013). Air capacity of the soils also tends to increase as the water content between pores and bulk density decreases (Reynolds et al., 2007). The low air contents of vertisols indicate a very low free water potential compared to the water-holding capacity of the soils. Thus, most of the water that

Table 4. Pearson linear correlation coefficients between vertisol characteristics.

	Dbfc	Dbod	Dp	COLE	VRfc	VRpwp	Pfc	Pod	Clay	OC	EC	FC	PWP	AWC	RAW	WHC	AC
Dbfc	1.00																
Dbod	-0.27	1.00															
PD	0.00	0.68**	1.00														
COLE	-0.73**	0.64**	0.16	1.00													
VRfc	-0.95**	0.46	0.30	0.73**	1.00												
VRpwp	0.35	-0.97**	-0.50*	-0.71**	-0.49*	1.00											
Pfc	-0.91**	0.54**	0.33	0.77**	0.97**	-0.57*	1.00										
Pod	0.32	-0.99**	-0.56*	-0.70**	-0.47*	0.99**	-0.55*	1.00									
Clay	-0.65**	0.55*	0.19	0.73**	0.68**	-0.60**	0.76**	-0.60**	1.00								
OC	0.23	-0.74**	-0.70**	-0.42	-0.44	0.71**	-0.47*	0.70**	-0.26	1.00							
EC	0.22	0.38	0.35	0.02	-0.11	-0.32	-0.03	-0.34	-0.04	-0.23	1.00						
FC	-0.64**	0.29	-0.04	0.63**	0.60**	-0.35	0.64**	-0.34	0.93**	0.04	-0.13	1.00					
PWP	-0.54*	0.19	-0.15	0.53*	0.47*	-0.26	0.53*	-0.26	0.88**	0.23	-0.15	0.95**	1.00				
AWC	-0.52*	0.50**	0.21	0.55*	0.56*	-0.56*	0.63**	-0.52*	0.62**	-0.45	0.31	0.45	0.41	1.00			
RAW	-0.52*	0.50**	0.21	0.55*	0.56*	-0.56*	0.63**	-0.52*	0.62**	-0.45	0.31	0.45	0.41	1.00**	1.00		
WHC	-0.52*	0.50**	0.21	0.55*	0.56*	-0.56*	0.63**	-0.52*	0.62**	-0.45	0.31	0.45	0.41	1.00**	1.00**	1.00	
AC	0.30	-0.25	0.03	-0.42	-0.29	0.27	-0.34	0.29	-0.82**	-0.13	0.04	-0.90**	-0.89**	-0.26	-0.26	-0.26	1.00

Dbfc, bulk density at field capacity; Db, bulk density at oven-dry state; Dp, particle density; COLE, coefficient of linear extensity; VRfc, void ratio at field capacity; VRpwp, void ratio at permanent wilting point; Pfc, Porosity at field capacity; Pod, porosity at oven-dry state; OC, organic carbon content; EC, electrical conductivity in mmmhos/cm; FC, field capacity; PWP, permanent wilting point; AWC, available water capacity; RAW, readily available water; WHC, water-holding capacity; AC, air capacity. **Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

infiltrates into pores is retained in the profiles and causes vertic movements that in turn induce low permeability, surface ponding, poor aeration and floods in the rainy season (Duchaufour, 1997; Gidigasu and Gawu, 2013).

The organic carbon content of the vertisols, although very low, was almost evenly distributed throughout the profiles. This fact might be explained by the brassage and homogenisation of the whole profile by shrink-swell movements (Feller et al., 1996; Prusty et al., 2009; Temga et al., 2015). The low carbon contents of vertisols could be caused by prevailing dry conditions that hinder biomass production and instead amplify its mineralization rate (Aydinalp, 2010; Costa et al., 2015).

The hygroscopic water content increased with depth of all the vertisol profiles. Many authors have reported the capacity of a soil to retain humidity under laboratory conditions as a function of factors such as the texture, structure, organic matter content and the mineral composition (Astatke et al., 1995). Soils with heavy clayey texture and montmorillonitic mineralogy tend to hold their residual moisture stronger and will tend to show lower hygroscopic water contents than light textured non-smectitic soils (Cabidoche and Voltz, 1995; Laroche, 1996; Costa et al., 2015). This could justify the higher values for P_3 and P_4 despite their lower clay contents. Moreover, the CEC-to-clay ratio ranges from 0.53 to 0.71 suggesting mixed to dominant smectitic mineralogy according to FAO (2006). Previous studies (Nguetnkam et al., 2007; Azinwi Tamfuh et al., 2011) show that the studied vertisols are rich in smectite, associated to kaolinite and illite. The distribution of those clay minerals as well as organic matter with depth might be affecting the vertical distribution of hygroscopic water in

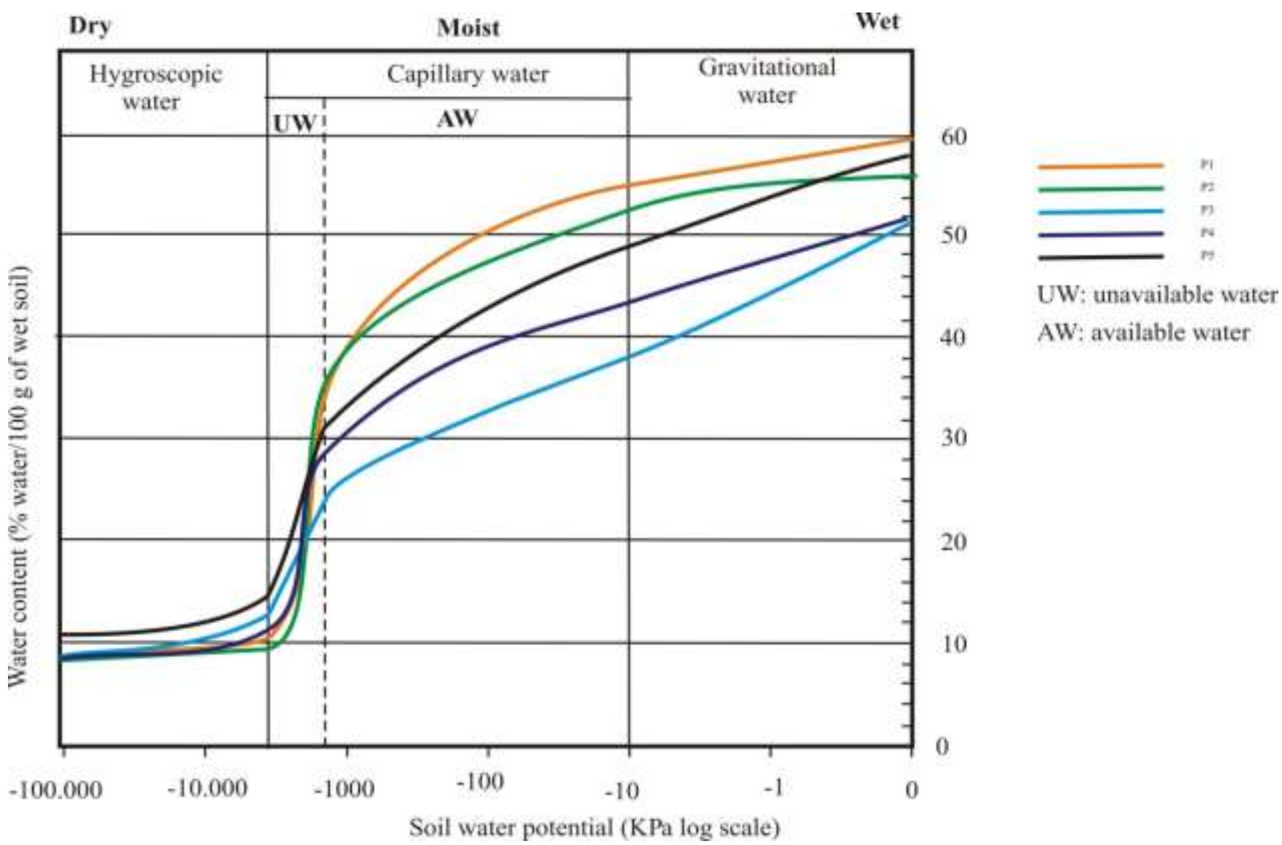

Figure 5. Soil-water characteristic (retention) curves of the different vertisol profiles (smooth curves fitted by cubic spline method).

Table 5. Distribution of soil water contents into classes (GEPPA, 1981).

Class parameter	1	2	3	4	5	6	7
Appreciation	Very low	Low	Low to moderate	moderate	Moderate to high	High	Very high
Water holding capacity (mm)	<60	60-100	100-150	150-300	300-450	450-600	>600
Available water (mm)	<30	30-50	50-75	75-150	150-225	225-300	>300
Readily available water (mm)	<20	20-35	35-50	50-100	100-150	150-200	>200

vertisols.

The capillary water of vertisols is high, held to soil particles by weak surface tension forces and is available to plants. During conditions of water stress, capillary water plays a vital role in maintaining crop performance. This is because soil desiccation is faster at the surface than at depth causing a higher water tension (pF) at the surface than at depth; this creates a water capillary current which moves from base to surface and, hence, water rises to the surface to be available to plants (Costa et al., 2015).

The moisture contents at field capacity and permanent wilting points were high for all the profiles, although lower for P_4 and P_5. These two parameters are mostly affected by the heavy clayey texture (Nordt and Driese, 2009). It seems that lower clay content tends to lower the field capacity and permanent wilting points like for P_3 and P_4. Similar results have been reported in Ethiopia by Page (1984) and Haider et al. (1988).

The water-holding capacity and plant available water capacity values were moderate to high for individual horizons, but global sums of values for each profile revealed very high water-holding and available water capacities according to GEPPA standards (GEPPA, 1981). The available water capacity of vertisols has been reported as 110.00 mm/m in Australia (Stace et al., 1968), 125.00 mm/m in the Sudan (Jewitt et al., 1979) and 230.00 mm/m in India (Gardner et al., 1988) for the uppermost metre depth of the soil profile. The moisture content in deeper layers decreases, apparently due to

Table 6. First two eigenvectors generated from the principal component analysis of the vertisol variables.

Variables	Principal components	
	PC 1	PC 2
	Clay /VIfc/VIod /COLE/AWC/RAW/ WHC / FC/Pfc/Pod/Dbfc/Dbod	PWP
Dbfc	-0.73*	0.35
Dbod	0.76*	0.52
Dp	0.38	0.65
COLE	0.84*	-0.08
VIfc	0.82*	-0.14
VIpwp	-0.80*	-0.43
Pfc	0.88*	-0.12
Pod	-0.79*	-0.45
Clay	0.89*	-0.36
OC	-0.55	-0.69
EC	0.17	0.54
FC	0.73*	-0.62
PWP	0.63	-0.71*
AWC	0.80*	0.10
RAW	0.80*	0.10
WHC	0.80*	0.10
AC	-0.53	0.58
Total loadings[A]	8.91	3.37
% variance explained	52.42	19.86
Cumulative % variance explained	52.42	72.28

Extraction method, Principal Component Analysis. Dbfc, bulk density at field capacity; Dbod, bulk density at oven-dry state; Dp, particle density; COLE, coefficient of linear extensity; VIfc, void ratio at field capacity; VIpwp, void index at permanent wilting point; Pfc, Porosity at field capacity; Pod, porosity at oven-dry state; OC, organic carbon content; EC, electrical conductivity in mmmhos/cm; FC, field capacity; PWP, permanent wilting point; AW, available water; RAW, readily available water; WHC, water-holding capacity; AC, air capacity; A, Sums of squared loadings; * Significant loadings exceeding ±0.70.

compression effect on matric potential (Rawls et al., 1982; Costa et al., 2015). These parameters are mostly affected by clay contents, profile depth, bulk density, and organic matter contents (Baize and Jabiol, 1995; Kamgang et al., 2011; Fasina et al., 2015). Duchaufour (1997) reported that particle size is inversely proportional to the force required to hold the water in the profile; this implies that the energy developed by a plant to extract this water may also be very high for those vertisols. The abundance of clayey fraction and a flat topography (<1% slope) further favour their water-holding potentials. Specifically, some factors like the hardness and presence of cracks when at dry state, high plasticity at humid state, very low infiltration rate and surface ponding could equally affect the water-holding capacity of vertisols.

The PWP-to-clay ratio ranged from 0.4 (well dispersed clays) to 0.6 (poorly dispersed clays). The surface horizons show higher ratios close to 0.6 for all studied profiles indicating that the organic matter might be playing a vital role in water retention (since it increases water content at 1500 kPa) and also helps to stabilise clays. However, the FAO (2006) reported that other soil-related factors might be causing deviation from the 0.4 value like the presence of low activity clays, and the occurrence of clay minerals within sand and silt fraction.

Repercussions of moisture properties on agricultural management strategies

Soil moisture has a major influence on a range of hydrological processes including flooding, erosion, solute transport and land–atmosphere interactions, as well as a range of geographic and pedogenic processes (Western et al., 2004; Patil et al., 2012; Fasina et al., 2015).

The high water retention of vertisols ensures safer and more productive cropping (Duchaufour, 1997; Gardner et al., 1988). It can assist crops to survive and even to grow during prolonged dry periods. Also, a high moisture-storage capacity permits crops to continue to grow for

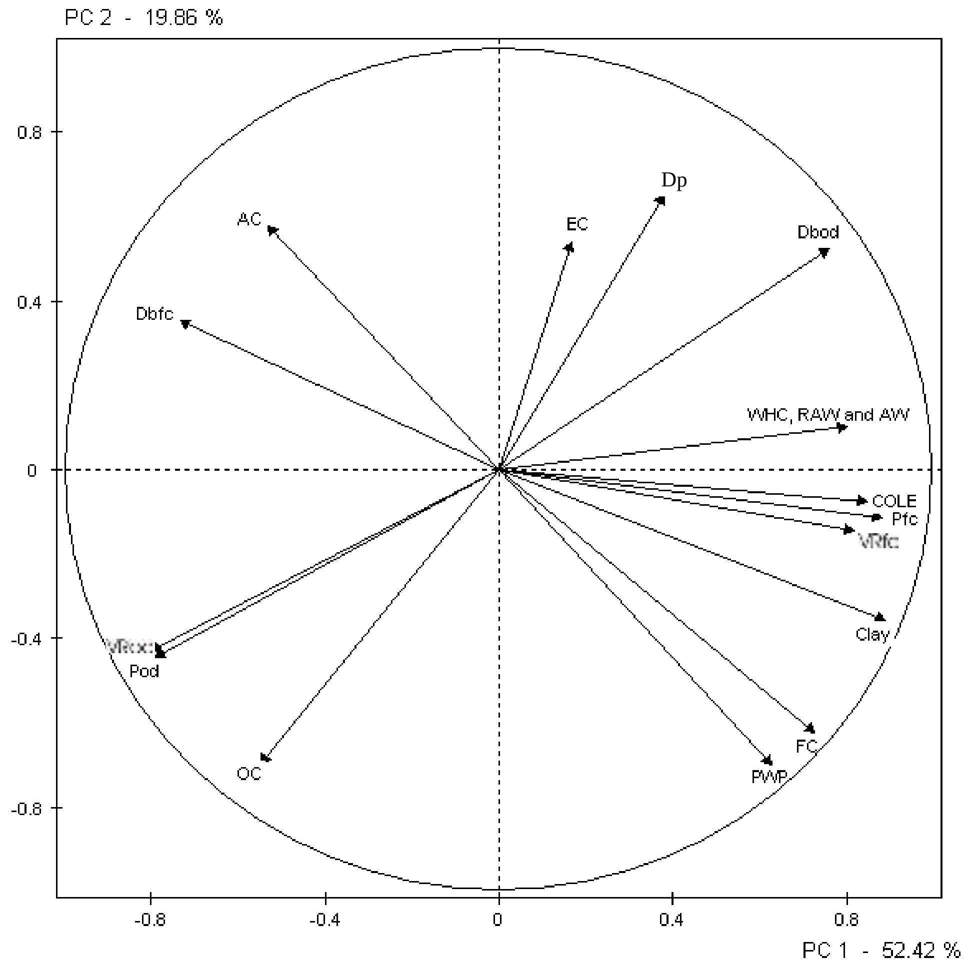

Figure 6. Graphical plots of the first two principal components on a factorial plane. Dbfc, bulk density at field capacity; Dbod, bulk density at oven-dry state; Dp, particle density; COLE, coefficient of linear extensity; VRfc, void ratio at field capacity; VRpwp, void ratio at permanent wilting point; Pfc, Porosity at field capacity; Pod, porosity at oven-dry state; OC, organic carbon content; EC, electrical conductivity; FC, field capacity; PWP, permanent wilting point; AW, available water capacity; RAW, readily available water; WHC, water-holding capacity; AC, air capacity.

several weeks after the cease of the rainy season ended,making it possible to cultivate two crops per year. However, despite their agricultural potentials, the vertisols presented numerous constraints to agricultural exploitation.

Their high plasticity causes them to stick to farm tools thus making tillage and weed control very difficult in the rainy season. The high bulk density is detrimental to plant growth on vertisols because few roots can penetrate a soil with bulk density above 1.60 g cm^{-3} (Cabidoche and Voltz, 1995; Likibi, 2010; Li et al., 2014). Tillage on vertisols is extremely difficult in the dry state, unless high energy machinery is used. Eswaran and Cook (1988) showed that optimum bulk density for plant growth is attained only when the vertisol structure offers the highest air content, since soil air is in continuous competition with soil water. Soil aeration and the possibility of normal plant development are indissociable and water storage capacity is an indicator of gaseous transfer (Duchaufour, 1997). This implies that a high air capacity enables an uninterrupted root and plant development. However, when all the pores become water-saturated during periods of flooding, air content reduces drastically hence compromising root respiration (Laroche, 1996; Pal et al., 2012; Li et al., 2014).

The surficial desiccation cracks of vertisols have several indirect effects on the crop performance (Kovda et al., 2017). Due to shrinkage and cracking, the water is not readily available to the roots, although the cracks might favour infiltration of water to deeper parts of the profile following the first rains (Eswaran and Cook, 1988; Pal et al., 2012).

In North Cameroon, attempted solutions involve developing management innovations to mitigate these constraints. Thus, farmers simply do not grow crops during the rainy season but rather on residual moisture of non-tilled soils at the end of the rains (Ambassa-Kiki et al., 1996). Also, most vertisols have simply been reserved for grazing, charcoal burning, forest reserves and small post-rainy season farming (Seiny Boukar et al., 1992; Ambassa-Kiki et al., 1996; Patil et al., 2012). Sowing into a dry seedbed ahead of the rains, growing crops on a raised bed to provide drainage and using furrows and waterways to conduct excess water from a watershed are all part of mitigation measures. Moisture conservation while inducing uniform soil wetting and maintaining suitable surface tilth requires deep tillage prior to the first rains. Mulching with plant residues, addition of non-vertisolic soils (alfisols, tank-silt, laterite, etc) could considerably help to drain excess water faster than the traditional flat seed beds (Astatke et al., 1995). This would enable early planting as opposed to traditional late planting. An established network of contoured ditches often help channel run-off and keep much of the surface water from causing erosion. Also, enclosed basins without drainage outlet, as earth-bunded rice plots, have been reported (Ambassa-Kiki et al., 1996). Similar types of land management systems have already been practised in Ethiopia for several decades (Desta, 1988). Some countries with vertisols (Argentina, Australia, Ghana, India, etc) have directed special attention to surface drainage through cambered beds, ridges, furrows, bunding, broadbanks, increasing fallow moisture accumulation by decreasing soil evaporation and storm runoffs, using rain when it falls by opportunity cropping, and matching crop strategies to plant available water and climate (Seiny Boukar et al., 1992; Coulombe et al., 1996; Corbeels, 2015). Moisture conservation during the dry season and removal of excess water during the wet season are crucial management practices clearly differentiating vertisols from other soil groups (Eswaran and Cook, 1988). The very high available water capacity of vertisol calculated from field capacity and permanent wilting point is often deceptive as not all the water is readily available to plants in the absence of water stress (Corbeels, 2015). At the end of the rainy season, the challenge is to reduce evapo-transpiration losses and conserve soil moisture so that a succeeding crop can be grown using stored moisture (Gardner et al., 1988).

Over all, vertisols form a considerable agricultural potential, but adapted management is a precondition for sustained production. Management practices for crop production ought to be primary directed at water control in combination with conservation of their fertility level.

Conclusions

The present work reveals that the topomorphic vertisols of the Benue floodplain in north Cameroon show deep profiles (2.00-2.50 m above the water table), a dark grey color, a heavy clayey texture, high coefficients of linear extensively (0.11-0.27 cm/cm), low organic matter and very low electrical conductivity. At field capacity, they show a very low bulk density, high porosity and a high void index. At oven-dry state, they exhibit very high bulk density (1.80-2.20 g cm^{-3}), very low porosity and very low void index. This high degree of reversibility with changing moisture content is related to vertic movements imposed by dominant montmorillonitic mineralogy. The moisture properties revealed very high water-holding capacity, very high plant available water, very high readily available water and very low air contents. Most of the vertisol characteristics are significantly correlated with the soil water properties, either negatively or positively; clay content best correlated with most of the soil properties. The PCA revealed a reduction of the 17 original variables to two principal components that explained more than 70.00% of the total variance expressed. These results suggest a strong relationship between the soil physico-chemical and moisture properties indicating that management practices for crop production on vertisols must be primarily directed at water control.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Ambassa-Kiki R, Aboubakar Y, Boulama T (1996). Zero-tillage for rice production on Cameroonian vertisols. Soil and Tillage Research 39:75-84.

Astatke A, Saleem Mohamed MA, El Wakeel A (1995). Soil water dynamics under cereal and forage legume mixtures on drained vertisols in the Ethiopian highlands. Agriculture and Water Management 27:17-24.

Aydinalp C (2010). Some important properties and classification of vertisols under Mediterranean climate. African Journal of Agricultural Research 6:449-452.

Azinwi Tamfuh P (2005). Petrological and analytical study of the vertisols of the Garoua Region (North Cameroon). Masters thesis, Fac. Sc., Univ. Yaounde 1, Yaounde, Cameroon, 72 p.

Azinwi Tamfuh PT (2012). Petrological, physico-chemical and mechanical study of the Benue watershed vertisols (Nord Cameroon): spatial analysis and agricultural potential evaluation. Th. Doc. PhD. Fac. Sc, Univ. Yaoundé I, 183 p.

Azinwi Tamfuh P, Djoufac Woumfo E, Tabi FO, Boukong A, Mvondo Ze AD, Bitom D, Kamgang Kabeyene VB (2016). Morphology, Physico-chemical Characteristics, Nutritional Status and Fertility Capability Classification of the Benue Floodplain Vertisols in North Cameroon. Journal of Geography, Environment and Earth Science International 6(1):1-15.

Azinwi Tamfuh P, Djoufac Woumfo E, Bitom D, Njopwouo D (2011). Petrological, physico-chemical and mechanical study of the topomorphic vertisol of the sudano-sahelian region of north Cameroon. The Bentham Open Geology Journal 5:33-55.

Baize D, Jabiol B (1995). Guide pour la description des sols. Éditions INRA, Paris. https://prodinra.inra.fr/?locale=en#!ConsultNotice:114525

Bhattacharyya T, Pal DK, Wani SP, Sahrawat KL (2016). Resilience of the semi-arid tropical soils. Current Science 110(9):1784-1788

Bruand H, Duval JP, Gaillard H, Darthout P, Jamagne M (1996). Variabilité des propriétés de rétention en eau des sols: importance de la densité apparente. Étude et Gestion des sols 3(1):12-28

Cabidoche YM, Voltz M (1995). Non-uniform volume and water content changes in swelling clay soil: II. A field study on a Vertisol. European Journal of Soil Science 46:345-355.

Chow VT, Maidment DR, Mays LW (2012). Applied Hydrology. Tata McGraw Hill. New Delhi, India 572 p.

Coulombe CE, Dixon JB, Wilding LP (1996). Mineralogy and Geochemistry of Vertisols. In: Ahmad, M., Mermut, A.(eds). Vertisols and Technology for their Management Texas: Elsevier Science Publisher, Texas pp. 115-200.

Corbeels M (2015). Adoption potential for conservation agriculture in Africa: a newly developed assessment approach (QAToCA) applied in Kenya and Tanzania. Land Degradation and Develeopment 26:133-141.

Costa JL, Aparicio V, Cerdà A (2015). Soil physical quality changes under different management systems after 10 years in the Argentine humid pampa. Solid Earth 6:361-371.

Desta B (1988). Soil fertility Research on some Ethiopian vertisols. In: Jutsi SC, Haque I., McIntire J., shares J. (eds). Proceedings of the Conference on the management of vertisols in sub-Saharan Africa, Addis Ababa. pp.223-231.

Diaz N, Dietrich F, Cailleau G, Sebag D, Ngounou Ngatcha B, Verrecchia EP (2016). Can mima-like mounds be Vertisol relics (Far North Region of Cameroon, Chad Basin)? GEMOR P. 5522.

Djoufac Woumfo E, Elimbi N, Pancder G, Nyada RN, Njopwouo D (2006). Caractérisations physico-chimiques et minéralogiques des vertisols de Garoua (Nord Cameroon). Journal des Annales de Chimie et Sciences de Materiaux 1:75-90

Duchaufour P (1997). Handbook of pedology: sol-végétation-environment. Masson, Paris 291 p.

Eswaran H, Cook T (1988). Classification and management related properties of vertisols In: Jutsi SC, Haque I, McIntire J, shares J (eds). Proceedings of the Conference on the management of vertisols in sub-Saharan Africa, Addis Ababa pp. 64-84.

Etia PM (1980). Climate and Climatic Zones of Cameroon. In: JA (ed). Les Atlas Jeune Afrique, Paris, France pp. 16-19.

Food and Agriculture Organization (FAO) (2006). Guidelines for soil description, a framework for international classification, correlation and communication. FAO, Rome. http://www.fao.org/3/a-a0510e.pdf

Fasina AS, Raji A, Oluwatosin GA, Omoju OJ, Oluwadare DA (2015). Properties, Genesis, Classification, Capability and Sustainable Management of Soils from South-Western Nigeria. International Journal of Soil Science 10:142-152.

Fassil K, Yamoah C (2009). Soil fertility status and Numass fertilizer recommendation of typic hapluusterts in the Northern Highlands of Ethiopia. World Applied Science Journal 6:1473-1480.

Fassil K (2009). Silicon status and its relationship with major physico-chemical properties of vertisols in of Northern Highlands of Ethiopia. College of Dryland Agriculture and Natural Ressources Management Journal 1:74-81.

Groupe d'Étude des Problèmes en Pédologie Appliquée (GEPPA) (1981). Synthèse des travaux de la commission de cartographie 1971- 1981. GEPPA (Groupe d'Étude des Problèmes en Pédologie Appliquée), Paris, France.

Gardner EA, Coughlan KJ, Silburn DM (1988). Soil water measurement and management of vertisols in Queensland (Australia). In: Jutsi SC, Haque I, McIntire J, shares J (eds). Proceedings of the Conference on the management of vertisols in sub-Saharan Africa, Addis Ababa pp. 188-200.

Gidigasu SSR, Gawu SKY (2013). The Mode of Formation, Nature and Geotechnical characteristics of Black Cotton Soils - A Review. Standard Scientific Research and Essays 1(14):377-390.

Grossman RB, Brasher BR, Franzmeier DP, Walker JL (1968). Linear extensibility as calculated from natural-clod bulk density measurements. In : Grossman RB, Brasher BR and Franzmeier (eds). Soil Science Society of America Proceedings 32, Madison, USA. pp. 570-573.

Haider G, Hordofa T, Endale B (1988). Irrigation water management for cotton on vertisols in the middle awash region of Ethiopia. In: Jutsi SC, Haque I, McIntire J, shares J (eds). Proceedings of the conference on the management of vertisols in sub-Saharan Africa, Addis Ababa pp. 166-182.

Holtz RD, Kovacs WD (1981). Introduction to geotechnical engineering. Ecole Polytechnique de Montréal, Montréal.

Jabiol B (2001). L'eau dans le sol. FIF-ENGREF, Paris. http://graduateschool.agroparistech.fr/site.php?id=28&fileid=58

Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S, Jones R, Kilasara M, Le Roux P (2013). Soil Atlas of Africa. European Commission, Publications Office of the European. Union, Luxembourg 176 p.

Jones DE, Holtz WG (1973). Expansive soils, the hidden disaster. American Society of Civil Engineering Journal 31:87-89.

Kamgang KBV, Likibi B, Ndome Effoudou PE, Ekodeck GE (2011). Mineralogy and geochemistry of vertisols at Ferngo, Lake Chad basin: their potential as raw materials for fired bricks. Faculté des Sciences de l'Université de Yaoundé 1, série Science de la Nature et de la Vie 38(1):30-44.

Kovda I, Goryachkin S, Lebedeva M, Chizhikova N, Kulikov A, Badmaev N (2017). Vertic soils and Vertisols in cryogenic environments of southern Siberia, Russia. Geoderma 288:184-195.

Laroche A, Gallichand J, Lagacé R, Pesant A (1996). Simulating atrazine transport with HSPF in an agricultural watershed. Journal of Environmental Engineering 122(7):622-630.

Letouzey R (1980). PhytogeographicMap of Cameroon. In: JA, (ed).Les Atlas Jeune Afrique, Paris, France pp. 20-24.

Li W, Han P, Yu L, Shi Y, Duan H, Yang P (2014). Research of relationships between initial moisture content of sand soil and its nutrient loss in Hulun lake basin. Journal of Applied Science 14:2073-2078.

Likibi B (2010). Altérologie des formations superficielles de la région de Maroua et potentialités de leur valorisation. Thèse Doct., Université de Yaoundé 1, Yaoundé, Cameroun 251p.

Liu YY, Evans JP, McCabe MF, de Jeu RAM, van Dijk AIJM, Su H (2010). Influence of cracking clays on satellite estimated and model simulated soil moisture. Hydrology and Earth System Sciences 14:979-990.

Lozet J, Mathieu C (1986). Dictionnaire des Sciences du Sol. Lavoisier, Paris.

Nelson DW, Sommers LE (1982). Total carbon, organic carbon and organic matter. In `Methods of Soil Analysis´ Part 2, Buxton, D.R. (eds), American Society of Agronomy Inc. and Soil Science Society of America Inc.: Madison, USA. pp. 539-579.

Ngounouno I (1993). Pétrologie du magmatisme cénozoïque de la vallée de la Bénoué et du plateau Kapsiki (Nord Cameroun). Thèse Doct., Université de Pierre-et-Marie Curie, Paris, France 280p.

Ngounouno I, Deruelle B, Demaiffe D, Montigny R (1997). New data on the Cainozoic volcanism of the Garoua valley (Upper Benue trough, northern Cameroon). Journal de l'Academie des Science 325:87-94.

Nguetnkam JP, Kamga R, Villiéras F, Ekodeck GE, Yvon J (2007). Pedogenic formation of smectites in a vertisol developed from granitic rock from Kaélé (Cameroon, Central Africa). Clay Minerals 42:487-501.

Njitchoua R, Fontes JC, Zuppi, GM, Aranyossi JF, Naah E (1995). Use of Chemical and isotopic tracers in studying the recharge processes of the upper cretaceous aquifer of the Garoua basin, Northern Cameroon. In Proceedings of the Vienne Symposium pp. 363-372.

Nordt LC, Driese SG (2009). Hydropedological model of vertisol formation along the Gulf Coast Prairie land resource area of Texas. Hydrology and Earth Systems Sciences 13:2039-2053.

Oicha T, Cornelis W, Verplancke H, Nyssen J, Deckers J, Behailu M, Haile M, Goovaerts B (2010). Short-term effects of conservation agriculture on Vertisols under tef (Eragrostis tef (Zucc.) Trotter in the northern Ethiopian highlands. Soil and Tillage Research 106(2):294-302.

Olivry JC (1986). Fleuves et rivières du Cameroun. MESRES-ORSTOM 9, Paris 733 p.

Özsoy G, Aksoy E (2007). Characterization, classification and agricultural usage of vertisols developed on neogen aged calcareous marl parent materials. Journal of Biological and Environmental Sciences 1(1):5-10

Page SLJ (1984). Effects of the physical properties of two tropical Cotton soils on their permanent wilting point and relative humidity, in relation to survival and distribution of *Meloidogyne acronea*. Revue Nématologique 7(3):227-232.

Pal DK, Wani SP, Sahrawat KL (2012). Vertisols of tropical Indian environments: Pedology and edaphology. Geoderma 189:28-49.

Patil NG, Pal DK, Mandal C, Mandal DK (2012). Soil water retention characteristics of vertisols and pedotransfer functions based on nearest neighbour and neural networks approaches to estimate awc. Journal of Irrigation and Drainage Engineering 138:177-184.

Prusty BAK, Chandra R, Azeez PA (2009). Distribution of carbon, nitrogen, phosphorus and sulphur in the soil in a multiple habitat system in India. Australian Journal of Soil Research 47:177-189.

Rawls WJ, Brakensiek DL, Saxton KE (1982). Estimation of soil water properties. In: Transactions American Society of Agricultural Engineers. Michigan, USA pp. 1316-1328.

Reichert JM, Albuquerque JA, Reinert DJ, Kaiser DR (2010). Water retention estimation and plant availability for subtropical Brazilian soils. In: Reichert J.M., J.A. (ed). pp. 197-20019th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010. Brisbane, Australia.

Reynolds WD, Drury CF, Yang XM, Fox CA, Tan CS, Zhang TQ (2007). Land management effects on the near-surface physical quality of a clay loam soil. Soil Tillage Research 96:316-330.

Rhoades JD (1982). Cation exchanges capacity. In: Page, AL., Buxton, R.H. & Miller Keeney, D.R. (eds). Methods of soil analysis. Madison, UDA, American Society Agronomy 16:149-158.

Seiny Boukar L, Floret C, Moukouri Kuoh H, Pointanier R (1992). Dégradation des vertisols dans le Nord Cameroun: modification du régime hydrique des terres et tentatives de réhabilitation. In: Libbey J. (ed). pp. 287-294. Utilisation rationnelle de l'eau des petits bassins versants en zone aride. AUPELF-UREF, Paris.

Shainberg I, Alperrovitch N, Keren R (1988). Effect of magnesium on hydraulic conductivity of Na-smectite-sand mixtures. Clays and Clay Mineals 36:432-438.

Sridharan A, Nagaraj HB (2010). Hydraulic conductivity of remolded fine-grained soils versus index properties. Geotechnical and Geological Engineering 23:43-60.

Stace HCT, Hubble GD, Brewer R, Northcote KH, Sleeman JR, Mulcahy MJ, Hallsworth EG (1968). A handbook of Australian soils. Relim Tech. Publ., S. Australia. Terman, G.L. (1979). Advances in Agronomy 31:189. http://oar.icrisat.org/4038/1/0048

Temga JP, Nguetnkam JP, Balo MA, Basga SD, Bitom D (2015). Morphological, physico-chemical, mineralogical and geochemical properties of vertisols used in bricks production in the Logone Valley (Cameroon, Central Africa). International Reseearch Journal of Geology and Mining 5(1):20-30

Van Gool D, Tille P, Moore G (2005). Land evaluation standards for land resource mapping. 3rd edn. Natural Resources Assessment Group, Department of Agriculture, South Perth, Western Australia. Link: http://www.asris.csiro.au/downloads/state_agencies/tr298.pdf

Vilain M (1997). La production végétale. Lavoisier, Paris. https://www.unitheque.com/Livre/lavoisier_-_tec_et_doc/Agriculture_d_aujourd_hui/La_production_vegetale_Volume_2-33593.html

Western AW, Zhou SL, Grayson RB, McMahon TA, Schl GB, Wilson DJ (2004). Spatial correlation of soil moisture in small catchments and its relationship to dominant spatial hydrological processes. Journal of Hydrology 286:113-134

Wubie AA (2015). Review on vertisol management for the improvement of crop productivity in Ethiopia. Journal of Biology, Agriculture and Healthcare 5(12):92-102.

Yerima BPK, Van Ranst E, Sertsu S, Verdoodt A (2013). Pedogenic impacts on the distribution of total and available Fe, Mn, Cu, Zn, Cd, Pb and Co contents of vertisols and vertic inceptisols of the Bale Mountain area of Ethiopia 8(44):5429-5439.

Vol. 13(33), pp. 1747-1753, 16 August, 2018
DOI: 10.5897/AJAR2016.11622
Article Number: 30103C558120
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Nitrogen fertilization in *Oncidium baueri* seedling growth

Jenniffer Aparecida Schnitzer*, Osmar Rodrigues Brito and Ricardo Tadeu de Faria

Department of Agronomy, Center for Agrarian Sciences, State University of Londrina, UEL, Londrina –PR, Brazil.

Received 29 August, 2016; Accepted 18 January, 2017

This study was conducted with the objective of evaluating the nitrogen fertilization in orchid seedling formation. The experiment was conducted in a greenhouse environment with a coated polypropylene mesh with retention capacity of 60% of the solar radiation flux at the greenhouse of the Department of Agronomy of State University of Londrina – PR, Brazil. One year old seedlings of the orchid species *Oncidium baueri* has been used (Lindl.) from *in vitro* propagation, with an average height of 8.0 ± 1.0 cm. The experimental design was completely randomized with four replications and the treatments resulted from a 2×7 factorial design in which the factors were two sources (urea and ammonium sulfate) and seven doses of nitrogen applied fortnightly (0.00, 0.75, 1.50, 2.25, 3.00, 3.75, and 4.50 mg/pot). The experiment was conducted for a period of one year and the following variables were evaluated: largest pseudobulb length, plant height, highest root length, leaf area, root number, dry matter, number of leaves, and Dickson quality index. The use of ammonium sulphate resulted in the highest average values to the length of the longest pseudobulb, plant height, leaf area, length of the longest root, and plant dry matter, except for the number of leaves and Dickson quality index. The application of nitrogen between 3.20 and 4.33 mg/pot resulted in the highest values for the length of the longest pseudobulb, number of roots, length of the longest root, number of leaves, plant height and Dickson quality index for *O. baueri* (Lindl.) orchid. The plant height and leaf area variables increased significantly with increasing doses of N regardless of the source used, but the length of the longest pseudobulb, number of roots and dry matter production of plant only increased when urea was used as a nitrogen source.

Key words: Orchidaceae, nitrogen, fertilization, vegetative development.

INTRODUCTION

The Brazilian market of flowers and ornamental plants has been following the world-wide tendency of expansion, especially in exports of flowers and ornamental plants which had an average growth of 11.92% per year in the period of 2000 to 2010. Despite having small reductions in the last years of this period, in 2010 the equivalent of 28.68 million BRL has been sold (Junqueira et al., 2011).

In floriculture, usually species are sold as potted plants

*Corresponding author. E-mail: je_uel@yahoo.com.br.

and, currently, due to an increased demand it is becoming promising to grow species with cut flowers characteristics (Mattiuz et al., 2006). Orchids are grown commercially worldwide as cut flowers or potted and represent about 8% of the commerce of ornamental plants (Chugh et al., 2009).

Orchidaceae is considered the oldest and largest family between monocots and ornamental plants with 600 to 800 types and 25.000 to 35.000 species (Garay, 1960; Sheehan, 1983). Moreover, it represents 7% of sold ornamental plants in the world (Van Der Pijl and Dodson, 1966). It also presents a great diversity of species and hybrids including terrestrial, epiphytes and rock plants. Orchids are among the most prized ornamental plants due to the beauty of its flowers, which vary widely in size, shape, fragrance and color combination that attracts consumers and make the plants reach higher commercial values (Mattiuz et al., 2006). The orchid cultivation has evolved in recent years becoming an economically important activity, especially some genres like *Oncidium, Cymbidium, Dendrobium, Phalaenopsis, Laelia* and *Cattleya* which stand out both for the internal market and for the export market of cut flowers (Hew and Yong, 1997; Mattiuz et al., 2006).

The genus *Oncidium* includes 315 epiphytic species, which 30% (nearly 94 species) native of Brazil (Ferrarezi, 2002). The Brazilian species *Oncidium baueri* (Lindl). is regarded of great ornamental potential for use in landscaping projects and primarily as a cut flower (Lorenzi and Souza, 2001).

The ornamental plants fertilization is primordial because the plant quality is a strategic factor in this activity (Tuzzi, 2011). It is also a key factor for the production of quality flowers, being used as a complement or alternative method in the control of diseases (Locarno et al., 2011). Among the essential nutrients provided by chemical fertilizers, nitrogen, phosphorus and potassium must be applied at appropriate levels to the requirements of each crop (Haag et al., 1993).

According to Lone et al. (2010), the application of water soluble macro and micronutrients can be performed by foliaceous or root application, or both simultaneously. However, to proceed fertilization, it is important to know the different stages of orchids' development cycle, so that it is possible to define which manure will be employed in the correct form (Campos, 2002).

In general, low nitrogen availability is a factor which limits the growth and productivity of plants, since it is required in all phases of plant development (Fernandes and Rossielo, 1995; Marschner, 1995).

In Brazil, among the most consumed nitrogenous fertilizers urea, ammonium sulfate and ammonium nitrate stand out (Sangoi et al., 2003), which have high water solubility and ready availability to plants (Contin, 2007).

Of all nitrogen fertilizers, urea stands out for its handling ease, lower cost, high solubility and compatibility for use in combination with other fertilizers, which makes it, from the economic point of view, potentially superior to the other sources (Scivittaro et al., 2004; Primavesi et al., 2004). On the other hand, it is considered a likely source of nitrogen loss by volatilization, depending on temperature, soil moisture and the amount and form of application (Ribeiro, 1996).

Research on mineral nutrition of orchids is scarce; however, the species need the same nutrients as other crops for their development (Araujo et al., 2007). According to Bernardi et al. (2004) for the orchids production on a commercial scale is necessary to conduct research in order to optimize forms of fertilization that are more efficient and have lower costs.

Considering the lack of information about fertilization of orchids, this study was conducted to evaluate nitrogen fertilization on *O. baueri* (Lindl.) seedlings formation.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse covered with polypropylene mesh with 60% retention capacity of the solar radiation flux belonging to the Department of Agronomy at the State University of Londrina – PR, Brazil (23 23 'S, 51° 11'W; 566 m). The orchid seedlings used were from the species *O. baueri* (Lindl.) from *in vitro* propagation, with one year old and average height of 8.0 ± 1.0 cm.

For the setup of the experiment, plastic pots with 7.3 cm of height and 10.0 cm in diameter were used. At the bottom of each pot, a layer of brick fragments was added to facilitate the drainage of any excess irrigation water. When drainage occurred, the water was collected and reapplied to the vessel to prevent a loss of nutrients.

To avoid possible nutrient limitation at the initial stage of establishment of plants, 15 days before the transfer of the seedlings, the application of a mixture of salts (dc) calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) was made maintaining the ratio Ca:Mg (3:1) applied 1.2 g/pot. On transplantation day, all pots received the application of 10 ml of a complete nutrient solution containing all essential nutrients except nitrogen, calcium and magnesium, being applied 300, 150, 40, 0.81, 1.33, 0.15, 4.0, 3.66 and 1.55 mg/kg of soil (adapted in this experiment to substrate) of P, K, S, B, Cu, Mo, Zn, Mn and Fe, respectively, according to the recommendations of Novais et al. (1991).

The experimental design was completely randomized with four replications and the treatments resulted from a factorial 2×7 in which the factors were two N sources (urea and ammonium sulfate) and seven biweekly doses (0.00, 0.75, 1.50, 2.25, 3.00, 3.75 and 4.50 mg/pot). Fertilization with nitrogen was carried out by applying 15 ml/pot solutions, to ensure the supply of doses to be tested.

The substrate composed of pine bark mixture, carbonized rice husk and coconut fiber in proportion (1:1:1 v/v/v), in each pot was added 70 g of substrate mixture. During the twelve months of the trial period, irrigations were performed daily with the goal of maintaining the humidity of the substrate at 70% of its maximum capacity of water retention, by the weighing and reposition of transpired water.

At the end of a year of installation, the experiment was finished by collecting shoot and root materials which were later sent to the Soil Laboratory of the Department of Agronomy at the State University of Londrina, where the following evaluations were performed: length of the largest pseudobulb, width of the largest pseudobulb, plant height, number of pseudobulbs, number of leaves, leaf area, number of roots, number of shoots, and the

Table 1. The largest pseudobulb length (LPL) (cm), plant height (PH) (cm), the highest root length (HRL) (cm) *Oncidium baueri* according to sources and doses of nitrogen applied every two weeks during the twelve months of cultivation.

N (mg/pot)	SA	LPL	UR	SA	PH	UR	SA	HRL	UR
	cm								
0.00	2.73^{A}*	-	2.85^{A}	15.40^{A}	-	14.03^{A}	12.65^{A}	-	11.45^{A}
0.75	2.83^{A}	-	2.96^{A}	17.00^{A}	-	14.88^{B}	15.75^{A}	-	11.48^{B}
1.50	3.02^{A}	-	3.03^{A}	18.63^{A}	-	19.50^{A}	17.78^{A}	-	16.43^{B}
2.25	3.16^{A}	-	3.20^{A}	19.20^{A}	-	19.98^{A}	19.53^{A}	-	17.45^{B}
3.00	3.60^{A}	-	3.33^{B}	26.33^{A}	-	20.60^{B}	19.60^{A}	-	17.78^{B}
3.75	4.79^{A}	-	3.87^{B}	29.80^{A}	-	25.08^{B}	25.00^{A}	-	19.53^{B}
4.50	2.96^{B}	-	4.03^{A}	24.83^{B}	-	27.08^{A}	17.35^{A}	-	16.45^{A}
CV (%)	-	4.98	-	-	5.05	-	-	5.14	-
DMS	-	0.24	-	-	1.51	-	-	1.25	-

SA: Ammonium sulfate; UR: Urea. Averages followed by the same letter in the lines do not differ between themselves, for the test of Tukey to 5%.

longest root length. After these assessments, the materials were washed with tap and distilled water and packed in paper bags and submitted to drying in a forced air oven maintained at a constant temperature of 65°C to constant mass. Next, all materials were weighed obtaining the dry matter of the area and plant roots. The data were used to calculate the Dickson quality index (DQI).

The leaf area was estimated following the methodology proposed by Stickler (1961) and consisted of using the following equation: $AF = 0.7458 \times C \times L$, where AF is the leaf area (cm^2); C is the maximum leaf length (cm), measured between the insertion point in the stem to the end of the leaf blade; L is the web width, measured in the larger position; and 0.7458 is a correction factor.

For the final evaluation of the seedlings quality, the Dickson Quality Index (DQI) was calculated following the proposal of Dickson et al. (1960). This variable is used primarily to assess the quality of forest seedlings such as eucalyptus, pine, anjico, etc. The DQI was calculated by employing the following formula: IQD = MST / [(M / DBP) + (MSPA / MSR)], where MST = total dry weight of the plant; H = shoot height; DBP = pseudobulb base diameter (replacing the original diameter of the formula collect); MSPA = shoot dry mass, and MSR = dry weight of the root system

The data were submitted to variance analysis and when necessary average values were compared by Tukey test at 5% or adjusted by polynomial regression equations.

RESULTS AND DISCUSSION

For width of the largest pseudobulb, pseudobulbs number and number of sprouts, no significant effects of nitrogen sources and tested levels were observed, indicating that these characteristics are independent of the nitrogen fertilization management.

The length of the largest pseudobulb of *O. baueri* (Lindl.) was influenced both by the sources as the nitrogen levels. The use of ammonium sulfate at doses of 3.00 and 3.75 mg N/pot resulted in higher values for the length of the pseudobulbs (3.60 and 4.79 cm, respectively), which significantly differ from urea. With the dose of 4.50 mg/pot, the greater length of pseudobulb (4.03 cm) was obtained with the application of urea (Table 1).

The plant height was influenced by nitrogen sources and doses. The use of ammonium sulfate at doses 0.75, 3.00 and 3.75 mg N/pot resulted in the highest plants of *O. baueri* (Lindl.). For the highest dose tested (4.50 mg/pot), the use of urea determined most of the plant height (Table 1). Comparing the effect of the sources of supply of N in the length of roots of the orchid plant species *O. baueri* (Lindl.), it was observed that the highest values were obtained using ammonium sulfate up to the dose of 3.75 mg/pot of N, applied every two weeks (Table 1).

When considering the effect of the doses of nitrogen, significant variations in the length of the largest pseudobulb was observed for both used sources, the use of ammonium sulfate enhanced the length of the largest pseudobulb adjusted to quadratic models with larger length estimated for the dose of 3.70 mg/pots of N, while for the urea the increases were linear, indicating that it would further increase if higher doses of N were applied (Figure 1A).

It was not found in the literature works which would allow making direct comparisons. For the few studies found, the researchers used formulated fertilizers NPK or NPK + micronutrients in the fertilization of orchids, as in the case of Dronk et al. (2012) who did not observe significant difference in the pseudobulb length in a clone of orchid cultivated in different substrates fertilized with NPK 10-10-10, in the corresponding dose of application of 5 mg/pots of N, and phosphorus and potassium.

For the two tested sources, significant effects of nitrogen rates for height of orchid plants were observed, setting the linear models with slightly higher values for ammonium sulfate (Figure 1B). Linear adjustment in this case indicates that two evaluated sources for the growth of plants still occurring of N rates higher than those tested were applied.

Similar results were obtained by Ferreira et al. (2007) when working with seedlings of bromeliad (*Neoregelia*

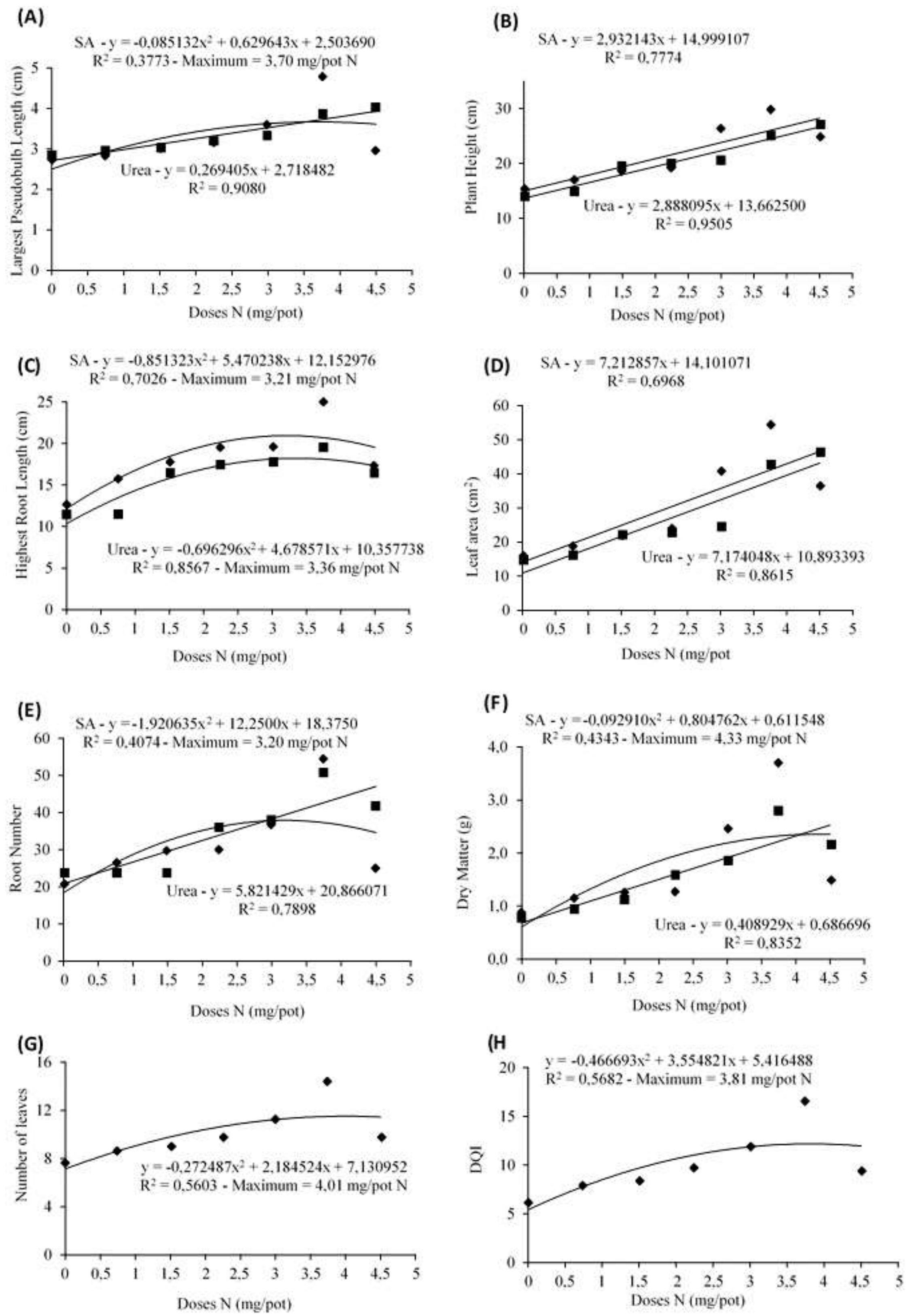

Figure 1. The largest pseudobulb length (A), plant height (B), highest root length (C), leaf area (D), dry matter (E), root number (F), Number of leaves (G) and Dickson Quality Index (DQI) for *Oncidium baueri* seedlings (H) according to sources and doses of nitrogen applied every two weeks during the twelve months of cultivation.

Table 2. Leaf area (LA) (cm²), number of roots/plant (NR), dry plant matter (DPM) of *Oncidium baueri* according to sources and doses of nitrogen applied every two weeks during the twelve months of cultivation.

N (mg/pot)	SA	LA	UR	SA	NR	UR	SA	DPM	UR
		cm^2						g	
0.00	15.96^{A}*	-	14.69^{A}	20.75^{A}	-	23.75^{A}	0.88^{A}	-	0.78^{A}
0.75	18.77^{A}	-	16.12^{A}	26.50^{A}	-	23.75^{A}	1.15^{A}	-	0.94^{A}
1.50	22.00^{A}	-	22.09^{A}	29.75^{A}	-	23.75^{A}	1.26^{A}	-	1.12^{A}
2.25	23.96^{A}	-	22.78^{A}	30.00^{B}	-	36.00^{A}	1.27^{A}	-	1.59^{A}
3.00	40.79^{A}	-	24.48^{B}	36.75^{A}	-	38.00^{A}	2.46^{A}	-	1.86^{A}
3.75	54.40^{A}	-	42.72^{B}	54.50^{A}	-	50.75^{A}	3.70^{A}	-	2.80^{B}
4.50	36.44^{B}	-	46.38^{A}	25.00^{B}	-	41.75^{A}	1.49^{B}	-	2.16^{A}
CV (%)	-	19.14	-	-	7.78	-	-	26.38	-
DMS	-	7.83	-	-	3.66	-	-	0.63	-

SA: Ammonium sulfate; UR: Urea. Averages followed by the same letter in the lines do not differ between themselves, for the test of Tukey to 5%.

cruenta), checked linear increases for height of the plants with the fortnightly application of urea solution of 0.1 and 2% by foliaceous pulverization. However, the results partially agree with those presented by Lone et al. (2010) who checked larger length of the air part of the hybrid *Cattleya intermedia Graham* ex Hooker × *Laelia purpurata* Lindley (Orchidaceae) with the fortnightly application of 200 mg of N/L using the formulated fertilizer 10-10-10. Bernardi et al. (2004) that worked with applications of 5.25, 10.51, 15.76. 21.01, 26.26 and 31.52 mg/pots, of nitrogen in the form of NH4+ and NO3- by solution of Sarruge (Sarruge, 1975) and observed linear growth increases of the *Dendrobium nobile* (Orchidaceae) plants, even working with two plants per pot.

For the purpose of doses, it was observed for the two tested sources, that the length of the largest root increased progressively with increasing N rates, significantly adjusting the quadratic functions. The maximum length of roots was estimated for the application of 3.21 and 3.36 mg/pot of N using ammonium sulfate and urea, respectively (Figure 1C). Similar results were observed by Wen and Hew (1993); Pan and Chen (1994) which found a greater root growth of the *Cymbidium sinense* orchid, with the conjoint application of nitrate and ammonium forms of N as supplemental fertilization. Ferreira et al. (2012) working with Orchid *Cattleya bowringiana,* micropropagated plantlets *in vitro* and observed a greater root length when nitrogen fertilization is used at a rate of 28.88 mg/pot of ammonium nitrate to the crop average.

Regarding the leaf area, significant differences between nitrogen sources only occurred at doses greater than 2.25 mg/pot of N. That is, at doses of 3.00 and 3.75 mg/pot of N, the highest averages were observed when using ammonium sulfate. However, with the dose of 4.50 mg/pot, the largest leaf area was obtained with the application of urea (Table 2). A similar result was observed by Oliveira et al. (2010) who found that the provision of 100 mg/dm^3 of nitrogen using ammonium sulfate provided a larger leaf area in ornamental sunflower plants than for plants fertilized with urea and calcium nitrate.

Concerning the number of plant roots, no differences were observed between the N sources to the dose of 1.50 mg/pot. Above this dose, the behavior was not regular, because sometimes the application of ammonium sulfate and the application of urea had the highest average values for the number of roots per plant (Table 2).

The results partially agree with those presented by Lone et al. (2010) who found an increasing number of hybrid roots *C. intermedia* Graham ex Hooker × *L. purpurata* Lindley (Orchidaceae) when twice a week a solution was applied which provided 10 mg/tray of N using a solution prepared with the fertilizer 10-10-10. In a study evaluating the effects of mineral fertilizer in orchid, Araujo et al. (2007) also had higher numbers of roots/plant in a *Cattleya loddgesii* ("Alba" × *C. loddgesii* "Atibaia") hybrid grown in trays (24 plants/tray) using foliar fertilization twice a week. The best result was obtained when the solution prepared with liquid fertilizer 08-09-09 contained 400 mg/L of N.

For the production of dry matter of the plants differences between sources of N were not observed until the dose of 3.00 mg/pot. At the dose of 3.75 mg/pot of N, the production was higher when using the ammonium sulfate and at the dose of 4.50 mg/pot, the urea use resulted in higher yield (Table 2).

When considering the effect of doses linear increases in leaf area were observed for the two tested sources, indicating that this variable can reach higher values with increases nitrogen rates (Figure 1D). According to Skinner and Nelson (1995) and Garcez Neto et al. (2002), a specific N supply is required because this nutrient is directly related to cell division and the elongation processes and therefore with the size and leaf area of each plant.

The results obtained partly agree with those found by Wang (1996), where by using six different commercial formulations of fertilizers, found linear increases in leaf area from 275 to 355 cm² for orchid plants of the genus *Phalaenopsis,* with increasing N concentration in the irrigation solution from 100 to 200 mg/L of N, regardless of the formula of the used fertilizer. According to Fernandez et al. (1994), nitrogen fertilization, regardless of the source considered, in addition to increasing the size and hence the leaf area also increases the leaf biomass accumulation rate.

When considering the dose effect to the number of plant roots, significant variations were observed for both sources of nitrogen. With the use of ammonium sulfate, it was possible to estimate the maximum number of roots with the application of 3.20 mg/pot. However, when the N source was urea, the root number increased linearly with tested doses, not allowing to estimate the dose which determines the maximum point (Figure 1E).

When considering the unique effects of doses of N in dry matter production of orchid plants, significant differences were observed for the two tested sources. When using ammonium sulfate, dry matter production of plant was set to the quadratic model allowing to estimate the maximum point for the dose of 4.33 mg/pot of N, while for urea, the increases were linear, not being possible to estimate the maximum point (Figure 1F).

The results corroborate those obtained by Oliveira et al. (2010), who worked with ornamental sunflower fertilized with 100 mg dm^{-3} of N and had higher dry matter production of plants with ammonium sulfate than with urea or calcium nitrate as nitrogen sources. The authors attributed the improved performance of ammonium sulfate to the likely contribution of the sulfur contained in the fertilizer to the improved nutritional balance of plants. The results also agree with those presented by Bernardi et al. (2004) who obtained an increase in the accumulation of reserves in the shoots of *Dendrobium nobile* (Orchidaceae) by increasing N rates of 21.01 and 26.26 mg/pot grown with two plants using Sarruge solution with 100 and 125% of the original concentration.

The number of leaves per plant differed significantly only with the tested doses of nitrogen. Thus, it was possible to determine the maximum number of leaves per plant with the dose of 4.01 mg/pot of N (Figure 1G).

Similar results were obtained by Wang and Gregg (1994) who also found increases in the number of leaves in the second year of cultivation of *Phalaenopsis* (Orchidaceae), with the increase of fertilization, using a formulated NPK fertilizer. Wang (1996) working with *Phalaenopsis* found an increase in the number of leaves when the N concentration was changed from 100 to 200 mg/L of irrigation solution with a commercial fertilizer composed of nitrogen, phosphorus and potassium. It can be said also that the results are similar to those presented by Amaral et al. (2009) who obtained more bromélia leaves (*Orthophytum gurkenii*) with an application of 250 mg N/plant using ammonium sulfate.

The Dickson quality index (DQI) is a variable commonly used for overall evaluation of quality seedlings of forest species, fruit, medicinal and perennial crops such as *Eucalyptus grandis* (Gomes et al., 2002), *Mikania glomerate* (Vidal et al., 2006), *Pinus taea (*Rossi et al., 2008), *Coffea arábica* (Marana et al., 2008) and *Erythrina velutina* (Melo and Cunha, 2008). This index is associated with the fixation success and survival of seedlings in the field. For Silva et al. (2002), good quality seedlings will ensure lower mortality reducing spending on replanting.

Adapting these situations to orchid seedlings, it can be said that good quality seedlings (larger DQI) will ensure lower losses for lack of fixation after transplantation and production of best quality flowers to meet the requirements of consumers and the commercial product enhancement. In this study, the DQI for the seedlings orchids *O. baueri* (Lindl.) was influenced only by nitrogen doses regardless of tested sources. In this case, it was possible to estimate that the maximum values for the DQI were obtained with application of dose 3.81 mg/pot of N (Figure 1H).

Conclusions

The use of ammonium sulfate resulted in higher average values for all tested variables except for number of leaves and Dickson quality index. Except for the largest root length, the use of urea in the highest dose tested always resulted in higher average values for other variables evaluated. For the variable largest pseudobulb length, number of root, highest root length and dry matter, maximum values were obtained with doses of 3.70, 3.20, 3.21 and 4.33 mg/pot of N, respectively, for the ammonium sulfate and 3.36 mg/pot of N, the largest root length when using urea. The plant height and leaf area of *O. baueri* (Lindl) increased significantly with increasing nitrogen rates regardless of the source used, but the largest pseudobulb length, number of roots and the production of dry matter only increased when urea was used as a nitrogen source. The number of leaves and the DQI were significantly influenced only by doses of nitrogen, being possible to estimate the maximum points for the doses of 4.01 and 3.81 mg/pot, respectively.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Amaral TL, Jasmim JM, Nahoum PI, Freitas CB, Sales CS (2009). Adubação nitrogenada e potássica de bromeliáceas cultivadas em fibra de coco e esterco bovino. Horticultura Brasileira 27(3):286-289.

Araujo AG, Pasqual M, Dutra LF, Carvalho JG, Soares GA (2007). Substratos alternativos ao xaxim e adubação de plantas de orquídeas na fase de aclimatização. Ciência Rural 37(2):569-571.

Bernardi AC, Faria RT, Carvalho JFRP, Unemoto LK, Assis AM (2004). Desenvolvimento vegetativo de plantas de *Dendrobium nobile* Lindl. fertirrigadas com diferentes concentrações da solução nutritiva de sarruge. Semina: Ciências Agrárias 25 (1):13-20.

Campos DM (2002). Orquídeas: manual prático de cultura. 3:140-141.

Chugh S, Guha S, Rao U (2009). Micropropagation of orchid: a review on the potential of different explants. Scientia Horticulturae 122:507-520.

Contin TLM (2007). Uréia tratada com inibidor da uréase NBPT na adubação de cana de açúcarcolhida sem despalha à fogo. Dissertação (Mestrado em Agricultura Tropical e Subtropical) – Instituto Agronômico de Campinas, Campinas 69f.

Dickson A, Leaf AL, Hosner JF (1960). Quality appraisal of white spruce and white pine seedling stock in nurseries. The Forestry Chronicle 36:10-13.

Dronk AG, Silva APV, Cuquel FL, Faria RT (2012). Desenvolvimento vegetativo de híbrido de orquídea em diferentes substratos. Semina: Ciências Agrárias 33(6):2109-2114.

Fernandes MS, Rossiello ROP (1995). Mineral nitrogen in plant physiology and plant nutrition. Critical Reviews in Plant Sciences 14(2):111-148.

Fernandez S, Vidal D, Simón E, Solé-Sugrañes L (1994). Radiometric characteristics of *Triticum aestivum* cv. Astral under water and nitrogen stress. International Journal of Remote Sensing 15(9):1867-1884.

Ferrarezi E (2002). As espécies do gênero *Oncidium* Sw. Sensu lato (Orchidaceae) do Estado do Paraná. Monografia Universidade Estadual de Londrina.

Ferreira CA, Paiva PDO, Rodrigues TM, Ramos DP, Carvalho JG, Paiva R (2007). Desenvolvimento de mudas de bromélia (*Neoregelia cruenta* (R. Graham) L.B. Smith) cultivadas em diferentes substratos e adubação foliar. Ciência e Agrotecnologia 31(3):666-671.

Garay LA (1960). On the origin of the orchidaceae. Botanical Museum Leaflets of Harvard University 19(3):57-96.

Gomes JM, Couto L, Leite HG, Xavier A, Garcia SLR (2002). Parâmetros morfológicos na avaliação da qualidade de mudas de *Eucalyptus grandis*. Revista Árvore 26(6):655-664.

Haag HP, Dechen AR, Carmello QQC, Monteiro FA (1993). Princípios de nutrição mineral; aspectos gerais. In: Simpósio sobre nutrição e adubação de hortaliças, 1, 1990, Piracicaba. Anais...Piracicaba: Associação Brasileira para Pesquisa da Potassa e do Fosfato pp. 51-73.

Hew CS, Younh JWH (1997). The physiology of tropical orchids in relation to the industry. World Scientific 331 p.

Junqueira AH, Peetz MS (2011). Balanço do comércio exterior da floricultura Brasileira. Boletim de Análise Conjuntural do Mercado de Flores e Plantas Ornamentais no Brasil. Disponível em: <http://www.grupocultivar.com.br>. Acesso em: 18 de novembro de 2012.

Locarno M, Fochi CG, Paiva PDO (2011). Influência da adubação silicatada no teor de clorofila em folhas de roseira. Ciência e Agrotecnologia 35(2):287-290.

Lone AB, Takahashi LSA, Faria RT, Assis AM, Unemoto LK (2010). Desenvolvimento vegetativo de orquídeas submetidas a diferentes formulações de macronutrientes e freqüência de adubação durante a fase de aclimatização. Semina: Ciências Agrárias 31(4):895-900.

Lorenzi H, Souza HM (2001). Plantas ornamentais do Brasil. Arbustivas, herbáceas e trepadeiras. 3.ed. Nova Odessa: Instituto Plantarum 1088p.

Marana JP, Miglioranza E, Fonseca EP, Kainuma RH (2008). Índice de qualidade e crescimento de mudas de café produzidas em tubetes. Ciência Rural 38(1):39-45.

Marschner H (1995). Mineral Nutrition of Higher Plants. Academic Press, London 889 p.

Mattiuz CFM, Rodrigues TJD, Mattiuz B (2006). Aspectos fisiológicos de orquídeas cortadas. Revista Brasileira de Horticultura Ornamental 12:21-30.

Melo RR, Cunha MCL (2008). Crescimento inicial de mudas de mulungu (*Erythrina velutina* Wild.) sob diferentes níveis de luminosidade. Ambiência – Revista do Setor de Ciências Agrárias e Ambientais 4:1.

Novais RF, Neves JCL, Barros NF (1991). Ensaios em ambiente controlado. In: Métodos de pesquisa em fertilidade do solo. EMBRAPA 392 p.

Oliveira FA, Oliveira FRA, Campos MS, Oliveira MKT, Medeiros JF, Silva O MP (2010). Interações entre salinidade e fontes de nitrogênio no desenvolvimento inicial da cultura do girassol. Revista Brasileira de Ciência do Solo 5(4):479-484.

Primavesi AC, PrimavesI O, Corrêa LA, Cantarella H, Silva AG, Freitas AR, Vivaldi LJ (2004). Adubação nitrogenada em capim-coastcross: efeitos na extração de nutrientes e recuperação aparente do nitrogênio. Revista Brasileira de Zootecnia 33(1):68-78.

Ribeiro AC (1996). Como evitar a perda do nitrogênio de adubo por volatilização**.** Boletim Informativo da SBCS 21(2):43-446.

Rossi VL, Amarante CVT, Fleig FD (2008). Crescimento e qualidade de mudas de *Pinus taea* L. submetidas à poda química de raízes. Ciência Florestal 18(4):435-442.

Sangoi L, Ernani PR, Lech VA, Rampazzo C (2003). Volatilização de N-NH_3, em decorrência da forma de aplicação de uréia, manejo de resíduos e tipo de solo, em laboratório. Ciência Rural 33:687-692.

Sarruge JR (1975). Soluções nutritivas. Summa Phytopathologica 1(3):231-233.

Scivittaro WBS, Oliveira RP, Morales CFG, Radmann EB (2004). Adubação nitrogenada na formação de porta-enxertos de limoeiro 'cravo' em tubetes. Revista Brasileira de Fruticultura 26(1):131-135.

Sheehan TJ (1983). Recent advances in botany propagation and physiology of orchids. Horticultural Reviews 5:279-315.

Silva RF, Antoniolli ZI, Andreazza R (2002). Efeito da inoculação com fungos ectomicorrízicos na produção de mudas de *Eucalyptus grandis* W. Hill ex Maiden em solo arenoso. Ciência Florestal 13(1):33-42.

Skinner RH, Nelson CJ (1995). Elongation of the grass leaf and its relationship to the phyllochron. Crop Science 35(1): 4-10.

Stickler FC, Wearden S, Pauli AW (1961). Leaft area determination in grain sorghum. Agronomy Journal 53:187-188.

Tuzzi M (2011). Produção e comercialização de plantas ornamentais na Empresa Fazenda do Jardim. Universidade Federal de Santa Catarina – UFSC, Trabalho de Conclusão do curso de graduação em agronomia.

Van Der Pijl L, Dodson CH (1966). Orchid flowers: Their pollination and evolution 214 p.

Vidal LHI, Souza JRP, Fonseca EP, Bordin I (2006). Qualidade de mudas de guaco produzidas por estaquia em casca de arroz carbonizada com vermicomposto. Horticultura Brasileira 24:26-30.

Wang YT, Gregg LL (1994). Medium and fertilizer affect the performance of *Phalaenopsis* Orchids during two flowering cycles. HortScience 29(4):269-271.

Wang YT (1996). Effects of six fertilizers on vegetative growth and flowering of *Phalaenopsi*s Orchids. Scientia Horticulturae 65:191-197.

Wen ZQ, Hew CS (1993). Effects of nitrate and ammonium on photosynthesis nitrogen assimilation and growth of *Cymbidium sinense*. Journal Singapore National Academy of Sciences 20/21:21-23.

Related Journals: