African Journal of Agricultural Research

Volume 12 Number 42 19 October, 2017
ISSN 1991-637X

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Vol. 12(42), pp. 3081-3087, 19 October, 2017
DOI: 10.5897/AJAR2017.12505
Article Number: 53F08A166387
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Livestock herders' perception on the causes and effects of *Senna obtusifolia* L. invasion in rangelands of Northern Ethiopia

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Received 7 June, 2017; Accepted 11 September, 2017

Livestock herders' perception on the invasion and effects of *Senna obtusifolia* L. were gotten from two locations (Kafta Humera and Tsegede) in Northern Ethiopia. From each location, three peasant associations were selected using key formants and group discussion. The invasion level of *S. obtusifolia* L. was higher near settlements and road side of continuously grazed lands of the study area. *S. obtusifolia L.* invasion is negatively affecting the grazing lands of the study area. Highly palatable grasses and herbaceous legume species were identified to be increasingly rarer from *S. obtusifolia* L invade grazing lands. Although unpalatable, herbaceous species was increased in invaded sites in the study area. The replacement of highly palatable grasses and legume species by less palatable and unpalatable herbaceous species in *S. obtusifolia* L infested grazing lands. This resulted in the shortage of quality and quantity forage for grazing animals near settlements leading to long distance travelling to search for animal feed, and subsequently with the reduction of livestock productivity. Although, *S. obtusifolia* invasion negatively affect the herbaceous vegetation and livestock productivity with no measure taken into place to control its invasion. Therefore, the collaboration of all stakeholders is needed to optimize the negative impacts of *S. obtusifolia* invasion.

Key words: Grazing lands, group discussion, invasive species, key informants, palatable herbaceous species.

INTRODUCTION

Plant invasion presents a serious threat to biodiversity management and conservation in many parts of the world (Grice, 2006). Invasive plant species that are hazards have shown detrimental environmental and socio economic impacts in East African dry lands (Obiri, 2011).

Invasive species remain one of the most understudied in developing countries (Pysek et al., 2008). In semi-arid rangelands, based on their impact and effect on grazing areas and natural pastures, invasive species cause massive losses in livestock production. Consequently, animal production in arid and semi-arid regions are faced with the problem of animal feed supply due to shortage of

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the growth of herbaceous species and biomass yield in rangelands (Boufennara et al., 2012).

Non-native invasive species can directly affect native communities by altering species richness, evenness, or diversity in recipient communities (Wardle et al., 2011). Non-native invasive plant species are well known threats to native ecosystems (Mack et al., 2000). Previous studies (Tessema et al., 2011; Solomon et al., 2007) reported that the excessive plant defoliation of rangelands by grazing damages plant tissues, and the compaction reduces plant species diversity and the percentage cover of the herbaceous vegetation which resulted in the disappearance of perennial grass species.

Subsequently, unpalatable and grazing tolerant annual species became dominant in heavily grazed patches and increase in the population of other non-woody, less palatable, unpalatable and poisonous plant species (Solomon et al., 2007). *Senna obtusifolia* L. is an aggressive invader of pasture and can completely dominate grass species, eradicating pasture growth and excluding stock. Carrying capacities can be reduced by as much as 85% (Mackey et al., 1997).

Rangeland degradation was identified as a serious problem in lowlands of western Tigray which resulted from the expansion of cultivation, continuous heavy grazing due to the high livestock pressure in a very limited area and population pressure due to re-settlement schemes (Solomon, 2015).

Expansion of legal and illegal cultivation and grazing practices, locally dubbed '*woferzemet*' was also increased from time to time as reported by Lemenih et al. (2014). These factors have resulted in the reduction of coverage in grazing lands available for communal grazing by livestock. In addition to its reduction in size, the grazing lands are poorly managed consequently, herbaceous invaders such as *Sennaobtusifolia, Acanthospermumhispidum* and *Xanthium abyssinicum* started to increase (Solomon and Yayneshet, 2014; Solomon, 2015).

Teame et al. (2014) also reported that invasive herbaceous species of *S. obtusifolia L.* invaded the lower altitude near the settlement and road sides in grazing areas of Tigray Region, Northern Ethiopia. Community perception plays an important role in natural resource management. Since herders are in close contact with their environment and livestock, they have rich knowledge about their environment, livestock and resource (Tafesse and Kassaye, 2004).

Through herding, they understood the ecological process and the relationship with the environment. However, there is no evidence regarding the livestock herders' perception on the causes and effects of *S. obtusifolia L*. invasion in rangelands of Northern Ethiopia. Therefore, the study was conducted with the objective of investigating livestock herders' perception on the causes and effects of *S. obtusifolia L*. invasion in rangelands of Western Zone Tigray Region, Northern Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Western Zone of Tigray, Northern Ethiopia. The geographical location of the study area is 13°42′ to 14°28′ north latitude and 36°23′ to 37°31′ east longitude (Mekonnen et al., 2011) sharing borders with Tahtay Adibayo Woreda, Sudan, Amhara region and Eritrea in the East, West, South and North respectively (Figure 1).

The altitude of the study area ranges from 500 to 3000 masl and consists of three agro-ecological zones (lowland, midland and highland) in which *kola* (lowland) represents 75%, *weynadegga* (midland) account for 15.7% and *dega* (highland) account for 9.3% of the land coverage of the zone. The zone receives annual rainfall which ranges from 600 to 1800 mm with maximum and minimum temperatures of 45°C and 12°C, respectively (ZOIC, 2015).

The study area, western Tigray covers a total area of 1.5 million hectares. The current coverage of grazing lands comprises of 116921.9 hectares (7.79%) from the total land cover. The total livestock population of the zone account for 767527, 87339, 579847, 1190, 1059, 62564, 8104, 811677 and 27451 for Cattle, Sheep, Goats, Horses, Mules, Donkeys, Camels, Poultry and Beehives, respectively (CSA, 2015).

The major livestock feed resources in the study area are natural pasture, crop residues, woody browses (shrubs, bush and tree) and other simple feed such as stubble, hay and tree foliages in which the majority of the feed resource are covered by natural pasture, and followed by crop residues (Gebrehaweria, 2011).

Selection of sampling sites

Purposive sampling procedure was followed to select two locations in the study area, Kafta Humera and Tsegede districts on the incidence of invasiveness of *S. obtusifolia L.* and three peasant associations (PAs) from each district of Baeker, Tirkan and Ruwasa from Kafta Humera, and Dedebit, Lekatit and Werie from Tsegede were selected purposively again based on the infestation of the invading species. According to ILCA (1990), field observation was followed by reconnaissance field trips with key informants prior to the group discussion throughout the study area with the purpose of assessing a general overview of the nature and distribution of invading species, and to evaluate herbaceous species structure at flowering stage of almost all herbaceous species.

Data collection

Prior to the group discussion, field observation was followed by reconnaissance field trips with 5 key informants from each sampling site (PAs). A total of 30 key informants (2 locations * 5 key informants * 3 PAs) were used in order to extract background information on the invasion status and effects of the invading species on the grazing lands. Following the field observation, group discussions were held with a total of 72 livestock herders (2 locations * 12Livestock herders * 3 PAs) to extract background information about their grazing lands in both locations and 3 PAs separately. For the group discussion, relevant questions were prepared in relation to the causes and effects of *S. obtusifolia* L. invasion. The livestock herders were selected by the development agents purposively depending on their experience in herding and rearing livestock.

Data analysis

Ranking analysis: Livestock herders' group discussion data related

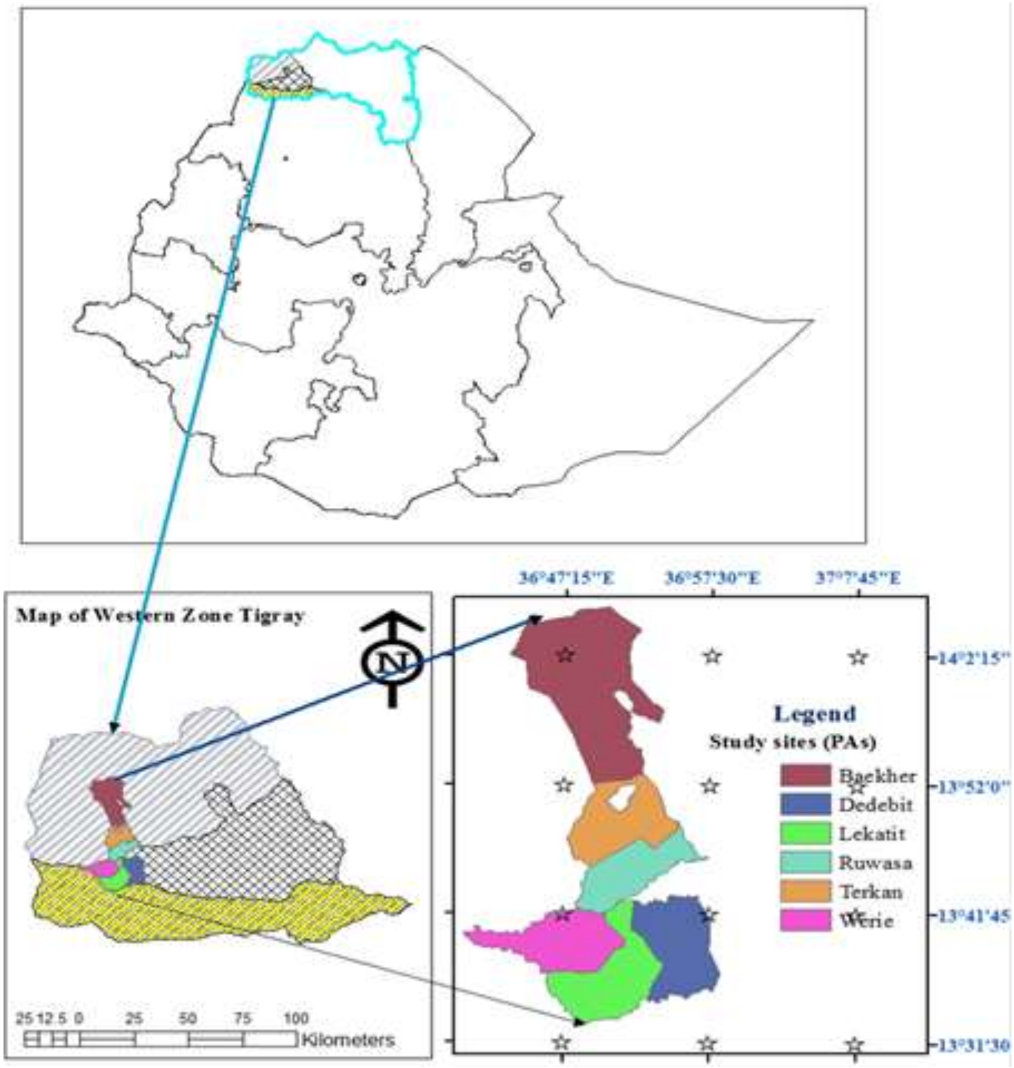

Figure 1. Gebrekiros (2016a) location map of the study area, western zone of Tigray region, Northern Ethiopia using ARC GIS 10.1.

to militating factors for invasion and main effects of *S. obtusifolia* L. invasion on their grazing lands and livestock productivity were analyzed using ranking index method (Musa et al., 2006).The index was computed as:

$$\text{Index} = \frac{\sum (7 * \text{rank } 1 + 6 * \text{rank } 2 + \cdots + 1 * \text{rank } 7) \text{ for an individual causing factors}}{\sum (7 * \text{rank } 1 + 6 * \text{rank } 2 + \cdots + 1 * \text{rank } 7) \text{ for all causing factors for invasion}}$$

A similar index was calculated for ranking the main effects of *S. obtusifolia* L. invasion. Values were assigned according the ranking order; highest value (7) was given for the first rank and lowest value (1) for the least (7th) rank in both items of the militating factors for invasion and main effects of *S. obtusifolia* L. invasion.

RESULTS AND DISCUSSION

Livestock herder's perception on the invasion of *S. obtusifolia* L.

In both study locations, the entire key informants and the focus group agreed that the degree of *S. obtusifolia* L. invasion was seen near the settlements and road side of the study area due to frequent allocation and overgrazing of their livestock. This was similar to the finding of Teame et al. (2014) who reported that *S. obtusifolia* L. invaded the lower altitude near the settlement of continuously grazed patches of Western Tigray Region, Northern Ethiopia.

Both key informants and participants of the discussions also indicated that the reason (causing factors) for the accelerated invasion of *S. obtusifolia* L. were encroachment of extensive cultivation, illegal cultivation

Table 1. Rank for main causes for Infestation of *S. obtusifolia* L. in grazing lands of Northern Ethiopia.

Causing factors for invasion	Rank index			
	NGD	N	Index	Rank
Encroachment of extensive cultivation	6	38	0.229	1
Continuous grazing in limited areas	6	33	0.199	3
Poor management of grazing lands	6	20	0.120	5
Reduction of grazing lands in size	6	22	0.133	4
Road construction	5	8	0.048	6
Re settlements programs	5	8	0.048	6
Illegal cultivation and grazing practices ('*woferzemet*')	6	37	0.223	2
Total	**-**	**166**	**1.00**	**-**

Source: Focus group discussion from 6 PAs (2016) of the study area. NGD: Number of group discussion.

and grazing practices (locally called 'woferzemet'), continuous grazing in limited areas, reduction of grazing, poor management of grazing lands, road construction and resettlements in rangelands of the study area which leads to continuous overgrazing in limited area of grazing lands.

Subsequently, unpalatable and grazing tolerant annual species became dominant in heavily grazed patches. This finding agrees with the reports of Tessema et al. (2011) and Solomon (2015) who indicated the dominance of unpalatable species in heavily grazed areas. The livestock herders perceived that encroachment of extensive cultivation was ranked as the first cause of *S. obtusifolia* L, followed by illegal cultivation and grazing practices (locally called '*woferzemet*'), continuous overgrazing in limited areas, reduction of grazing lands and poor management of grazing lands in size ranked from second up to fifth, respectively. Road construction and resettlements programs were ranked last (Table 1).

The encroachment of extensive cultivation towards the grazing lands was due to high population pressure which resulted from the resettlements schemes and illegal cultivation and grazing practices (locally called '*woferzemet*' meaning go and loot inside the grazing lands) which leads to over cultivation and over grazing of the limited grazing lands that speeds up the infestation of the invading species (Table 1).

Livestock herder's perception on the effects of *S. obtusifolia* L.

The participants of the field trip and group discussion argued that in the past 5 years, *S. obtusifolia* L. had rapidly increase its infestations on the continuously grazed patches in the near settlements similar to the report of Teame et al. (2014) and Bio Net-Eafrinet (2011). As a result, it is seen as a displaced native herbaceous species according to Mackey et al. (1997).

Consequently, some important and highly palatable grasses species such as *Pennisetum pedicellatum, Echinochloa spp, Rottboelia cochinchinensis, Dinebra retroflexa* and *Setaria pallide-fusca,* and legume species such as *Rhaynochosia minima, Rahynochosia malacophylla* and *Ipomoea purprea* which were dominant species of the grazing lands are being replaced by less palatable and unpalatable herbaceous species in *S. obtusifolia* L. infested grazing lands of the study area.

Subsequently, unpalatable herbaceous species such as *S. obtusifolia* L. itself*, Xanthium abyssinicum and Acanthospermum hispidum* replaced the grazing lands of the study area in consistence with previous findings of Solomon (2015) and Gebrehaweria (2011). The replacement of highly palatable grasses and legume species by less palatable and unpalatable herbaceous species in *S. obtusifolia* L. infested grazing lands of the study area resulted to the shortage of quality and quantity forage for grazing animals near settlements, leading to long distance travelling to search for animal feed, and subsequently with the reduction of livestock productivity.

According to the key informants and livestock herders in the group discussion, animal food shortage, livestock poisoning, decline in animal holding per household, death of livestock, decline in herbaceous vegetation, decline of animal productivity and soil erosion were identified as main effects of *S. obtusifolia L*. invasion effects in the grazing lands of Northern Ethiopia.

The participants of the group discussion perceived that decline in herbaceous vegetation (palatable species) was ranked as the first effects of *S. obtusifolia* L. invasion, followed by animal food shortage and decline of animal productivity in the study area. Soil erosion was rank as the last and followed by livestock poisoning as impacts of *S. obtusifolia* L. invasion in grazing lands of the study area (Table 2).

According to the personal and key informant's field observation, *S. obtusifolia* L. has been able to germinate early in the beginning of wet season and attain maturity early in the mid wet season before the native herbaceous species (Figure 2). Its early germination and maturation was able to take an advantage to form dense cover over the native herbaceous species. Consequently, it

Table 2. Rank for main effects of *S. obtusifolia* L. invasion in grazing lands of Northern Ethiopia.

Effects of invasion	Rank index			
	NGD	N	Index	Rank
Decline of animal productivity	6	30	0.189	3
Decline in animal holding per household	6	24	0.151	4
Animal food shortage	6	36	0.226	2
Death of livestock	5	14	0.088	5
Decline in herbaceous vegetation	6	42	0.264	1
Soil erosion	3	6	0.038	7
Livestock poisoning	3	7	0.044	6
Total	**-**	**159**	**1.000**	**-**

Source: Focus group discussion from 6 PAs (2016) of the study area. NGD: Number of group discussion.

Figure 2. Gebrekiros (2016b) Photograph showing early germination and maturation of *S. obtusifolia* L. at three consecutive stages of growth from western zone of Tigray region, Northern Ethiopia.

suppresses the growth of palatable native herbaceous vegetation (Figure 2).

This finding is in line with previous study of Dorning and Cipollini (2006) who noted that invading species negatively affects native species in reducing germination, growth, survival and reproduction. Awodoyin and Ogunyemi (2008) confirmed that *S. obtusifolia* L. has the ability to grow fast and forms a close basal cover, which was able to recycle nutrients from the subsoil and suppress the growth of other herbaceous species.

Therefore, the dominance of *S. obtusifolia* in these grazing areas reduced the performance and seed production of the palatable native herbaceous vegetation's which are essential for the grazing animals, thereby promoting the invading species to increase its seed contribution to the soil seed banks and consequently, observed with increase in its infestation in the grazing lands in time and space (Figure 2).

However, no action was taken yet by the Woreda zonal level and kebelle level in Kafta Humera to control its invasion. Unlike Kafta Humera, farmers in Tsegede tried to reduce the impact of *S. obtusifolia* L. by hand weeding at its early stage and mowing at the flowering stage. But it was not practiced in organized manner at the kebelle level. The livestock herders in Tsegede perceived that hand weeding at its early stage of the invading species is an effective measure of controlling even though it is tedious to control vast areas, and also they indicate that the invasive species emerge (germinate) once per a production season. But mowing at the mid stage of the invading species had an adverse effect on animal and human being foot injuring due to its hard stem after mowing.

The key informants agreed that the invading species has more adverse effects to the environment and economy of the study area by monopolizing the grazing lands. As a result, they perceived that it needs urgent interventions involving all stakeholders (Governmental institutions, Local None Governmental institutions, Local Community and others) to control the spread of the species, which is currently at an unprecedented rate spread. Community and others) to control the spread of the species, which is currently at an unprecedented rate.

CONCLUSION AND RECOMMENDATION

S. obtusifolia L. invaded the lower altitude near the settlement and road side of continuously grazed patches in Western Tigray Region, Northern Ethiopia. Some important and highly palatable grasses species such as *P. pedicellatum, Echinochloa spp, R. cochinchinensis, D. retroflexa* and *S. pallide-fusca,* and legume species such as *R. minima, R. malacophylla* and *Ipomoea purprea* which were dominant species of the grazing lands were replaced by less palatable and unpalatable herbaceous species in *S. obtusifolia* L. infested grazing lands of the study area. Subsequently, unpalatable herbaceous species such as *S. obtusifolia* L. itself*, Xanthium abyssinicum and A. hispidum* replaced the grazing lands of the study area.

Senna obtusifolia L. was able to germinate and attain maturity early before the native herbaceous species, growing fast and forms a close basal cover over the native herbaceous species. Consequently, this suppresses the growth of native herbaceous vegetation via shading effect. S. obtusifolia L. invasion negatively affect herbaceous vegetation composition of the grazing lands of the study area which are used as animal forage which are desirable herbaceous species. As a result, livestock productivity is declining.

In the study area, collective action of the local community and other stakeholders to rehabilitate degraded lands are widely practiced. However, such important activities are not practiced in controlling invasive plant species. Therefore, collective actions of local community and all stockholders in controlling the invasion of *S. obtusifolia* should be practiced.

For better and effective control of the invading species, management approaches need to be perceived by local community aiming for socio-economic, as well as ecological sustainability. Therefore, awareness creation should be given to the local community on the negative impacts of *S. obtusifolia* invasion to optimize control success.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

ACKNOWLEDGMENTS

The author would like to extend his earnest indebtedness to Tigray Agricultural Research Institute (TARI) and Humera Agricultural Research Center (HuARC) for the financial grant. He would also like to express his deepest respect and heart-felt appreciation to the farmers (Livestock herders) and development agents of the study area for their cooperation throughout the entire study.

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Vol. 12(42), pp. 3088-3098, 19 October, 2017
DOI: 10.5897/AJAR2017.12642
Article Number: DA4966266390
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Characterization of sweet potato accessions in Malawi using morphological markers and farmers' indigenous knowledge system (IKS)

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Received 9 August, 2017; Accepted 29 August, 2017

Characterization of landraces is central to any conservation measures devised for sweet potato in Malawi. Studies were therefore conducted using seven morphological descriptors and farmers' indigenous knowledge systems (IKS) to investigate the phenotypical diversity of 286 landraces and 35 introductions of sweet potato from the north, south east and lower Shire. The accessions were planted in a check plot design at Bvumbwe Agricultural Research Station. The results showed that farmers' knowledge (IKS) is a means for preliminary characterization of accessions as evidenced by elimination of 75 duplicate accessions by 12 farmers. Analysis of variance (ANOVA) showed that all accessions and populations were phenotypically variable ($p \leq 0.01$) and Chi-square test of the morphological descriptors used in the study varied significantly among the three eco-geographical areas and among the landraces and introductions ($p \leq 0.05$ and $p \leq 0.01$), implying high variability of the accessions. However, the accessions clustered at 50% dissimilarity and generally irrespective of eco-geographical origin, signifying some similarity probably due to gene flow. Shannon Weaver Diversity Index (H') indicated that different traits had different source areas of highest diversity which were significantly different (**$p \leq 0.05$); nonetheless Shire Valley had the highest mean diversity for all traits (H'=0.67) which was significantly different from the other two populations** (**$p \leq 0.05$) inferring that the lower shire would be ideal for *in situ* conservation of sweet potato diversity.**

Key words: Field evaluation, germplasm, phenotype, population, root crop, variability.

INTRODUCTION

Plant genetic resources for food and agriculture (PGRFA) which comprise diversity of genetic material contained in landraces, modern cultivars, wild relatives and other wild species are the basis of global food security (Rao, 2004). Sweet potato (*Ipomoea batatas* (L.) Lam) is one of the most important staple and food security root crops in the world, ranked second after cassava in area and production in the tropical and sub-tropical regions (FAOSTAT, 2012; Boney et al., 2014). In the Sub-Saharan Africa, over 3 million hectares are under sweet potato cultivation (Low and Van Jaarswels, 2008).

In Malawi, sweet potato comes second after cassava as a food security root crop and is most widely grown in the country as evidenced by its production increase of 370% between 1995 and 2006 (Famine Early Warning System/Ministry of Agriculture and Food Security (FEWS/MoAFS), 1995, 2006). While the crop is traditionally important in Malawi, especially during years of drought which affect maize production negatively, little research in its landraces variability and associated productivity has been done. It is generally accepted that an understanding of genetic variability, which is manifested through phenotypic differentiation, is vital for any crop improvement through possible choice of appropriate selection and breeding programs (Demelie and Aragaw, 2016). Thus establishment of levels of phenotypic or morphological variations and detection of variants and possible duplicates is irreplaceable for genetic improvement and conservation of sweet potato (Lin et al., 2007). Morpho-agronomic characterization enables efficient utilization of germplasm collections in breeding programs by provision of links between genetic relationships and specific traits of agronomic importance, including tuber yield and yield components (Khoury et al., 2010; Elameen et al., 2011; Laurie et al., 2013; Mohammed et al., 2015). Owing to relative ease of study and inexpensiveness, morphological characters have been variously used to characterize and differentiate sweet potato accessions, assess comparative reaction and susceptibility to pests, diseases and other stresses etc. (Yada et al., 2010; Elameen et al., 2011; Vimala et al., 2012; Norman et al., 2014; Rahman et al., 2015; Amoatey et al., 2016; Mbithe et al., 2016; Su et al., 2016). Therefore, this study was conducted to characterize existing local and introduced sweet potato accessions in order to evaluate phenotypic diversity for effective utilization in breeding programs.

MATERIALS AND METHODS

Germplasm collection

Collection of sweet potato germplasm accessions was conducted following guidelines from Karonga, Mzuzu, Blantyre and Shire Valley Agricultural Development Divisions (ADDS) offices (Figure 1) which indicate areas of high production and varietal diversity in Malawi. A total of 268 accessions were collected from farmers' fields in 2004 in Karonga, Chitipa, Mzimba, Mulanje, Phalombe, Nsanje and Chikwawa districts (Figure 1 and Table 1) and brought to Bvumbwe Agricultural Research Station for planting and field evaluation before morphological characterization in the successive years. The collection districts and the experimental site were characterized by different altitudes, longitudes and latitudes, soils, rainfall amounts and temperatures (Table 2).

Differentiation of sweet potato accessions by farmers using indigenous knowledge system (IKS)

A complementary study by 12 experienced sweet potato farmers (key informants) who grew large numbers of cultivars per field and randomly sampled from survey areas of Chikwawa and Nsanje was done at Bvumbwe Agricultural Research Station field at harvesting time. The farmers, who were not donors of germplasm from Chikwawa and Nsanje Districts, were subjected to interviews aimed at verifying their knowledge regarding cultivar names and meanings, cultivar distinguishing attributes, uses and cropping systems. The complementary study was conducted to assess if the accessions collected were a true representation of the cultivars grown in the two districts by either identifying cultivars in the Bvumbwe field or providing a list of missing cultivars. Involvement of the key informants also facilitated identification of obvious duplicates and accessions tagged as 'unknowns'. The farmers were first interviewed individually and indoors using a questionnaire to give names and characteristics of cultivars grown in their area. After indoor interviews, farmers were asked to identify accessions in the Bvumbwe field. The complementary study was also designed to reveal similarities or differences between the Northern and Southern Region collections with the aid of farmers.

Experimental design

Sweet potato vines (25 to 30 cm long) were planted along the ridges at 30 cm apart on 24th and 28th of January, 2004 and 2005, respectively following standard procedures which included plots laid in a check plot design consisting of 2 tractor ploughed ridges of 3 m long and 90 cm apart. For each accession, 10 cuttings were planted on a 3 m ridge in two replicates. The fields were weeded using hand hoes. Fertilizer and pesticides were not used in the field. The same design was implemented each year.

Morphological characterization

Following procedures outlined by Huaman et al. (1999), key morphological descriptors (Table 3) were used to conduct detailed comparisons aimed at isolation of potential duplicates among the accessions. Characterization of sweet potato above ground morphology started at 80 to 100 days after planting in accordance with recommendations outlined by Mok and Schmiediche (1998). Seven International Board for Plant Genetic Resources (IBPGR) descriptors for sweet potato (CIP et al., 1991; Huaman, 1991), with

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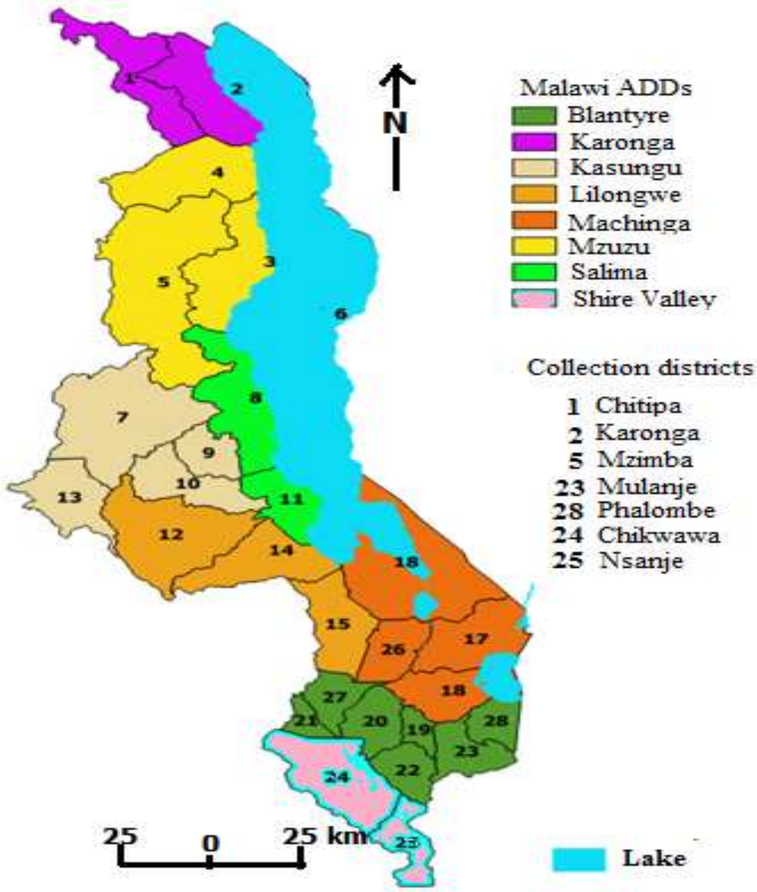

Figure 1. Map of Malawi showing sweet potato accessions collection sites and Agricultural Development Divisions (ADDs).

Table 1. Number of sweet potato accessions collected per district and farmer in Malawi.

District	Accessions per district		Number of farmers per district			Cultivars per farmer	
	Number	%	Interviewed	Donors	%	Mean	Maximum
North							
Chitipa	58	22	20	12	60	4.83	12
Karonga	29	11	20	8	40	3.62	6
Mzimba	46	17	20	13	65	3.54	12
South							
Chikwawa	42	16	20	11	55	3.81	8
Nsanje	77	29	20	12	60	6.41	16
South East							
Phalombe	12	4	20	4	20	3.00	3
Mulanje	4	1	20	2	10	2.00	2
Total	268	100	140	62	44		
Mean	38.26	14.29	20	8.86	44	3.85	8.43
± SD	25.54			4.34		1.40	5.16

SD = standard deviation.

Table 2. Eco-geographical characteristics of sweet potato accessions collection and experimental sites

Eco-geographical site	Classifying variable
Northern Region (Chitipa, Karonga, Mzimba)	Mid to high altitude (700 to 1500 m. a. s. l), soil type (lithosols), annual rainfall range (900-1209 mm), mean temperature range (16.9 to 27.3°C)
South Eastern Region (Phalombe, Mulanje)	Mid altitude (600 to 700 m. a. s. l), soil types(Ferruginous), annual rainfall range (800-1629 mm), mean temperature range (17.8 to 29.0°C)
Lower Shire Valley (Chikwawa, Nsanje)	Low altitude (100 to 200 m. a. s. l), soil type (alluvial soils), annual rainfall range (890-1142 mm), mean temperature range (20.9 to 32.7°C)
Bvumbwe Agricultural Research Station	High altitude (1164 m. a. s. l), soil type (Ferruginous), mean annual rainfall (1219 mm), mean temperature range (12.0 to 26.7°C)

m. a. s. l = Meters above sea level

Table 3. Phenotypic classes of morphological traits used for diversity analysis in sweet potato in seven districts in Malawi.

Character	Abbreviation	Characteristic	IBPGR/ CIP code	No. of classes
Vine inter node length	VL	Very short (<3 cm); short (3 to 5 cm); intermediate (6 to 9 cm); Long (10 to 12 cm); very long (>12 cm)	1, 3, 5, 7, 9	5
Vine inter node diameter	VD	Very thin (< 4 mm); thin (4 to 6 mm); intermediate (7 to 9 mm); thick (10 to 12 mm); very thick (>12 mm)	1, 3, 5, 7, 9	5
Vine tip hairiness	TP	None; sparse; moderate; heavy; very heavy	0, 3, 5, 7, 9	5
Leaf lobe number	LN	1, 3, 5, 7, 9	1, 3, 5, 7, 9	5
Petiole pigmentation	PP	Green; green with purple near stem; green with purple near leaf; green with purple at both ends; green with purple stripes; purple with green near leaf; some petioles purple others green totally and mostly purple	1, 2, 3, 4, 5, 6, 7, 8, 9	9
Storage root shape	RS	Round; round elliptic; elliptic; obovate; ovate; oblong; long oblong; long elliptic; long irregular or curved.	1, 2, 3, 4, 5, 6, 7, 8, 9	9
Predominant flesh colour	FC	White; cream; dark cream; pale yellow; dark yellow; pale orange; intermediate orange; dark orange; strongly pigmented with anthocyanins	1, 2, 3, 4, 5, 6, 7, 8, 9	9
Total classes				47

VL= Vine internode length; VD=Vine internode diameter; TP=Vine tip hairiness; LN=Leaf lobe number; PP=Petiole pigmentation; RS=Storage root shape; FC=Predominant flesh colour

a total of 47 different character states (classes) were used to conduct discriminatory analysis of the accessions (Table 3). Morphological indicators on roots were done at harvest (5 months after planting). Morphological traits data were generated from four randomly sampled plants per accession. The descriptors were qualitatively and quantitatively scored (Huaman, 1991).

Data analysis

Morphological data analysis

The mean values of all sampled observations for the seven phenotypic traits (Table 3) over three eco-geographical sources and two accession status (landraces and introductions) were analyzed for their variance and significance using Agrobase^{TM} (Agronomix Software Inc., 1999). Accessions were grouped into three populations: North, South East and Lower Shire Valley based on agro-ecological zones (Figure 1). Accessions were also categorized as either landraces or introductions to compare their morphological differences. Statistical package for social scientists (SPSS) was used to obtain frequencies of the average data over two years. The χ^2 analysis was carried out to test deviation from the overall mean of all the characters and sources of origin. The variation in frequency in the multi-category attributes was analyzed using the Shannon-Weaver Diversity Index (*H'*) (Shannon and Weaver, 1948) to measure phenotypic diversity for each trait (Grenier et al., 2001; Adugna and Labuschagne, 2002). The index was calculated by the formula:

$$H' = -\sum_{n=1}^{n} pi \log_e pi \quad (1)$$

where n is the number of character states (classes) and p_i is the proportion of entries in the ith category of an n-class (total number of accessions, N) attribute (Pielou, 1969; Jain et al., 1975). If a trait was mainly represented by one category in the database, a low index value was assigned, but if an attribute was evenly represented among all of the categories, a high index value was assigned. The additivity of H' allowed characters to be pooled over groups (Tolbert et al., 1979). The average diversity (Ĥ') over n traits was estimated as:

$$\hat{H}' = \sum H'/n \quad (2)$$

The interpretation was that the greater the number of variants in each phenotypic class of a given character and the more equal their proportions, the greater was the diversity (Pielou, 1969). The minimum value of the index was zero for a uniform population. The value of the index increases with increase within population variability and reaches maximum value when all phenotypic classes have equal frequencies (Yang et al., 1991). To test for the differences among pairs of Ĥ' values at P< 0.05, a t- statistic according to Jain et al. (1975) was used as given by the formula:

$$t = (H'_1 - H'_2)/[\mathrm{var}\,(H'_1) + \mathrm{var}\,(H'_2)]^{1/2} \quad (3)$$

The degrees of freedom (df) of the t test was determined by the formula:

$$df = [\mathrm{var}(H'_1) + \mathrm{var}\,(H'_2)]^2/[\mathrm{var}(H'_1)^2/N_1 + \mathrm{var}(H'_2)^2/N_2] \quad (4)$$

where N_1 and N_2 are the number of entries used in calculating var (H'_1) and var (H'_2), respectively. The variance was provided by the following formula:

$$\mathrm{var}(H') = [\sum_{i=1}^{n} pi \log_e^2 pi - (\sum_{i=1}^{n} pi \log_e pi)^2/N] + [n-1/2N^2] \quad (5)$$

Cluster analysis of morphological markers

The data on morphological traits of 59 accessions were transformed into binary data matrixes. The presence of a character state in a particular class for morphological traits was recorded as 1 and 0 for present and absent, respectively. Based on the presence/absence, dissimilarity coefficients were generated using the SIMINT module (NTSYS pc 2.11c software) (Rohlf, 2001). The default parameter DIST (average genetic distance) was used to generate the binary data matrix. Dendrograms were generated from the Sequential Agglomerative Hierarchical and Nested (SAHN) clustering method using the unweighted pair group method and arithmetic average (UPGMA) (Sneath and Sokal, 1973; Rohlf, 2001) using NTSYS pc 2.11.

RESULTS AND DISCUSSION

Accession identification and duplicate assessment by farmers

In the complementary identification studies at Bvumbwe Research Station, a long term sweet potato farmers from Nsanje and Chikwawa, major sweet potato growing areas, competently identified cultivars grown in their districts including three from Phalombe which were obvious duplicates of accessions from their areas. Below ground and above ground phenotypic features were used for identification. In total, with the aid of the farmers, 75 phenotypic and obvious duplicates were identified, tagged and eliminated. This outcome is consistent with the fact that from time in memorial farmers have used morphological traits to distinguish different cultivars of crops including sweet potato (Zimmerer and Douches 1991; Rodriguez-Bonilla et al., 2014). However, using the same features, farmers could not identify cultivars from Mzimba, Chitipa and Karonga except two, tsambalimodzi from Mzimba, which was also collected as ‘unknown 13’ from Karonga, called supuni/namasupuni in Nsanje, Chikwawa and Phalombe; and Kadidimi which was identified as Thinda of Chikwawa and Nsanje which also share names with other cultivars Babache and Mfumu. The failure of the twelve farmers to identify cultivars from the northern districts and relate them with their cultivars is a convincing indication that the accessions from the northern districts were phenotypically different from the collections of the southern districts probably due to genetic, climatic or soil differences other than ethnic preferences (Rodriguez-Bonilla et al., 2014). Nevertheless, the results suggest that farmers’ indigenous knowledge system (IKS) can be used for preliminary discrimination analysis of accessions to eliminate obvious duplicates and classify accessions before validation by morphological descriptors analysis (Changadeya et al., 2012).

Sweet potato morphological diversity analysis

Upon removal of 75 obvious duplicates out of the original 268 accessions, 193 landraces and 35 introductions were subjected to morphological variation assessment.

Morphological variability in sources of origin

An analysis of variance (ANOVA) on the seven traits was used to differentiate the populations under study. The mean squares for analysis of variance over the two years (2004 and 2005), three eco-geographical populations (north, South east and Lower Shire) and two populations (Landraces and Introductions) are presented in Table 4.

Table 4. Mean squares of ANOVA on sources of origins of sweet potato accessions.

Source	df	VL	VD	TP	LN	PP	RS	FC
Entry	227	4.87**	3.66**	3.92**	4.29**	3.21**	4.09**	3.45**
Years	1	1.63^{ns}	0.65^{ns}	0.48^{ns}	0.97^{ns}	1.72^{ns}	1.36^{ns}	1.23^{ns}
Eco-geographical populations	2	1.83*	2.77*	1.93*	3.49**	2.19*	3.42**	2.22*
Status	1	3.78**	2.63*	3.11**	2.93*	1.81*	2.34*	2.31*

df=Degrees of freedom; *, **= Significant at p<0.05 and 0.01 respectively; ns=not significant; VL=Vine internode length; VD=Vine internode diameter; TP=Vine tip hairiness; LN=Leaf lobe number; PP=Petiole pigmentation; RS= Storage root shape; FC=Predominant flesh colour.

Table 5. Chi-square for sources of origin on seven morphological traits of sweet potato.

Source	VL	VD	TP	PP	FC	RS	LN
	χ^2	χ^2	χ^2	χ^2	χ^2	χ^2	χ^2
Eco-geographical populations	12.72*	28.92**	13.87	17.98*	6.33*	28.88*	7.36*
Status populations	16.41**	17.22*	13.81	14.93*	16.12*	23.02*	7.23*

*, **= Significant at p<0.05 and 0.01 respectively. VL= Vine internode length; VD=Vine internode diameter; TP=Vine tip hairiness; LN=Leaf lobe number; PP= Petiole pigmentation; RS= Storage root shape; FC=Predominant flesh colour.

Variability among the accessions (entry) and populations was highly significant (p<0.01) for the seven traits, indicative of the existence of a wide range of morphological diversity within and among sources of origin for these traits. Accession variability contributed a larger proportion of the variance (Table 4) than the year and populations. Since seasonal variability (years) was absent in the seven traits, means of the two years were used for analysis. The findings in this study are concomitant with what Mbithe et al. (2016) found among 11 Ugandan sweet potatoes, where ANOVA analysis of 22 descriptors showed high variability of most morphological characters. High phenotypic variation among sweet potato genotypes has been variously demonstrated (Karuri et al., 2010; Maquia et al., 2013; Demelie and Aragaw, 2016). It generally originates from natural random mutations that are accelerated by asexual propagation through vines (Purugganan and Fuller, 2009; Roullier et al., 2011, 2013b).Traditional communal vine sharing among farmers further increases the rate of mutations among individual cultivars.

Distribution of traits over sources of origin

A χ2 test (Table 5) was used to compare the distributions of character states in the different sources of origin. Phenotypic percent frequencies of the character states in their respective classes are presented in Table 6. The chi-square test for homogeneity of frequencies of character classes of a trait showed that traits varied significantly (P < 0.05 and 0.01) among the three eco-geographical and two status populations. The total proportion of trait exceeded the anticipated, demonstrating highly significant inter-population differences in character frequencies. The performance of accessions under field conditions at Bvumbwe showed wide ranges of variability exhibited by frequencies in the various character states and sources of origins signifying prevalence of diversity among the accessions. Internode diameter is a very important characteristic in cultivar release as it affects vine sprouting after planting in the field. Very thin vines easily dry up when planted due to excessive heat and moisture stress. Cultivar survival under farmers' selection and natural forces (drought, chilly temperatures, sun heat) may therefore be very low if vines are very thin. Very few accessions were observed in the very thin category in all the sources of origin. Selection against the very thin vine accessions may have contributed to low frequency due to failure of vines to survive under harsh field conditions. Accessions in the intermediate thickness prevailed among the populations with South East population having the highest accessions (54%) of the intermediate thickness. While the frequencies for very thick vines were low across sources of origins, the introduced population had the highest frequency (14%) and the landrace had 7% (Table 6). The introductions had 2% very thin, 17% thin, 46% intermediate, 21% thick and 14% very thick. The introductions are therefore a good source of the very thick vines which is an important attribute in harsh field conditions.

Vine internode length (>12 cm) also affects sprouting as only a few nodes (at most 2 to 3) are available for sprouting on a 25 to 30 cm long planting vine. It is

Table 6. Distribution (%) of morphological character classes of sweet potato by sources of origin on N (number) accessions.

Population	N	Internode diameter					Inter node length					Tip hairiness					Petiole pigmentation								
		1	3	5	7	9	1	3	5	7	9	0	3	5	7	9	1	2	3	4	5	6	7	8	9
NR	101	2	32	45	18	13	4	31	54	9	2	32	49	18	1	0	34	6	11	18	6	3	0	11	11
SE	12	0	15	54	29	3	3	63	19	15	0	29	50	21	0	0	71	0	9	0	0	0	0	8	13
SV	80	1	11	52	33	5	11	50	39	1	1	40	42	14	2	3	28	18	10	18	6	0	0	6	17
Landraces	193	1	19	50	27	7	6	48	37	8	1	34	47	18	1	1	44	8	10	12	4	1	0	8	14
Introductions	35	2	17	46	21	14	11	60	29	0	0	23	54	14	7	9	40	0	14	14	0	0	3	20	9

Population	N	Predominant root flesh colour								Root shape									Leaf lobe number				
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	1	3	5	7	9
NR	101	31	47	10	7	1	1	1	3	11	6	16	3	8	0	4	20	32	13	26	43	9	10
SE	12	44	23	13	17	0	1	0	3	2	15	0	8	0	4	2	33	38	38	19	25	13	6
SV	80	20	62	7	10	1	1	0	1	2	7	7	7	2	2	7	33	35	8	14	13	28	37
Landraces	193	32	44	6	11	1	1	1	3	5	9	8	6	3	2	4	29	35	20	20	27	17	18
Introductions	35	49	10	13	0	3	6	3	17	26	29	13	6	11	9	6	0	0	1	22	66	0	11

recommended that at planting, three to four nodes should be inserted underground (Government of Malawi (GoM), 1996). Vine sprouting is high when more nodes are buried in the soil at planting as opposed to one or two nodes which may easily dry up in soils with limited moisture content. The majority of accessions across the geographical sources (Table 6) had short and intermediate internode length. The SE population had the highest accessions in the intermediate category (63%) followed by Shire Valley population (50%).

The Northern population had a high number of accessions in thick category (54%). The very short and very long internode lengths were very few although present in all populations with the Shire Valley exhibiting the highest number of the very short internodes (11%). The landraces had very few accessions that were very short (6%), long (8%) and very long (1%) internode lengths which entailed that there has been selection against these traits. The introduction registered none for long to very long but were a good source for very short (11%), short (60%) and the intermediate (29%) lengths. A released variety Tainung had a combination of very thin vines and long internode lengths. The cultivar has problems with sprouting, hence one of the reasons of failure to establish in the farming communities.

Most of the accessions in the study were in the categories of no hair, sparsely present and moderately present. While the South East and Northern populations did not register accessions in the heavy to very heavy hairiness categories, the Shire Valley population had heavy (2%) to very heavy hairiness (3%) accessions (Table 6). The high percentage of heavy hairy accessions in the low altitude areas which are also characterized by high temperatures is attributed to selection against the heavy insect attacks. Reference accessions were Nyamajoya ya Malawi (the hairy one from Malawi) and Nyamajoya ya Mozambique (the hairy one from Mozambique) which were said to be less preferred by elegant grasshoppers which are leaf eaters and problem insects in the area.

The results also showed that the green colour of petiole pigmentation for the South East population was the highest (71%). Not all character states of petiole pigmentation were represented in the nine classes in all sources of origin where the green coloured petioles constituted 44% of the landraces (Table 6). Accessions in the 'purple with green near leaf' are totally missing among the landraces. The introductions constituted 40% of the green petioles but had no representation in green with purple near stem, green with purple at both ends and green with purple stripes which were supplemented by the landraces in the germplasm (Table 6). While the majority of the accessions had the white, cream and yellow root flesh colour, the distribution of the accessions among the character states of the root flesh colour was absent in other states in different

Table 7. Estimates of H' and Ĥ of sweet potato populations using morphological traits.

Source	N	H'							Ĥ	± SE
		VL	VD	TP	LN	PP	RS	FC		
NR	101	0.85	0.68	0.42	0.60	0.55	0.39	0.67	0.59	0.03
SE	12	0.67	0.62	0.38	0.33	0.39	0.17	0.58	0.45	0.01
SV	80	0.71	0.65	0.40	0.84	0.60	0.65	0.82	0.67	0.02
± SE		0.01	0.03	0.02	0.01	0.03	0.02	0.02	0.01	
Landraces	193	0.72	0.64	0.40	0.61	0.53	0.45	0.69	0.58	0.02
Introductions	35	0.57	0.64	0.84	0.53	0.70	0.69	0.57	0.65	0.02
± SE		0.04	0.01	0.03	0.02	0.03	0.01	0.04	0.02	

geographical areas. The landraces had a total of 44% of the cream accessions and 32% of the white ones while the introductions had only 10% of the cream and 49% of the white. The introductions are a source of the dark orange (17%) which were only 3% in the landrace.

Among the local geographical areas, the majority of the accessions had elliptic and long irregular root shapes with landrace averaging 29 and 35%, respectively. Such root shapes are generally a problem when processing (peeling) and marketing. The Shire Valley population had however a higher frequency of the round roots (11%). When compared with the landraces, the introductions had mostly the round (26%) and round elliptic (29%) roots which have good marketing values. Number of lobes is a trait which is represented in all character states ranging from 18 to 22% among the character traits in the landraces. Most of the introductions however had five lobes (66%) and none had seven lobes.

Shannon weaver diversity index on morphological traits

Shannon and Weaver Index (H') as a measure of diversity has been used extensively to estimate the phenotypic diversity in crop germplasm collections (Yoon et al., 2000; Kebebew et al., 2002; Upadhyaya et al., 2002). Table 7 shows results of Shannon Weaver Index (H') calculated to compare phenotypic diversity of characters between populations. Table 7 shows that the different traits had different source areas of highest diversity which were significantly different at $p \leq 0.05$. For instance, vine internode length (VL) highest diversity was in the Northern population (0.85) while the number of lobes (LN=0.84) and root flesh colour (FC=0.82) had highest diversity in the Shire Valley population. These results therefore suggest that some sources have the potential to offer highest diversity for a particular trait(s) than others. The introduced accessions however are the highest sources of tip hairiness (0.84).

Based on the average diversity calculated for the different sources of origins and using the t-test, the Shire Valley had the highest diversity (H'=0.67) which was significantly different from the other two populations at $p \leq 0.05$. The mean Shannon-Weaver Diversity observed in the lower Shire sweet potato was higher than what Bellatreche et al. (2017) reported on 23 accessions of wheat using nine agro-morphological traits (H'=0.59) in which the authors concluded that the wheat accessions showed high phenotypic diversity. The differences in diversity within a character class in the present study could be attributed to diversity in weather conditions, soil type and a wide range of altitude. In addition, natural selection (such as drought) as well as artificial selection by farmers may have selected for the prevailing characters that are different from site to site resulting in the present morphological diversity (Roullier et al., 2011, 2013b). Similarly, the introductions, some deliberate (introduction for orange fleshed sweet potato) have contributed to the diversification of phenotypic traits in Malawi.

Morphological cluster analysis

A total of 59 accessions out of 193 landraces and 35 introductions, that showed wide morphological distances within and among the three geographical populations were sampled for morphological cluster analysis and further microsatellite markers analysis (data not shown). UPGMA-based cluster analysis on binary data of seven morphological traits and 59 (50 landraces and nine introductions) sweet potato accessions, are shown in Figure 2. The morphological clustering grouped the accessions into three main clusters A, B and C consisting of a singleton accession in clusters B, 27 in cluster A and 31 accessions in cluster C. The clusters A and C comprised accessions from all sources under study namely North, South East, Shire Valley and introductions while the singleton cluster contains accession Tchubatchuba from the Northern population. The clusters A and C were further sub- grouped to establish any

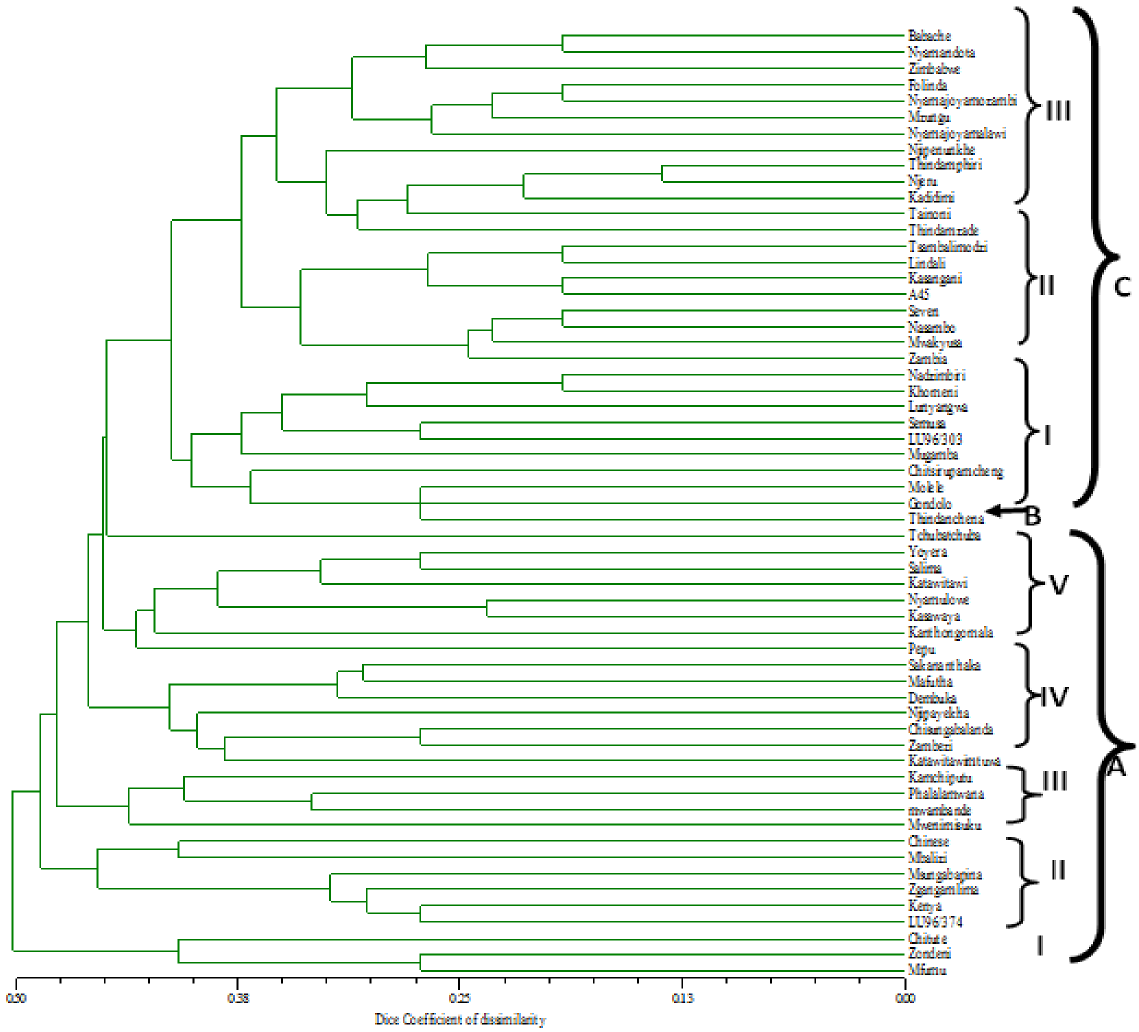

Figure 2. Cluster analysis of 59 sweet potato accessions on seven IBPGR morphological traits.

possibilities of the accessions to cluster according to sources of origin.

The composition of sub clusters I, II, III and IV of main cluster A contained accessions from all sources of origins while sub cluster V contained accessions from the Northern population and included Yoyera which was also sampled in the Shire Valley. While sub cluster I of main cluster C contained accessions from all sources of origins, sub cluster II contained accessions from the North including Tsambalimodzi which was also sampled from the Shire Valley and an introduction A45, which originates from the Republic of South Africa. All the accessions in sub cluster III of C originated from the Shire Valley.

Dice coefficient of dissimilarity ranged from 0.00 to 0.50 showing high dissimilarity among the accessions which complements the ANOVA findings. However, some accessions in sub-clusters showed some eco-geographical associations based clustering, suggesting a genetic distinction. This observation is divergent from what Gichuru et al. (2006) found, where morphological clustering was irrespective of geographical origin among Tanzanian, Kenyan and Ugandan accessions. However, the trend among sweet potato to cluster according to geographical source has been reported using molecular methods such as random amplified polymorphic DNA (RAPD) (Gichuki et al., 2003), amplified fragment length polymorphism (AFLP) (Zhang et al., 1998) and selective amplification of microsatellite polymorphic loci (SAMPL) (Tseng et al., 2002). In general, in this study most accessions clustered irrespective of eco-geographical origin signifying some similarity among them which could stem from gene flow abetted by historical tradition of sharing vines among farmers (Roullier et al., 2013a), as well as massive distribution of sweet potato vines by NGOs particularly during years of drought.

Conclusion

The current study on morphological characterization has revealed that high phenotypic diversity exists among and within populations of sweet potato with Shire Valley exhibiting the highest diversity (H'=0.67). The study also showed that the level and type of character variability is not uniformly distributed in all geographic regions hence some regions are a high source of some morphological traits and not others. The knowledge held by farmers (IKS) can be used as a first means for characterization to eliminate obvious duplicates and classify accessions before use of any marker.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are sincerely thankful to the Malawi government, Ministry of Agriculture and Food Security; the International Program in the Chemical Sciences (IPICS) under International Science Program (ISP); the International Potato Centre (CIP) and the International Institute of Tropical Agriculture (IITA)/Southern Africa Root Crops Research Network (SARRNET)/ for their financial, material and technical support throughout the project. They are also grateful for technical support during field work provided by Mrs P Pamkomera, Messers M.N. Nsanjama, T. Chilanga, W.M. Matululu, Ms. A. Mchiela and Officers in-charge of Makoka, Chitedze, Chitala, Lunyangwa and Baka research stations.

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Vol. 12(42), pp. 3099-3105, 19 October, 2017
DOI: 10.5897/AJAR2017.12368
Article Number: A9C6B4266391
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Agronomic performance of wheat as a function of different spacing and sowing densities in two agricultural years

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Received 10 April, 2017; Accepted 13 September, 2017

Optimization of the use of agricultural inputs and the efficient management of the wheat crop can increase the yield potential per unit area. Thus, the objective of this study was to evaluate the agronomic performance of a wheat cultivar in function of different spacing and sowing densities in two agricultural years. The experiment was performed during the 2010 and 2011 agricultural years. The experimental design was a randomized complete block design in a factorial 3 x 4. The first factor was comprised of three spacings (13, 17 and 21 cm between rows), and the second factor consisted of four sowing densities (200, 300, 400 and 500 viable seeds m^2). The results obtained showed that the lowest densities evaluated (200 and 300 seeds m^2) promoted greater number of spikelets per ear, length of ears, number of grains in 10 ears and weight of one hundred grains, as well as, a smaller number of unviable tillers per m^2. The shortest spacings evaluated (13 and 17 cm) promoted greater mass of spikes per m^2 and greater accumulation of dry mass of plants. The grain yield and hectoliter weight were not influenced by the density and spacing. The yield was higher in the year, 2011 as compared to 2010.

Key words: *Triticum aestivum*, competition between plants, spatial distribution of plants.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important and most consumed cereals in the world. With an estimated global production of 730 million tons for the 2016/2017 crop year (CONAB, 2017), wheat grain is produced mainly for human consumption, and its processing that generates by-products are also used in animal production.

In Brazil, production reached approximately 6.56 million tons in that same agricultural year, which did not meet the national demand of this grain. However, the country

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has the potential to reach higher levels of production to supply the domestic consumption market. Since the beginning of the 1980s, Paraná has been the leading agricultural producer of this cereal, contributing 50% of its national production in the last harvest (CONAB, 2017).

The increase in yield potential under tillage conditions has been of fundamental importance for Brazil to reach self-sufficiency in the production of this cereal (Silveira et al., 2010). The increase of wheat crop productivity depends on a set of strategies aimed at greater utilization of the area and the field conditions in which it is submitted.

In addition, the cultural management that results in the increase of the number of tiller can effectively contribute to the achievement of higher yields of the crop (Valério et al., 2009), because the density of sowing can provide a better balance of yield components, especially due to the difference in tillering capacity of the cultivars, resulting in better yield (Silveira et al., 2010; Benin et al., 2012; Fioreze et al., 2012). The density of sowing is important, mainly due to the difference in tillering capacity of the cultivars (Valério et al., 2013).

The seeding density and spacing between lines when suitable influence the competition among the wheat plants, and thus provide a consequent improvement in light interception by the canopy and in the use of environmental resources (Chen et al., 2008; Valério et al., 2009). The competition between plants and their effects are crucial in the production of tillers and act directly on the grains yield and its components (Ozturk et al., 2006). However, wheat genotypes with different potential of tillers respond in such differentiated ways to sowing density and to the number of plants per area.

In this way, genotypes with high potential of tillers are dependent on adequate adjustment of seeding density, because they compete for more light and nutrients (Valério et al., 2009). In turn, the genotypes with reduced potential of tiller exhibit less countervailing effect and, therefore, depend on high seeding densities to maintain the yield (Valério et al., 2008).

Thus, the optimal adjustment of the number of plants per area can be decisive for achieving stability and balance of yield components of wheat crop (Valério et al., 2009). Thus, the objective of this study was to evaluate the agronomic performance of the wheat cultivar BRS 208 in function of different spacing and sowing densities in two agricultural years.

MATERIALS AND METHODS

The experiment was conducted during the agricultural years of 2010 and 2011 in the municipality of Marechal Cândido Rondon, west region of Paraná State, situated at a latitude of 24°33'40''S and longitude 54°04'00'' W, with an altitude of 410 m. The local climate, classified according to the Köppen, is the subtropical Cfa type, with rainfall well distributed during hot summers. The predominant soil type is an Eutroferric Red Latosol. The chemical and physical characterization of the soil at a depth of 0 to 10 cm had the following characteristics:

pH ($CaCl_2$) = 5.69; exchangeable Al ($cmol_c\ dm^{-3}$) = 3.76; Ca ($cmol_c\ dm^{-3}$) = 9.38; Mg ($cmol_c\ dm^{-3}$) = 2.72; P (Mehlich) ($mg\ dm^{-3}$) = 8.43; K ($cmol_c\ dm^{-3}$) = 1.34; organic matter ($g\ dm^{-3}$) = 28.43; CTC ($cmol_c\ dm^{-3}$) = 17.20 V (%) = 78.14; sand ($g\ kg^{-1}$) = 64.08; silt ($g\ kg^{-1}$) = 492.92; clay ($g\ kg^{-1}$) = 443.0.

The values of temperature and rainfall during the experimental period are presented in Figure 1. The experimental design was randomized blocks with four replications in a factorial scheme of 3 x 4, consisting of three spacings (13, 17 and 21 cm between rows) and 4 seeding densities (200, 300, 400 and 500 seeds m^2), conducted during the harvests of 2010 and 2011. Each experiment consisted of 48 plots, having 2 m width and 6 m lenght, with 12 m^2 area.

The cultivar used was the BRS 208. The experiment was installed in the period of May to September, 2010 and 2011. The soil of the area under study was under no-tillage system, and had a predecessor crop to soybean. Before the implementation of the experiment, the desiccation of the plant material present in the area was performed with the application of the herbicide glyphosate (1,560 g ha^{-1} of the a.i).

The basic fertilization in the furrows of the sowing was performed taking into account the soil analysis and recommendations for the crop by applying 250 kg ha^{-1} 77 of the formulated 78 NPK 08-20-20. The side dressing fertilization was performed with urea at a dose of 150 kg ha^{-1} 79 at the beginning of tillering.

During the experiments, the application was performed with post-emergent herbicide metsulfuom-metilíco at a dose of 6.6 g ha^{-1} in the control of the major weeds. Applications of insecticide were carried out: dimetoato at the dose of 0.630 L ha^{-1} and clorpirifós at a dose of 0.75 L ha^{-1} to control aphid and caterpillar. For disease control, two applications of fungicide were used: 0.8 L ha^{-1} of pyraclostrobin + epoxiconazole and 0.75 L ha^{-1} of propiconazole.

The evaluations were performed at the end of the crop cycle being considered as useful area, one-meter square located in the center of each experimental plot. The number of fertile tillers m^{-2}, number of infertile tillers m^{-2} and the number of ears m^{-2} were evaluated. The hundred grain mass and yield and corrected values for 13% of humidity were also determined. In addition, 10 ears were collected within the useful area of each experimental plot for the ratings of the length of the ear and the number of grains per ear. The hectoliter weight was evaluated in balance, especially for hectoliter mass of 0.25 L, with water content of the grain corrected to 13% of moisture, using a sample of each experimental plot.

A joint analysis of data collected was performed during the two harvests (2010 and 2011). The data were subjected to analysis of variance through F-test. When the value was significant at a level of 5 or 1% of probability, the Tukey test was applied for comparison of averages. The regression analysis was performed when the F-test was significant for seeding density. For the statistical analysis, the program SAEG 9.1 was used.

RESULTS AND DISCUSSION

Table 1 presents the average values of the number of tillers per m^2 as a function of different spacings, densities and the agricultural years evaluated.

In the agricultural year 2010, the effect of interaction between the different spacing and sowing densities was observed, and the spacing of 13 cm between rows when used with density of 200 seeds m^2 resulted in greater numbers of tillers per m^2 (429.50) in relation to the other

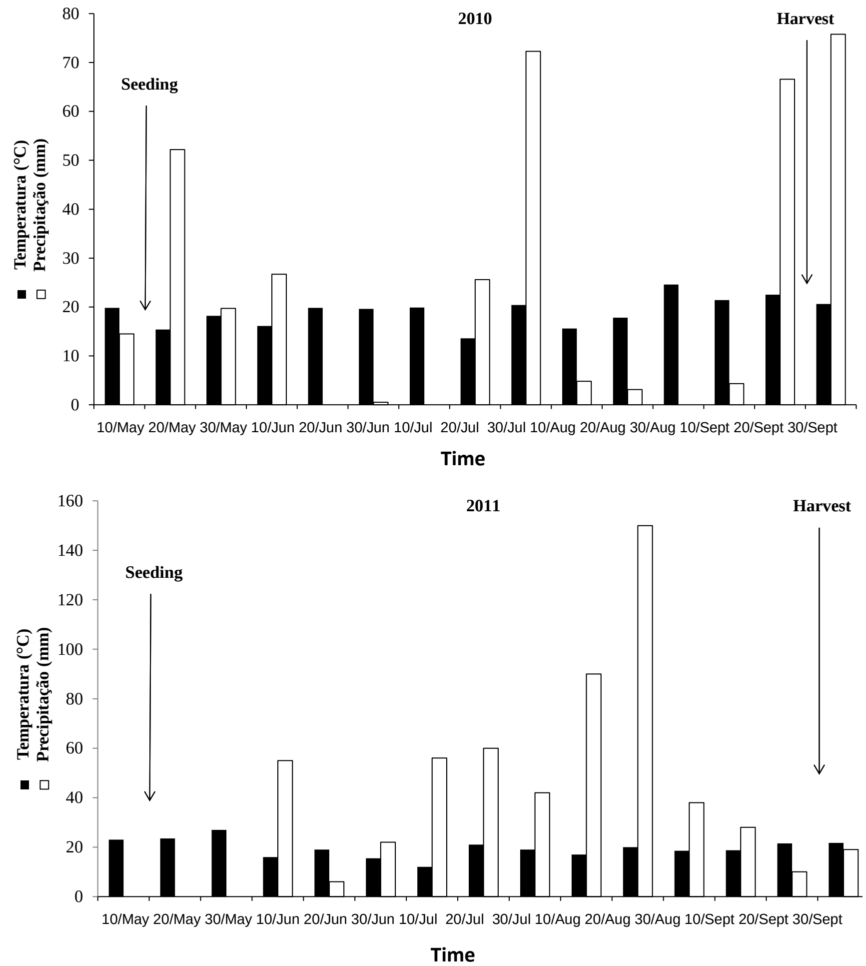

Figure 1. Average temperature (°C) and precipitation (mm) that occurred during the experiments (harvests 2010 and 2011), Marechal Cândido Rondon – PR.

Table 1. Number of tillers per m^2 of wheat cv. BRS 208, in function of different spacing between lines, densities and crop years (2010 and 2011), Marechal Cândido Rondon, during harvests 2010 and 2011.

Agricultural year	Density (Seeds m^2)	Spacing (cm)		
		13	17	21
2010	200	429.0^{cA}	400.5^{dB}	39.00^{dB}
	300	447.0^{bcA}	443.00^{cA}	451.75^{cA}
	400	464.75^{bA}	465.25^{bA}	480.25^{bA}
	500	519.25^{aB}	532.00^{aB}	550.25^{aA}„
2011	200	417.75^{dA}	415.50^{dA}„	411.75^{dA}
	300	456.50^{cA}	447.50^{cA}	462.25^{cA}
	400	476.50^{bA}	472.00^{bA}	488.25^{bA}
	500	532.00^{aA}	520.75^{aA}	532.50^{aA}
DMS	Spacing	18.70		
	Density	17.01		
	Year	14.17		

Averages having" and not followed by the same small letter in the column (densities) and capital letter on the row (spacings) differ at the 5% level of significance by the Tukey test.

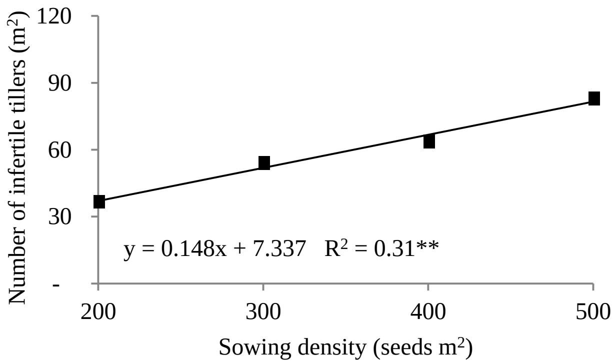

Figure 2. Number of infertile tillers per m^2 of wheat cv. BRS 208, in function of the sowing densities of 200, 300, 400 and 500 seeds per m^2, Marechal Cândido Rondon, harvests 2010 and 2011.

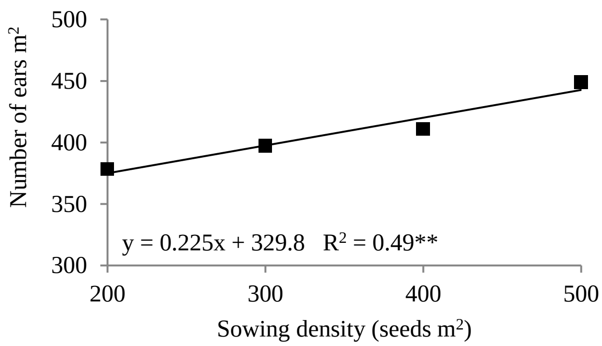

Figure 3. Number of ears of wheat, per m^2 cv. BRS 208, in function of the sowing densities of 200, 300, 400 and 500 seeds per m^2, Marechal Cândido Rondon, harvests 2010 and 2011.

spacings. Whereas, in the density of 500 seeds per m^2, the spacing of 13 and 17 cm between rows resulted in a smaller number of tillers per m^2 when compared with the spacing of 21 cm (550.25). In the comparison of the other spacings, no significant difference was found.

Regarding the effect of the different seeding densities, it can be observed that within the two years of the experiment (2010 and 2011), the highest density tested (500 seeds m^2) resulted in a greater number of tillers per m^2. However, it is worth mentioning that at the density of 500 seeds per m^2, it was observed to be about 520, 532 and 550 tillers per m^2, for the spacing of 13, 17 and 21 cm, respectively, that is, on average, a plant produced a little more than 1.0 tiller, whereas in the density of 200 seeds per m^2, it was observed for these spacings, average value of 415 tillers per m^2, that is, a plant produced on average, more than 2 tillers.

Thus, it is observed that there is a decrease in the number of tillers per plant as the density of seeding increased. Fernandes (2009) and Valério et al. (2008) also found a reduction in the number of tillers in function of increased density. It is important to emphasize that different wheat cultivars respond differently to increased density in relation to the potential issue, development or survival of tillers (Silveira et al., 2010), effect which may possibly have occurred in the present study, depending on the characteristics of the cultivar used.

A rising linear behavior for the number of infertile tillers per m^2 was observed as it increased the density of seeding, regardless of the spacing used (Figure 2). The results showed that the largest number of seeds per m^2 caused the wheat plants to increase their capacity to generate unproductive tillers.

These results are in agreement with those obtained by Alvarenga et al. (2009), who reported a lower number of fertile spikelets with the increase of density and sowing. According to Sparkes et al. (2006), the quality of light reflected on the plant is a key factor in the viability of tillers, and with increase in density, there is a high incidence of extreme red light at the bottom of the plants, reducing the quality of the light absorbed by the plant. Hence, increase in the number of seeds per area can lead to competition between plants and thus a consequent increase in the number of infertile tillers by area (Ozturk et al., 2006; Valério et al., 2008).

The effect of seeding density in relation to the number of ears per m^2 is shown in Figure 3. The spacings of 13, 17 and 21 cm between lines did not differ among themselves, showing a growing linear trend in the number of ears per m^2 with the increase of seeding density. Gross et al. (2012) working with different sowing densities also verified an increase in the number of spikes per area as a function of the increase in the number of seeds per area. For Valério et al. (2009), wheat in general, when cultivated under reduced sowing densities express a smaller number of ears per unit area. Whereas, concerning the number of spikelets per ear (Figure 4), there was an opposite effect to that obtained for the number of ears per m^2 (Figure 3), and this variable demonstrated a rising linear behavior in proportion to the increase in the number of seeds per m^2 with averages ranging from 14.5 and 13.2 spikelets per ear for the lowest and highest density tests, respectively.

Results that corroborate with those obtained in the present study were obtained by Gross et al. (2012) where they obtained smaller mean spikelets per spikes as a function of the increase of plant density. Thus, the reduction of the number of spikelets per ear, may be a consequence of competition specifically for light, water and nutrients, due to a larger number of seeds per area.

The average values of length of ear decreased linearly as a function of densities tested, but regarding the different spacings, significant differences between treatments were not observed (Figure 5). The sowing density influenced negatively, the length of ear ranging from 6.2 to 5.8 cm for densities of 200 to 500 seeds per m^2, respectively. Similar results were obtained by Filho et

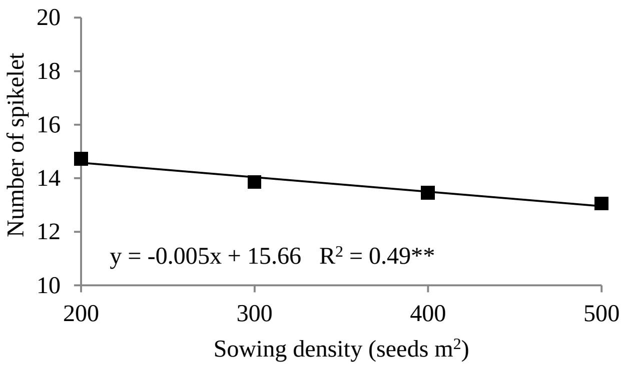

Figure 4. Number of spikelet per ear of wheat cv. BRS 208, in function of the sowing densities of 200, 300, 400 and 500 seeds per m^2, Marechal Cândido Rondon, harvests 2010 and 2011.

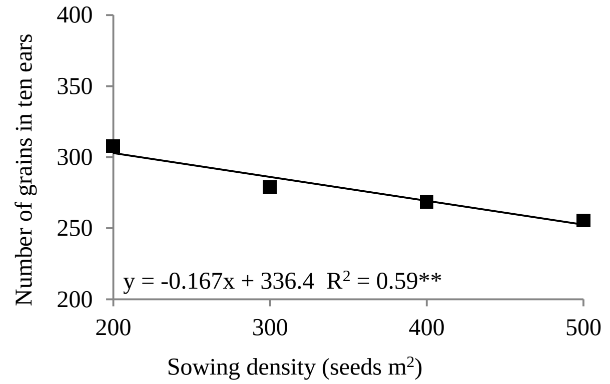

Figure 6. Number of wheat grains cv. BRS 208, in function of the sowing densities of 200, 300, 400 and 500 seeds per m^2, Marechal Cândido Rondon, harvests 2010 and 2011.

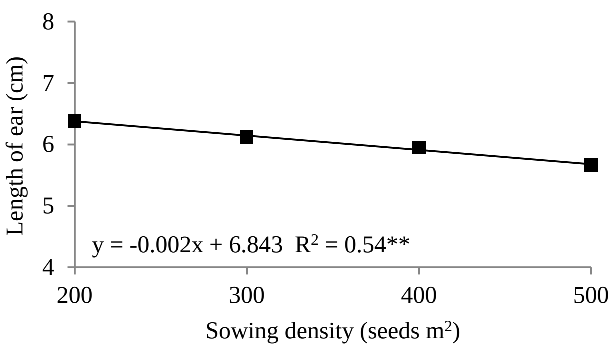

Figure 5. Length of wheat ear cv. BRS 208, in function of the sowing densities of 200, 300, 400 and 500 seeds per m^2, Marechal Cândido Rondon, harvests 2010 and 2011.

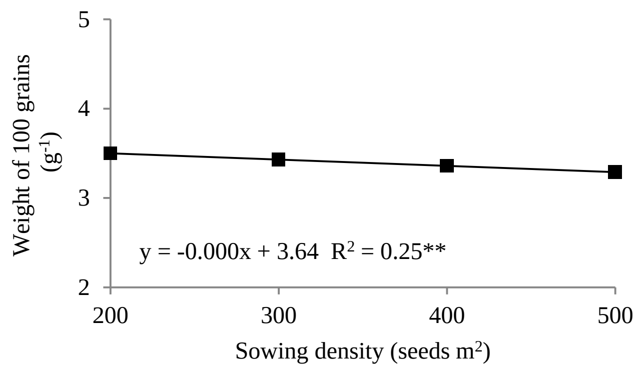

Figure 7. Weight of 100 grains of wheat cv. BRS 208, in function of the sowing densities of 200, 300, 400 and 500 seeds per $m^{2,}$ Marechal Cândido Rondon, harvests 2010 and 2011.

al. (2008) and Alvarenga et al. (2009), where they found a reduction in the length of the wheat ears in proportion to the increase of the density of seeds per $m^{2.}$

In relation to the number of grains in ten ears (Figure 6), it is possible to observe that this variable had a similar behavior to the length of the ear (Figure 5), where a linear reduction in function of the densities of 200, 300, 400 and 500 seeds per m^2 was observed, with values of 303.3, 281.2, 272.2 and 254.2 seeds in ten ears, respectively.

The same way, Teixeira Filho et al. (2008), Valério et al. (2008) and Alvarenga et al. (2009) working with different seeding densities in the wheat crop, verified negative linear behavior for the number of grains per spike due to the increased sowing density. This fact can be associated with increased competition for light and nutrients, resulting from the largest population of fertile tillers per unit area (Ozturk et al., 2006).

For the mass of 100 grains, no significant effects were observed as a function of the spacings, but only as a function of the different densities (Figure 7), showing a linear behavior decrease due to increase in the number of seeds per area. This is possibly due to the high competition between plants for resources of the environment during their development. Similar results were obtained by Fernandes (2009), who verified that the increase in sowing density resulted in the reduction of one hundred grain mass. This author confers this reduction to the existing competition due to the increase in seed sowing density. However, Tavares et al. (2014) found no significant difference for grain mass at densities of 150 to 450 m² plants.

The grain yield and hectolitric weight of cv. BRS 208 obtained in the present study was not influenced by the factors between line spacing and sowing density. Several authors (Gross et al., 2012; Teixeira Filho et al., 2008) also observed that productivity is not influenced by sowing density.

For the variable hectolitric, Tavares et al. (2014)

Table 2. Grains yield (PROD) and hectoliter weight (PH) of the cultivar BRS 208, in two agricultural years (harvests 2010 and 2011), Marechal Cândido Rondon.

Agricultural year	PROD (kg ha^{-1})	PH (%)
2010	2572.02[b]	74.62[b]
2011	2878.52[a]	77.10[a]
DMS	67.97	0.36

Averages not followed by the same small letter in the column differ at the 5% level of significance by the Tukey test.

obtained similar results. Thus, similarity of the results in the present work can be considered normal for the densities used. However, Barbieri et al. (2013) working with four cultivars of wheat in populations of 140 to 350 plants m^2, concluded that the yield varies according to the genotype used, and some cultivars have a lower capacity of compensation in relation to others, that is, each cultivar has a different performance when subjected to random plant reduction.

The results of grain yield and hectoliter weight, regarding the two agricultural years are shown in Table 2. The yields obtained in the two years of cultivation, lies within expectations for the western region of Paraná State, reaching average values of 2572.02 and 2878.52 kg ha^{-1}, for the years, 2010 and 2011, respectively. However, when compared with the averages of productivity, it was evident that the year 2011 had better response, having obtained significantly higher value than the year 2010. The planting performed in 2011, also resulted in significantly higher values for the variable, hectoliter weight (73.94%).

It is observed in the year 2011, that the averages of hectoliter weight and the final productivity of the cultivation were higher as compared to the year, 2010. These results can be explained in function of greater regularity of precipitation in 2011 or even the existence of precipitation in the final period of grain filling and maturation of culture, with the period approximately between 20 and 10 days before harvest, indicating that this weather variable influenced the yield of the crop during the first year of cultivation (2010) as shown in Figure 1.

Santos et al. (2012) reports that wheat cultivars subjected to water deficit at the beginning of flowering, obtained lower phytomass and grain yield. According to Guarienti et al. (2005), the water excess within 21 days prior to harvest negatively affects the hectoliter weight and the grains yield. Thus, these effects may explain the differences obtained in the components mentioned above in the two years of cultivation in this study.

The responses obtained for grain production in this study showed a direct relationship dependent of the performance of each component of production evaluated. In a general way what can be seen in relation to the results obtained in the analysis of the harvests of 2010 and 2011, was that high seeding densities responded significantly to the variables directly related to the increase in the number of seeds per m^2, that is, the number of tillers per area and ears per area evaluated. However, these responses are not reflected in the most important components of production, grain mass and yield, also, a negative reflection for components of grains per ear and spikelets per spike is observed.

Conclusions

1. The increase in sowing density reflected in increase in the number of tiller per m^2 of cultivar BRS 208; however, it reduced the number of tiller per plant and increased the number of infertile tiller per m^2.
2. Increasing sowing density resulted in a higher number of ears per m^2, but reduced the number of spikelets in the ears.
3. The ear length, number of grains in ten ears and mass of one hundred grains reduced as a function of the increase in seeding density.
4. Productivity and hectoliter weight were not influenced by density and spacing.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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academicJournals

Vol. 12(42), pp. 3106-3111, 19 October, 2017
DOI: 10.5897/AJAR2017.12520
Article Number: A3345CD66393
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Potential of plant ethanolic extracts on *Meloidogyne incognita* control in tomato

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Received 14 June, 2017; Accepted 21 September, 2017

Nematodes are obligatory parasites that compromise agricultural production worldwide. The use of alternative methods to replace the chemical pesticides in the control of this pest is increasingly growing, due to its pollution to the environment. In order to evaluate the biocidal effect of plant extracts, combinations of extracts of Neem (*Azadirachta indica*), croton (*Croton campestris*) and manioc (*Manihot esculenta*) were used in the control of root knot nematode, *Meloidogyne incognita* in tomato plants. The extracts were obtained from dried leaves and exposed to cold extraction with ethanol, under reduced pressure, with the aid of rotaevaporador. The application of the treatments took place 72 h after inoculation of suspension with 4,000 eggs/juveniles in the region of the root. Extracts from croton and cassava promoted plant height in the order of 26.75 and 34.50%, respectively; while neem extract inhibited the numbers of nematode juveniles in the root (51.34%), croton (50.85%), and manioc (41.31%). As for juveniles in the soil, only 47.33% was reduced in cassava. However, the mix of the extracts potentiated the effects on improvement of growth parameters and reduction of nematode parasitism.

Key words: Alternative control, *Meloidogyne incognita*, *Solanum lycopersicum*.

INTRODUCTION

The tomato crop (*Solanum lycopersicum* Mill), cultivated in almost all parts of the world, has high productivity losses by means of the direct interference of phytonematodes on the root system, hindering the absorption of water and nutrients (Cantu et al., 2009). Among the nematodes present in Brazilian production

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fields, the *Meloidogyne* genus and, mainly, the species *Meloidogyne incognita* is considered important not only for the high aggressiveness, but also for parasitizing different crops of agronomic characteristics, which guarantees its greater survival in production areas (Zanella et al., 2005).

Considering the damage potential to crops, the search for innovation of methods other than chemical nematicides is increasing, due to the negative effects on the environment (Ferraz and Freitas, 2004). The increasing information on the impacts caused by pesticides, together with the reduction of management costs, makes it increasingly common to use alternative methods to control pests and diseases (Almeida et al., 2005).

Several researches with plant extracts using the most varied species and distinct parts of plants have been increasingly evident, due to the ability of some plant species to produce antifungal as well as nematotoxic substances (Atti-Santos, 2010; Mateus et al., 2014; Almeida et al., 2016), synergised to the possibility of molecule's rapid biodegradation and low toxicity to animals and humans (Neves et al., 2005).

The vegetable species produce primary and secondary metabolites, which are products of chemical reactions with specific functions in plant physiology. The primary compounds are based on their normal development, taking as example, the phytohormones that act in different phenological stages of the plant (Gardiano et al., 2008). Secondary metabolites, such as alkaloids, fatty acids, isothiocyanates, acyanogenic glycosides, terpenoids and phenolic compounds, directly assure the defense action against the presence of pathogenic invaders that may impede its cycle, as well as attract or repel other organisms, such as phytonematodes (Ferraz et al., 2010; Gardiano et al., 2011).

Leaf extracts of nettle (*Fleurva aestuans*), neem (*Azadirachta indica*), castor bean (*Ricinus communis*) and manioc (*Manihot esculenta*) under preparaton in different forms have demonstrated potential in the control of *M. javanica* (Almeida et al., 2012). Of the possibilities that justify this action, are the release of nematotoxic substances in the soil, such as isothiocyanates and derivatives (Zasada and Ferris, 2004), as well as the induction of resistance to plants when exposed to abiotic substances, such as extracts (Métraux, 2001).

The objective of this study was to evaluate the effect of different ethanolic extracts, separated and combined, applied in the soil for the control of *M. incognita* in tomato.

MATERIALS AND METHODS

Location and experiment conduction

The experiment was carried out in a greenhouse (9°04'45" S and 44°18'46" W) at the Federal University of Piauí, Campus Profa, Cicnobelina Elvas, in Bom Jesus-PI. The average temperature of the greenhouse during the experiment conduction was 29.25°C, with maximum and minimum averages of 33.5 and 25.0°C, respectively.

The substrate used consisted of soil + sand + manure mixture in a ratio of 3:2:1 (v/v), respectively. The substrate was autoclaved before handling at 120°C for 1 h. It was distributed in polypropylene pots of 5 dm^3 capacity and sown with three seeds of tomato cv. "Santa Cruz", which was considered highly susceptible material to *M. incognita*. Fifteen days after sowing, thinning was performed, limiting the experimental unit with one plant per pot.

Subsequently, each plant was inoculated with an aqueous suspension containing 4,000 eggs/juveniles of *M. incognita*, calibrated by Peters's chamber, distributed in three openings 3.0 cm deep, spaced 2.0 cm apart around tomato seedlings. After inoculation, the plants were conditioned only to irrigation in the first three days. Afterwards, the extracts were applied directly in the soil into the pots, using 100 mL of the solution in each treatment at the concentration of 100 g L^{-1}. Two applications were performed at 15-day intervals. As a control, the chemical treatment (Carbofuran®) was considered as a negative control, with 0.2 g of diluted product in water in single application, and the positive control was with water.

Leaf extracts of the plant species, neem (*Azadirachta indica* A. Juss), croton (*Croton campestris* A. St.-Hil) and manioc (*Manihot esculenta* Crantz) were collected from the region in the second half of 2015. The leaves were dried at air temperature and ground in knife mill to obtain 100 g in powder form for each species. Then, they were subjected to the cold extraction with ethanol PA. The solutions were filtered and concentrated under reduced pressure, with the aid of a rotavaporator at 60°C to remove the solvent, obtaining the extracts under viscous appearance, according to the methodology described by Matos (1997). The extracts were prepared 24 h before the applications were performed.

The experimental design was completely randomized, with sixteen treatments with five replications. Fourteen treatments were constituted by different combinations of plant extracts and the nematicide, Carbofuran as follows: Neem, Croton and Manioc's plant extracts; Neem + Croton; Neem + Manioc; Croton + Manioc; Neem + Croton + Manioc; Neem + Carbofuran; Croton + Carbofuran; Manioc + Carbofuran; Neem + Croton + Manioc + Carbofuran; Croton + Manioc + Carbofuran; Neem + Croton + Carbofuran; Neem + Manioc + Carbofuran) and two controls.

Plant development characteristics

The evaluations were carried out sixty days after inoculation, corresponding to the extracts exposure period to the nematodes in tomato plants. The crop growth parameters evaluated were: plant height (PH) performed using a graduated ruler; stem diameter (SD) by digital pachymeter; fresh shoot biomass (FSB), dry shoot biomass (DSB), fresh root biomass (FRB), dry root biomass (DRB), using a semi-analytical balance and root volume (RV), performed by volume difference, using a graduated beaker containing a determined water volume. The root volume was obtained by difference between the initial and final volume.

Parasitism characteristics

For the evaluation of nematode parasitism, the galls's numbers (GN) were determined, using a magnifying glass, manual counter and for egg masses number (EMN), the roots were washed in running water and colored by immersion in 0.015% Floxin B solution for 15 min. To quantify the juvenile number in the soil (JNS), they were extracted from 100 cm^3 of soil by centrifugation and flotation (Jenkins, 1964). Estimation of root juvenile numbers (Coolen and D'herde, 1972) and counting were done using optical microscope and Peters's blade.

Statistical analysis

Data were subjected to variance analysis and, when significant, the means were compared by Scott-Knott Test at the 5% probability level. In order to satisfy the basic hypothesis of residuals's normal distribution, the absolute values of plots of the NG and EMN variables were transformed using the square root of "x + 1" and, the data processing was performed using the statistical software Assistat (Silva and Azevedo, 2002).

RESULTS AND DISCUSSION

Agronomic characteristics of tomato plants

The use of single and/or combined plant extracts had a positive influence on some characteristics of vegetative development of tomato plants. Most of the treatments differed statistically from positive (water) and negative (chemical) controls.

For plant height (PH), cróton extracts and manioc leaves, when used alone, had increases of 26.75 and 34.50%, respectively, in relation to the positive control, and did not differ statistically from the results observed with the tested chemical. It was also evidenced that extracts in mixture of some plant species presented satisfactory results, in vegetative development for PH, in the order of 28.50% with neem+croton; 30.50% for neem+manioc and 31.50% for neem+croton+manioc (Table 1). It is possible that the extracts, at some time, provide nutrients or even, serve as a tonic to the plants and thus, respond more effectively to the presence of nematodes.

Similar results were obtained by Olabiyi (2008), on the vegetative development of tomato plants, when the aqueous extracts of different plant species, were applied on the soil for *M. incognita* control. Coimbra et al. (2006), using mint leaf extract, obtained 98% immobility with the species *Scutellonema bradys*. Almeida et al. (2012), testing neem, nettle and castor leaves as extracts sources, obtained a reduction of more than 90% in gall numbers of *M. javanica* in tomato plants. According to Gardiano et al. (2009), the plant extracts efficiency that ensure significant plant development is possibly related to the reduction of nematode feeding capacity in the soil, promoted by action of some present compounds.

As for fresh shoot biomass (FSB), only manioc extract applied separately, showed an increase of 14.80%, similar to chemical control (Table 1). For mixtures of plant extracts, a better effect was observed on the combinations with croton+manioc (13.60%), neem+croton (16.00%) and neem+croton+manioc (18.33%). All extracts, when mixed with carbofuran, presented higher efficiency in comparison with the positive control, except for croton+carbofuran. Some researchers (Martinez, 2002; Coimbra et al., 2006) pointed out that the antimicrobial capacity of the extracts, in reducing nematode aggressiveness, is related to the presence of secondary compounds such as alkaloids, fatty acids, isothiocyanates, phenolic compounds, tannins and others, besides the availability of minerals (Ritzinger et al., 2004), making better, the nutrients absorption by the plants, therefore, a greater reaction to the pathogenic effects.

For the fresh root biomass (FRB), only the single croton extract differed from the positive control, with increased for the variable with 67.20%. Among the mixture of extracts, the results were more promising, since neem+croton (77.11%); neem+manioc (83.10%) and nem+croton+manioc (98.32%) had a positive influence on root protection. It is possible that the combinations of the extracts contributed to the release of substances with nematicidal activity which favored a better root system development of tomato plants.

The tomato plants accumulated less dry root biomass (DRB) when treated with single plant extracts. Only the mixtures of neem+croton, neem+manioc and neem+croton+manioc were able to promote greater protection of the plant in a similar way as chemical control. There was no effect of the extracts on root diameter and root volume (Table 1). Ritzinger and Fancelli (2006) pointed out that plants infested by *Meloidogyne* genus exhibited reduction in the root system growth, as a result of less accumulation of phytomass, but these damages vary depending on the reaction power of the plants to the effects of environmental conditions on planting.

Among the extracts applied on the soil, there was variation for some parasitism characteristics in the tomato roots (Table 2). The reduction in gall numbers (GN) was observed in two treatments when the extracts were mixed with carbofuran. However, even with low effect in the reduction of GN, it is noticed that the egg mass numbers (EMN), except for extracts of neem; neem+manioc and nem+croton+carbofuran, differed statistically from the positive control which shows that the presence of galls does not necessarily reflect the high density of viable egg masses.

However, the use of unmixed extracts on the tested chemical croton, manioc, neem+croton and neem+croton+manioc showed the highest reductions of EMN (47.75, 34.83, 48.96 and 45.31%, respectively) of *M. incognita* in the tomato rhizosphere. In turn, some extracts in combination with carbofuran did not show negative influence on the active principle of the product; also, there was no interference of the chemical with the secondary compounds present in the extracts.

Studies on croton species point to the presence of several classes of secondary metabolites including flavonoids, alkaloids, tannins and terpenoids (Payo et al., 2001), as well as essential oils rich in mono and sesquiterpenoids, besides phenylpropanoids (Palmeira-Junior et al., 2006). In the manioc leaves, the secondary

Table 1. Plant height (PH), stem diameter (SD), fresh shoot biomass (FSB), fresh root biomass (FRB), dry shoot biomass (DSB), dry root biomass (DRB) and root volume (RV) of tomato plants inoculated with *Meloidogyne incognita* treated with plant extracts and nematicide.

Treatment	Characteristics/ agronomics						
	PH (cm)**	**SD^{ns} (mm)**	**FSB* (g)**	**FRB* (g)**	**DSB**(g)**	**DRB** (g)**	**RV^{ns} (mL)**
Water	80.00^{b}	0.26^{a}	62.58^{b}	21.50^{b}	12.53^{b}	6.27^{a}	33.40^{a}
Carbofuran	109.60^{a}	0.34^{a}	82.07^{a}	34.20^{a}	27.60^{a}	8.12^{a}	33.00^{a}
Neem	93.00^{b}	0.27^{a}	66.94^{b}	22.60^{b}	13.58^{b}	2.58^{b}	30.00^{a}
Croton	101.40^{a}	0.30^{a}	62.56^{b}	35.94^{a}	15.52^{b}	3.42^{b}	35.00^{a}
Manioc	107.60^{a}	0.28^{a}	71.84^{a}	30.01^{b}	16.70^{b}	1.92^{b}	27.00^{a}
Neem/Croton	102.80^{a}	0.32^{a}	72.59^{a}	38.08^{a}	17.00^{b}	4.54^{a}	34.00^{a}
Neem/Manioc	104.40^{a}	0.30^{a}	64.11^{b}	39.36^{a}	15.26^{b}	4.48^{a}	35.00^{a}
Croton/Manioc	92.80^{b}	0.31^{a}	74.05^{a}	28.64^{b}	14.78^{b}	2.18^{b}	24.00^{a}
Neem/Croton/Manioc	105.20^{a}	0.32^{a}	71.09^{a}	42.64^{a}	16.02^{b}	5.08^{a}	38.00^{a}
Neem/Carbofuran	101.40^{a}	0.30^{a}	67.56^{b}	28.60^{b}	17.90^{b}	3.98^{b}	27.00^{a}
Croton/Carbofuran	90.00^{b}	0.25^{a}	54.93^{b}	25.76^{b}	12.92^{b}	2.20^{b}	24.00^{a}
Manioc/Carbofuran	107.20^{a}	0.34^{a}	75.22^{a}	33.00^{a}	18.98^{b}	2.76^{b}	30.00^{a}
Neem/Croton/Manioc/Carbof	92.40^{b}	0.30^{a}	72.22^{a}	33.90^{a}	15.38^{b}	3.24^{b}	33.00^{a}
Croton/Manioc/Carbof.	115.80^{a}	0.33^{a}	80.15^{a}	32.21^{a}	17.50^{b}	5.26^{a}	45.00^{a}
Neem/Croton/Carbofuran	105.60^{a}	0.24^{a}	80.32^{a}	39.89^{a}	16.97^{b}	3.92^{b}	40.00^{a}
Neem/Manioc/Carbofuran	110.40^{a}	0.33^{a}	84.63^{a}	42.24^{a}	18.36^{b}	4.58^{a}	37.00^{a}
C.V (%)	9.49	20.07	17.31	30.64	26.4	51.83	47.07

*,**Significant at 5 and 1% probability by F test, respectively; ^{ns}not significant. Means followed by the same letters do not differ by Scott Knott test.

Table 2. Gall numbers (GN), egg masse numbers (EMN), hatched juvenile numbers in the root (JNR) and juvenile numbers in the soil (JNS) of *M. incognita* after application via plant extracts and nematicide.

Treatment	Characteristics/parasitism			
	GN (Unt)	**EMN (Unt)**	**JNR (Unt)**	**JNS (Unt)**
Water	12.26^{a}	8.21^{a}	14.16^{a}	12.19^{a}
Carbofuran	4.04^{c}	4.16^{c}	4.14^{c}	5.30^{b}
Neem	12.87^{a}	9.50^{a}	6.89^{c}	8.10^{b}
Croton	12.41^{a}	4.29^{c}	6.96^{c}	8.02^{b}
Manioc	11.42^{a}	5.35^{b}	8.31^{b}	6.42^{b}
Neem/Croton	11.96^{a}	4.19^{c}	6.34^{c}	7.57^{b}
Neem/Manioc	12.07^{a}	8.69^{a}	7.80^{b}	7.94^{b}
Croton/Manioc	11.22^{a}	5.66^{b}	8.94^{b}	8.05^{b}
Neem/Croton/ Manioc	11.58^{a}	4.49^{c}	8.29^{b}	7.78^{b}
Neem/Carbofuran	7.49^{b}	4.26^{c}	4.33^{c}	6.62^{b}
Croton/Carbofuran	7.64^{b}	4.75^{c}	4.31^{c}	7.11^{b}
Manioc/Carbofuran	13.11^{a}	4.03^{c}	6.05^{c}	5.16^{b}
Neem/Croton/ Manioc/Carbofuran	12.90^{a}	6.50^{b}	5.35^{c}	5.59^{b}
Croton/ Manioc /Carbofuran	11.59^{a}	5.45^{b}	5.13^{c}	7.60^{b}
Neem/Croton/Carbofuran	11.35^{a}	8.37^{a}	5.65^{c}	7.99^{b}
Neem/ Manioc /Carbofuran	12.26^{a}	6.10^{b}	8.22^{b}	6.49^{b}
C.V (%)	18.87	13.92	35.02	29.31

*,**Significant at 5 and 1% probability by F test, respectively; ^{ns}not significant. Means followed by the same letters do not differ by Scott Knott test.

metabolites such as phenolic compounds, lectins and trypsin inhibitors are present (Melo et al., 2007).

The presence of these secondary metabolites has been previously confirmed with nematicidal activity (Chitwood, 2002), besides the possibility of these compounds being present in several plant species, in reducing the parasitic activity of different species of nematodes (Mateus et al., 2014).

The use of manioc and croton has been verified in different areas of study to control some microbial species that cause economic losses. Nasu et al. (2010), using “manipueira”, a by-product of manioc flour, verified that when applied on the soil, it reduced *M. incognita* satisfactorily, with a decrease in the gall number and an increase in the biomass of tomato roots. The same authors attributed this efficiency to the presence of cyanogenic compounds, which may have a toxic effect on nematodes. Matias et al. (2010) when evaluating different plant species in the extracts preparation, observed excellent results of antibacterial activity with *Croton campestris*, inhibiting the growth of *Escherichia coli* and *Staphylococcus aureus* strains. These results confirm the potential of the compounds present in the plants, to act on different pathogenic microorganisms, hindering their mobility and, consequently, reducing parasitism.

M. incognita parasitism characteristics in tomato plants

All the extracts reduced the juvenile number in the root (JNR) of the tomato plants (Table 2). In the treatments in which the extracts were isolated separately from neem and croton or in mixture with Carbofuran, there was no difference with the chemical treatment and differed statistically from the control (water).

Reductions were observed in the JNR of *M. incognita* in tomato for extracts of plants based on neem (51.34%) and croton (50.85%) as compared to the control (water). Studies with croton extract for the control of phytonematodes are scarce; however, its leaves are used for the treatment of pathogenic organisms (Matias et al., 2010). According to Silva (2007), the croton species are aromatic and are characterized by the essential oils production, which have fumigant action and can be used to combat some pests and substitute other similar product effect. Similarly, *C. campestris* hexanic extracts have demonstrated efficiency in the control of other microbiological agents, mainly by the apolar characteristics of its chemical constituents such as tannins, flavonols and terpenes (Coutinho et al., 2010).

The results obtained with neem extracts corroborate with that of Doihara (2005) who studied the effect of neem oil and other substances on hatching, penetration and reproduction of *M. incognita* in melon plants, and observed after 168 h of exposure to eggs, reduction in the hatched second stage juvenile number in comparison with the control.

The juvenile number in the soil (JNS) was reduced in the presence of the extracts, in single and mixed form, as well as with the nematicide. The extracts applied on the soil is more vulnerable to the extract's chemical compounds effects, showing that these extract molecules do not reduce its viability with immediate efficiency. However, Gobbo-Neto and Lopes (2007) showed some environmental factors (temperature, humidity and precipitation) that may interfere with production rate of plant secondary metabolites, which may have a negative effect on pest’s control.

Even so, several results are promising in the use of plant extracts in phytonematodes control. This practice will become an alternative management for small and medium producers and an economically viable possibility with less toxicity to the environment.

Conclusion

The extracts presented different results when used alone and mixed; potentiated or neutralized the agronomic characteristics and the phytonematodes management. The croton extract has a suppressive effect on egg mass number, with results similar to carbofuran. The number of nematodes in the root reduced substantially with the presence of neem and croton extracts. The extract of the manioc leaf had greater effect on the reduction of soil nematodes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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academicJournals

Vol. 12(42), pp. 3112-3119, 19 October, 2017
DOI: 10.5897/AJAR2017.12619
Article Number: 79CE65666397
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Nitrogen, phosphorus, and potassium fertilizer effects on cassava tuber yield in the coastal district of Dondo, Mozambique

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Received 25 July, 2017; Accepted 29 August, 2017

Meeting an increasing demand for cassava (*Manihot esculenta* Crantz) by industrial and commercial food sectors requires basic agronomic information on fertilizer requirements and appropriate fertilizer recommendations for high tuber yield and quality. A no-till study involving twenty fertilizer treatments consisting of different combinations of nitrogen (N), phosphorus (P), and potassium (K) fertilizer rates was initiated in 2013 at Milha-14, in the coastal district of Dondo, Sofala province, Mozambique. The objective of the study was to assess cassava yield performance under different soil fertility and smallholder farm conditions. Applying only 60 kg/ha N (fertilizer combination: 60-0-0 kg/ha N-P_2O_5-K_2O) yielded less (8.5 tons/ha) compared to the unfertilized control treatment (14.7 tons/ ha). Applying 60 kg/ha N combined with 60 kg/ha P_2O_5 (60-60-0 N-P_2O_5-K_2O kg/ha) yielded the highest (27.7 tons/ha; $p < 0.05$). No response to K was observed, but K additions are recommended to avoid K mining.

Key words: Cassava, tuber yield, fertilizer.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial, multi-use, subsistence crop domesticated in Brazil (Hillocks et al., 2002a) and grown throughout the tropics (Food and Agricultural Organization of the United Nations (FAO, 2013). Cassava provides edible leaves and tubers (Boansi, 2017; Li et al., 2010) and is produced almost

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exclusively by small-scale, resource-poor farmers (El-Sharkawy, 2004) on nutrient-depleted soils (Mariscal, 1984), in mono- or poly-culture (El-Sharkawy, 2004). Due to the ability of cassava to produce reasonable yields in areas with poor soil fertility (Boansi, 2017) where other crops would not thrive (Fermont, 2009), most farmers in Africa under-fertilize or do not fertilize cassava (El-Sharkawy, 2004). Cassava is rarely grown as a main crop, but instead fills the important niche of being a "hunger" crop or the crop of last resort.

Mozambique produces surplus cassava despite falling into the category of countries that use little or no fertilizer in cassava production (FAO, 2011). Cassava alone contributes to approximately 6% of the country's gross domestic product (GDP) (FAO-Mozambique, 2010) and about 628 kcal per person per day. The latter contribution places Mozambique among the top three countries globally that rely on cassava for caloric intake (El-Sharkawy, 2004). In the 1960s, cassava was more than 45% of the diet, but by 2006 its share decreased more than 40% due to the increased market share of other products such as maize (*Zea mays*). Even with its decreased market share, cassava remains one of the main food products in Mozambique. Maize, which had a high diet share in the early 2000s, has decreased from 25 to 20% in food intake share. This decrease was attributed to lower yields and increased imports of other commodities such as wheat and rice (Promar Consulting, 2011).

In Mozambique, about 75% of the economically active population is engaged in agriculture (Gwarizimba, 2009). The majority of the population are small-scale resource-poor farmers who farm on 1.78 ha average. Cassava is produced extensively throughout the country (Promar Consulting, 2011), almost entirely for household consumption (Gwarizimba, 2009). The cassava cropping season is variable because the cropping season and harvest date is dependent upon the type of cassava grown (Promar Consulting, 2011) and household consumption needs. Cassava is an excellent niche crop for subsistence households because it can be harvested almost continuously over several months and up to a couple years (Donovan and Tostão, 2010). Cassava is typically planted in November and harvested between July and October. For many varieties, maximum cassava yields occur after 10 to 12 months.

Cassava Brown Streak Disease (CBSD) and African Cassava Mosaic Disease (ACMD) impact cassava production (Boansi, 2017; Hillocks et al., 2002b). It is estimated that the CBSD disease alone has affected more than 50% of the cassava production with more aggravation in the Northern provinces of Nampula and Zambezia. To address this issue, the government of Mozambique has taken steps to identify and promote disease-free and disease-resistant varieties (Promar Consulting, 2011). Presently, Mozambique is the fifth largest producer of cassava in Africa, second only to Angola in Southern Africa (FAO, 2011), and has an average tuber yield of approximately 6 tons/ha (Dias, 2012; Promar Consulting, 2011), which is about 40% less than the continent's average (10 tons/ha) (Mkamilo and Jeremiah, 2005) and yields that fail to meet the growing demand for emerging bioethanol, brewery, and cassava-based bread industries. To meet home and commercial demands, there is a need for research to offset the yield gap through work on improved cultivars and planting material including; to determine fertilization rates to offset low soil fertility; developing appropriate farm tools; developing agronomic practices for cassava mono- and polyculture; and evaluating the cassava value chain including transport from rural areas (EC-FAO, 2007).

Agronomic research demonstrates that significant increases in cassava yield are possible when optimum fertilizer rates are applied (Howeler, 1981; Howeler and Cadavid, 1990; Graner and Coury, 1955; Ezui et al., 2016; de Cequeira and Howeler, 1980; Howeler et al., 2006). Kamaraj et al. (2008) reported cassava response to an increased level of N, P and K fertilizer up to 150% over the normal recommended rate of 60-60-160 kg/ha N-P_2O_5-K_2O for optimum yields in a study conducted on poor sandy loam and sandy clay loam soils (classified as Typic Ustropepts) (Soil Survey Staff, 2010) in Northwestern India. Increasing fertilizer rates to 90-90-240 kg/ha also yielded more tubers than a relatively higher rate of 120-120-320 kg/ha. These studies also suggest that fertilizer recommendation rates for high cassava tuber yields can vary widely depending on the region and agro-ecological conditions that determine the nutritional status of the soil.

According to Imas and John (2013) and CIAT (1992), K deficiency in cassava can be corrected with an application of 50 to 100 kg K_2O/ha (as KCl), but the rate is dependent upon soil fertility status. In P depleted soils, high rates of P fertilizer are needed for one or two consecutive cropping seasons to increase the available P in the soil to a level where yield is not limited by its deficiency. Cassava is highly efficient in P use and has low P uptake per ton, subsequent P applications can be gradually reduced. Howeler and Cadavid (1990) recommended application of 50 to 100 kg/ha N per cropping season in soils with low organic matter and available N. Overall, current fertilizer recommendation rates from cassava producing countries, including Latin America and Asia, range from 30 to 100 kg/ha N, 25 to 100 kg/ha P_2O_5, and 60 to 100 kg/ha K_2O (Howeler, 1981). These recommendations are comparable with those of the FAO (2013), which range from 50 to 100, 10 to 20, and 65 to 80 kg/ha for N, P_2O_5 and K_2O, respectively, depending on the nature of the soil and desired yield levels. Even though many cassava producing countries still lack fertilizer rate recommendations for cassava production, research

Table 1. Selected chemical and physical properties of soil of Milha-14, Dondo District, Mozambique.

Parameter	Level	Method of analysis
pH unitless	4.9	KCl (ASTM, 2001)
P mg kg^{-1}	6	Bray extract
K mg kg^{-1}	149	$NH4^+$ acetate
Ca mg kg^{-1}	215	$NH4^+$ acetate
Mg mg kg^{-1}	60	$NH4^+$ acetate
Na mg kg^{-1}	16	$NH4^+$ acetate
Organic matter (%)	1.03	Walkley-Black

Methods listed in the table are described by NCR-13(2011). Soil pH was obtained from a 1:2.5 soil:solution ratio. P, K, Ca, Mg, and Na levels are reported in mg/kg.

cited suggests that yields can be increased, but only if fertilizer rate research is conducted regionally with respect to soil type, agroecosystem, and cassava cultivar (Toro and Atlaa, 1980).

The objective of this study was to determine combination(s) of N, P, and K fertilizer rates for high cassava tuber yields for Milha-14 in the coastal Dondo district, Sofala province, Mozambique. A no-till fertilizer study was conducted to determine cassava tuber yield response to different combinations of N, P, and K fertilizer rates under smallholder farmer conditions.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Milha-14 (19° 25′ 54.0″ S, 34° 43′ 28.6″ E), in the coastal district of Dondo, province of Sofala, in Mozambique, over the 2013/2014 agricultural year. Mozambique is divided into ten agro-ecological regions (MAF, 1996) based upon climate, soil type, elevation, and farming system (Maria and Yost, 2006). The regions are designated by prefix "R" that stands for "region" followed by a number that ranges from one to ten. Milha-14 falls within agro-ecological region R5 (MAF, 1996). R5 has an altitude ranging from 0 to 200 m above sea level, annual average temperature of 24°C, rainfall ranging from 1,000 to 1,400 mm, and soil texture ranging from sand to sandy loam. These agro-ecological attributes make R5 suitable for cassava production (MAF, 1996) despite the low soil pH and nutrient availability as evidenced by soil analysis results shown in Table 1. Nevertheless, the soils at Milha-14 are relatively young, suggesting that they have been eroded and re-deposited by water. On-site observations suggest that it is likely that the soils at Milha-14 are inceptisols with a high water table at or near the surface throughout the year. These characteristics prevent drainage and lead to near continuous waterlogging as evidenced by iron and manganese redoximorphic features. An aquept is likely the dominant suborder (Soil Survey Staff, 2010).

Experimental approach, design and treatments

Despite its overall suitability, Milha-14 lacks basic N, P and K fertilizer recommendations for cassava production and high cassava tuber yield. The experiment was initiated in March, 2013 and encompassed twenty treatments consisting of different combinations of contrasting N, P, and K fertilizer rates shown in Table 2 arranged in a completely randomized design (CRD) with each treatment replicated four times. Fertilizer rates were based upon the oxide forms of P and K and N as elemental (N, P_2O_5, and K_2O). The treatments were derived from general NPK fertilizer recommendation rates for cassava production in tropical regions (FAO, 2013; Howeler, 1981). Each nutrient was applied as a single fixed rate (Table 2: treatments 2 through 4) with N, P_2O_5, and K_2O applied at 60, 60, and 150 kg/ha, respectively and/or (2) combined with two single fixed rates at an increasing rate (Table 2: treatments 5 through 20). The treatments were compared among themselves and against an unfertilized control (check) treatment. Maximum fertilizer rates were defined based on maximum fertilizer response(s) reported in the literature (Howeler, 1981; Howeler and Cadavid, 1990). Cassava yield response is quite sensitive to fertilizer additions above the minimum required; sufficiency of one nutrient can lead to yield decreases when combined with another fertilizer nutrient. Using fertilizer rate relationships from previous studies seemed the most pragmatic approach.

A plot size of 4 m × 4 m was adopted for each fertilizer combination or treatment. Planting was done manually by inserting stem-cuttings into the soil at a spacing of 1 m × 1 m. A local bitter variety named *Tapioca* was used because of its resistance to ACMD, a major yield limiting factor in R5. Fertilizer was applied manually; urea, single super phosphate (SSP), and potassium chloride (KCl) were used as the N, P, and K sources, respectively. The N, P, and K were applied as basal fertilizer. Plots were weeded manually at the onset of the cropping season. The plots had four rows and four plants per row, making a total of 16 plants per plot. Tubers were dug by hand in March, 2014. The area harvested (net plot) consisted of four central plants selected from two central rows from where yield was estimated. During harvesting, traces of charcoal were uncovered in the subsoil, suggesting that the site was used for making charcoal. Charcoal production has many negative impacts on the environment (Msuya et al., 2011) including soil compaction due to wood transportation and the many charcoal burial sites. The site received a total rainfall of 1,832 mm which was unevenly distributed (Figure 1). As a result, the site remained waterlogged most of the cropping season due to poor drainage and a high water table.

Data collection and analysis

Yield data from the harvestable area (net plot) was used for

Table 2. Summary of average cassava tuber yield on fresh weight basis.

Treatment	Fertilizer rate in kg/ha			Tuber yield (tons/ha)
	N	P_2O_5	K_2O	
1	0	0	0	14.7 (2.6)[bcd]
2	60	0	0	8.5 (1.3)[d]
3	0	60	0	16.7 (3.8)[abcd]
4	0	0	150	22.9 (1.9)[abc]
5	0	60	150	25.5 (7.2)[ab]
6	25	60	150	25.9 (6.6)[ab]
7	50	60	150	24.0 (3.8)[abc]
8	75	60	150	13.1 (1.8)[cd]
9	100	60	150	20.6 (4.3)[abc]
10	60	0	150	18.4 (3.5)[cd]
11	60	30	150	17.3 (1.7)[cd]
12	60	60	150	13.6 (0.9)[cd]
13	60	90	150	22.8 (2.6)[abc]
14	60	60	0	27.7 (3.6)[a]
15	60	60	30	15.8 (2.4)[bcd]
16	60	60	60	22.3 (4.7)[abc]
17	60	60	90	21.5 (4.4)[abc]
18	60	60	120	20.9 (7.3)[abc]
19	60	60	150	19.8 (0.7)[abc]
20	60	60	180	25.9 (2.9)[ab]
LSD	-	-	-	11.7

Values in parentheses are standard errors of means. Treatments sharing superscripts are not statistically different ($p>0.05$).

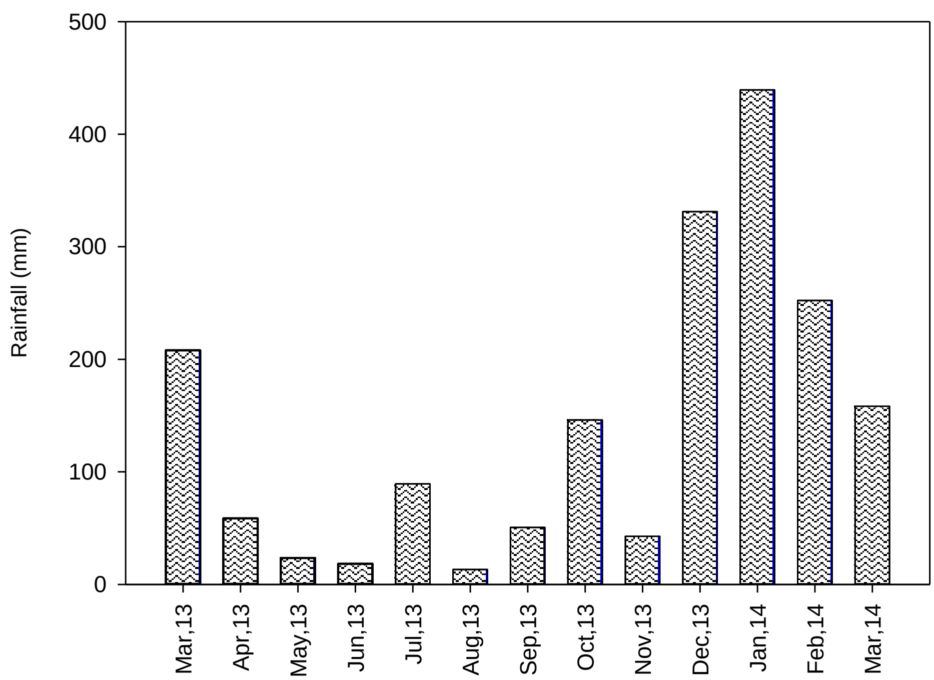

Figure 1. Total monthly rainfall (mm) recorded in 2013/2014 cropping season in Dondo.

statistical analysis which was performed using analysis of variance (ANOVA) and means compared using least significant difference (LSD) comparisons at a Type I error rate of α = 0.05 (SAS, 2011). Data collection also included soil measurements. Six soil samples were randomly collected from a 0 to 30 cm depth interval across the experimental plots and combined into one composite sample which was subject to a series of analyses procedures for selected soil chemical and physical properties shown in Table 1.

RESULTS AND DISCUSSION

Soil analysis

Results of soil analysis showed that the soil at Milha-14 was acidic and low in organic matter and selected nutrients as shown in Table 1, with Ca and Mg in particular, available in low and marginally low amounts, respectively. The soils are inceptisols with aquept as the likely dominant suborder (Soil Survey Staff, 2010), with a high water table at or near the surface throughout the year which leads to near continuous waterlogging, resulting in an overall poor soil fertility and failure to meet the crop's nutritional requirement as described by Howeler (2002).

Yield response

Table 2 summarizes the average cassava tuber yield (fresh weight basis) responses in tons/ha to different combinations of contrasting N, P, and K fertilizer rates. The results showed that there was a significant increase in no-till cassava tuber yield due to fertilizer addition ($p < 0.05$), demonstrating that the crop responds to fertilizer application as was reported in several studies (Polthanee and Wongpichet, 2017; Ezui et al., 2016; Osundare, 2014; Agbaje and Akinlosotu, 2004; Graner and Coury, 1955; Krochmal and Samuels, 1970; de Cequeira and Howeler, 1980).

Application of selected single fixed rate of K resulted in higher yield than that of N but equal to that of P (treatments 4 vs. 2 and 3, Table 2). On the other hand, applying 60 kg/ha N alone (treatment 2: 60-0-0 kg/ha N) yielded lowest (8.5 tons/ha) compared to not applying any fertilizer (treatment 1: 0-0-0; 14.7 tons/ha), suggesting that added N results in additional above ground biomass but not in additional tuber yield. However, applying 60 kg/ha N along with 60 kg/ha P (treatment 14: 60-60-0) yielded highest, 27.7 tons/ha. This yield surpassed that of the unfertilized control treatment almost two-fold and the national average yield (~6 tons/ha dry wt.; Dias, 2012). Increasing N rate along with that of K led to a decrease in the overall cassava tuber yield (Figure 2: treatments 10 through 13 vs. 5 through 9 and 14 through 20). These findings contrast those of Graner and Coury (1955) who reported the poorest tuber yields from a study conducted in Campinas, Brazil, when P was omitted, and N response similar to that obtained when P was added, whereas response to K was much less significant.

Cassava response to P was also reported by Krochmal and Samuels (1970) and de Cequeira and Howeler (1980), whose findings suggest that application of P leads to an increase in tuber yield and increased yield response to both N and K in Brazil's situation. According to Graner and Coury (1955), this high cassava P response is likely due to phosphorylation of starch reserves necessary for vegetative growth in the early stages of development. On the other hand, this response to P may also reflect, to some extent, the amount of P present in the soils at the site (Fermont, 2009) or in the stem-cuttings when they are set out in the field. Howeler and Cadavid (1990) also reported cassava response to P, with its best response found in infertile oxisols with the exception of those soils with high mychorrizal population.

Results of the study suggest that in spite of its role in cassava top growth and tuberization (Agbaje and Akinlosotu, 2004), K does not seem to be a limiting factor of production. Figure 2 shows a decrease in cassava tuber yield with increasing K rates (treatments 14 through 20). These findings contrast a recent study conducted in Northeastern Thailand by Polthanee and Wongpichet (2017), who reported that cassava had removed the greatest quantity of K in the storage roots compared to leaf and stems, and another in West Africa by Ezui et al. (2016) where K was found to be the primary cassava tuber yield limiting nutrient with requirements ranging from 140 to 160 kg/ha (CTCRI, 1983). This decrease in cassava tuber yield with increasing K rates agrees with Agbaje and Akinlosotu (2004); only sufficient K levels are required to stimulate cassava response to other nutrients such as N, as their excess may result in more biomass at the expense of tuber production as is common in sugarbeet production (Moraghan and Horsager, 1991). Conversely, cassava tuber yield was reported to respond positively to K when cassava was grown continuously in the same field (Howeler and Cadavid, 1990), which suggests that both N and P, as well as K individually play important roles in the overall cassava tuber production with its requirements depending more on the agro-ecology (including soil parent material) of the area where its production is intended and management practices adopted.

Factors affecting yield response

Field observations suggest that several biotic and abiotic factors may have contributed to the large variability in the experimental results (Table 2, LSD = 11.7). The high water table and excessive rainfall, lack of land preparation (due to the use of no-till planting which

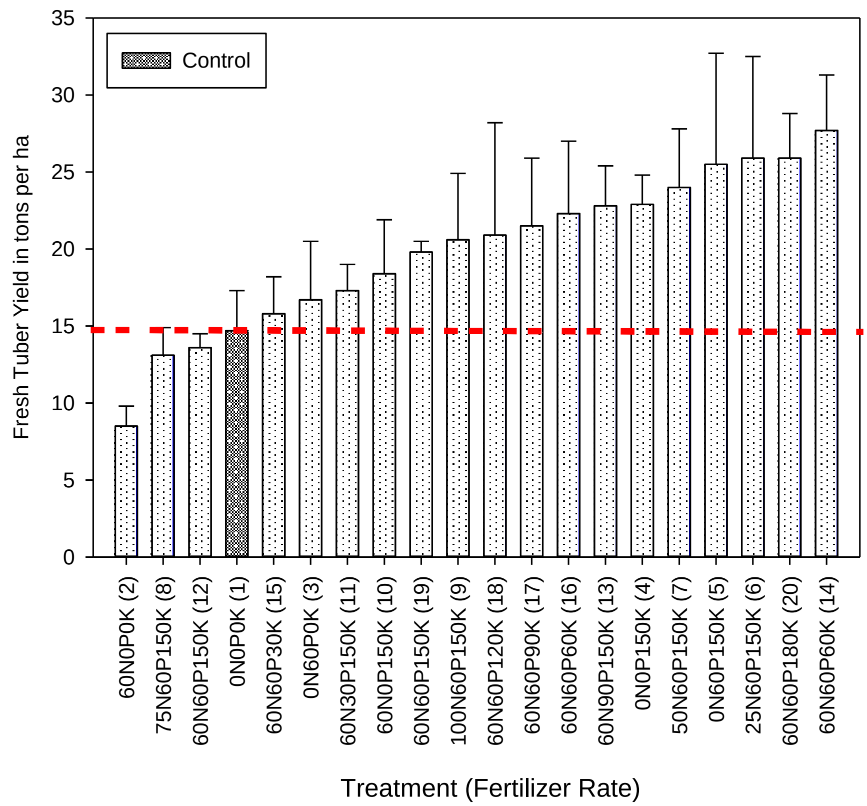

Figure 2. Cassava tuber yield response to different combinations of contrasting N, P, and K fertilizer rates. Yields are reported in fresh weight basis. Bars are the standard error of the mean. The dashed line is the control (no fertilizer) treatment mean. Numbers in parentheses are treatment numbers from Table 2.

obviated the construction of hills for the plants) and quality planting material (too much variability in planting material) are examples of these factors. Despite the shallow water table and in contrast to traditional practices, land preparation at the site did not include tilling the plots and hilling a practice which, according to FAO (2013), is used to keep the roots above the water table. The same source has pointed out that the risk of waterlogging is very high in shallow and poorly drained and heavily compacted soils especially when first rains are intense. During routine field visits it was observed that the site was waterlogged throughout most of the cropping season due to the shallow depth to water table and the fact that the amount of rainfall (1,830 mm total, Figure 1) received during the study period was approximately 50% greater than the average rainfall of that area (1,200 mm annually) (MAF, 1996). According to Agbaje and Akinlosotu (2004), although cassava can thrive in unfavorable conditions, excessive rainfall can affect the lifespan of added fertilizer in the soil, its retention and availability to the crop, and consequently may affect tuber formation and quality (Duluora, 2012; FAO, 2013).

In a study on the influences of temperature and rainfall on the yields of maize, yam and cassava among rural households in Delta State, Nigeria, Emaziye (2015) reported a negative relationship between rainfall and yields of maize, yam and cassava with decreased yield observed in all three crops due to increased rainfall. Mbanasor et al. (2015) also looked at the impact of rainfall on cassava productivity. In their study, they found a positive short-term but negative long-term effect of rainfall on cassava tuber yield. Similarly, a recent analysis of sensitivity of crop yield to extreme weather in Nigeria by Ajetomobi (2016) also found a negative effect of excess within-season rainfall on cassava yield with each 1% increase in rainfall resulting in 2.15% decrease in yield of cassava.

The presence of charcoal in the soil has also been associated with added fertilizer-use efficiency. Charcoal can simulate slow release of N, P, and K because of its effect on nutrient release dynamics and potentially on alterations to the soil microbial population. In their soil fertility work with ammonium sulfate additions to media containers with various levels of charcoal additions, Steiner et al. (2009) observed that less N, undetectable levels of P, and more K was leached in charcoal containing pots due to the chemical composition of K-rich charcoal. In a similar study, Steiner et al. (2008) reported increased retention of applied N fertilizer on a highly weathered Amazonian Oxisol with organic amendments that included charcoal. These findings suggest that once in the field, charcoal adsorption sites can compete with cassava for N and increase available K. Thus, the added fertilizer/nutrient use efficiency can be affected by charcoal additions.

Due to the impact of ACMD and CBSD (Boansi, 2017; Hillocks et al., 2002b), finding sufficient disease-free planting material was difficult at the study onset. Cassava transplant cuttings should be robust (Polthanee and Wongpichet, 2017) including only the middle brown-skinned portions of the stem and approximately 20 to 25 cm long with 5 to 8 nodes (James et al., 2000). Low quality plant material is one of the major causes of poor cassava tuber yields (Polthanee and Wongpichet, 2017) in Africa and Latin America (FAO, 2013). Owing to an increased incidence of ACMD and CBSD in Northern and Central Mozambique (Promar Consulting, 2011), successful cassava production in these areas requires that disease-free and/or disease-resistant material are used.

According to James et al. (2000), stem cuttings taken from portions of the plant other than the middle (top and bottom) dehydrate very quickly, are less hardy and therefore less resistant to pests and diseases, hence they are not suitable for planting and production of high quality tuber(s). In relating the growth and productivity of cassava grown from different portions of the cassava stem to climate parameters in Southeastern Nigeria, Eke-Okoro et al. (1999) also reported poor growth and productivity of stem cuttings taken from the top green and bottom portions of the plant. Coupled with site variability, depth to the water table, and variability of stem cuttings used for planting material, tree stumps between some of the plots may have impacted overall yield response to added fertilizer and led to greater variability in the data. It is important to note that after considerable search for a research site, this was the only site available for this research.

Conclusion

Cassava tuber yield was significantly increased by fertilizer addition. A combined application of 60-60-0 kg/ha is suggested for high cassava tuber yield(s) at Milha-14. On the other hand, taking into consideration the fact that cassava tubers remove more K than N and P, one season's results are not enough for drawing a solid conclusion. More research is needed to verify if this fertilizer combination (rates) can sustain high cassava tuber yields in the long term.

Alternatively, crop removal of K could be estimated and added into the fertilizer mix to avoid K mining as application of single fixed rate of K resulted in higher yield compared with those of N and P. The combined applications of 60-0-0, 75-60-150, and 60-60-150 kg/ha N-P_2O_5-K_2O yielded less compared to the unfertilized control treatment. Results from this study show clearly that there is potential to increase cassava tuber yield towards meeting the growing demand for cassava in an emerging bioethanol, brewery and cassava-bread industry.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) sponsored by the U.S. Agency for International Development's Bureau of Food Security and the University of Tennessee for funding. The authors are also grateful to CleanStar-Mozambique for the technical support and the farmers of Milha-14 for their support with the field work.

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academicJournals

Vol. 12(42), pp. 3120-3128, 19 October, 2017
DOI: 10.5897/AJAR2017.12701
Article Number: 0292ACB66399
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

The latest research progress of forest economics and analysis: Based on the review and analysis of studies in the two international authoritative journals

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Received 29 August, 2017; Accepted 21 September, 2017

As a cross discipline, the study scope of the forest economics has expanded continuously. Based on the review and analysis of the study in the two international authoritative journals, "Journal of Forest Economics" and "Forest Policy and Economics" from 2010 to 2014, this paper discussed the latest research progress of forest economics and the main contents of the study in order to provide a reference for the construction of the disciplinary system of the forest economics and its development. By using the method of cluster and variance analyses, the study points out that although the research of forest economic scope is expanding constantly, the contents of the research of forest economics mainly focus on the study of forest resources utilization and its benefits, forest management and economic analysis, as well as timber production and its market research. The paper suggests that construction of the disciplinary system of the forest economics in the world also should begin with the core contents and the latest research progress of forest economics, build a scientific system of theories and methods for it step by step, keep pace with the times, and the research contents should be renewed and improved constantly.

Key words: Cluster analysis, discipline system, forest economics, forest management, research progress.

INTRODUCTION

Forest economics is a cross-discipline subject, which studies the mutual effect of social, economic and forest ecosystems, how the latest research results of economics is applied into the development of social, economic and forest ecosystems, and how the research is providing theoretical direction and practical reference to its theories and practices (Kant et al., 2013). In recent years, the research scope of forest economics has expanded unceasingly. However, the recent advances and the contents of the research are unknown to us. Based on the review and analysis of the two international authoritative journals, Journal of Forest Economics and

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Forest Policy and Economics from 2010 to 2014, this paper discusses the research development and main contents of forest economics, thus providing a reference to the construction and development of the system of forest economics, as well as the reform of forest economic management in the world.

RESEARCH PROGRESS

Since Faustmann model was put forward in 1849, the research of the forest economy had been gradually formed and had attracted great importance from then on, so it was with the forest economics (Faustmann et al., 1849). Started from the research of the Faustmann optimal harvest model, the forest economics research scope has largely expanded from the study of the optimal harvest model under the economic net income maximization to the optimal model including ecological benefits, social benefits, tax and fee system and the international trade and other factors with the macroeconomic investment theory brought in (Xie et al., 2007). According to the statistics, there are more than 500 articles about Faustmann model since it was first proposed (Kant et al., 2013). However, based on many assumptions and inferences, the Faustmann model is simply a part, but not the whole of forest economic research. Forest economy is a cross-discipline subject, which involves society, economy, forestry ecosystem, etc. It needs to establish a scientific discipline system that could be able to cover the relevant knowledge, and to go through the constant competition, refute, rational criticism, discussion of the theoretical knowledge and practice of the verification process. In recent years, rapid development of forest economy has been achieved. The scope of the forest economics has been gradually expanded and the research in some extent is now being developed especially after 2003 (Schlüter and von Detten, 2011), with the introduction of the post-Keynesian consumer theory, behavioral economics, social choice theory, nonlinear programming, and discounting theory and methods.

In 1974, the economist P. A. Samuelson gave a speech named the sustainable forestry economic harvest. In his speech, he pointed out that the policy target of traditional forest economic management, to some extent, can be defined as a means of maintaining sustainable timber production or largest timber production (Samuelson, 1995). Then he also indicated that this definition was questioned by some economists. He suggested that when we do research on the largest timber production, we should take both "internal" and "external", land rent, interest rate, inflation rate, income, taxation, labor force, land-use change, etc., into consideration (Hartman, 1976).

Forests provide not only the economic value of the products, such as timber, fruit, rubber, etc., but also provide the value of the non-wood products, noted by Peters et al. (1989) in a research of the evaluation of rain forest. These values should also give high priority even in choosing the optimal rotation period (Peters et al., 1989).

Park et al. (1998) when doing the research on economic problems of the temperate and tropical forest land use, also pointed out that the value of forest carbon sink, species conservation, etc., should be given high priority when determining the value of the forest land.

On the 23rd International Forestry Research Organization Conference in 2010, when Kant et al. (2003, 2013a, 2013b) were giving a summary on the research front of forest economy, they stated that the new institutional economics, behavioral economics, public choice theory, related theories and methods of income, in recent years, have been introduced into the study of forest economics, which further expanded the research scope of forest economy. In the later research summary after the conference, they discussed the latest research theories and methods with personnel concerned and made a sum up of the main research contents and cutting edges at present.

The main research contents are as follows:

(1) Forest management decision making research on multi-objective utilization and forest ecosystem management (Arthur, 1994).
(2) An exploration of the connotation and definition of forest economy. They hold the opinion that economics is a discipline that studies and explains the relationship between human beings and the relationship triggered by different systems.
(3) The research on the dynamical problems caused by the non-linear relationship between forest ecosystem and economic system.
(4) The research on aesthetics, spirits, and cultural value of the forestry. Though all of these are not so important in ecosystem services and their value was mistakenly evaluated on the market; the public choice theory should be adopted for valuation, which is also an important part of forest economics field study.
(5) Urbanization changes people's values, so the social needs of forest recreation, ecosystem services, and environment friendly forest management activities have also increased. These needs not only change the research contents of forest economics, but also becomes an important part of it.
(6) The application of neoinstitutional economics in forest economic research. The main research should be focused on the exploration of the relationship between forestry administrative structure and resource users by related theory of neoinstitutional economics, especially on the study of application to watershed harnessing.
(7) The research of forestry long-term production management and decision-making. It has been the contents worth studying that the uncertainty of climate change has led to different expectations from the forestry

production operators for forestry revenue, and in turn caused many management and decision-making problems.

(8) The research of the compensation and payment framework between the society and ecosystem, especially the compensation and payment framework that is based on the social economy and social system.

(9) The research of the market mechanism of the forest ecosystem services, especially the research that could be applied to the spontaneous market mechanism formed by both the sellers and buyers who has the willingness to pay for the forest ecosystem services.

(10) The research of the design for forest ecosystem services payment. High priority should be given to the cases of the intersystem payment design.

(11) The research of the forest carbon sinks and forest carbon sinks to offset the carbon emissions. Forest carbon sinks is not only an environmental problem but also a basic issue of human rights. Studies must be embarked on to solve this problem; everyone should have the same right of carbon emission (Wang and Wilson, 2007).

In a word, since forest economics made its debut, with the introduction of different schools of economic theories and methods, the contents and scope of forest economy research have gradually expanded and forest economics finally came into being (Schlüter and von Detten, 2011). This paper mainly collected the papers in the Journal of Forest Economics and Forest Policy and Economics and did research on the latest research development and contents by the means of cluster analysis and analysis of variance, and also hope that this study can be used as a reference to the development of the discipline of forest economics.

RESEARCH METHODS

This paper analyzes the latest research development and contents by the means of cluster analysis and variance analysis.

Cluster analysis, a multivariate statistical technique to classify samples or indicators, is consisted of hierarchical clustering and K-Means clustering (quick clustering). Hierarchical clustering attempts to identify relatively homogeneous groups of cases (or variables) based on selected characteristics, using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left. K-Means clustering can handle large numbers of cases based on selected characteristics into k homogeneous groups. Its clustering is faster compared with the hierarchical clustering. Specifically, in this study hierarchical clustering was mainly used, and Between-groups Linkage was used in cluster method. When measuring the distance of cases (or variables), the Squared Euclidean Distance was also used.

ANOVA, short for analysis of variance, is a statistical technique for studying the observed variability characteristics of variables and independent variables. The variability is reflected through the significance testing of the mean difference of two or more samples. In the research, the differences between different research contents were analyzed to summarize the up-to-date research trends and the main research contents of forest economics. Specifically, ANOVA was used showing that different clusters do differ and gives information on each variable's contribution to the separation of the groups.

Research data

A total of 685 research articles and critiques in the two main international authoritative journals from 2010 to 2014 were collected to make a base for this study.

As the recognized authoritative academic forest economics and policies journals in the world, Journal of Forest Economics and Forest Policy and Economics mainly publish stringent standards of research articles of forestry economy and policy reviewed anonymously by peers. Social sciences and humanities related research papers that would have an impact on forest economy can also be published in the two journals; but these papers must have specific theories, conception and methods. So far the two journals are indexed in SCI, SSCI, EI, etc. In 2014, the impact factor of Journal of Forest Economics is 1.143 and 1.488 for five consecutive years (Journal of Forest Economics, 2015). While the impact factor of Forest Policy and Economics is 1.856 and 2.129 for five consecutive years (Forest Policy and Economics, 2015).

First of all, main research contents of the 685 articles of the two journals in 2010 to 2014 were extracted through “look up” and “select” tool in EXCEL of Microsoft Office and classified into groups. Secondly, the number of articles of different groups was counted, respectively, so was the percentage of total articles. The top 10 studied contents of articles in the two journals were sum up and the rest of the articles were all put into the group of “others”. The statistics of the articles published in the Journal of Forest Economics and Forest Policy and Economics in 2010-2014 is shown in Tables 1 and 2.

RESULTS

According to the statistics in Tables 1 and 2, Table 3 shows the top 10 study contents between 2010 and 2014 on the basis of the percentage of the total number of paper for the different study contents.

As is shown in Table 3, carbon sequestration evaluation stands first with 12.86%; 11.43% of the total number of papers, which ranks second, study the forest management and economic analysis; fewer papers cover the content of forest recreation evaluation with 5.71%.

Cluster analysis has been used in the study of the 10 research contents for finding out the latest research progress and the main research contents. Firstly, the ten research contents can be clustered into 4 groups by quick clustering. This procedure attempts to identify relatively homogeneous groups of research contents based on the ranks and the percentage of the total number of papers; the statistics of initial cluster centers for 4 clusters are shown in Table 4. Here, the method is iterated and classified, convergence criterion is 0, maximum iterations is 10, and the Euclidean distance between the case and the cluster center used to classify the case. The iteration history of quick cluster is shown in Table 5. Secondly, under the hierarchical clustering, the tree diagram of hierarchical clustering is as shown in Figure 1.

It was clearly observed that it can be divided into 4 groups by systematic cluster analysis in the top 10

Table 1. The statistics of the articles published on the Journal of Forest Economics in 2010-2014 (in descending order).

S/N	Main research contents	Number of papers	Percentage of the total number of papers
1	other	36	25.71
2	carbon sequestration evaluation	18	12.86
3	forest management and economic analysis	16	11.43
4	Forest owners ‘conservation benefit	12	8.57
5	optimal selective logging and its cost	11	7.86
6	the energy use of forest	10	7.14
7	timber production analysis	10	7.14
8	forest recreation evaluation	8	5.71
9	private forest	7	5
10	optimal forest harvest age	7	5
11	climate change affection	5	3.57
	total	140	100

Source: Journal of Forest Economics (2015).

Table 2. The statistics of the articles published on the Forest Policy and Economics in 2010-2014 (in descending order).

S/N	Main research contents	Number of papers	Percentage of the total number of papers
1	other	291	53.39
2	wood product and market	40	7.34
3	public and private forest landowners management	35	6.42
4	community forest management	34	6.24
5	forest ecosystem service management	24	4.4
6	forest-related conflicts	23	4.22
7	participatory forest management	23	4.22
8	conservation of forestry resources	20	3.67
9	carbon sequestration and CO_2 reduction management	20	3.67
10	biodiversity conservation	18	3.3
11	energy use production	17	3.12
	total	545	100.00

Source: Forest Policy and Economics (2015).

Table 3. The top ten research contents from 2010 to 2014.

Ranks	Contents	Number of papers	Percentage of the total number of papers	The journal sources
1	carbon sequestration evaluation	18	12.86	1
2	forest management and economic analysis	16	11.43	1
3	forest owners’ conservation benefit	12	8.57	1
4	optimal selective logging and its cost	11	7.86	1
5	wood product and market	40	7.34	2
6	the energy use of forest	10	7.14	1
7	timber production analysis	10	7.14	1
8	public and private forest landowners management	35	6.42	2
9	community forest management	34	6.24	2
10	forest recreation evaluation	8	5.71	1

1: Journal of Forest Economics; 2: Forest Policy and Economics.

Table 4. Initial cluster centers.

Items	Cluster			
	1	2	3	4
Number of papers	34	16	40	8
The percentage of the total number of papers	6.24	11.43	7.34	5.71
Ranks	9	2	5	10

Table 5. Iteration history[a].

Iteration	Change in cluster centers			
	1	2	3	4
1	0.515	0.321	8.88E-016	2.302
2	0.000	1.622	0.000	0.615
3	0.000	0.000	0.000	0.000

[a] Convergence achieved due to no or small change in cluster centers. The maximum absolute coordinate change for any center is 0.000. The current iteration is 3. The minimum distance between initial centers is 6.100.

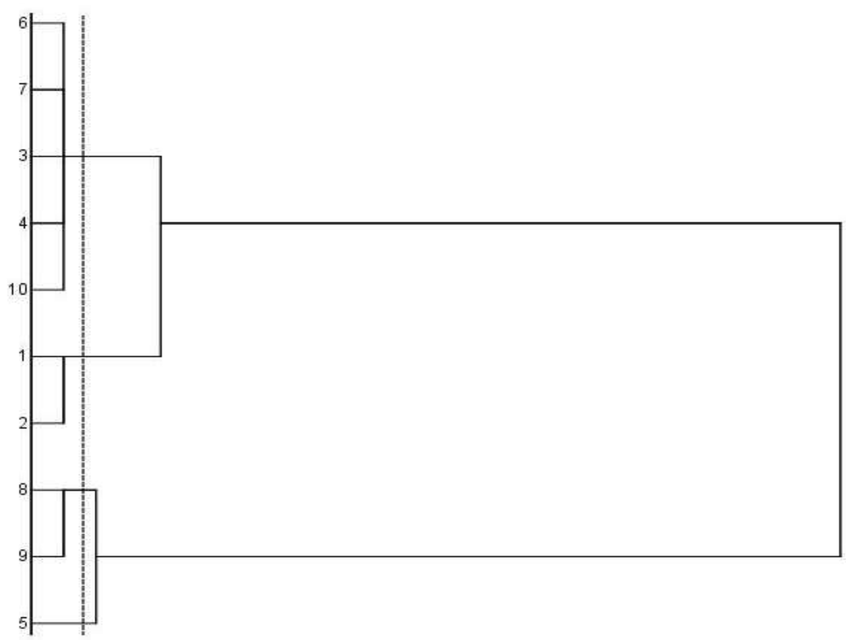

Figure 1. Research contents clustering figure of forest economics. It can be divided into 4 groups in the top 10 research contents. That is the first group (6, 7, 3, 4, 10), the second group (1,2), the third group (8,9) and the fourth group (5). 1=carbon sequestration evaluation: 2=forest management and economic analysis; 3= forest owners' conservation benefit; 4= optimal selective logging and its cost; 5= wood product and market; 6=the energy use of forest; 7= timber production analysis; 8= public and private forest landowners management; 9=community forest management; 10=forest recreation evaluation.

research contents from Figure 1.

First group: {6,7,3,4,10}

Second group: {1,2}
Third group: {8,9}
Fourth group: {5}

Table 6. ANOVA's Table of cluster analysis.

Items		Sum of squares	df	Mean square	F	Sig.
Paper	Between groups	27996.042	3	9332.014	13129.054	0.000
	Within groups	135.050	190	0.711	-	-
	Total	28131.093	193	-	-	-
The percentage of the total number of paper	Between groups	819.079	3	273.026	852.749	0.000
	Within groups	60.833	190	0.320	-	-
	Total	879.911	193	-	-	-

Table 7. Test of homogeneity of variances.

Items	Levene statistics	df1	df2	Sig.
Paper	65.036	3	190	0.000
The percentage of the total number of paper	92.940	3	190	0.000

Specifically, the four groups are as follows:

(1) The first group: The energy use of forest, timber production analysis, forest owners' conservation benefit, optimal selective logging and its cost, and forest recreation evaluation, and can be summarized as the research of forest utilization.
(2) The second group: Carbon sequestration evaluation, forest management and economic analysis, and can be summarized as the research of forest management and economic analysis.
(3) The third group: Public and private forest landowners management, community forest management, and can be summarized as the research of public forest, private forest and forest management.
(4) The fourth group: Wood product and market, and can be summarized as the research of wood product and market.

To further unveil the differences among the four groups, variance analysis has been used in the study. The ANOVA's Table is shown in Table 6.

As is shown in the Table 6, the significant differences of the four clustering results show statistical analysis. For the articles published on the two journals from 2010 to 2014, the F-value is 13129.054 and significance level is 0. While for the percentage of the total number of paper, the F-value is 852.749 and significance level is 0. The significance levels of both are less than 0. Therefore, the significant differences of the four clustering results show the clustering results is rational and of statistical significance.

One-Way ANOVA was also used to find out the discrepancy in different groups of clustering results. When equal variances were assumed, the Least Significant Difference was chosen; when the equal variances were not assumed, the Tamhane was chosen. The results are shown in Table 7. From Table 7, it can be clearly seen that test of homogeneity of variances shows the clustering results of the four groups is unequal with the variance of articles and the percentage of the total number of papers is 65.036 and 92.940, respectively, which also means the variances are not assumed. Therefore, we use the method of Tamhane to analyze the differences of the clustering results of the four groups. The final analysis is shown in Table 8.

It can be seen from Table 8 that the standard error of groups 2 and 3 is 0.130; the significance level is 0.996, higher than 0.05. It means that though the cluster result of the four groups is rational, groups 2 and 3 should be integrated as one group. So we put forest management and economic analysis and management of public and private forest landowners, community forest management together and name it as forest management and economic analysis. Then the new classification should be the group of the study of the forest management and economic analysis, management of public and private forest landowners and community forest management. By the means of cluster analysis and variance analysis, the latest research development and contents of forest economics is the study of the benefits of forests, the forest management, the economic analysis of forests, and the timer production and marketing. All the statistics analysis and results also show that this conclusion is rational and of statistical significance. Though there are differences between the research development and the research contents, they are the representative research direction for forest economics.

DISCUSSION

The research of the forest economy has made great

Table 8. Multiple comparisons.

Dependent variable		Between groups		Mean difference	Std. Error	Sig.	95% Confidence interval	
							Lower bound	Upper bound
Paper	LSD	1	2	6.686*	0.187	0.000	6.320	7.050
			3	-22.941*	0.197	0.000	-23.330	-22.550
			4	-17.448*	0.177	0.000	-17.800	-17.100
		2	1	-6.686*	0.187	0.000	-7.050	-6.320
			3	-29.627*	0.178	0.000	-29.980	-29.280
			4	-24.135*	0.156	0.000	-24.440	-23.830
		3	1	22.941*	0.197	0.000	22.550	23.330
			2	29.627*	0.178	0.000	29.280	29.980
			4	5.493*	0.168	0.000	5.160	5.820
		4	1	17.448*	0.177	0.000	17.100	17.800
			2	24.135*	0.156	0.000	23.830	24.440
			3	-5.493*	0.168	0.000	-5.820	-5.160
	Tamhane	1	2	6.686*	0.251	0.000	6.010	7.360
			3	-22.941*	0.174	0.000	-23.430	-22.450
			4	-17.448*	0.184	0.000	-17.960	-16.940
		2	1	-6.686*	0.251	0.000	-7.360	-6.010
			3	-29.627*	0.181	0.000	-30.120	-29.130
			4	-24.135*	0.191	0.000	-24.650	-23.610
		3	1	22.941*	0.174	0.000	22.450	23.430
			2	29.627*	0.181	0.000	29.130	30.120
			4	5.493*	0.061	0.000	5.330	5.660
		4	1	17.448*	0.184	0.000	16.940	17.960
			2	24.135*	0.191	0.000	23.610	24.650
			3	-5.493*	0.061	0.000	-5.660	-5.330
Percentage of the total number of paper	LSD	1	2	4.780*	0.125	0.000	4.530	5.030
			3	4.847*	0.132	0.000	4.590	5.110
			4	5.856*	0.119	0.000	5.620	6.090
		2	1	-4.780*	0.125	0.000	-5.030	-4.530
			3	0.067	0.120	0.573	-0.170	0.300
			4	1.076*	0.104	0.000	0.870	1.280
		3	1	-4.847*	0.132	0.000	-5.110	-4.590
			2	-0.067	0.120	0.573	-0.300	0.170
			4	1.009*	0.112	0.000	0.790	1.230
		4	1	-5.856*	0.119	0.000	-6.090	-5.620
			2	-1.076*	0.104	0.000	-1.280	-0.870
			3	-1.009*	0.112	0.000	-1.230	-0.790
	Tamhane	1	2	4.780*	0.180	0.000	4.300	5.260
			3	4.847*	0.124	0.000	4.500	5.190

Table 8. Contd.

	4	5.856*	0.125	0.000	5.510	6.200
2	1	-4.780*	0.180	0.000	-5.260	-4.300
	3	0.067	0.130	0.996	-0.290	0.420
	4	1.076*	0.130	0.000	0.720	1.430
3	1	-4.847*	0.124	0.000	-5.190	-4.500
	2	-0.067	0.130	0.996	-0.420	0.290
	4	1.009*	0.011	0.000	0.980	1.040
4	1	-5.856*	0.125	0.000	-6.200	-5.510
	2	-1.076*	0.130	0.000	-1.430	-0.720
	3	-1.009*	0.011	0.000	-1.040	-0.980

*The mean difference is significant at the 0.05 level.

progress in term of the scope since Faustmann model was put forward in 1849 (Deegen and Seegers, 2011). However, seen from the research results, the latest progress and research contents focus on the studies of the utilization and returns of forests, the forest management, forest economic analysis, timber production, and timber market. Though the research depends mainly on the articles published on the two international authoritative journals in 2010 to 2014, and it may come to a situation that the contracted contents could not exactly or absolutely reflect the true and whole contents of these articles, or a situation that the research may have done a rough classification, the research results will be greatly helpful and have some reference meaning to such relative studies on forest economy.

With the introduction of the new schools of economic theories and the new technical means, the research contents of forest economy expand unceasingly. All of these have become a trend for forestry research. Besides, the study of new problems and application of multi-disciplines have also become the research directions for forest economy. Hence, it is of great importance for the building of theoretical system of forest economics that forest economic research should not only pay attention to the application of new theories and multiple disciplines, but also should give high priority to the new techniques in solving economic problems of forestry.

Research of the forest economy has a long history (Liu et al., 2008). From the study of wood cutting the reform of forestry rights and the forestry output value calculation to the study of the evaluation of forest ecosystem services at the moment, the world's forest economic researches have always been influenced by the different government's policies and strongly linked with the different government's policies in different periods (Tian, 2013; Zhang, 2014). On the one hand, this will be conducive to solve the practical problems in different developing periods in different countries; on the other hand, this will be against the shaping and development of the theoretical system of forest economy. Therefore, it is imminent to build the theoretical system of forest economics based on the research problems in this field.

Conclusions

It can be seen from the related research reviewed and the analysis of cluster and variance on the Journal of Forest Economics and Forest Policy and Economics that forest economics is an integration of sciences with continuously expanded range of study, which mainly adopts multidisciplinary and interdisciplinary approach to doing research on related economic problems. However, though the scope of research expanded so much, the latest development of the research and the research contents mainly focus on the studies of the utilization and returns of forests, the forest management, forest economic analysis, timber production and timber market. The building of the discipline of forest economics and the research of forest economics in the world should also embark on these issues and build a scientific system of theories and step by step methods.

In addition to the traditional subjects of forest economy, behavioral economics, complex and multiple equilibria, institutional economics, organizational economics, welfare economics and other theories which had not been studied and responses introduced in the research of forest economics, new theories and methods should also be taken into consideration when studying the new forest economic problems. These researches should not be constrained by being guided with different countries' policies in different periods. It should be kept in pace with the research contents and should be renewed and improved constantly worldwide. That is, it should also be stressed when building the discipline of forest economics in the world and the system of theories and methods.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors gratefully acknowledged the support of forestry soft science research project of State Forestry Administration (2015-R19) in China and graduate student course construction project in Beijing Forestry University (HXKC15025).

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