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Full Length Research Paper

Assessment of genetic variability for yield and attributed traits among rice doubled haploid (DH) lines in semi-arid zone Sudan

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Anther culture is one of the biotechnology tools using for quick recovery of fixed breeding pure lines in rice. The development of new rice varieties is highly dependent on genetic diversity in desirable agronomic traits. Therefore, this study aimed to identify potential genotypes having the characters of Tongil-type and to study suitable traits of tested Double Haploid (DH) lines which can be applied in breeding program. Twenty advanced DH lines along with one local check were planted in a randomized complete block design with three replications during autumn seasons of 2017 and 2018. All evaluated genotypes exhibited a wide and significant variation in the twelve measured traits. The highest heritability related with high genetic advance was recorded for the number of tillerplant^{-1}, biomass yield, plant height, and grain yield. Genotypic coefficient of variation and genetic advance were recorded for number of tillersplant^{-1} and plant height in both seasons. Moreover, there was a highly significant and positive correlation of grain yield with number of panicle per m^2 (0.76), number of filled grain per panicle (0.71), number of tillersplant^{-1} (0.69), panicle weight (0.45) and biological yield (0.45). Based on productive tillers number, number of filled grainspanicle^{-1}, number of panicle per m^2, biological yield and grain yield, the lines KF323819, KF323895, KF323826, KF323893, KF323847, KF323855 and KF323885 were high potential could be considered as a new type of aerobic rice in Sudan. In additions, hybridization of these high yielding could be used to achieve higher heterosis among the genotypes and developing reliable selection indices for improvement rice breeding programs.

Key words: Double haploid, anther culture, yield components, broad sense heritability and path coefficient analysis.

INTRODUCTION

Rice (*Oryza sativa* L.) is the world's leading cereal crop as more than half of the world's population is dependent

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on it as their staple food (Bashir et al., 2010). The rising world population is increasing rapidly; rice production needs to be increased to meet its demands in the coming years in order to keep pace with increasing population mainly in Asia and Sub-Saharan Africa (Anyaoha et al., 2018). It is estimated that a 50% increase in rice grain yield may be required by 2050 to keep hunger away (Pang et al., 2017). This important cereal is cultivated and consumed in White Nile State in the Sudan but its production is characterized by poor yields resulting from use of low farm inputs and cultivation of unimproved cultivars with poor yield potentials (Osman et al., 2012). Hence, improving rice yield potential or its yield under various conditions is the foremost task for rice breeders (Ali et al., 2017).

The most sustainable way to increase rice production is via genetic and breeding improvements (Fischer, 2015). Perhaps even more importantly, rice breeding enables the integration of novel traits, which is essential in achieving yield stability in the changing climatic conditions we are facing (Dawson et al., 2015). The challenge for contemporary plant breeding is not only to integrate new traits into our crops, but to accelerate the genetic gain of its breeding programs at the same time, in order to achieve a doubling in speed of yield increase (Dwivedi et al., 2015).

Anther culture is a tissue culture procedure which can be applied in a breeding in order to accelerate the process of gaining pure lines (Herawati et al., 2010). With the development of doubled haploid (DH) techniques on improving the speed of genetic gain when applied in breeding programs, as well as their importance and diverse applicability in basic and applied research (Roy and Mandal, 2005). Anther culture breeding system which can shorten varietal development cycles by 3~5 years allow breeders to improve existing local varieties. DH techniques have been, and are being, used to accelerate the breeding programs of a range of crops, most notably maize, wheat, rice and barley (Seguí-Simarro, 2015).

Rice researchers in South Korea have made breakthrough in yield potential that occurred from modifying the existing high yield plant type to improve biomass, harvest index, reaching 7-8 tons/ha in polished rice. This occurred by formulating prototypes of semi-dwarf rice cultivars called ‘Tongil-type’ (TGT) through wide crosses between indica and japonica cultivars using Anther culture techniques. The desired characters of the TGT rice are compact growth, good number of productive tillers, big panicles and good grain filling (120-200 grains), semi dwarf (80-100 cm in height), erect and thick leaves with dark green colour, medium earliness (100-130 days), deep rooting system, soft and sticky endosperm and high resistance to major pests and diseases (Khush and Brar, 2002). Recently, a huge DH progenies were obtained from interspecific crosses between Tongil-type and Japonica with African varieties and wild species including *Oryza glaberrima, Oryza longistaminat* and *Oryza rufipogon*. Many of them were distributed to different African countries in order to determine the agronomic character stabilities for further selection of desirable characters, particularly in terms of yield components and yield. This will be serving as good resources for improving yield potential of local varieties particularly in the Sudan.

The magnitude of genetic variability provides useful information with regard to the possibility and extent of improvement that may be expected in the characters through breeding and selection. Breeders are interested in evaluating genetic diversity based on morphological characteristics as they are inexpensive, rapid, and simple to score. Moreover, this evaluation could be useful in developing reliable selection indices for important agronomic traits in rice. Therefore, the main objective of the present investigation was to assess the existing genetic variability and to select DH lines of aerobic rice having the characters of the Tongil-type and japonica to establish relationship in yields and its components and utilization of the available population in future rice breeding programs.

MATERIALS AND METHODS

Study site and experimental design

A total of 1027 independent lines, each containing one or a few plantlets that were regenerated from separated calli, were produced through anther culture of the (F_2 – F_3) generations derived for 14 interspecific crosses among Korean Tongil-type (Semi-dwarfism, high-yielding potential, earliness, medium amylose and medium-long grain,) and Japonica (Earliness, low-medium amylose, soft and sticky endosperm) with African varieties and wild species including *O. glaberrima, O. longistaminata*, and *O. rufipogon* (high biomass, disease resistance and low yield). They were established at Tissue Culture Laboratory *Africa-Rice St. Louis*. Of these 597 double Haploid lines were grown at Sahel Station in observation yield trial (OYT) then after several series of selection and fixation, in advanced generation,105 potential lines with the required adaptive traits were received and conducted in OYT; then again selected the superior 20 DH lines along with one check namely Kosti-1, were grown for two consecutive seasons (2017 and 2018) during the rainy season under irrigated condition; at White Nile Research Station Farm (latitude 14° 24 N and longitude 33° 22 E), Kosti of the Agricultural Research Corporation (ARC) Sudan. The soil of the experimental plots was classified as vertisol with high clay content (40 to 65%), less than 1% organic carbon, low in available nitrogen (0.03% total nitrogen) and medium in available P_2O_5 (406 to 700 ppm total phosphorus); pH values is slightly alkaline ranging from 7 to 8.2. The climate was semi-arid (Table 1).

The experimental plots were laid out in randomized complete block design (RCBD) with three replications. In both seasons deep plough, harrowing and leveling were practiced to prepare experimental area. The seeds were drilled on July 7th and 5th of 2017 and 2018 in turn, using a seed rate of 80 kg /ha. The plot size was 3 × 6 m with 0.2 m apart consisting of 15 rows giving a total area of 18 m^2. Recommended fertilizers of Urea and Triple Super Phosphate (TSP) at the rate of 129 kg N ha^{-1} and 43 kg P_2O_5 ha^{-1}, respectively were used. TSP was applied as basal dose during final land preparation. Nitrogen was top dressed in two equal split doses

Table 1. Monthly means of selected meteorological data recorded during 2017 and 2018 seasons at White Nile Research Station (WNRS).

Month	Season 2017				Season 2018			
	Temperature (°C)		Rainfall	R.H	Temperature (°C)		Rainfall	R.H
	Max	Min	(mm)	(%)	Max	Min	(mm)	(%)
June	39.1	26.2	8.1	6.2	42.8	23.2	8.1	64
July	34.8	23.7	162	69	34.5	24.0	171.6	75
August	33.6	26.4	63.11	64	37.0	21.6	92.9	77
September	33.4	24.1	60.6	49	39.0	19.0	63.6	74
October	36.8	24.3	17.7	38	37.3	24.2	36.6	75
November	35.8	21.9	00.0	40	39.5	17.5	00.0	36
December	33.7	18.9	00.0	46.8	40.6	16.8	00.0	39

at 21 days after sowing and the other before panicle initiation. Hand weeding was performed three times per season. All plots were irrigated at sowing and then at weekly intervals until it reached the flowering stage and then every 3 days. All other agronomic practices were applied as per the recommendation for rice production in the two seasons to raise a healthy rice crop.

Data collection

Data were collected on days to heading (days from sowing to the time when the 50% of the plants were headed) and days to maturity (days from sowing to the time when 80% of the panicles reached full maturity). Then at harvest, plant height (cm), panicle length (cm), panicle weight (g), number of tillersplant^{-1}, number of filled grainspanicle^{-1}, percent of unfilled grains panicle^{-1}, 1000 grain weight (g), grain yield (t/ha) and Biological yield (t/ha) based on grain yield per plot were recorded. The data were collected according to standard evaluation systems for rice standard evaluation system (SES) (IRRI. 2002); ten randomly selected plants in the net harvested area of each plot were used for data collection.

Statistical analysis

Analysis of variance (ANOVA) was carried out on the data to assess the genotypic effects and their interaction using general linear model (GLM) procedure for randomized complete blocks design in SAS (version 9.1). Estimates of variance components were generated and combined analysis of variance was done for the traits in which the mean squares were homogenous. The phenotypic and genotypic variances and their coefficients, heritability in the broad sense and genetic advance were computed according to the formula described by Singh and Chaudhary (1985). Means for each season were used to compute simple linear correlation coefficients. Path coefficient analysis was used to partition the simple linear correlation coefficients, combined over seasons, between grain yields/ha and four other traits; namely number of panicle per m^2, number of filled grainspanicle^{-1}, number of tillersplant^{-1} and plant height (cm) at maturity, into the direct and indirect effects.

RESULTS AND DISCUSSION

The results showed that there is a presence of acceptable amount of variability among the genotypes. This gives an opportunity for rice breeders to improve those traits through selection and hybridization to improve the desired traits. The range and mean of genotypes for all studied traits also indicated wide ranges of variation which also revealed possible amount of variability among the genotypes (Table 2).

The broad sense heritability is the relative magnitude of genotypic and phenotypic variances for the traits and it is used as a predictive role in selection procedures. This gives an idea of the total variation ascribable to genotypic effects, which are exploitable portion of variation. The characters that showed relatively high heritability estimates (≥ 90%) were number of panicle/m^2 (98.1 and 97.5), panicle length (97.1 and 98.1), number of tiller/plant (95.5 and 93.5), 1000 grain weight (95.3 and 93.7), number of unfilled grain/panicle (93.4 and 94.0) and plant height (91.5 and 93.7) in both seasons respectively, indicating the optimizing of homogeneous of these lines and their improvement could be achieved by mass selection. Similar results were reported by Sohrabi et al. (2012). This indicated that selection of these traits would be more effective as compared to others. The moderate heritability estimate for grain yield was attributed to the fact that yield is a complex trait and is controlled by many genes. Since high heritability does not always indicate high genetic gain. Heritability with genetic advance considered together should be used in predicting the ultimate effect for selecting superior varieties (Anyaoha et al., 2018; Ahmed et al., 2018). High genetic advance and heritability were recorded for the number of tiller/plant, number of unfilled grain/panicle, biological yield t/ha, plant height, and grain yield t/ha. These results suggested that these traits were primarily under genetic control and selection for these traits can be achieved through their phenotypic performance. High heritability estimates with low genetic advance observed for days to heading, days to maturity and panicle weight indicated non additive type of gene action and that genotype × environment interaction played a significant role in the expression of the traits.

The genetic analysis of quantitative traits is a prerequisite for plant breeding programs, which can lead

Table 2. Estimates of means, range, heritability in broad sense (h2B), genotypic (GCV) and phenotypic (PCV) Coefficients of variation, genetic advance as percentage of the mean for 12 traits in 21 rice genotypes grown at the WNRS Farm, seasons 2017 and 2018.

Trait	Years	Mean±SE	Range	H^2B%	GCV%	PCV%	GA%
Days to heading	1	71.1±0.7	63-87	88.4	6.74	7.16	13.05
	2	87.2±1.6	54-114	89.6	1.77	1.86	3.48
Days to maturity	1	86.9±0.8	77-100	84.3	5.45	5.94	10.31
	2	77.5±0.2	75-81	88.3	5.42	5.44	11.12
Plant height (cm)	1	84.5±1.7	54-114	91.7	14.49	15.13	28.57
	2	88.7±0.5	85-97	93.6	13.51	13.61	27.65
Panicle length (cm)	1	22.8±0.3	18-28	97.1	10.71	10.86	21.76
	2	22.9±0.3	18.5-27	98.1	23.12	23.71	28.84
Panicle weight (g)	1	3.3±0.1	2.2-4.5	92.5	14.56	14.98	9.15
	2	3.7±0.1	3.3-5.0	92.5	2.12	2.19	4.25
No. of tillers/plant	1	3.8±0.1	2.0-5.0	95.5	23.97	24.53	48.27
	2	3.4±0.1	2.2-4.6	93.5	24.74	25.73	49.02
No. of panicles/m^2	1	346.7±7.0	243-423	98.1	15.82	15.98	32.29
	2	350.6±7.0	213-410	97.5	15.26	15.45	31.05
No. of filled grain/panicle	1	92.2±1.8	62-126	85.2	12.24	13.26	23.27
	2	88.0±1.7	64-112	88.2	15.14	15.20	31.06
No. of unfilled grain/panicle	1	14.0±0.6	3.0-25.0	93.4	34.36	34.82	39.84
	2	13.4±0.7	5.0-24.0	94.0	38.66	38.85	39.26
Thousand grain weight (g)	1	22.3±0.4	17.3-34.4	95.3	13.10	13.42	26.35
	2	23.7±0.3	18.0-28.7	93.7	10.90	11.26	21.74
Grain yield (t/ha)	1	6.0±0.1	4.4-8.2	88.7	14.39	15.27	27.91
	2	5.4±0.1	3.2-7.6	89.4	20.77	20.94	42.43
Biological yield (t/ha)	1	13.1±0.3	8.3-18.8	89.4	16.50	17.45	32.14
	2	14.5±0.4	7.0-21.0	87.4	17.97	19.22	34.61

to a systemic method of design and to the appropriate planning of plant breeding strategies. The current study suggests that the packed cell volume (PCV) was higher than the Genotypic Coefficient of Variability (GCV) for all traits. This was also the case for all the traits observed in another study; Osman et al. (2012) which reported that the environmental effect on any trait is indicated by the magnitude of the differences between the genotypic and phenotypic coefficients of variation. Large differences reflect a large environmental effect, whereas small differences reveal a high genetic influence. In this study, the small differences between the PCV and GCV for most of the traits, such as days to heading, plant height, panicle length, number of unfilled grain per panicle, 1000 grain weight and grain yield t/ha, represented some degree of environmental influence on the phenotypic expression of these characters. It also suggests that selection based on these characters would be effective for future crossing programmes. The other traits, which showed a higher difference between PCV and GCV, indicated that the environmental effect on the expression of those traits is higher and that selection based on these characters independently is not effective for further yield improvement. The highest PCV recorded for number of unfilled grain/panicle (34.8-38.9) and numbers of tiller/plant (24.5-25.7) in both seasons were also recorded by the following researchers (Mulugeta et al., 2011; Abebe et al., 2017).

The results further revealed that most of the traits exhibited wide range of variability (Table 3a-b). The late heading and maturing genotypes were KF323877 and KF323892, while the early flowering and maturing genotype was KF323886, KF323841 and KF323819; as compared to the local check variety (Kosti-1) most of the genotypes showed extra early maturity period. However, only four genotypes were late maturing than the local check Kosti-1. This suggested the chance of selecting earliness genotypes which can escape terminal moisture and drought stress. The range for plant height was 58.5 to 112.8 cm with genotype KF323885 as the tallest and genotypes KF323883 as the shortest. According to IRRI irrigated rice plant height is classified as semi-dwarf (less than 110 cm), intermediate (110-130 cm) and tall (more than 130 cm). Based on this classification, in the present study 90.4% of the tested genotypes group are under the semi-dwarf class. This indicated that the tested genotypes had inherent variability in stature to develop lodging resistant varieties (semi-dwarf) that will have

Table 3a. Mean of growth aspects of 20 double haploid lines grown at White Nile Research station Farm (WNRSF) combined over two seasons, 2017 and 2018.

Genotype	DH	DM	PLH	PL	PW	NTP
KF323892	78.7^{ab}	95.2^{ab}	91.3^{de}	24.5^{c}	2.7^{i}	2.8^{e}
KF323886	71.1^{d}	82.3^{h}	74.4^{i}	19.6^{h}	2.8^{hi}	3.5^{d}
KF323846	72.7^{d}	85.7^{efgh}	73.7^{i}	24.2^{c}	3.3^{f}	2.0^{f}
KF323826	79.7^{ab}	91.5^{cd}	86.8^{defg}	22.1^{e}	4.1^{a}	4.5^{b}
KF323896	72.5^{d}	85.8^{efgh}	82.6^{gh}	19.5^{h}	3.3^{f}	2.6^{e}
KF323877	82.0^{a}	97.7^{a}	88.6^{efgh}	26.1^{b}	3.7^{bcd}	4.6^{ab}
KF323891	71.5^{d}	97.0^{a}	84.9^{efg}	25.55^{b}	3.7^{bcd}	3.0^{e}
KF323893	73.2^{cd}	84.8^{fgh}	101.8^{b}	21.6^{ef}	3.6^{bcd}	4.8^{ab}
KF323847	72.3^{d}	84.2^{gh}	90.1^{def}	22.1^{e}	3.8^{bc}	4.7^{ab}
KF323855	73.5^{cd}	85.8^{efgh}	73.0^{i}	21.1^{fg}	3.9^{ab}	4.8^{ab}
KF323864	78.5^{ab}	92.3^{bc}	88.9^{defg}	24.1^{c}	3.6^{cde}	4.0^{c}
KF323841	71.2^{d}	82.3^{h}	84.0^{fgh}	22.2^{e}	2.3^{j}	2.6^{e}
KF323819	71.2^{d}	82.5^{h}	93.6^{cd}	23.2^{d}	3.3^{f}	4.6^{ab}
KF323883	73.2^{cd}	86.0^{efg}	58.5^{j}	18.6^{i}	2.4^{j}	3.0^{e}
KF323885	74.5^{cd}	85.7^{efgh}	112.8^{a}	27.6^{a}	2.7^{i}	4.0^{c}
KF323852	74.2^{cd}	86.8^{efg}	98.6^{bc}	23.4^{d}	3.4^{ef}	3.7^{cd}
KF323851	76.7^{bc}	88.5^{de}	89.6^{def}	20.8^{g}	3.5^{def}	3.0^{e}
KF323854	74.5^{cd}	85.7^{efgh}	77.8^{hi}	25.8^{b}	3.1^{g}	3.7^{cd}
KF323895	72.5^{d}	86.0^{efg}	73.1^{i}	22.0^{e}	3.3^{f}	5.0^{a}
KF323848	72.3^{d}	85.8^{efgh}	89.2^{defg}	24.6^{c}	4.1^{a}	3.8^{cd}
Kosti-2 CK	72.5^{d}	87.8^{ef}	93.5^{cd}	20.5^{g}	3^{gh}	3.0^{e}
CV%	4.4	3.5	7.1	2.6	5.4	10.3
SE	0.48	0.46	1.15	0.21	0.05	0.08
Pro> F	*	**	**	*	*	**

*, ** Significant at 0.05 and 0.01 probability respectively. DH, Days to 50% heading; PW, Panicle weight gram; DM, Days to maturity; NTP, No. of tiller/plant; PLH, Plant height centimeter; PL, Panicle length centimeter.

higher response to nitrogen application. Also there is reported variation in plant height by Akinwale et al. (2011), Atif and Khalid (2013) and Abebe et al. (2017). The local check panicle length recorded was 20.5cm with maximum value of 27.6 cm and minimum value of 18.6 cm for KF323885 and KF323883, respectively. Based on the IRRI irrigated rice classified argument, the present finding showed that there is enough medium variability for panicle length among the genotypes for improving panicle architecture and grain yield due to high association of this trait that determines the number of grains it can hold (Table 3a).

The range for number of filled grainspanicle^{-1} was 71.5 to 110.5 for genotypes KF323841 and KF323847, respectively. The range of percentage of unfilled grainspanicle^{-1} was 5.8 to 21.2 for genotypes KF323886 and KF323892 respectively (Table 3b). Adequate number of fertile grains/panicle and heavy grains are important traits, which should be considered in selection for high yield genotypes (Osman et al., 2012; Abebe et al., 2017). Relatively range performance was revealed among the studied traits, grain yield (4.03-7.40 t/ha) with a local check grain yield of 4.68 t/ha. The genotypes significantly varied for grain yield and about 76.2% of the genotypes had higher grain yield than the standard check (Kosti-1). Among the genotypes, KF323819, KF323895, KF323826, KF323893, KF323847, KF323855 and KF323885 were the top yielders with corresponding grain yield of 7.40, 6.95, 6.87, 6.82, 6.69, 6.56 and 6.35 t/ha, respectively. The local check (Kosti-1) was the medium yielder (4.68) (Table 2b). Thus, the existence of enough variability among genotypes was highly significant. Hence, it offers a better scope for further selection of promising DH genotypes in rice breeding program particularly selection based on yield is reliable.

Yield is a complex product being influenced by several independent quantitative characters. Breeders always look for variation among traits to select desirable types. Some of these characters are highly associated among themselves and with seed yield. The analysis of the correlations among these characters and their associations with grain yield is essential to establish selection criteria. When more characters are involved in correlation study it becomes difficult to ascertain the characters which really contribute toward yield. The relationships existing between 12 quantitative traits

Table 3b. Mean of growth aspects of 20 double haploid lines grown at White Nile Research station Farm (WNRSF) combined over two seasons, 2017 and 2018.

Genotype	NPM	NFGP	NUFGP	TGW	Yth	Bth
KF323892	266.3^{h}	79.3^{fghi}	21.2^{a}	23.9^{bcde}	4.20^{jk}	13.13^{fghi}
KF323886	277.3^{gh}	86.5^{defg}	5.8^{h}	21.6^{efgh}	5.33^{hi}	12.08^{ghij}
KF323846	312.3^{f}	82.8^{efgh}	9.0^{g}	23.8^{bcde}	5.27^{gh}	13.36^{fgh}
KF323826	393.0^{b}	102.2^{ab}	15.7^{cd}	21.9^{efgh}	6.87^{abc}	17.45^{a}
KF323896	277.3^{gh}	78.0^{hig}	16.0^{bcd}	22.6^{efgh}	4.50^{ijk}	13.7^{defgh}
KF323877	375.3^{c}	99.0^{bc}	12.0^{ef}	25.5^{bc}	5.45^{efgh}	15.3^{cdf}
KF323891	365.0^{cd}	90.7^{cde}	10.3^{fg}	19.87^{h}	5.63^{efg}	12.0^{hij}
KF323893	408.7^{a}	96.0^{bc}	9.5^{fg}	24.7^{bcd}	6.82^{bc}	14.7^{cdef}
KF323847	418.0^{a}	110.5^{a}	10.3^{fg}	23.5^{cdef}	6.69^{bc}	16.66^{ab}
KF323855	418.^{a}	102.0^{ab}	8.0^{gh}	23.3^{cdefg}	6.56^{bc}	16.31^{abc}
KF323864	341.3^{e}	94.0^{bcd}	13.8^{de}	22.5^{efdg}	5.97^{de}	12.96^{fghi}
KF323841	284.0^{g}	71.5^{i}	17.5^{bc}	20.3^{h}	4.03^{k}	9.9^{kl}
KF323819	414.0^{a}	102.0^{ab}	15.5^{cd}	23.8^{bcde}	7.40^{a}	17.98^{a}
KF323883	276.3^{gh}	72.3^{i}	20.5^{a}	22.3^{efgh}	4.43^{jk}	8.53^{l}
KF323885	360.0^{d}	85.5^{defgh}	21.0^{a}	21.5^{fgh}	6.35^{cd}	15.66^{bc}
KF323852	317.7^{f}	94.0^{bcd}	12.0^{ef}	26.3^{b}	5.53^{efgh}	13.78^{defg}
KF323851	345.0^{e}	77.2^{hi}	18.8^{ab}	20.5^{gh}	5.42^{def}	15.2^{bcde}
KF323854	393.0^{b}	94.0^{bcd}	10.2^{fg}	21.9^{efgh}	5.87^{def}	13.45^{efgh}
KF323895	408.3^{a}	108.0^{a}	9.5^{fg}	23.3^{cdefg}	6.95^{ab}	11.45^{ijk}
KF323848	360.6^{d}	87.2^{def}	16.3^{bcd}	24.7^{bcd}	5.24^{gh}	14.56^{cdfef}
Kosti-2 CK	278.0^{gh}	72.8	15.2^{cd}	30.3^{a}	4.68^{ij}	10.46^{jk}
CV%	3.7	8.4	17.9	9.1	8.5	11.3
SE	4.89	1.22	0.45	0.27	0.10	0.26
Pro> F	**	**	*	**	**	**

*, ** Significant at 0.05 and 0.01 probability respectively. NPM, No. of panicle/m^2;' TGW, 1000 grain weight; NFGP, No. of filled grain/panicle; Yth, Grain yield ton/hectare; NUFGP, No. of unfilled grain/panicle; Bth, Biological yield ton/hectare.

represented as simple correlation coefficients are presented in Table 4. Correlation of yield and other traits is important in indirect selection for high yield improvement in crop genotypes (Idris et al., 2012). There was a highly significant and positive correlation of grain yield with number of panicle per m^2 (0.76), number of filled grain per panicle (0.71), number of tillers per plant (0.69), biological yield (0.45) panicle weight (0.45), plant height (0.23) and panicle length (0.18) (Table 4). Conversely, grain yield exhibited negative significant correlation with number of unfilled grain per panicle (-0.33), days to 50% heading (-0.13), and days to maturity (-0.21). The significant and positive correlation with grain yield is a strong indication that these traits are major factors in improving grain yield; also suggests that selection directed towards these characters will be effective in ensuring high grain yield in Double haploid rice. These results collaborate with the finding of Ogunbayo et al. (2014) who observed a positive and significant correlation between grain yield and number of filled gain per panicle. Also these results were in agreement with that reported by Kato et al. (2008). The negative correlation obtained between days to heading and days to maturity and grain yield indicate that grain yield can be improved by selecting early maturing genotypes.

Partitioning of yield and yield component into direct and indirect effect revealed that number of panicle per m^2 had the highest direct positive contribution (0.400) to the grain yield t/ha and also had positive indirect effect on grain yield t/ha through number of filed grain/panicle (0.220), number of tillers/plant (0.120) and plant height (0.020) (Table 5). Many research workers reported similar findings (Surek and Beser, 2003; Abdulfiyaz et al., 2011; Sanni et al., 2012). The direct effect of number of filled grains/panicle on grain yield was the second largest (0.309); it had positive indirect effect on grain yield through number of panicle per m^2 (0.280) and number of tillers/plant (0.120) and plant height (0.001). The direct effect of number of tillers/plant on grain yield t/ha was the third largest (0.170), and its indirect effect through number of panicle per m^2 (0.290) and number of filled grain/panicle (0.210). The direct effect of plant height on grain yield was the fourth largest (0.122). It had positive indirect effect on grain yield through number of tillers/plant (0.030), number of filled grains/panicle (0.010) and number of panicle per m^2 (0.070). indicate that both correlation and path coefficient analysis suggested these

Table 4. Simple linear correlation coefficients between 12 pairs of traits in DH rice using (combined over two seasons 2017-2018).

Traits	DH	DM	PLH	PL	PW	NTP	NPM	NFGP	NUFG	TGW	YTH
DM	0.48**	1									
PLH	0.20*	0.09*	1								
PL	0.18*	0.30**	0.42**	1							
PW	0.13*	0.18*	0.11*	0.11*	1						
NTP	0.15*	-0.08*	0.18*	0.11*	0.39***	1					
NPM	0.11*	-0.06	0.16*	0.29***	0.61***	0.73***	1				
NFGP	-0.3	-0.02	0.03	0.18*	0.50***	0.71**	0.71**	1			
NUFG	0.11*	0.07*	0.22*	0.067*	-0.34***	-0.24**	-0.34**	-0.50***	1		
SGW	0.18*	0.07*	0.18*	-0.03	0.10*	0.03	-0.04	-0.03	-0.08*	1	
YTH	-0.13*	-0.21*	0.23*	0.18*	0.45***	0.69**	0.76**	0.71***	-0.33**	0.13	1
BTH	0.25**	0.03*	0.38***	0.21*	0.47***	0.41***	0.55**	0.42***	-0.09*	0.08*	0.45**

*, ** Significant at 0.05 and 0.01 probability respectively. NPM, No. of panicle/m^2;' TGW, 1000 grain weight; NFGP, No. of filled grain/panicle; Yth, Grain yield ton/hectare; NUFGP, No. of unfilled grain/panicle; Bth, Biological yield ton/hectare; TGW, 1000 grain weight; NTP, No. of tiller/plant; DM, Days to maturity; PLH, Plant height centimeter; PL, Panicle length centimeter; NPM, No. of panicle/m^2; NUFG, No. of unfilled grain/panicle; PW, Panicle weight gram; DH, Days to 50% heading;

Table 5. Path coefficient analysis of the direct and indirect effects of the different yield components and their simple correlation.

Trait	Effect via				Simple correlation with grain yield/ha
	No. of Panicles/m^2	No. of filled grain/panicle	No. of tillers/plant	Plant height (cm)	
No. of panicles/m^2	0.400	0.220	0.120	0.020	0.76**
No. of filled grain/panicle	0.280	0.309	0.120	0.001	0.71***
No. of tillers/plant	0.290	0.210	0.170	0.020	0.69**
Plant height (cm)	0.070	0.010	0.030	0.122	0.230*

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels respectively.

four traits should be considered in further selection procedures for higher grain yield.

Conclusions

In conclusion, the present study identified the presence of adequate genetic variability among 21 tested genotypes. Hence, the information generated from this study, rice breeder can be exploited for future rice breeding program. The study was also carried out for one sit and two seasons. Therefore, it is advisable to select and grow the highest yielding genotype (KF323819, KF323895,KF323826, KF323893, KF323847, KF323855 and KF323885) at least in more than three locations (National Yield Trial); considering. major rice growing areas to make sound recommendations for release Moreover, it is recommended that future rice research should explore molecular means to further confirm the outcome of DH lines study findings, in order to do an efficient selection process.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Growth and yield of finger millet (*Eleusine coracana* L.) (Garten) as affected by varying nitrogen levels at Mubi, Adamawa State, Nigeria

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A field experiment was conducted at the Teaching and Research Farm of the Adamawa State College of Agriculture at Mubi, Nigeria to determine effect of Nitrogen fertilization on the growth and yield of Finger Millet (*Eleusine coracana* L. (Garten). Results indicated that all the growth and yield components were significantly ($p \leq 0.05$) influenced by increasing nitrogen fertilizer application rates. The highest performances for all the parameters were recorded at the application rate of 600 kg Nha^{-1}. Growth and yield components were found to be positive and linearly related to increasing nitrogen rates. It is therefore recommended that Finger millet be fertilized with 600 kg Nha^{-1}, at Mubi.

Key words: Finger millet, nitrogen fertilization, savanna ecological zone, nutritious, semi-arid.

INTRODUCTION

Finger millet (*Eleusine corocana* L. Garten) called “tamba” in Hausa language, a staple food crop in the semi-arid tropics of South Asia and Africa (Malinda et al., 2015), is said to be the third most important cereal crop in India (Saraswathi et al., 2017) and is a minor cereal crop that belongs to the Orchideccae subfamily. The crop has been highly valued by traditional farmers for its nutritious values, drought resistance, early maturing and ability to survive under low chemical input requirement (Malinda et al., 2015; Bhomte et al., 2006; Wekha et al., 2016). In addition, it has low pest problems and hence low storage problems.

The crop has a total production of five million tons over a land area of 4.0 to 4.5 million hectares with India as the World-leading producer of 5 million tons followed by Africa with about two million tons (Mathew and Luigi, 2011; Tsado et al., 2016). Finger millet is cultivated in the northern part of Nigeria with a production capacity rated as 44% on the African continent (Tsado et al., 2016).

The grain is more nutritious than other cereals and hence called nutrition millet in India (Sandhya et al., 2017; Bekele et al., 2016; Tsado et al., 2016). It provides sustaining diet for diet related patients, nourishing for infants and its straw is a valuable fodder for animals (Sandhya et al., 2017; Bekele et al., 2016).

Finger millet has the ability to survive very well in different agro-climatic conditions where there is as low as 400 mm of rainfall and temperature above 15°C and

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can be grown throughout the year (Malinda et al., 2015). It can be grown for weed control and can be grown on poor soil (Ibrahim et al., 2018).

Despite the importance of the crop to the farmer nutritiously and for its low input requirements (Bekele et al., 2016), the crop suffers from low yield due to the poor fertility status of the soils in sub-Saharan Africa (Malinda et al., 2015) and paucity of information on how to improve its productivity. It is important therefore, to optimize the nutrient management practices and other related factors affecting finger millet cultivation in order to attain better yields under the comparatively marginal local growing conditions. Unfortunately, compared to the major cereal crops the recommendations available for nutrient management of finger millet in the study area are scarce, limiting the ability of agricultural extension officers to assist subsistence farmers.

It is in line with the above, that the study was carried out to determine the effect of varying levels of nitrogen fertilizer on the growth and yield of finger millet in the study area.

MATERIALS AND METHODS

The study was conducted in the 2004 and 2005 rainy seasons on the Teaching and Research Farm of the Adamawa State College of Agriculture at Mubi, Adamawa State, Nigeria.

Mubi is situated at latitude 11°E and Longitude 13°N in the Southern Sudan Savanna Zone of Nigeria. The area has a mean annual rainfall of 1000 mm with temperature ranging between 18 and 27°C, that is,favourable for the cultivation of the crop.

The field was laid in Randomized Complete Block Design. The treatments were varying levels of Nitrogen; T1 (0 kg N/ha), T2 (100 kg N/ha), T3 (200 kg N/ha), T4 (400 kg N/ha) and T5 (600 kg N/ha), these were replicated four (4) times. A total of 20 experimental units each size 4m x 3m with 0.5 m path between them giving a total area of 297 m^2. Each plot was ploughed manually with hoe. The seeds sourced from Jos, Plateau State Nigeria, were planted in rows 75 cm apart and 20 cm between stands at the rate of five seeds per hole and after germination thinned to two per hole. Prior to planting, phosphorus and phosphate fertilizer were applied to the plots to allow for adequate solublization and subsequent availability to the plants. Weeding was first done immediately after germination and subsequently whenever necessary.

Nitrogen fertilizer in the form of urea was applied in accordance with the treatments four weeks after germination.Data collected were those of plant height, leaf area, leaf length, leaf width, number of fingers per plant, dry matter yield, root dry weight and the grain yield. The data collected were analyzed using Analysis of Variance (ANOVA) appropriate for the experimental design at 5% significance level and means were separated using Fisher's LSD at 5% probability. Regression analysis was also carried out to estimate the relationship between the parameters measured and the applied Nitrogen fertilizer.

RESULTS AND DISCUSSION

Plant height

The results from Table 1 shows that application of nitrogen fertilizer has resulted into significant ($p \leq 0.05$) increase in the plant height compared to the control. The result shows that treatment T5 gives the highest plant height of 102.5 cm while the control gives the lowest plant height value of 52.50 cm. However, plant height at 100 (T2) and 200 (T3) kg/Nha do not differ significantly ($p \leq 0.05$). Increase in plant height with respect to increase in Nitrogen rate was also found to be positively related (r = 0.99**). This relationship has accounted for 98% (r^2 = 0.98) of the variability in height.

Leaf area

The leaf area of finger millet was significantly ($p \leq 0.05$) influenced by Nitrogen application rates with treatment T5 and T1 yielding the largest area of 110.67 cm^2 and the smallest area of 52.99 cm^2 respectively. However, the result also reveals that, leaf are at T1 and T2 were statistically similar but with T2 having higher leaf area than T1. In a similar manner, T4 and T5 were also statistically similar with T5 having larger area than T4. The result also reveals that there was a significant and positive linear relationship (r = 0.99**) between increasing rate of Nitrogen fertilizer application and the leaf area of finger millet.

Leaf length

The results from Table 1 also reveals that, increase in Nitrogen fertilizer application rate has significantly ($p \leq 0.05$) influenced the leaf length of finger millet in the study area. The results shows that, treatment T5 (600 kg N/ha) yielded the longest leaf length of 62.83 cm and treatment T1 (control) yielded the shortest leaf length of 49.62 cm. However, the result also indicated that, leaf length at T1 and T2 were not significantly different ($p \leq 0.05$) but with T2 yielding longer leaf length of 53.32 cm than T1 (49.62 cm). In a similar manner, leaf length at T3, T4 and T5 were also statistically similar, but with T5 yielding longest among the three treatments of 62.83 cm, followed by T4 (62.40 cm) and T3 (59.70 cm). The leaf lengths were also found to be positively related (r = 0.90**) to the increase in Nitrogen levels.

Leaf width

The leaf width of finger millet was found to be significantly ($p \leq 0.05$) influenced with the increasing Nitrogen levels with treatment T4 and T5 giving the largest width of 1.94 cm and treatment T1 giving the smallest width of 1.26 cm. However, the result also reveals that leaf width at T1 and T2 were statistically with T2 giving larger width of 1.46 cm than T1 (1.26 cm). In a similar manner, leaf widths at T3, T4 and T5 were also statistically similar ($p \leq 0.05$) but with T5 giving the largest leaves in descending

Table 1. Growth and yield of finger millet under varying Nitrogen levels at Mubi, Adamawa State, Nigeria.

Nitrogen levels (kg Nha^{-1})	Plant height (cm) 12WAS	Leaf area (cm^2) 12WAS	Leaf length (cm) 12WAS	Leaf width (cm) 12WAS	No. of tillers/plant 12WAS	No. of spikelets (fingers per spike (head) 12WAS	Dry matter of whole plant (g) 12WAS	Root dry weight/plant (g) 12WAS	Grain yield (tones ha^{-1})
0	52.50	52.99^a	49.62^a	1.26^a	1.76^a	5.25	24.55	4.00	0.75^a
100	62.00^a	61.45^a	53.31^a	1.46^a	2.75^{ab}	7.00^a	28.45	5.33	1.00^a
200	68.00^a	70.40^a	59.70^b	1.78^b	3.25^b	7.00^a	35.15	5.88^a	1.29
400	79.25	97.91^b	62.40^b	1.94^b	3.75^b	10.75	48.22	6.17^a	1.75^b
600	102.25	110.67^b	62.83^b	1.94^b	5.00	12.75	58.10	9.22	2.01^b
$LSD_{p\leq0.05}$	7.40	18.50	4.53	0.27	1.13	1.53	2.98	0.54	0.29
C.V. (%)	12.49	30.18	8.62	2.98	8.99	7.52	7.52	6.89	0.95

Means with the same letters under the same column do not differ significantly ($p \leq 0.05$)

order to T3. The result also discovered that a linear positive relation ($r = 0.85^{**}$) exists between increasing Nitrogen fertilizer application rate and leaf width.

Number of tillers per head

Tiller development in small grain crop is an index of biological yield (Fageria, 2007). In this study, variation in Nitrogen application rates was found to have significantly ($p \leq 0.05$) influenced the increase in the number of tillers. The result reveals that, treatment T5 yielded the highest number of tillers of 5.00, while treatment T1 (control) yielded the number of tillers of 1.76. However, number of tillers at T1 and T2 were found to be statistically similar but with T2 having higher number of tillers than T1. In a similar manner, number of tiller at T2, T3 and T4 were also found to be statistically similar ($p \leq 0.05$) but with T4 having the highest number of tillers among the three in descending order. In addition, a positive linear relation ($r = 0.98^{**}$) was observed between increasing Nitrogen application rates and tillering ability of the finger millet.

Number of fingers per head

The number of fingers per head just like the number of tillers is a measure of biological yield of a crop (Fageria, 2007). The result from Table 1 shows that, number fingers produced was significantly ($p \leq 0.05$) influenced by the increasing levels of Nitrogen fertilizer. The number of fingers corresponding to the treatment levels are; 5.25, 7.0, 7.0, 10.75 and 12.75 corresponding to T1, T2, T3, T4 and T5 respectively. However, number of fingers at T2 and T3 were not significantly different ($p \leq 0.05$) but were higher than the control (T1). In addition, results from Table 2 shows that, number of fingers were positively related ($r = 0.99^{**}$) with the increase levels of Nitrogen fertilizer.

Dry matter yield (DMY)

Increase in dry matter yield is an index of growth and development of a crop. The result of this study shows that, DMY is significantly ($p \leq 0.05$) influenced by varying level of Nitrogen fertilizer; with T5 yielding the highest DMY of 58.10 g and T1 yield the lowest DMY of 24.55 g. The result also reveals that there is a linear positive relationship ($r = 0.99^{**}$) between DMY and increasing rate of Nitrogen fertilizer application.

Root dry weight (RDW)

The root dry weight of finger millet was found to increase significantly ($p \leq 0.05$) under varying Nitrogen application rates. The highest RDW of 9.22 g was obtained at T5 while the Control yielded the lowest RDW of 4.00 g. However, the the RDW at T3 (5.33 g) did not differ significantly ($p \leq 0.05$) with that at T4 (5.88 g). From the result, RDW was also observed to be positively correlated ($r = 0.95^{**}$) to the increasing Nitrogen levels.

Grain yield

Varying application rates of Nitrogen fertilizer was found to significantly ($p \leq 0.05$) enhance the grain yield with the highest application rate (T5) yielding the highest grain yield of 2.01 tons/ha, while the

Table 2. Relationship between varying Nitrogen levels and growth and yield components of Finger Millet at Mubi, Adamawa State, Nigeria.

Growth and yield components	Coefficient of linear correlation (r)	Coefficient of determination for linear regression (r^2)
Plant height	0.99**	0.98**
Leaf area	0.99**	0.98**
Leaf length	0.90**	0.81**
Leaf width	0.85**	0.72**
No. of tillers per plant	0.98**	0.96**
No. of Fingers per head	0.99**	0.98**
Dry matter for whole plant	0.99**	0.98**
Root dry weight	0.95**	0.90**
Grain yield	0.99**	0.98**

control (T1), yielded the lowest grain yield of 0.75 tons/ha. However, yield at T1 and T2 were found to be statistically similar ($p \leq 0.05$), but with T2 having the higher yield of 1.00 tons/ha. In a similar manner, the yield obtained at T4 and T5 were also statistically similar with T5 having the higher yield of 2.0 ton/ha than T4 (1.75 ton/ha). In addition, the result (Table 2) shows that grain yield is positively and linearly related ($r = 0.99$) to increasing Nitrogen fertilizer.

In general, the results indicated that finger millet responds well to increase in Nitrogen fertilizer levels (Gupta et al., 2012).

DISCUSSION

The positive contribution of increasing Nitrogen Fertilizer levels to the growth and yield components of finger millet could be attributed to its ability to supply Nitrogen in the soil solution throughout the growth period of the crop. A study performed by Ahmad et al. (2018) on response of maize cultivars to Nitrogen levels shows that, grain yield of maize is significantly ($p \leq 0.05$) influenced by increasing levels of Nitrogen application. A similar result was also observed by Malinda et al. (2015).

It was also discovered in studies performed on effect of different amounts of Nitrogen fertilizer on grain yield of forage corn by Leila and Ali (2014) that, Nitrogen have significant ($p \leq 0.05$) effect on the forage grain yield.

This positive influence of increasing Nitrogen on the growth and yield components of finger millet that has translated into longer, wider and larger leaves was also discovered in a similar study by Kumara et al. (2007) and Tsadoet al. (2016). These might have enhanced the utilization of solar energy for higher and better photosynthetic activities (Bekele et al., 2016). In addition, the longer and wider leaves produced could be the reason for enhancing the height of the plants. The significant relationship between the increasing Nitrogen levels and the yield and growth components could also be attributed to the optimum photosynthetic activities in addition to the availability of the Nitrogen in the presence of adequate moisture in the soil. This corroborated the statement made by Gupta et al. (2012) that said, "Finger Millet responds well to Nitrogen application".

In summary, the study discovered that, increasing Nitrogen levels have positive effect on the growth and yield components of finger millet in the study area. This is similar to the results obtained by Tsado et al. (2016) in a study performed on the performance of finger millet as influenced by Nutrient sources in Kaduna and Minna, Nigeria and a study performed by Patil et al. (2015).

CONCLUSION AND RECOMMENDATIONS

From the results obtained in this study, it could be concluded that, finger millet responded well with increasing Nitrogen fertilizer application rate. In addition, application of Nitrogen fertilizer at the rate of 600 kg N/ha could be recommended for Finger millet production in the study area.

The practice of integrated fertility management, where artificial fertilizer and organic manure are used is recommended for further studies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of agricultural wastes on some soil physicochemical properties of ultisol, growth parameters and yield of cocoyam (*Xanthosoma mafafa*) at Umudike, southeastern Nigeria

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This research was conducted on a degraded Ultisol at the Eastern farm of Michael Okpara University of Agriculture, Umudike during 2014 and 2015 planting seasons, to determine the effect of different rates of sawdust and poultry manure application on soil physicochemical properties of acid sandy Ultisol, and growth and yield of cocoyam. The treatments comprised of two organic amendments at five levels each: Sawdust (0, 2, 10, 15 and 20 t/ha) and poultry manure (0, 2, 4, 6 and 8 t/ha), which were combined to produce 24 treatment combinations and a control. The treatments were assigned randomly to the plots and incorporated into the soil two weeks before planting. The treatment combinations were laid out in Randomized Complete Block Design (RBCD) and replicated three times in a factorial experiment. Data were collected on plant height, number of leaves, leaf area, corms, cormels and total yield. Soil samples were collected with core samplers for physical properties such as soil bulk density and total porosity using soil auger at 0 to 15 cm, at the end of the experiment for chemical analysis such as soil pH, organic carbon, available phosphorus, total nitrogen, exchangeable acidity and total exchangeable cations such as K^+, Ca^{2+}, Mg^{2+} and Na^+. The soil physicochemical properties were significantly improved with mostly higher rates of sawdust and poultry manure over control, which positively modified cocoyam growth and yield. The cocoyam leaf area, plant height, number of leaves, corms, cormels and total cocoyam yield increased significantly with application of 8 t/ha PM. The total cocoyam yield amounted to 17.73 t/ha in 2014 and 15.15 t/ha in 2015. Results of this research showed that agro-wastes such as poultry manure and sawdust have the potentials for increasing cocoyam production and soil fertility.

Key words: Sawdust, poultry manure, bulk density, total nitrogen, soil fertility.

INTRODUCTION

Food is a basic necessity of man and its production largely depend on soil fertility. Consequently, management of soil fertility is pre-requisite for continuous food production and sustainability of soil resources. Soil fertility

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depletion is mainly due to intensive and continuous cropping with application of low levels of fertilizer, causing a negative balance between nutrition supply and extraction from the soil. Continuous cropping makes tropical soils highly vulnerable to soil degradation. Hence, they are characterized by low organic matter, low pH, high erosion and structurally unstable aggregates with limited capacity to hold water (Oguike et al., 2006). Soil degradation increases soil acidity, nutrient leaching and soil nutrient imbalance. These are associated with the continuous use of inorganic fertilizers and the polluting effects of the fertilizers on the environment have also made these fertilizers unsuitable for maintenance of soil fertility (Agbede et al., 2013). The use of agro-wastes as soil amendments is a sustainable means of improving soil fertility and productivity. It therefore imperative to incorporate animal manure, recycle secondary crop products and other organic wastes to improve soil fertility and enhanced crop yield (Mbah et al., 2010).

Sawdust, though impacts good structural attributes to the soil, have little or relatively low effects on soil chemical properties due to its low surface area as well as low degradability due to high carbon and low nitrogen content. It could cause nitrogen immobilization, resulting in depressed plant growth and reduced microbial respiration (Eneje and Ukwuoma, 2005). An increase in organic carbon in soil was observed with the application of sawdust as an organic amendment (Eneje and Ezeakolam, 2009).

Poultry manure has been regarded as the most valuable of all organic manures produced by livestock (Okonkwo et al, 2009). Moreover, the nutrient content of poultry manure is among the highest of all animal manures, and the use of poultry manure as soil amendment for agricultural crops will provide appreciable quantities of all the major plant nutrients. It also improves biological activities, soil fertility and soil chemical properties (Omisore et al., 2009). Poultry manure supplies the essential nutrients especially nitrogen, phosphorus and potassium required for maximum crop production (Ibeawuchi 2010).

Cocoyam (*Xanthosoma mafafa*) is a staple food grown for its edible corms, cormels and leaves. Fresh cocoyam and its leaf contains about 70 to 80% water, 20 to 75% carbohydrate and 1.5 to 3.0% protein, significant amounts of vitamin C, iron, calcium, phosphorus, thiamine, riboflavin, niacin and carotene (Udo 2005; Chukwu, 2010). It contains over 80% and 240% higher digestible crude protein than yam and cassava respectively as well as higher amount of essential minerals such as calcium, magnesium and phosphorus (Chukwu and Nwosu, 2008; Okoye et al., 2008). Cocoyam has the smallest starch grain size (1-4 micrometer) relative to yam (10-70 µm) and cassava (15-17 micrometer) (1 - 4 µ) relative to yam (10 - 70 µ) and cassava (15 - 17 µ). This confers on cocoyam both higher digestibility and biodegradability, making it suitable food for potentially allergic infants and persons with gastro-intestine disorders and for the treatment of diabetes (FAO, 1990).

Sawdust as an organic amendment is not frequently used because of its high carbon to nitrogen ratio. It is an important byproduct in processing timber and is high in carbon content. The supply of nitrogen with poultry manure can help prevent nitrogen immobilization by the high carbon content of sawdust. This will be of great benefit to soils with low organic matter content, resulting in greater improvement in soil physicochemical properties and cocoyam growth and yield.

The objective of this study was to determine the effect of sawdust and poultry manure combinations on some soil physicochemical properties of acid sandy Ultisol and on some growth parameters and yield of cocoyam.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Michael Okpara University of Agriculture Research farm in Umudike (Longitude 07° 33'E, Latitude 05° 29'N, Altitude 122 m). The climate is essentially tropical humid. The area has a total rainfall of 2177 mm per annum, annual average temperature of about 26°C. The rainfall pattern is bimodal: a long wet season from April to July is interrupted by a short "August break" followed by another short rainy season from September to October or early November. Dry season stretches from early November to March (NRCRI, 2015).

Experimental layout

The field was mechanically cleared, ploughed, harrowed and ridged in both 2014 and 2015 planting seasons. The ridges were made at 1 m apart in a plot size of 4 m by 4 m with a furrow of 0.5 m. The total experimental area was 1496 m^2 (68 m by 22 m). The treatments comprised of sawdust (SD), sourced from Timber shade, Umuahia: the treatments were applied at five levels including 0, 2, 4, 6 and 8 t/ha and poultry manure (PM), which was sourced from National Root Crop Research Institute Umudike, was applied at five levels including 0, 5, 10, 15 and 20 t/ha, which were combined to produce 24 treatment combinations and a control. These treatment applications was done in 2014 and repeated in 2015. The treatment combinations were laid out in Randomized Complete Block Design (RBCD) and replicated three times in a factorial experiment.

Soil sampling and collecting

A composite soil sample was collected before treatment application for the characterization of the experimental site. Soil samples were collected with core samplers for physical properties such as soil bulk density and total porosity. Soil samples were collected using soil auger at 0 to 15 cm, at the end of the experiment for chemical analysis. The soil samples were air-dried at room temperature, and sieved through a 2 mm sieve. The soil pH was determined in 1:2.5 soil- to- water ratio using pH meter (Thomas, 1996). The organic carbon was determined using dichromate wet oxidation method of

Walkey – Black as explained by Nelson and Sommers (1996). Available phosphorus was determined by Bray 2 method as described by Bray and Kurtz (1945). Total nitrogen was determined using Kjeldahl method (Bremner, 1996). Exchangeable cations such as K^+, Ca^{2+}, Mg^{2+}, and Na^+ were determined according to Summer and Miller (1996).

Planting and weeding

The test crop for the experiment was cocoyam which was sourced from National Root Crop Research Institute Umudike: was planted at a spacing of 1 m by 1 m with one corm sown per planting hole on the crest of the ridge at the depth of 15 cm, given a total plant population of 16 plants per plot. Weeding was manually done with hoe at 2, 8, 13 and 17 weeks after planting.

Collection of growth and yield data

Data were collected on plant height, number of leaves, and leaf area using the method of Agueguia (2008) at 4, 8, 12 and 16 weeks after planting and the average measurements were used. Also, data on total yield of cocoyam (corms and cormels) were collected at harvest at 10 months.

Data analysis

All the data collected were subjected to analysis of variance (ANOVA) for factorial experiment in RCBD using GENSTAT software and the treatment means were separated using the Fisher's Least Significant Different (FLSD) at 5% probability level.

RESULTS

The properties of the experimental soil (Table 1) indicate that the soil is sandy loam, slightly acidic, with low organic carbon, nitrogen, available phosphorus and exchangeable bases. The organic amendments used in the study (Table 2) showed that poultry manure has higher values in total nitrogen, available P and exchangeable bases (K, Na, Mg and Ca) while sawdust has higher values in organic carbon, organic matter and C:N ratio.

Effect of sawdust and poultry manure on soil physical properties

The soil bulk density decreased significantly ($p < 0.05$) over control with application of poultry manure at various rates, but the lowest values obtained were 0.991 gcm^{-3} in 2014 and 0.892 gcm^{-3} in 2015 with 2 t/ha PM (Table 3). Also, the application of sawdust at different rates significantly ($p<0.05$) decreased bulk density with the lowest values of 0.919 gcm^{-3} in 2014 and 0.827 gcm^{-3} in 2015 recorded with the application of 20 t/ha SD. The lowest values recorded with SD were lower than that of PM in both planting seasons. The interactions of SD and PM also have significant effect on the soil Bulk Density.

The soil total porosity increased significantly ($p < 0.05$) over control with application of poultry manure at various rates, but the highest values obtained were 62.60% in 2014 and 66.36% in 2015 with 2 t/ha poultry manure (Table 3). Also, the application of SD at different rates significantly ($p<0.05$) increased total porosity with the highest values of 65.32% in 2014 and 66.79% in 2015 recorded with the application of 20 t/ha SD. The highest values recorded with SD were higher than that of PM in both planting seasons. The interactions of SD and PM also have significant effect on the soil total porosity.

Effect of sawdust and poultry manure on soil chemical properties

Effect of sawdust and poultry manure on soil pH (water), exchangeable acidity and available phosphorus

The soil pH increased significantly ($p < 0.05$) over control with application of Poultry Manure at various rate, and the highest values obtained were 6.33 with 8 t/ha PM in 2014 and 7.63 with 2 t/ha PM in 2015 (Table 4). Likewise, the application of sawdust at different rates significantly ($p<0.05$) increased soil pH with the highest values of 6.07 in 2014 and 7.66 in 2015 recorded with the application of 20 t/ha SD. The interactions of SD and PM also have significant effect on the soil pH.

The Soil Exchangeable Acidity decreased significantly ($p < 0.05$) over control with application of poultry manure at various rates, but the lowest values obtained were 1.093 cmol+/kg with 8 t/ha PM in 2014 and 1.501 cmol+/kg in 2015 with 6 t/ha PM (Table 4). Also, the application of sawdust at different rates significantly ($p<0.05$) decreased Soil Exchangeable Acidity with the lowest values of 2.003 cmol+/kg with in 2014 and 1.763 cmol+/kg in 2015 recorded with the application of 20 t/ha SD. The lowest values recorded with PM were lower than that of SD in both planting seasons. The interactions of SD and PM also have significant effect on the soil exchangeable acidity.

The Soil Available Phosphorus increased significantly ($p < 0.05$) over control with application of poultry manure at various rate, but the highest values obtained were 14.546 mg/kg in 2014 with 8 t/ha PM and 21.854 mg/kg in 2015 with 6 t/ha PM (Table 4). Also, the application of Sawdust at different rates significantly ($p<0.05$) increased Soil Available Phosphorus with the highest values of 10.904 mg/kg in 2014 and 17.964 mg/kg in 2015 recorded with the application of 20 t/ha SD. The highest values recorded with PM were higher than that of SD in both planting seasons. The interactions of SD and PM also have significant effect on the soil available phosphorus.

Table 1. Physical and chemical properties of soil used for the experiment before treatment application.

Soil properties	2014 planting season	2015 planting season
Sand (%)	77.62	78.79
Silt (%)	10.50	7.84
Clay (%)	11.88	13.37
Textural class	Sandy loam	Sandy loam
Soil pH (water)	5.28	5.31
Soil pH (0.01$CaCl_2$)	4.07	4.10
Organic carbon (%)	1.57	1.75
Organic matter (%)	2.71	3.01
Total N (%)	0.14	0.14
Available P (mg/kg)	7.80	8.20
Exchangeable acidity (cmol+/kg)	3.61	3.12
Potassium (cmol+/kg)	0.05	0.06
Calcium (cmol+/kg)	2.10	2.30
Magnesium (cmol+/kg)	1.20	2.00
Sodium (cmol+/kg)	0.13	0.16
Bulk density (g/cm3)	1.31	1.28
Total porosity (%)	50.68	51.55

Table 2. Chemical properties of organic amendment used for the study.

Properties	Poultry manure	Sawdust
Organic carbon (%)	14.47	46.42
Organic matter (%)	24.95	80.03
Total N (%)	1.85	0.30
C: N ratio	7.82	154.73
Available P (mg/kg)	0.80	0.34
Potassium (cmol+/kg)	2.76	0.98
Calcium (cmol+/kg)	13.80	2.60
Magnesium (cmol+/kg)	2.80	2.10
Sodium (cmol+/kg)	1.37	0.90

Effect of sawdust and poultry manure on soil organic matter, total n and total exchangeable bases

The soil organic matter increased significantly ($p < 0.05$) over control with application of poultry manure at various rate, but the highest values obtained were 1.183% in 2014 with 4t/ha PM and 5.352% in 2015 with 8 t/ha PM (Table 5). Also, the application of sawdust at different rates significantly ($p<0.05$) increased Soil Organic Matter with the highest values of 1.404% in 2014 and 6.226% in 2015 recorded with the application of 20 t/ha SD. The highest values recorded with PM were higher than that of SD in both planting seasons. The interactions of SD and PM also have significant effect on the Soil Organic Matter.

The soil nitrogen increased significantly ($p < 0.05$) over control with application of poultry manure at various rate, but the highest values obtained were 0.245% in 2014 and 0.187% in 2015 with 8 t/ha PM (Table 5). Also, the application of sawdust at different rates significantly ($p<0.05$) increased soil nitrogen with the highest values of 0.215% in 2014 and 0.167% in 2015 recorded with the application of 20 t/ha SD. The highest values recorded with PM were higher than that of SD in both planting seasons. The interactions of SD and PM also have significant effect on the soil nitrogen.

The soil total exchangeable bases increased significantly ($p < 0.05$) over control with application of poultry manure at various rate, but the highest values obtained were 8.304 cmol+/kg in 2014 with 8 t/ha PM and

Table 3. Effect of sawdust and poultry manure on soil bulk density and total porosity in 2014 and 2015 planting seasons.

Treatments	Bulk density (g/cm^3)		Total Porosity (%)	
	2014	2015	2014	2015
Poultry manure				
0	1.083	0.994	59.13	62.64
2	0.991	0.892	62.60	66.08
4	0.994	0.893	62.49	66.36
6	0.995	0.898	62.45	66.11
8	0.992	0.899	62.57	66.34
LSD 0.05 PM	0.006	0.006	0.273	0.256
Sawdust (t/ha)				
0	1.036	1.054	60.90	60.23
5	1.009	0.906	61.92	65.81
10	1.007	0.906	62.00	65.81
15	0.986	0.886	62.79	66.57
20	0.919	0.827	65.32	66.79
LSD 0.05 SD	0.006	0.006	0.273	0.256
LSD 0.05 SD * PM	0.014	0.014	0.610	0.573

Table 4. Effect of sawdust and poultry manure on soil pH (water), exchangeable acidity and available phosphorus.

Treatments	Soil pH		Exchangeable acidity (cmol+/kg)		Available P (mg/kg)	
	2014	2015	2014	2015	2014	2015
Poultry manure						
0	5.68	7.47	3.785	2.462	2.026	12.086
2	5.90	7.63	3.462	2.109	2.942	10.802
4	6.03	7.60	2.156	2.231	7.863	13.727
6	6.14	7.60	1.459	1.501	9.032	21.854
8	6.33	7.54	1.093	1.677	14.546	20.045
LSD 0.05 PM	0.028	0.026	0.036	0.028	0.098	0.250
Sawdust (t/ha)						
0	5.92	7.45	2.751	2.097	3.734	14.447
5	5.98	7.55	2.565	2.114	5.437	14.465
10	6.05	7.53	2.380	1.9997	6.683	17.582
15	6.05	7.65	2.257	2.011	9.492	14.055
20	6.07	7.66	2.003	1.763	10.904	17.964
LSD 0.05 SD	0.028	0.026	0.036	0.028	0.098	0.250
LSD 0.05 SD * PM	0.063	0.059	0.081	0.062	0.220	0.557

8.402 cmol+/kg in 2015 with 4 t/ha PM (Table 5). Also, the application of Sawdust at different rates significantly (p<0.05) increased soil total exchangeable bases with the highest values of 7.723 cmol+/kg in 2014 with 20 t/ha SD and 8.367 cmol+/kg in 2015 with 15 t/ha SD. The highest values recorded with PM were higher than that of SD in both planting seasons. The interactions of SD and PM also have significant effect on the soil total exchangeable bases.

Cocoyam growth parameters

Effect of sawdust and poultry manure on leaf area of cocoyam

The various rates of poultry manure application recorded higher cocoyam leaf area values that were significant (p<0.05) over control (Table 6). The poultry manure application at 8 t/ha recorded highest cocoyam leaf area

Table 5. Effect of sawdust and poultry manure on soil organic matter, total nitrogen and total exchangeable bases.

Treatments	Soil organic matter (%)		Total nitrogen (%)		TEB ($cmol^+/kg$)	
	2014	2015	2014	2015	2014	2015
Poultry manure						
0	0.857	4.975	0.154	0.130	6.885	7.935
2	1.168	5.314	0.180	0.161	8.299	8.067
4	1.183	4.966	0.191	0.158	7.233	8.402
6	1.030	5.096	0.198	0.175	7.101	7.808
8	1.177	5.352	0.245	0.187	8.304	8.188
LSD 0.05 PM	0.029	0.035	0.003	0.005	0.032	0.171
Sawdust (t/ha)						
0	0.756	4.417	0.168	0.162	7.429	7.648
5	1.264	4.827	0.187	0.164	7.538	8.026
10	0.847	4.687	0.194	0.165	7.497	8.314
15	1.087	5.612	0.203	0.153	7.634	8.367
20	1.404	6.226	0.215	0.167	7.723	8.046
LSD 0.05 SD	0.029	0.035	0.003	0.005	0.032	0.171
LSD 0.05 SD * PM	0.065	0.077	0.007	0.010	0.072	0.381

Table 6. Effect of sawdust and poultry manure on leaf area of Cocoyam (cm^2).

Treatments	Months after Planting (MAP)							
	1	2	3	4	1	2	3	4
	2014				2015			
Poultry manure								
0	433	847	1357	1640	455	883	1399	1700
2	845	1373	2113	2324	874	1394	2133	2346
4	1124	1681	2587	2872	1144	1701	2608	2893
6	1396	1935	3119	3280	1417	1956	3139	3301
8	1606	2173	3820	3947	1629	2193	3841	3966
LSD 0.05 PM	100.9	146.7	223.6	220.0	100.0	143.8	216.6	208.6
Sawdust (t/ha)								
0	581	1020	1641	1711	605	1053	1685	1770
5	825	1344	2151	2354	845	1364	2172	2364
10	1067	1578	2520	2824	1087	1599	2540	2845
15	1280	1816	3041	3309	1300	1837	3061	3330
20	1664	2254	3642	3877	1683	2273	3662	3898
LSD 0.05 SD	100.9	146.7	223.6	220.0	100.0	143.8	216.6	208.6
LSD 0.05 SD * PM	225.6	NS	500.1	492.0	223.7	NS	484.2	466.5

values at various months after planting (MAP) in 2014 and 2015, with the highest value of 3947 cm^2 in 2014 and 3966 cm^2 in 2015 recorded at four MAP. Likewise, the application of SD at various rates recorded higher cocoyam leaf area values that were significant ($p<0.05$) over control. The SD application at 20 t/ha recorded highest cocoyam leaf area values at various months after planting (MAP) in 2014 and 2015, with the highest value of 3877 cm^2 in 2014 and 3989 cm^2 in 2015 recorded at 4MAP. The interaction between PM and SD at various MAP in both planting seasons also had significant effect on cocoyam leaf area except that of the two MAP.

Effect of sawdust and poultry manure on number of leaves of cocoyam

The various rates of poultry manure application recorded

Table 7. Effect of sawdust and poultry manure on number of cocoyam leaves.

Treatments	Months after planting (MAP)							
	1	2	3	4	1	2	3	4
	2014				2015			
Poultry manure								
0	4.33	12.67	15.93	21.00	5.53	13.93	17.40	21.40
2	5.67	14.60	20.07	22.40	7.47	16.40	22.93	24.47
4	5.33	15.60	19.67	22.47	7.53	17.80	22.60	25.20
6	6.20	19.27	23.00	24.53	8.87	21.40	24.93	26.60
8	8.33	18.13	24.20	31.40	10.60	21.47	26.73	33.80
LSD 0.05 PM	0.80	1.30	1.70	2.35	0.90	0.90	1.57	2.37
Sawdust (t/ha)								
0	4.20	11.60	15.27	17.33	6.27	12.93	16.67	18.47
5	5.40	13.67	17.93	19.67	7.20	16.07	20.67	21.47
10	6.00	15.27	19.87	22.07	8.07	17.73	22.00	24.67
15	6.67	17.00	21.87	25.40	8.87	19.53	24.47	27.73
20	7.60	22.73	27.93	25.13	9.60	25.27	30.80	28.47
LSD 0.05 SD	0.80	1.30	1.70	2.35	0.90	0.90	1.57	2.37
LSD 0.05 SD * PM	NS	NS	NS	NS	NS	NS	NS	NS

higher number of cocoyam leaves values that were significant (p<0.05) over control (Table 7). The poultry manure application at 8 t/ha recorded highest cocoyam number of leaves at various months after planting (MAP) in 2014 and 2015, with the highest value of 31.40 in 2014 and 33.40 in 2015 recorded at four MAP. Likewise, the application of SD at various rates recorded higher cocoyam number of leaves values that were significant (p<0.05) over control. The sawdust application at 20 t/ha recorded highest cocoyam number of leaves values at various MAP in 2014 and 2015 except for that of four MAP in 2014, whose highest value (25.40) was obtained with 15 t/ha SD, and 28.47 t/ha SD in 2015 recorded at four MAP. The interaction between PM and SD at various MAP in both planting seasons have no significant effect on cocoyam number of leaves.

Effect of sawdust and poultry manure on cocoyam height

The various rates of PM application recorded higher cocoyam height values that were significant (p<0.05) over control (Table 8). The poultry manure application at 8 t/ha recorded highest cocoyam leaf area values at various MAP in 2014 and 2015, with the highest value of 111.63 cm in 2014 and 117.26 cm in 2015 recorded at four MAP. Likewise, the application of SD at various rates recorded higher cocoyam height values that were significant (p<0.05) over control. The sawdust application at 20 t/ha recorded highest cocoyam leaf area values at various MAP in 2014 and 2015, with the highest value of 109.51 cm in 2014 and 110.22 cm in 2015 recorded at four MAP. The interaction between PM and SD at various MAP in both planting seasons had no significant effect on cocoyam height.

Effect of sawdust and poultry manure on corms, cormels and total yield of cocoyam (t/ha) at harvest

Cocoyam corm yield increased significantly (p<0.05) over control (Table 9) at various rates of PM application in both 2014 and 2015 planting seasons, with the highest yield values of 6.52 t/ha in 2014 and 6.68 t/ha in 2015 with the application of 8 t/ha PM. Similarly, corm yield increased significantly (p<0.05) over control (Table 9) at various rates of SD application in both 2014 and 2015 planting seasons, with the highest yield values of 6.48 t/ha in 2014 and 6.13 t/ha in 2015 with the application of 20 t/ha SD. Interactions between PM and SD on corm yield was not significant in both 2014 and 2015 planting season but corm yield was generally higher with applications of PM than SD.

Cocoyam cormel yield increased significantly (p<0.05) over control (Table 9) at various rates of PM application in both 2014 and 2015 planting seasons, with the highest yield values of 10.73 t/ha in 2014 and 8.47 t/ha in 2015 with the application of 8 t/ha PM. Similarly, cormel yield increased significantly (p<0.05) over control (Table 9) at various rates of SD application in both 2014 and 2015 planting seasons, with the highest yield values of 10.65 t/ha in 2014 and 7.53 t/ha in 2015 with the application of 20 t/ha SD. Interactions between PM and SD on cormel

Table 8. Effect of sawdust and poultry manure on height of Cocoyam (cm).

Treatments	Months after planting (MAP)							
	1	2	3	4	1	2	3	4
	2014				2015			
Poultry manure								
0	17.15	37.02	53.53	66.59	21.59	42.59	59.65	67.85
2	22.71	50.25	72.51	84.51	27.66	55.65	73.71	86.17
4	25.08	59.08	81.31	93.17	30.06	62.83	81.96	94.03
6	26.35	61.52	89.81	102.57	30.75	65.30	104.69	104.12
8	30.37	68.91	97.00	111.63	35.31	78.29	104.69	117.26
LSD 0.05 PM	2.22	4.40	3.98	4.62	1.88	3.57	3.22	2.86
Sawdust (t/ha)								
0	11.29	41.64	60.37	73.06	15.53	48.38	66.55	78.40
5	19.15	48.90	70.91	84.09	24.47	54.54	75.10	86.91
10	24.23	55.13	78.63	92.89	29.15	60.23	80.60	92.77
15	31.19	61.63	86.75	98.92	35.37	65.55	88.01	101.13
20	35.81	69.47	97.51	109.51	40.84	76.02	99.83	110.22
LSD 0.05 SD	2.22	4.40	3.98	4.62	1.88	3.57	3.22	2.86
LSD 0.05 SD * PM	NS	NS	NS	NS	4.2	7.99	7.21	6.39

Table 9. Effect of sawdust and poultry manure on corms, cormels and total yield of cocoyam (t/ha) at harvest.

Treatments	Corms (t/ha)		Cormels (t/ha)		Total yield (t/ha)	
	2014	2015	2014	2015	2014	2015
Poultry manure						
0	2.17	1.81	2.92	2.18	5.09	3.99
2	3.33	3.13	5.15	4.47	8.48	7.60
4	3.50	4.20	7.23	5.80	10.73	10.00
6	5.25	5.73	8.02	6.65	13.27	12.38
8	6.52	6.68	10.73	8.47	17.25	15.15
LSD 0.05 PM	0.713	0.533	0.919	0.838	1.340	1.340
Sawdust (t/ha)						
0	2.48	3.04	3.60	3.70	6.08	6.74
5	3.13	3.88	6.27	4.18	9.40	8.06
10	3.98	4.24	8.07	5.45	12.05	9.69
15	4.68	4.27	10.50	6.70	15.18	10.97
20	6.48	6.13	10.65	7.53	17.11	13.66
LSD 0.05 SD	0.713	0.533	0.919	0.838	1.027	1.027
LSD 0.05 SD * PM	NS	NS	NS	NS	NS	NS

yield was not significant in both 2014 and 2015 planting season but cormel yield was generally higher with applications of PM than SD.

Cocoyam total yield increased significantly ($p<0.05$) over control (Table 9) at various rates of poultry manure application in both 2014 and 2015 planting seasons, with the highest yield values of 17.25 t/ha in 2014 and 15.15 t/ha in 2015 with the application of 8 t/ha PM. Similarly, cocoyam total yield increased significantly ($p<0.05$) over control (Table 9) at various rates of sawdust application in both 2014 and 2015 planting seasons, with the highest yield values of 17.11 t/ha in 2014 and 13.66 t/ha in 2015 with the application of 20 t/ha SD. Interactions between PM and SD on corm yield was not significant in both

2014 and 2015 planting season but cocoyam total yield was generally higher with applications of PM than SD.

DISCUSSION

The soil bulk density and total porosity (Table 3) improved with the application of PM and SD. The reduction in soil BD and increased TP could be attributed to the increased microbial activity associated with increased nutrient availability due to the soil amendments applied, leading to the pulverization of soil. The increased soil TP is associated with the reduction in soil BD because of the direct relationship between them. Similar results have been reported by Eneje and Ezeakolam (2009); and Onwudike et al. (2015) with application of organic wastes.

The soil pH increased with application of organic wastes such as PM and SD (Table 4). The ability of the organic manure to increase soil pH was due to the presence of basic cations contained in the organic wastes, which were released upon microbial decarboxcation. The increased soil pH observed agrees with the reports of Chigbundu et al. (2010), Adeyele et al. (2010) and Magagula et al. (2010) with the application of organic wastes.

The soil available P increased with application of organic wastes such as PM and SD. The increased soil available P may be attributed to the release of liming effects of organic wastes, through the release of calcium and magnesium from the decomposition of the organic wastes, thus precipitating $Al(OH)^3$ and increasing soil pH, thereby releasing the adsorbed P, which enhanced the availability of soil available P, and as well as the high P available in the organic wastes. Similar results were reported in other studies (Onwuka, 2008; Mbah and Mbagwu, 2006; Okonkwo et al., 2009; Ayeni et al., 2009) with the application of organic wastes.

The application of organic wastes such as PM and SD decreased soil exchangeable acidity. The reduction in soil exchangeable acidity could be attributed to the ability of the organic wastes to release of basic cations on decomposition, thus precipitating $Al(OH)^3$. Similar results were reported by Asawalam and Onyegbule (2009) and Adeyele et al. (2010) with the application of organic wastes.

The soil nitrogen increased with application of organic wastes such as PM and SD. The increased soil Total N may be due to the mineralization of organic-bound nutrients from the decomposition of the organic wastes. The increased soil total N observed agrees with the reports of Mukiibi (2008); Mbah et al. (2010) and Adeyele et al. (2010) with the application of organic wastes.

The organic wastes application such as PM and SD increased soil organic matter. The increased soil organic matter could be attributed to the high C:N ratio of the organic waste and the release of organic-bound nutrients from the decomposition of the organic wastes. The increased soil organic carbon observed agrees with the results of previous studies (Eneje and Ukwuoma, 2009; Adeyele et al, 2010; Ayuba et al., 2005) where increased organic matter has been reported with the application of organic wastes.

The soil total exchangeable bases increased with application of organic wastes such as PM and SD. The increased soil TEB could be attributed to the greater capacity of nutrient retention of the amended soils. Similar results were reported by Kparmwamp et al. (2004) and Ano and Agwu (2005) with the application of organic wastes.

The effects of organic wastes on leaf area (Table 6), number of leaves (Table 7), and plant height (Table 8) showed a greater increase in cocoyam growth parameters. This might be due to the decomposition of the organic wastes and consequently, its nutrient release, which created a better soil environment for plant to take up nutrients. Similar results were reported by Uwah et al. (2011); Agbede and Adekiya (2016); Obasi et al., (2009); Onwudike et al. (2015) and Iwuagwu et al. (2017).

The results of the effects of organic wastes on cocoyam corms, cormels and cocoyam total yield (Table 9) indicate that there was a greater yield. The increased weight of cocoyam corms, cormels and total yield were due to the improved soil properties, which made the nutrients available for plant uptake and manifested on the crop yield. Similar results were reported in other studies (Chukwu et al., 2009b; Agbede and Adekiya, 2016; Ojeniyi et al., 2013; Udom and Lale, 2017; Iwuagwu et al., 2017).

Conclusion

The results from this study have shown that the incorporation of organic wastes such as PM and SD, solely or in combination improved the physicochemical properties of the soil and increased cocoyam growth and yield at an increasing rate such as 8 t/ha PM and 20 t/ha SD. The organic waste such as SD is important due to its high carbon content, and PM, due to its high N and exchangeable bases. The supply of N sources such as poultry manure, increases the rate organic matter decomposition and prevents N immobilization, and the high organic carbon content of sawdust produced great benefits to soils. Proper organic manuring requires the combinations of single manures that will encourage maximum microbial activity, to enhance the release of soil nutrients in available forms and reduce nutrient loss trough fixation, immobilization and leaching. Therefore, organic wastes such as poultry manure and sawdust could be used by poor farmers, who cannot afford fertilizers due to its high cost, for sustainable agricultural production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Market prospects and willingness to pay for indigenous products: The case of Morama (*Tylosema esculentum*)

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This study analyzes the market potential of the underutilized indigenous Morama (*Tylosema esculentum*) products by determining the consumers' preferences and willingness to pay. Simple random sampling was used to select 372 respondents to participate in the cross-sectional survey. Contingent valuation method was used to determine the customers' willingness to pay and the two-step Heckman selection model was employed to analyze the factors that influence the willingness to pay for the different Morama products. The majority of the respondents were knowledgeable of Morama and its product; consequently 84% showed interest in purchasing products developed from Morama. About 90% were willing to purchase Morama oil whereas 87% were willing to purchase Morama butter at least twice a month and 82% would be willing to buy Morama snack bar at least three times a month. The results indicate that Morama products have the potential to penetrate the market and hence can be used to improve both the standard of living for rural communities and household food security and thus alleviate poverty. The mean willingness to pay for Morama oil and butter are comparable to the conventional product, indicating that these products have good market prospects and can compete and potentially substitute the current products if domesticated and commercialised.

Key words: Morama, market prospects, willingness to pay, consumers' preferences, two-step Heckman selection model, contingent valuation.

INTRODUCTION

Interest in indigenous products has risen as the world attempts to fight poverty, malnutrition and improve rural livelihoods (Okello et al., 2015) under changing climatic conditions. Indigenous products are traditional and spontaneously found food that are less deleterious to the environment, provide for cultural needs and reserve the cultural heritage and are associated with a certain local areas (Balogh et al., 2016). Harvesting, utilization and

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marketing of indigenous products has been central to the livelihoods of most African communities, however it is characterized by underutilization (Muok, 2019). Studies have shown that indigenous products are highly nutritious containing macronutrients, micronutrients, dietary phytochemicals (Ngemakwe et al*.,* 2017) and vitamins, that are not found in exotic products; therefore awareness and consumption of these can reduce malnutrition among poor rural households (Okello et al*.,* 2015; Muok, 2019). However, besides the nutrition value of the indigenous products other social, economic and environmental dynamics exist that determines their use. The major environmental factors are the location and the seasonality of the indigenous products (Dkhar and Rao, 2019). Socially, subjective norms tend to have an influence on the use of the indigenous products (Sana et al*.,* 2018). Economically, the indigenous products are valued for the food security relief they bring to impoverished communities and developments around areas where it is found (Mbhenyane, 2017).

Botswana has a semi-arid climate and it is estimated that one year in three consecutive years, arable agriculture in Botswana fails due to lack of rainfall and general lack of surface water (Brinkhurst, 2010), and according to Ministry of Environment, Natural Resources Conservation and Tourism (2019), the country is forecasted to experience high average temperatures of 25.9-26.9 and a decrease in seasonal and annual precipitation. Despite the erratic rainfall, Botswana is endowed with various indigenous products (Madisa and Tshamekang, 1997), which are found and consumed by rural communities. The major indigenous fruits that have penetrated the market are morula (*Sclerocarya birrea*), motsentsela (*Berchemia discolor),* mogwana (*Grewia flava*), mmilo (*Vangueria infausta*) and morojwa (*Azanza garkeana*) (Lepetu et al*.,* 2015). Though some products such as morula have infiltrated even the exotic markets (Ndeinoma, 2018), most of the indigenous products are characterized by low popularity and are highly overtaken by the common demand for exotic products. Poverty in Africa has always been a major menace to humanity especially of provision of food and Botswana is not an exception. To address poverty in rural communities requires a broader focus on the diet-relevant indigenous products used in different communities, as well as to determine which products contribute to the associated health benefits and hence increase crop diversity (Baldermann et al*.,* 2016).

Domestication and commercialization of indigenous food plants can help rural communities build resilience against climate change. According to Mojeremane and Tshwenyane (2004b), rural communities in Botswana mostly use indigenous food plants as a hunger coping strategy to sustain their livelihoods (Mojeremane and Tshwenyane, 2004b). Several studies conducted in Botswana (Mojeremane and Tshwenyane, 2004a, b) and elsewhere (Akinnifesi et al., 2008a; Getachew et al., 2005; Balemie and Kebebew, 2006) have shown that the importance of indigenous food plants is increased during times of food shortage and famine. According to Akinnifesi et al. (2008a), 60 to 85% of the rural people in Southern Africa face food shortages for 3 to 4 months in a year and use indigenous food plants to sustain their livelihoods. Indigenous food plants also provide income-generation and employment opportunities which are often lacking in rural areas (Lepetu et al*.,* 2015). In addition, these have the potential to significantly contribute to rural development, and reduction in hunger, malnutrition, and gender inequality (Ngemakwe et al*.,* 2017). Mojeremane and Tshwenyane (2004a) noted that some indigenous food plants also provide goods and services such as medicine, building material, firewood, fodder and shade.

Most indigenous food plants are comparable or have higher nutrient content than their domesticated or exotic counterparts, most are rich in iron, zinc, vitamin A, C, E, folic acid, proteins, carbohydrates and minerals (Agte et al., 2000; Singh and Garg, 2006). Besides indigenous vegetables, rural people in Botswana also use indigenous fruit to supplement their diet (Legwaila et al., 2011). According to World Health Organization (2005), daily consumption of indigenous food plants in sufficient quantities can help prevent numerous diseases. Similarly, Barany et al. (2001) have found that indigenous food plants can improve the nutrition and health of children, the elderly and boost the immune system of HIV/AIDS patients. Morama (*Tylosema esculentum*), also known as gemsbok bean, is an under-utilized wild legume native to the Kalahari region of Southern Africa (Van der Maesen, 2006). The bean has attracted attention as a plant resource with economic potential for exploitation, with successful experimental cultivation being reported in Kenya, Israel, Australia and United States of America. It contains approximately 30% protein and 40% oil (Mosele et al., 2011); it has similar composition with groundnuts and soybeans (Ntare, 2007).

T. esculentum is a long-lived perennial legume native to arid areas of Southern Africa. It occurs naturally in the drier areas of Southern Africa, including Botswana and Namibia, where it is to a small extent harvested as a wild plant for human consumption (Amarteifio and Moholo, 1998). It is widespread in these areas, with large populations in Botswana (around the central Kgalagadi), Eastern parts of Namibia, while smaller populations are found in the South Africa provinces of Limpopo, North West and Gauteng (Castro et al., 2005). The plant is adapted to the harsh conditions of Botswana and Namibia, which are characterized by low rainfall and nutritionally poor soils (Hartley et al., 2002). This makes it a potential crop for semi-arid and arid agriculture. It is most common to eat the Morama beans as mature beans when the seeds are surrounded by a hard and woody seed coat, which has reddish to brownish colour. But the beans can also be eaten when they are still immature green beans. The mature Morama bean has a very low moisture content as the dry matter content ranges from 93.4 to 98.7% (Agte et al., 2000), which makes it ideal for long-term storage. Despite its traditional use as a food source in Botswana and Namibia, little is known about the germplasm diversity, genomic variability and relationships between the different ecotypes (National Academy of Sciences, 1979; National Research Council, 2006; Keegan and Van Staden, 1981). Jordaan et al. (2009) noted that the seeds are usually roasted, imbuing them with a more palatable flavour - comparable to cashews or chestnuts.

Market potential for Morama products

The Morama bean can also be processed into various value-added products including plant-based milk, oil, and canned beans. The milk of the Morama bean is a creamy white water extract very similar to dairy milk or soymilk and can similarly be consumed in the form of a refreshing and nutritious beverage (Mpotokwane et al., 2013). Though not available commercially, the milk of the Morama bean has high levels of sodium (47.9 mg/100 g) and iron (3.7 mg/100 g) compared to soymilk and dairy milk, with a much lower calcium content (6.8 mg/100 g) (Jackson et al., 2010). Morama oil resembles almond oil, and is suitable for domestic purposes, with a pleasant nutty flavour (FAO, 2010). The oil consists of about 24-48% rich in mono and di-unsaturated fatty acids, it has no cholesterol. The oil extract can be used as a body lotion to prevent itchiness of the skin; oil can also be used ritually as a cleanser for girls after their first menstruation. According to Chingwaru et al. (2011) the high oil content of the beans is believed to prevent constipation as it lubricates the alimentary contents. A mixture of Morama roots and leaves can be ground and made into tea to help improve women's health, especially in post menstrual periods (Chingwaru et al., 2007).

Morama is an example of the many under-utilized indigenous species native to Botswana with great agricultural potential; it can provide unique strategic opportunities to address and support food security efforts and improve the livelihoods of vulnerable populations in Botswana (Jackson, 2017). With only a few people selling these products there is therefore a great gap in the market which can be exploited through development of new food products or value addition that will target both the local Botswana and international consumer markets. The result will be a greater demand for value added products and the emerging crops themselves; thus improving livelihoods for vulnerable communities (poverty alleviation). Currently, in Botswana, indigenous food plants including Morama products are sold by women and children in both formal and informal markets in rural and urban areas. The markets are seasonal and very limited (Faria et al., 2011). In urban and peri-urban areas, sales are conducted near shopping centers and from door to door. The sale of indigenous food plants provides cash income (Kadu et al., 2006) used to buy food; pay children's school fees, uniform and other household needs. However, markets in Botswana (Taylor et al., 1996) and other developing countries favor exotic food plants than their indigenous counterparts because they have been researched and developed.

Domesticated or exotic food plants are widely promoted and their uses and management techniques are well known. In contrast, indigenous food plants have received little attention in terms of research, development and promotion in Botswana, despite their large market potential. Taylor et al. (1996) noted that the variety of indigenous food plants sold in formal markets is lower when compared to informal markets. They further indicated that the formalization of markets is constrained by lack of infrastructure and products of variable quality that are always available in small quantities. In the past, Morama was not marketed like any other wild berries or fruits; it was used for households' consumption by hunter-gatherer populations. Only small quantities of Morama are sold in the villages, mostly by neighbours, or in nearby towns or villages by villagers who temporarily act as street vendors. Prices vary between villages as they are determined by the seller, in accordance with their weight, prices also depend on Morama being (un) shelled, fresh, raw and or roasted. Prices may increase if Morama is sold in nearby towns. Small-scale and medium-scale farmers also sell Morama to local people. The current market for Morama products in Botswana is characterized by; low prices poor and information on growing, limited market access, limited involvement of retailers and shortage of raw materials due to poor yields (Faria et al., 2008).

Commercialization and value addition of indigenous fruit plants have been put forward as a possible solution to alleviate poverty in resource poor communities (Akinnifesi et al., 2007). Such initiatives would provide income-generating opportunities for these communities as well as serve as an incentive to value and conserve natural resources more. Morama commercialization, within a formal and local market, is therefore a result of the impact of the monetary economy, together with other food products it became a source of instant cash. Morama is sold to the local market throughout the year, but supply significantly increase in the months of April when the gathering season starts, that is when sellers will make great profits from sales of Morama (Jackson et al., 2010). In areas where Morama is found, people sell besides roads to people passing by as temporary street vendors. However, it is imperative to establish the market prospects and willingness to pay for Morama to inform commercialization and value addition decisions.

For indigenous products to impact the rural households it is important to study the demand side by analyzing the market potential and prospects of Morama products based on the products ability to eradicate poverty, to assess the consumers' willingness to pay and also make an assessment of the preferred products by the consumers. Morama is one of the indigenous wild legumes found in Botswana that can improve the welfare of the people in areas where it is found and beyond. However, there is still a gap in knowledge of the factors that influence consumers' willingness to pay for Morama products and the market potential for Morama products as most empirical work has focused on processing, chemistry, nutrition and processing of Morama bean (Campanaro et al*.,* 2019; Ngemakwe et al*.,* 2017; Ohui Yeboah et al*.,* 2017; Nepolo et al*.,* 2015; Takundwa et al*.,* 2015). Thus this study was aimed at analyzing the market potential and prospects of Morama products based on the products' ability to eradicate poverty, to assess consumers' willingness to pay for Morama products and to also make an assessment of the preferred products by the consumers. From the literature, it was mentioned that the market is limited; the study therefore analyzed the market potential and prospects of the products in the Kweneng Region and Gaborone. It was an objective to expand the market of the products so they could be found anywhere and anytime by the consumers. Little research has been undertaken on the market potential and the prospects of Morama products; moreover, the products themselves are not penetrating the market intensively. The levels of poverty in the Kweneng District have been found to be high but the Morama plants are readily available; they are perennial. There is little awareness on the potential of these products and their prospects. Exotic products are mostly sold in our markets; people are still not informed of the potential of the indigenous products especially Morama.

METHODOLOGY

Study area and sampling design

The survey was conducted in Kweneng and Southern Districts of Botswana (Figure 1). The two districts were purposely selected where the former is the geographical location with Morama abundance but also has relatively high levels of poverty in the country; whereas the latter is the main economic hub in the country. In particular, Gaborone (24° 39' 11.7252'' S and 25° 54' 24.4512'' E) as the capital city of Botswana was chosen as it could provide the greatest market potential locally due to its cosmopolitan make up and Molepolole (24.3966° S, 25.4970° E) as the catchment village for areas where Morama is found. The Kweneng District has a population of about 304, 549 (Statistics Botswana, 2011) and covers an area of 35, 890 square kilometers. The Kweneng District is characterized by hot, semi-arid climate with an average rainfall of between 450 and 500 mm annually, most of which is received during summer season from November to April. The majority of the Kweneng District residents are engaged in agriculture as the major activity and source of livelihood. The survey was pre-tested as Matshwabisi village (24.1830° S, 25.2736° E) in Kweneng District for understand-ability to reduce bias and enhance validity of the results. A simple random sampling method was used to select the total sample of 372 respondents in both the urban and rural areas. Empirical data on the potential market and prospects of Morama products and the consumers' willingness to pay for Morama products were collected through a structured questionnaire consisting of both open and closed-ended questions. The target respondent was the individual consumer expected to make decisions relating to consumption and willingness to pay given the various demand on an individual's income. Data were analysed using SPSS 25 and STATA 15.

Contingent valuation procedure

The contingent valuation method (CVM) is a survey-based methodology for eliciting values people place on goods, service, and amenities. It is used to fill a substantial void by providing a way to estimate values when the markets do not exist and revealed preference methods are not applicable (Champ et al., 2003). Subsequently, one would want to know how much money people are willing to pay for underutilized indigenous plant products relative to conventional products in the market. One of the advantages of CVM is the ability to estimate the price of goods that are not currently available, but can be availed at a future time (Baker et al., 2014). Due to unavailability of the proposed value-added Morama products, CVM is used to elicit consumer preferences, estimating their values of these goods through a hypothetical market.

Empirical model specification

In the current study, the two-step Heckman selection model was used following Bett et al. (2013) to analyze the consumer's WTP for Morama products currently not available in the market (Morama oil, butter, snack) so as to account for potential selection bias. The first step in the Heckman two-stage selection bias correction procedure determines whether or not the respondent decides to pay anything, and the second stage determines the amount paid (Heckman, 1979). The probit model is used in the first stage to estimate Equation 1 and obtain the inverse Mill's ratio. Each respondent was asked whether they are willing to pay more for each of the Morama products. Respondents who answered 'yes' were given a hypothetical scenario and asked if they would be willing to pay a higher price for Morama products than a comparable conventional product available in the market. The respondent was expected to answer 'yes' if willing to pay more or 'no' otherwise. In either case, the respondents were allowed to state the maximum amount they were willing to pay for the Morama products. The price was thus the amount the respondents were willing to pay for a product relative to the status quo, $X \geq 0$, such that WTP = 0 if $X \leq 0$; and WTP = if $X > 0$, where WTP is 1 if the respondent is willing to pay a price higher than the current price for a conventional product, and 0 otherwise. The probit model to determine factors that influence WTP decision was thus specified as:

$$WTP_i = \beta_0 + \beta_i S_i + \beta_i P_i + \beta_i Y_i + \varepsilon_i \text{ and } i = 1 \ldots\ldots, n; \quad (1)$$

where WTP_i is the stated willingness to pay for the i^{th} individual, S_i is the vector of observable socio-economic characteristics of the individual, including the consumption behaviour such as frequency of purchase, quantities consumed and expenditure on comparable conventional products; P_i is the vector of characteristics of the products, and Y_i is a vector of income. ε_i is the error term or random variable accounting for unobservable characteristics assumed to be normally distributed with mean 0 and variance σ^2. The unknown parameter estimates are estimated by the maximum likelihood (ML) method using the probit regression model to obtain the inverse mile's ratio (IMR). In the second stage, the Ordinary Least Squares (OLS) equation is used to determine factors that influence the amount consumers are willing to pay for Morama products. The OLS equation was specified as:

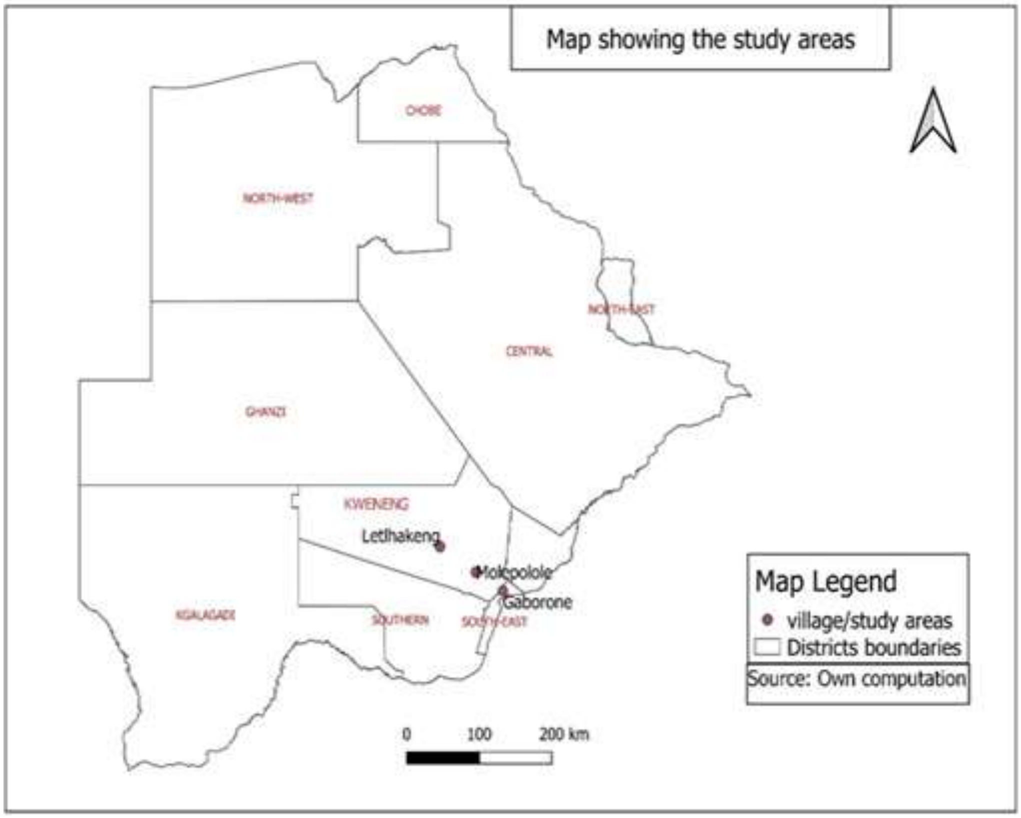

Figure 1. Study area.

$$X_i = \beta_0 + \beta_i S_i + \beta_i P_i + \beta_i Y_i + \beta_i IMR + \varepsilon_i \quad \text{and } i = 1 \ldots\ldots, n; \qquad (2)$$

where X_i is the maximum amount consumers are willing to pay for Morama products.

RESULTS

Socio-economic characteristics of respondents

This study results indicate that a total of 314 respondents are willing to pay while 58 are not willing to pay for Morama products. Further, 46, 63 and 48% are willing to pay for Morama butter, oil and snack respectively. From the sample of 372 respondents, 55% were females and 45% males. The average education level for the sampled respondents was found to be 12 years of schooling, which is equivalent to higher secondary level in Botswana. The mean household size was 6 including both children and adults and the mean age for the respondents was 34, as shown in Table 1.

Product knowledge, location and willingness to pay

Selected variables being location of the respondents and the knowledge of the health benefits of Morama products were examined against the willingness to pay and their results are presented in Table 2. The results show that 52% of the respondents are from the urban area (Gaborone) while 48% are from the rural area or peri-urban (Letlhakeng and Molepolole). Of those who are from the urban areas, 69% (out of 372 respondents) are willing to pay for Morama products while 31% of them are not willing to pay. In the rural or peri-urban areas, 98% of the respondents are willing to pay while 2% are not willing to pay. A comparison between rural or peri-urban and urban areas indicates that of those who are willing to pay for Morama products, 40% are from the urban areas while 60% are from the rural or peri-urban areas. Out of the 58 respondents who are not willing to pay, 94.8% of them are from the urban areas while 5.2% are from the rural or peri-urban areas.

According to the results, 66% of the respondents have knowledge of the Morama products. Of those who have knowledge, 75% are willing to pay. 56% of respondents in urban areas do not have knowledge of Morama products while 25% of respondents in the rural areas do not have knowledge of Morama products.

Consumers' preferences for Morama products

Consumers' preference when selecting Morama products was studied. Figure 1 shows a summary of multi-category

Table 1. Average educational level, household size and age of respondents

Variable	Mean	Standard deviation
Education	12.1	3.8
Household size	6	4.3
Age	34	10.8

Table 2. Product knowledge and location.

Location	Willing		Non-Willing		Total		χ^2
	No.	Percentage	No.	Percentage	No.	Percentage	59.3
Urban	125	40	55	94.8	180	48.4	
Rural	189	60	3	5.2	192	51.2	
Total	**314**	**100**	**58**	**100**	**372**	**100**	
Knowledge of Morama products							
Yes	236	75	10	17.2	246	66	73.3
No	78	25	48	82.3	126	34	
Total	**314**	**100**	**58**	**100**	**372**		

chart of responses. The products each had their own attributes which were on a likert scale from not important to very important, attributes; appearance, aroma and taste were common for the products. The respondents viewed the three attributes of appearance, aroma and taste for all products as very important, snack bar had the highest percentages for the attributes 65.3, 60.8 and 77.7% respectively followed by butter at 59, 56.1 and 75.8% respectively; percentages for oil preferences were 53.2, 46 and 64.2% respectively.

The residuals in the oil was also an attribute studied and it showed that less than half about 40.3% of the respondents perceived residuals as very important to consider. Butter had two more attributes that were considered the stickiness and spreadability and these were very important to the respondents with 53.1 and 65.4% respectively. Two attributes that were specific to the snack bar were hardness on first bite and gumminess; these are generally viewed as very important at 54.4 and 45% respectively. Generally, all attributes of the products were perceived to be very important to the respondents, showing that people consider product attributes in their purchases. Figure 3 shows the reasons for purchasing Morama among respondents who are willing to pay for Morama products. Respondents were made to rate five possible reasons for purchasing Morama products according to 'important[1]' and 'not important[2]'. More than 95% of the respondents indicated that all the possible reasons for purchasing the product are important.

Average willingness to pay and expenditure on conventional products

Table 3 shows the respondents expenditure on conventional products (oil, butter and snack bar) in the market for both the urban and rural area. On average households purchase a 2 L of oil and 500 g jar of butter per month. The results further indicate that respondents purchase around six 50 g of snack bars per month. 50 g bars of snack and purchased conventional oil less frequently (1.30 times) than all other products per month. These results can be translated into the potential frequency for purchasing Morama products if introduced in the formal market. The results or the average WTP for the Morama products indicate that consumers value them competitively against the available conventional products.

Econometric results

This section presents the estimations for the probit and the OLS model for three Morama products being, Morama oil, butter and snackbar. The results were obtained by estimating a two-step Heckman selection model.

The results in Table 4 shows a probit and OLS estimates of factors that influence the respondents WTP for Morama oil. Amongst the fifteen independent variables analysed, nine were statistically significant

[1] Important is an aggregate score indicating those who considered the reason for purchasing, important and very important.

[2] No important is an aggregate score indicating those who considered the reason for purchasing, not important, slightly important and moderately important.

Table 3. Average household consumption and expenditure for conventional products.

Product	Conventional			Non-conventional
	Frequency	Quantity	Current average price	Mean WTP
Oil	1.30	1 × 2 L	75.00	42.90
Butter	1.31	1* 500 g jar	21.85	21.40
Snack bar	2.31	6 *50 g bars	8.40	8.28

Table 4. Heckmann two-step selection results for WTP for Morama oil.

Variable	Probit		OLS	
	Coefficient	Standard error	Coefficient	Standard error
Lnage	0.2066	0.3204	-0.2972	0.2974
Gender	0.1723	0.1644	-0.1437	0.1449
Lneducation	-0.2535	0.2620	0.3675***	0.1389
LnHHsize	0.4395***	0.1064	-0.2494*	0.1387
LnIncome	0.1830***	0.02794	-0.2328***	0.06702
Consumption	-0.5410**	0.2363	0.3799	0.2336
Frequency	0.3163***	0.07369	-0.2022**	0.09540
Taste	1.424***	0.5437	-0.8048	0.7014
Safer	0.1457	0.4031	-0.2851	0.5344
Environment	0.2715	0.3989	-0.5178	0.5184
Local trade	0.3989	0.4186	-0.0030	0.5228
Supermarket	0.5240**	0.2148	-0.5836**	0.2627
Food security	-0.1227	0.1613	0.1801	0.1549
LnPrice_oil	-0.3013	0.2009	0.3458**	0.1733
Freq_oil	0.7771***	0.2471	-0.5750***	0.2176
Constant	-4.3647***	1.9238	4.275*	2.5682
IMR	-		0.1070	0.5191
N	372		372	
Prob > F	-		0.000	
Prob > Chi^2	0.000		-	

*, **, ***: statistically significant at 10, 5 and 1% respectively.

when using confidence interval of 99% (p=0.01), 95% (p=0.05) and 90% (p=0.1) in influencing respondents WTP for Morama oil. The results indicate that WTP for Morama oil was influenced by education, household size, natural log income, consumption, frequency, taste, supermarket, natural log price of oil and current frequency of purchase of conventional oil. The results also show that without any of the tested variables *ceteris paribus* there would be a negatively high significance WTP for Morama oil by the respondents.

The results in Table 5 show the probit and OLS estimates of factors that influence the respondents' WTP for Morama butter. A total of fifteen independent variables were analyzed. Of these, five of the variables were statistically significant when using confidence intervals of 99% (p=0.01) and 90% (p=0.1) in influencing respondents WTP for Morama butter. The variables that were found to significantly influence WTP for butter are anticipated frequency and current frequency of conventional butter. The results also show that *ceteris paribus* there would be a negatively high insignificant WTP for Morama butter by the respondents.

Estimates of the factors affecting the WTP for snack bar are presented in Table 6. The results are obtained from the probit and OLS model. The probit model estimated that the WTP for Morama products is positively associated with the WTP for snack bar products. Respondents that are willing to pay for Morama products are less willing to pay for the specific snackbar product and the results are significant ar 5% level. The respondents that prefer hard snack bars are also less willing to pay for Morama snack bar. These may be because consumers anticipate the Morama snack bars to be smooth. Similarly, those that frequently purchase

Table 5. Heckman two-step selection results for WTP for Morama butter.

Variable	Probit		OLS	
	Coefficient	Standard error	Coefficient	Standard error
Lnage	-0.3454	0.2692	-0.3143	0.4697
Gender	0.0137	0.1366	-0.0612	0.1048
Lneducation	0.0712	0.1459	-0.0814	0.09881
LnHHsize	0.1058	0.08854	0.2274	0.1393
LnIncome	0.0358	0.02381	0.0109	0.04879
Consumption	-0.1082	0.1836	-0.0389	0.1587
Frequency	-0.1101*	0.06152	0.1502	0.1393
Taste	-0.2113	0.3625	-0.3362	0.3301
Safer	0.0354	0.3974	-0.0674	0.2646
Environment	-0.2608	0.4059	-0.3493	0.3274
Local trade	0.2951	0.5313	0.3338	0.5002
Supermarket	0.1383	0.1931	-0.03021	0.2217
Food security	-0.2061	0.1363	0.1027	0.2602
LnPrice_butter	0.1496	0.1521	-0.02858	0.1674
Freq_butter	0.5585***	0.2035	0.4665	0.6732
Constant	0.6956	1.7196	3.06272***	1.01155
IMR	-		-1.8722	1.7502
N	372		372	
Prob > F	-		0.0000	
Prob > Chi^2	0.0683		-	

*, **, ***: statistically significant at 10 and 1% respectively.

Table 6. Heckmann two-step selection results for WTP for Morama snack bar.

Variable	Probit		OLS	
	Coefficient	Standard Error	Coefficient	Standard Error
LnAge	0.1587	0.2658	-0.4843**	0.2401
Gender	0.1400	0.1364	-0.1790	0.1731
LnEducation	-0.1024	0.1361	0.1138	0.1497
Lnhhsize	-0.024879	0.09050	0.01948	0.06218
Lnincome	0.03885	0.02382	-0.001109	0.4472
Consumption	-0.0524	0.1828	0.1504	0.1268
Buy	-0.6786***	0.2051	1.4720**	0.7263
Healtheir	0.06713	1.03140	-0.07652	0.2160
Safer	0.2868	0.4076	0.05312	0.3874
Tastier	-0.3336	0.3986	-0.02206	0.4289
Envi	-0.2828	0.4327	0.1394	0.3265
Local trade	-0.4813	0.5033	0.4052	0.5941
Supermarket	-0.1852	0.1908	-0.01454	0.2509
hhfoodsecurity	-0.05568	0.1367	0.1751**	0.09822
Snack hard	-0.4999***	0.1827	0.2586	0.5514
Snack freg	-0.4538***	0.1593	0.7836	0.5152
Ln price	-0.1300	0.1230	0.04033	0.1634
Constant	1.8042	1.6960	1.8604*	0.9481
IMR			-1.3346	1.6767
N	372		372	
Prob > F	-		0.0000	
Prob > Chi^2	0.0109		-	

*, **, ***: statistically significant at 10, 5 and 1% respectively.

conventional snack bars are less willing to pay for the Morama snack bars if introduced in the market under the probit model estimation.

The OLS estimates show a negative association between age and WTP at 10% significance level. The results imply that, a 1% increase in age of the respondent/consumer will lead to a 0.5% decrease in the amount the consumer is willing to pay for snack bar, holding other factors constant. A respondent who indicated that he/she is willing to buy Morama products is likely to pay around 3.9% more than the mean price for the snack bar product at a 10% significance level. Lastly, respondents that indicated that processing of the products is important for food security are willing to pay 0.47% more than the average WTP.

DISCUSSION

WTP and market prospects for Morama oil

Education positively influenced the amount of money anticipated to be spent on Morama oil; a percent increase in education will increase the amount spent on Morama oil by P0.37. Consistently, Oviahon et al. (2011) and Villano et al. (2016) found that education positively increases consumers's WTP for food products. Education is important as it creates critical thinkers, problem solvers and innovative leaners (Makwinja, 2017); in this study it showed on average both in urban and rural area Botswana is doing well in educating its citizen with an average 12 years which is high school qualification. Therefore, it should be made a priority in schools to educate the pupils on the values and benefits of indigegnous products. The household size had positive significant influence on respondents' willingness to pay for Morama oil, but it had a negative influence on the amount the respondents would spend on Morama oil showing that as household increase by a percent the amount spent will reduce by P0.14. On the contrary, Oviahon et al. (2011) found that as the household size increases more of the indigenous products would be purchased.

Income had a significant and positive influence on WTP for Morama oil. The increase in income was significant at 1% probability. On the other hand, income as a factor of the amount respondents would pay for Morama oil was negative and significant showing that respondents would pay P0.23 less for Morama oil. These results are consistent with Mwema et al. (2012) who found that household income has a negative and significant relationship with indigenous products dependency, as diverse incomes lead to assorted options that they can choose from. Consumption patterns had a positive and significant WTP for Morama oil; similarly, Shin et al. (2017), after evaluating consumer's attitude, found that consumption patterns positively influence WTP for food products.

The anticipated frequency of purchase of Morama products had a significant and positive 31.6% chance of influencing respondents WTP. Frequency of purchase is important in making forecasts of customized supply and demand to optimize both sales and gross margins of the products (Sriwaranun et al., 2015). Unrelatedly, the anticipated frequency of purchase negatively influenced the amount that respondents are WTP by P0.20. Respondents confirmed the importance of taste in accepting Morama oil and the results show a positively significant influence of taste on respondents WTP for Morama oil. According to Jackson (2010), consumers indicated that they would buy better tasting Morama products as compared to the current unpleasant bitter tasting products. Consequently, Chowdhury et al. (2011) and Fan et al. (2019) found taste of food products to be of positive influence on consumer's WTP for the products. The preferred supermarket outlet for Morama oil had a 52.4% positively significant chance of influencing respondents WTP but it had a negative relationship with the amount the respondents were WTP of P0.58. Current frequncey purchase of conventional oil had a positively signficant influence on respondents' WTP for Morama oil by 77.7%. *Ceteris paribus*, the amount that respondenst are WTP for Morama oil will be P4.28.

WTP and market prospects for Morama butter

The anticipated frequency of purchase of Morama products had a negative significant influence on respondents WTP for Morama butter; it showed that as the anticipated frequnecy increases WTP will decrease by 11%. This results can be explained by uncertianity that respondents have about unknown products. This phenomenon was described by Riebe (2003) and Sriwaranun et al. (2015) that buyers prefer less of smaller or unpopular brands because they prefer steady products. Marketing of the Morama products should be prioritized to increase the product's popularity. Current frequency of purchase of conventional butter products significantly influences respondents' WTP for Morama butter; thus as the current frequency of purchase of conventional butter products increases the frequency in WTP for Morama butter would increase by 55.8%. This results show that respondents will purchase products that they perceive to be healthy, tastier, safe for environment as evident in Figure 2 with the reason for purchase all scoring more than 95%. *Ceteris paribus*, the amount spent on Morama butter would significantly increase by P6.56 as compared to conventional products.

WTP and market prospects for Morama Snack-bar

According to the results, the highly ranked consumers'

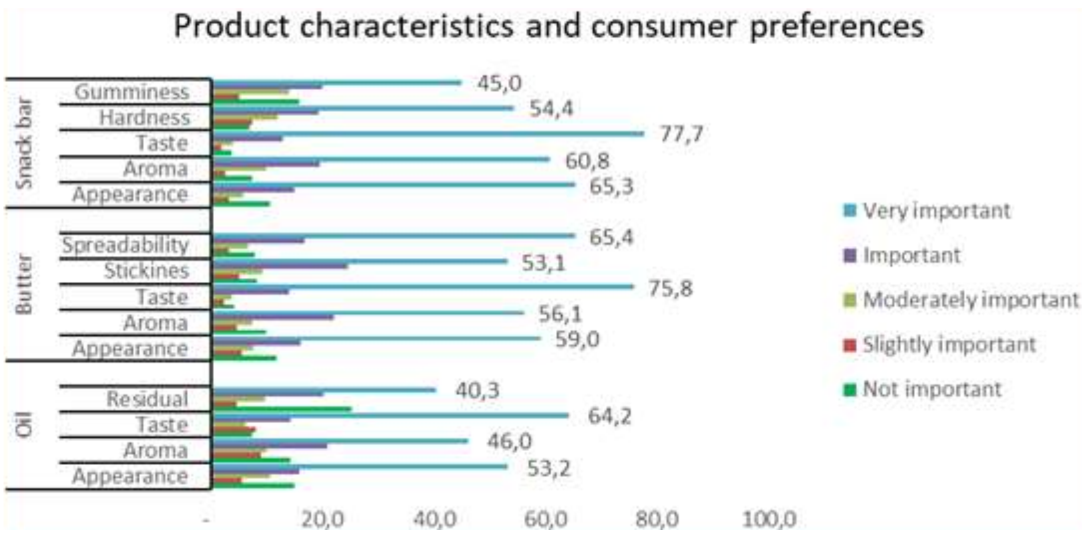

Figure 2. Consumer preferences when selecting products.

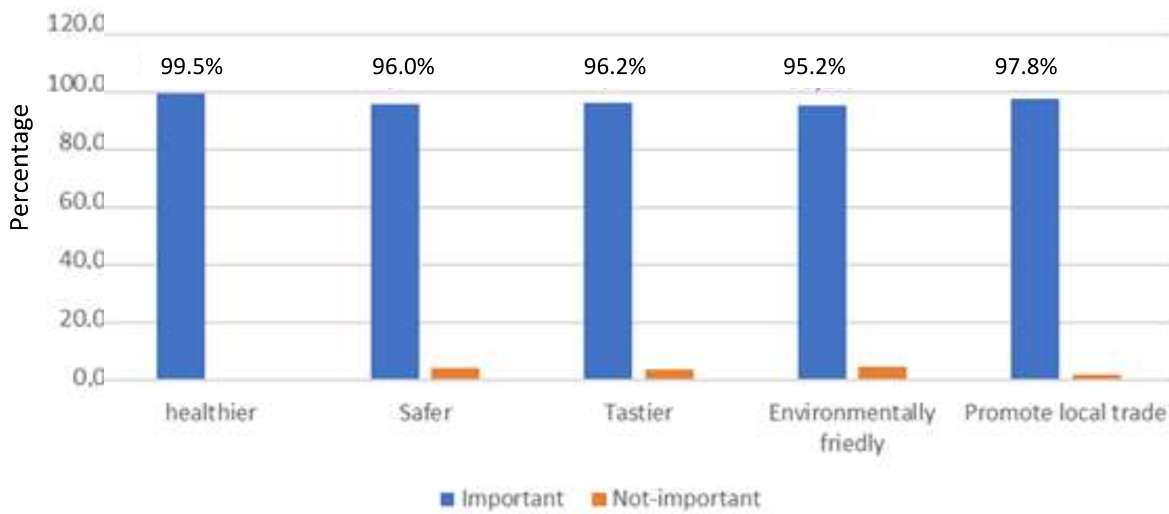

Figure 3. Reasons for purchasing Morama products.

preference for the snack bar is taste, followed by appearance, aroma, hardiness and gumminess. Therefore, these attributes are expected to affect the consumers' WTP for the Morama snack bar. Accordingly, the results from Table 6 show that consumers who prefer hardiness as an attribute for the snack bar product are less likely to buy Morama snack bars. It is likely that the consumers envisage that the product will be soft and hence outside their preference. This can be attributed to lack of knowledge of the product. Vinceti et al. (2013) imply that knowledge on the product positively influences WTP.

The other negative association is between those who are willing to purchase all Morama products and the snack bar. Of all the people who indicated that they are willing to pay for the Morama products, less are willing to pay for the snack bar and the difference between the two groups is significant. These can be because of perception consumers have on the product, that it does not have the qualities of the current conventional products (e.g. hardiness) as previously stated. Those that frequently buy conventional snack bars are less willing to buy the Morama product, that is, they will prefer to continue consuming the current conventional product they are used to. However, it is worth noting that for those that are willing to pay, they are willing to pay at a more competitive average price. For example, the average WTP for snack bar is P8.28 against an average conventional price of P8.40. Respondents competetively value the non-market products against the available conventional products. Moreover, it has been found out that consumers who are interested in buying all the products are willing to pay more (1.4% more than mean price) for the snack bar than those who are not. These results reveal that, those that are willing to pay for the Morama snack bar value it highly. However, it should be noted that the amount decreases with increase in age. A 1% increase in age decreases the amount a person is willing to pay by 0.5%. Older people are not willing to pay more. These statements concide with WTP study findings by Mbenyane (2017); the study analysed the willingness to pay for indeginous leafy vegetables in South Africa and found out that the older persons in semi-urban areas were not willing to pay.

Interestingly respondents that believe that promotion of indeginous products will improve households' food security are willing to pay more than the mean WTP and the result is significant in agreement with Faria et al. (2011). Even though, the results show that people may not be willing to switch to the new snack bar products, those that are willing to pay are also willing to pay more thus they value the product highly.

Conclusion

The results suggest a high market potential for the assessed Morama products with a relatively similar willingness to pay as comparable conventional products. Morama oil has the highest demand followed by Morama snack bar and butter. The determinants of demand for Morama products are location, income, education, frequency of purchase for conventional products, preferred market outlet, consumer beliefs (products will improve households' food security), and age. A high percentage of respondents in rural and peri-urban areas, who are more likely to be familiar with the Morama products, are willing to pay for these products. From the results, it is evident that respondents who have a positive willingness to pay value the products competitively against the existing conventional products. This may imply that the products are able to compete if introduced and potentially substitute the current products. The comparable WTP implies that Morama products can compete with conventional products and can potentially substitute the current products if domesticated and commercialised. These results therefore provide useful information on consumers' preferences and market prospects for the different Morama products that will enable policy makers, researchers and rural communities to initiate appropriate interventions to instigate market demand and consequently build resilience and thus promote sustainable incomes and poverty reduction.

RECOMMENDATIONS

The products are currently not available in the formal market and the results suggest a high entrepreneurial opportunity for rural producers mainly through collection, cultivation processing and value addition. The results also indicate that, promotion and marketing have the potential to increase people's knowledge about the products and consequently affect their WTP. Therefore, more information on the importance of Morama products including their health benefits should be availed to the public through different channels in different areas including the urban and regional and international markets. With processing, value addition and marketing, the products have the potential for building resilience against climate change and thus poverty reduction among rural communities as well economic and agricultural diversification and trade. Though there is on-going research and also policy support for the development of the forest and range resources sector under the micro, small and medium enterprises, more is needed in terms of implementation and developing the products for the market and to benefit from their entrepreneurial prospect. Further research could assess the Morama products value chain and potential capacity building incentives to ensure sustainable production and thus sustainable development of rural communities.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Physical and mechanical properties of cement bonded strand board produced from *Gmelina arborea* (Roxb.) harvesting residues

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Finding use for residues from felling operations has been a major focus on increasing volume recovery of harvested woody biomass. Strands and sawdust processed from left-over of *Gmelina arborea* residues recovered from the forest were used to produce cement bonded composites. Physical and mechanical properties of the boards were assessed showing the relationship between diverse variables such as density, wood strand and sawdust proportions. Three levels of mixing ratio and 5 levels of material blending proportion were adopted for the board formation, the mixing ratios of cement to wood material were 1:1, 2:1 and 3:1, while the wood materials were varied at 5 different levels: 100:0, 75:25, 50:50, 25:75 and 0:100 of strand to sawdust. The boards' density recorded 800, 900 and 1000 kg/m^3. Mean water absorption ranged from 16.88±10.28 to 56.36 ±11.70%, while thickness swelling ranged from 0.21±0.20 to 5.43±0.99%. The mean values for the mechanical properties ranged from 1988.35±92.26 to 6526.90±186.06 (N/mm^2) for modulus of elasticity (MOE) and 1.03±0.59 to 5.90±3.76 (N/mm^2) for modulus of rupture (MOR). The result indicated that board produced at the highest mixing ratio 3:1 and at 75:25 of material blending proportion of strand to sawdust had best physical properties value and highest strength properties value. The analysis of variance carried out showed that both mixing ratio and material blending proportion had significant effect on the water absorption and modulus of elasticity while only mixing ratio had significant effect on the thickness swelling and modulus of rupture of the board. The board produced can be used as an alternative to particleboard, solid wood, asbestos, etc., for construction works at the same time increasing recovery volume.

Key words: Strand, sawdust, *Gmelina arborea*, physical, mechanical properties.

INTRODUCTION

Wood, a natural product of biological origin made up of cellulose, hemicelluloses and lignin has been a major material of construction to man. The pre-historic man used it both as fuel and for primitive shelter and it

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contributed immensely to man's survival. The pre-historic man-made composite materials were straw and mud combined to form bricks for building construction. Wood is a major raw material for cement composite board because it is readily available and its fibrous nature. Primary wood wastes are wastes from the forest, secondary wood wastes are post-industrial wood waste generated when wooden products such as furniture, cabinets and doors are made and post-consumer wood wastes which can include anything from construction and demolition debris to packaging (Sadiku, 2012).

In the present era of environmental consciousness, more and more material are emerging in construction, furniture and other sectors as substitutes for wood. Wide range of plastics, synthetic material, metals, etc., is being used to substitute wood. However, the real wood substitution and service to environment are possible if this material is sustainable as well as renewable. Efficient utilisation of plantation species, particles and fibres obtained from various lignocellulosic materials including agro wastes to develop panel product is thus certainly a rational and sustainable approach (Ogunrinde, 2012). Forest throughout Nigeria and the rest of tropical countries are diminishing at an alarming rate of 3.5% (about 350,000-400,000 ha) per annum in land coverage over the past 50 years in Nigeria (Oyebo, 2006). The natural forests are increasingly being depleted in Nigeria through indiscriminate extraction of economic trees and encroachment for other purposes such as large scale agriculture, urbanization and industrial development. In general, there are two types of forestry residues, primary forestry residues produced while harvesting timber, such as tree tops, branches and stumps, and secondary forestry residues produced during processing of forest materials or products, such as sawdust, bark and scrap wood. Less than 80% of the harvested trees during logging operation are taken away from the forest, the rest are left in the forest as residue. In Nigeria, forest industry, residue comprises nearly half the total wood volume. This coupled with the vast generation of waste during wood processing operations substantially reduce wood resource availability for industrial processing (Ogunrinde and Owoyemi, 2015). An ITTO study estimated that the timber industry in the Amazon generated 49.7 million m^3 of waste per year, including 28 million m^3 (57%) of logging residues and 20 million m^3 (40%) in sawmills. Forestry generates about 9.83 million m^3 of wood residues, comprising 5.1 million m^3 of logging residues, 2.2 million m^3 of primary manufacturing residues, 0.91 million m^3 of plywood residues and 0.9 million m^3 of secondary residues such as sawdust (Auke and Jaap, 1997). Any lignocellulosic waste matter can therefore be turned into boards through appropriate technology development. These approaches offer much simpler materials for future use in comparison to solid wood logs (Bratkorich and Gephart, 2000). Wood Strand Cement Board (WSCB), a class of recently-developed panels composed of long and thin wood strands bonded with Portland cement, it is less susceptible than plywood and OSB to severe weathering, fungal growth and insect attack. WSCB panels exhibit good durability, structural strength, resistance to fire, high resistance to rot, fungal decay and attack by termites and other vermin. Furthermore, they are easily nailable, exhibit excellent screw-holding capacity and can be easily coated or painted (Ogunwusi, 2012).

METHODOLOGY

Raw material procurement

The materials used for this study include harvesting residues of *Gmelina arborea* wood collected from the Forestry and Wood Technology Department Plantation in Akure. Ordinary Portland cement was purchased from fresh consignment from the local cement dealer, while the chemical additive (calcium chloride) was purchased from the Scientific Chemical Laboratory in Akure. Other equipment used include, caul plates, press, wooden mould of 350 × 350 mm, weighing balance, Vernier caliper, oven and freezer.

Material preparation

G. arborea strand were produced from fletched harvesting residues using surface planning machine and milled to strand lengths of 20 and 0.5 mm thickness while the circular sawing machine was used to produce the sawdust (Plates 1 and 2) after which the strand and the sawdust were pre-treated by boiling it in hot water for 30 min at temperature of 90°C according to procedure adopted by Ajayi and Fuwape (2005) to remove the inhibitory substances that may likely affect the setting of the cement used as binding agent. The strands and the sawdust were air dried for 14 days at the composite laboratory to attain moisture content of 12% approximately prior to use. A wooden mould of 350 mm × 350 mm was constructed which serves as the formwork for the mat formation. The materials are of two types and in 5 flake/sawdust blending proportion of 100:0, 75:25, 50:50, 25:75 and 0:100 and three levels of cement/material mixing ratio of 1:1, 2:1 and 3:1.

Board formation

The chemical additive used was weighed based on the percentage of the cement used (3% weight) in each sample and the water was calculated in accordance with method developed by Simatupang et al. (1991). The dry weight of the pre-treated strand and sawdust were taken differently and the weight of the binding agent (Ordinary Portland cement) used also was taken. The required quantity of additive used were dissolved in the required quantity of water; all were thoroughly mixed together with hand to form a uniform mix and then filled into the mould made from wooden frame of the required sizes placed on a metal caul plate and later covered with polythene sheets to enhance easy de-moulding and prevent the sticking of the board on the plate.

The boards were pre-pressed for easy laying to get a smooth and balanced density size board and later transferred to the cold press and press under a pressing pressure to form the required thickness (8 mm) for 24 h. The boards (350 × 350 × 8 mm) were later removed from the mould and conditioned for 28 days to allow for further curing of the boards. All sample boards were produced according to the chart in Figure 1. The procedure was repeated for different levels of mixing ratio and material blending proportion. The

Plate 1. Processed *Gmelina* strands.

Plate 2. *Gmelina* sawdust.

board produced was trimmed to sizes and later cut into sample size for laboratory investigation.

Conducted test

The density, water absorption and thickness swelling were examined according to ASTM D570-98 2005. Specimens were cut into size of 150 mm × 150 mm. The water absorption test samples were weighed first before soaking and the initial weight recorded. The tested samples were then placed horizontally in a large container of water. These samples were soaked in water for 24 h, thereafter boards were weighed using weighing balance to determine water absorption and thickness. Also flexural test (Modulus of elasticity and Modulus of rupture) were carried out according to ASTM C1225 (2005).

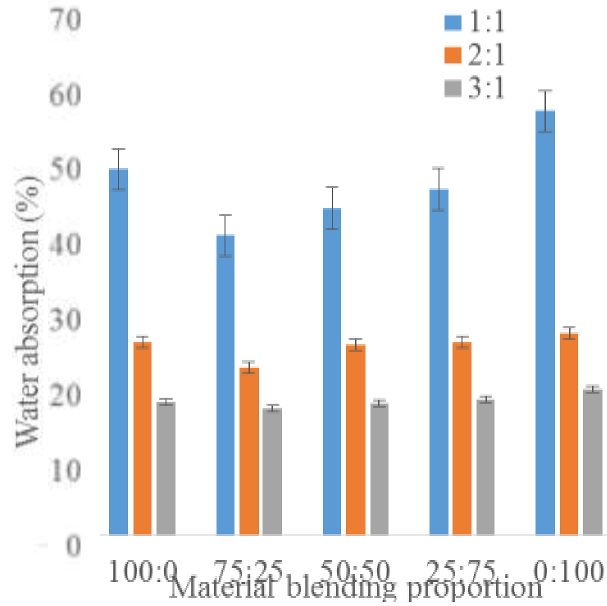

Figure 1. Effect of mixing ratio and material blending proportion on water absorption.

The experimental design used for this study was 3 × 5 factorial experiment in Completely Randomized Design, the combination of which gave 15 treatments as shown in Table 1 each with three replicates giving a total of 45 board samples for the study. The design for the experiment involved two variables; the first variable is the mixing ratio (factor M) at three levels of 1:1, 2:1 and 3:1 (that is, cement to material), the second variable is material blending proportion (factor B) at 5 levels of 100:0, 75:25, 50:50, 25:75 and 0:100 of strand to sawdust.

RESULTS AND DISCUSSION

Effects of production variables on board physical properties

The density value ranged between 863.16 and 1050.10 kg/m^3 from mixing ratio 1:1 to 3:1. The board produced at the highest mixing ratio of cement to material had the highest density value while the least density was produced at the lowest mixing ratio of cement to wood material 1:1. The analysis of variance showed that there was significant difference among the board density both at mixing ratio and blending proportion level. The mean value for water absorption after 24 h immersion in water as shown in Table 2 was between 15.64±2.66 and 45.62±2.85% for cement/material mixing ratio boards produced from the material blending proportion of 100% sawdust recorded the highest value as against the blend of 75% strand with 25% sawdust which had the least water absorption value, while for thickness swelling, it ranged from 1.14±0.38 to 5.43±0.99%. The results for the physical properties showed that board produced with the

Table 1. Treatment combination table.

Parameter		Material blending proportion (BP)				
		BP1 (100:0)	BP2 (75:25)	BP3 (50:50)	BP4 (25:75)	BP5 (0:100)
Mixing ratio (MR)	MR1 (1:1)	MR1BP1	MR1BP2	MR1BP3	MR1BP4	MR1BP5
	MR2 (2:1)	MR2BP1	MR2BP2	MR2BP3	MR2BP4	MR2BP5
	MR3 (3:1)	MR3BP1	MR3BP2	MR3BP3	MR3BP4	MR3BP5

Table 2. Mean values for water absorption, thickness swelling, modulus of elasticity and modulus of rupture.

Mixing ratio (MR)	Material blending proportion (BP)	Density (kg/m^3)	Water absorption (WA)%	Thickness swelling (TS)%	Modulus of elasticity (MOE) (N/mm^2)	Modulus of rupture (MOR) (N/mm^2)
MR 1:1	BP1 100:0	863.16	42.09±4.93	5.43±0.99	2096.89±173.24	1.20±0.37
	BP2 75:25	863.16	34.92±0.32	2.27±1.81	3091.27±148.55	2.19±0.62
	BP3 50:50	863.16	42.08±3.05	4.70±3.21	2616.14±138.29	1.29±0.69
	BP4 25:75	863.16	41.67±2.76	4.96±3.62	2278.52±100.64	1.26±0.12
	BP5 0:100	863.16	45.62±2.85	5.38±1.10	1988.35±92.26	1.03±0.59
MR 2:1	BP1 100:0	933.92	25.44±1.08	2.73±0.41	2721.41±129.47	2.28±0.22
	BP2 75:25	933.92	19.61±3.93	1.57±1.10	4007.98±161.62	3.48±3.72
	BP3 50:50	933.92	23.56±3.63	2.31±1.01	3730.22±104.29	2.27±0.22
	BP4 25:75	933.92	25.13±3.36	3.08±3.20	2872.11±114.81	2.03±0.28
	BP5 0:100	933.92	26.85±4.64	3.48±3.39	2248.10±103.80	1.28±0.21
MR 3:1	BP1 100:0	1050.10	17.75±4.94	1.55±1.68	2958.50±181.60	3.84±1.56
	BP2 75:25	1050.10	15.64±2.66	1.41±0.97	6526.90±186.06	5.90±3.76
	BP3 50:50	1050.10	16.88±10.28	1.14±0.38	5873.22±126.03	4.44±2.07
	BP4 25:75	1050.10	17.96±5.90	1.04±0.27	3438.05±108.85	4.09±0.38
	BP5 0:100	1050.10	19.50±1.67	1.21±0.20	2292.33±4.83	3.79±0.98

Table 3. Analysis of variance for the board physical and mechanical properties.

Source	df	WA	TS	MOE	MOR
Mixing ratio	2	3420.855*	45.570*	11628706.60*	36.263*
Material blending proportion	4	74.855*	3.111^{ns}	8676654.289*	2.269^{ns}
MR×BP	8	26.154^{ns}	2.235^{ns}	1559088.571^{ns}	1.245^{ns}
Error	30	35.666	3.802	2648601.852	2.457
Total	44	-	-	-	-

*Significant (p< 0.05). ^{ns}not significant (p> 0.05). MR×BP denotes interaction between mixing ratio and material blending proportion.

highest mixing ratio at 3:1 had the lowest value, the result was minimal compared to board produced from equal proportion of cement binder to material (MR 1:1). Analysis of variance carried out at 5% probability level to test for significant differences on the thickness swelling is presented in Table 3, the results showed that there was significant difference in the water absorption and thickness swelling at the mixing ratio level and material blending proportion level Duncan Multiple Range Test was used in the separation of the means at 5% probability level (Tables 4 and 5).

Wood density is considered to be the most important among wood characteristic because it determines to larger extent properties like water holding capacity and strength (Adedeji and Ajayi, 2008) and this is reflected in the properties of the board produced. As the board density increased, WA and TS decreased while the MOE and MOR increased, this indicated that board density has

Table 4. Duncan multiple range test (DMRT) for mixing ratio.

Mixing ratio	Water absorption (WA)%	Thickness swelling (TS)%	Modulus of elasticity (MOE) N/mm^2	Modulus of rupture (MOR) N/mm^2
1:1	46.92^a	4.55^a	2414.24^b	1.39^b
2:1	25.14^b	2.63^b	3115.96^b	2.27^b
3:1	17.91^c	1.07^c	4163.82^a	4.42^a

Alphabets with the same letter show that there is no significant difference. Alphabets with different letter show that there is significant difference.

Table 5. Duncan Multiple Range Test (DMRT) for material blending proportion.

Material blending proportion	Water absorption (WA)%	Thickness swelling (TS)%	Modulus of elasticity (MOE) N/mm^2	Modulus of rupture (MOR) N/mm^2
100:0	30.70^{ab}	3.23^a	2592.27^{bc}	2.78^a
75:25	26.32^b	1.75^a	4452.08^a	3.46^a
50:50	28.81^{ab}	2.71^a	4073.19^{ab}	2.67^a
25:75	29.89^{ab}	3.03^a	2862.89^{abc}	2.46^a
0:100	34.22^a	3.02^a	2176.26^c	2.09^a

Alphabets with the same letter show that there is no significant difference. Alphabets with different letter show that there is significant difference.

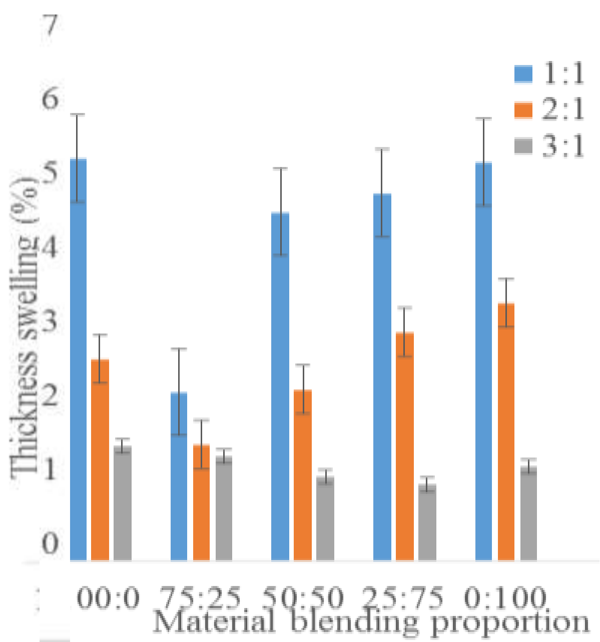

Figure 2. Effect of mixing ratio and material blending proportion on thickness swelling.

effect on the WA, TS, MOE and MOR. This is in agreement with the previous work by and Ajayi and Fuwape (2005) that board density also proved to have significant effect on the cement bonded board produced from agricultural waste. The water absorption and thickness swelling observed in this study showed higher values with increase in the quantity of sawdust in term of material blending proportion and decreased with increase in cement content in term of mixing ratio. These observations agreed with the findings of IKOB (2002) revealing that increase in cement content caused improvement in the physical properties of the board. All the boards produced from the mixture of strand and sawdust showed relatively high resistance to WA and TS compared to the one produced from pure strand and pure sawdust as shown in Figures 1 and 2 for both water absorption and thickness swelling. Similar trend or variation in the board has also been reported by Ajayi (2000).

Effects of production variables on board flexural properties

The mean values for modulus of elasticity (MOE) and modulus of rupture (MOR) for the boards produced was between 1988.35±92.26 and 1.28±0.21 N/mm^2 and 6526.90±186.06 and 5.90±3.76 N/mm^2 for MOE and MOR for mixing ratio (Table 2). The response of the boards to elasticity showed that increase in mixing ratio of cement to the strand and sawdust (MR 1:1) to MR3 (3:1) and decrease in sawdust content in the material blending proportion from 100% of strand (BP1) to 100% of sawdust (BP5) showed increase in the modulus of elasticity of the board produced. The board with the highest MOE value was obtained from the highest mixing ratio of (MR 3:1) and material blending proportion of 75:25 (BP2). Figures 3 and 4 show the trend of MOE and MOR mean value. The result of the analysis of variance (ANOVA) in Table 3 showed mixing ratio and material blending proportion has significant effect on the MOE and MOR. The result of the follow-up test with Duncan

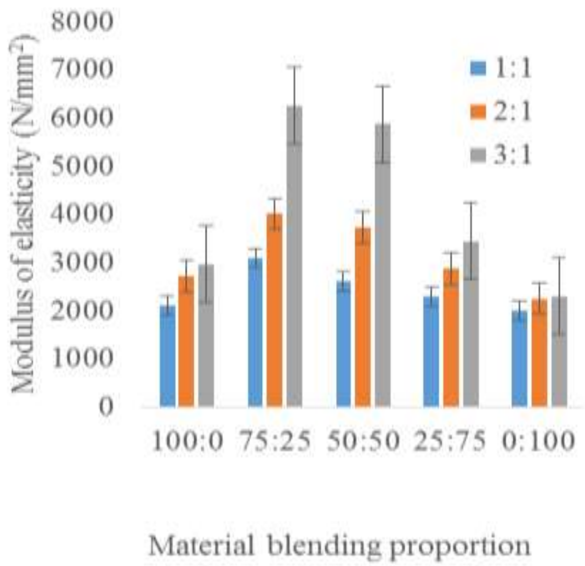

Figure 3. Effect of mixing ratio and material blending proportion on modulus of elasticity.

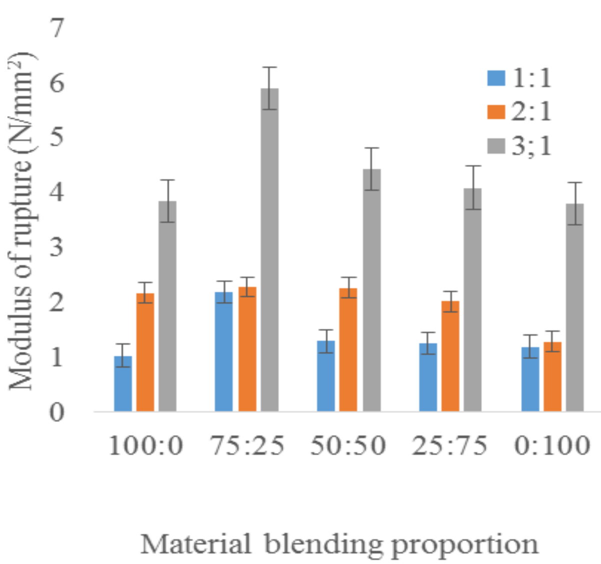

Figure 4. Effect of mixing ratio and material blending proportion on modulus of rupture.

Multiple Range Test (DMRT) carried out at 0.05 level of significance showed the effect of each level of mixing ratio and material blending proportion on MOE and MOR. Material blending proportion of board produced at 75:25 (strand: sawdust) proportion has the highest mean value while board produced at 100:0 (Pure sawdust) has the lowest mean value. Badejo (1989) in his study showed that strand geometry is highly correlated with board key properties, including MOE, MOR, internal bonding strength, etc. The extensive study of Semple and Evans (2004) confirmed this assertion that long strand particles rather than small particleboard flakes should be used when the aim is to produce boards of high strength. As there is a relationship between surface and volume ratio of particles, a greater surface area needs more adhesive for equivalent internal bonding development (Li et al., 2004). Ma et al. (2002) compared the MOE of boards containing strands of different thicknesses and reported that they showed slight differences. Owoyemi and Ogunrinde (2013) asserted that the flexural properties of a composites board are strongly correlated with board density.

Conclusions

Wood strand cement board (WSCB), a class of wood panel product composed of long and thin wood strands bonded with Portland cement compared favourably with particleboard, solid wood, asbestos and plywood in the construction of residential, industrial, commercial, and agricultural buildings. It is a versatile material that is suitable for both interior and exterior applications. This study provided an opportunity to increase the volume recovery of harvested tree through production of value added material like wood cement strand board and full utilization of all categories of waste by blending them together at different proportion to achieve targeted technical formulations. The boards produced showed relatively good resistance to water and high strength properties as a result of increased density.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Agroclimatic risk zoning of mango (*Mangifera indica*) in the hydrographic basin of Paraná River III, Brazil

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Mango cultivation is one of the key economic agricultural activities of fruit in Brazil. In Southern Brazil, mango presents vulnerability thanks to its frost sensitivity, indicating the relevance of climate studies to improve the production and agricultural techniques, in the context of sustainable agriculture and climate change. Agroclimatic zoning should be one of the first information to be considered when starting its cultivation. The objective of this study is to carry out climatic risk zoning for mango tree (*Mangifera indica*) in the basin of Paraná River III, Brazil. Meteorological data from 43 stations, from 1976 to 2018, were used. The climatic risk analysis was based on the requirements of the mango for precipitation, water balance, average annual temperature, and frost tolerance. The occurrence of frosts is the key restrict factor for production in the area of study. This meteorological factor restricted mango cultivation in the central-eastern portion of the basin. In other areas, the risk is present but the mango cultivation is recommended.

Key words: Climate aptitude, climate variability, agricultural planning.

INTRODUCTION

Fruticulture is an activity that makes a key contribution to the national economic development of Brazil. In this scenario, mango cultivation is one of the agriculture activities, presenting an increasing performance in recent years (Aguiar and Do Nascimento, 2011). Mango tree exhibits droughts periods tolerance; however for the southern Brazil the specie is sensitivity to the occurrence of frosts, demonstrating the importance of agroclimatic studies to improve the production (Olson and Alvarado-Cárdenas, 2016). As a segment of agriculture, mango production presents risks that meteorological elements provide in the variability in production and sensitivity in the management of fruit species (Comer, 2018; Conceição et al., 2018; De Matos et al., 2018; Borges et al., 2019; Medeiros et al., 2018; Dai et al., 2019; Santana et al., 2019; Shezi et al., 2019). The applicability of

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studies of meteorological elements on a global scale, and the purpose of elaboration of agroclimatic risk zoning is to improve sustainable agricultural management, decision-making, agricultural planning and agricultural policies (Caramori et al., 2008; Ricce et al., 2013; Santi et al., 2018). The agroclimatic risk zoning consists of different levels of scales and exhibits the aptitude and risks from the specific areas for crops cultivation, through maps. The zoning considers the hydroclimatic requirements of each crops species (Ricce et al., 2018; Caldana et al., 2019).

Nowadays, Brazil is the one of the largest world producers and exporters of mango. This agricultural activity is relevant not just for farmers but also to create jobs and income into the national territory, especially in the Northeast (Pereira et al., 2005). Given its economic importance and nutritional value, mango is the seventh most cultivated fruticulture in the world and the third most cultivated in tropical regions, almost 100 countries (Olson and Alvarado-Cárdenas, 2016). In Brazil, only 3.1 thousand hectares are in totally production to insert data from the basin (Ipardes, 2019).

In this sense, it is necessary to study alternatives that promote the climate aptitude of the mango. Meteorological variables are responsible for 80% of the variability of the production of mango. The Paraná State, Brazil, is located in an area of climatic transition, being essential studies of this genesis for agricultural planning and decision making for agriculture in the region (Caramori et al., 2008). The establishment of agricultural planning and more aptitude models is essential for the mango adaptation for cultivation and does not harm the environment using excessive natural resources, in the context of climate change and sustainable agriculture. The purpose of this study is to perform climate risk agricultural zoning for the mango in the hydrographic basin of Paraná River III.

MATERIALS AND METHODS

Climate variability

The hydrographic basin of Paraná River III is located in a Cfa climate, which means that it has a humid subtropical climate according to the Köppen climate classification. This is characterized by the absence of drought seasons and by summers with higher average temperatures. This climate is controlled by air masses from tropical regions (the Atlantic Tropical Mass and the Continental Tropical Mass) and the Atlantic Polar Mass. In addition, the Continental Equatorial Mass can influence the Cfa climate zone during the summer season. Due to the temperature and humidity differences in these climatic masses, the area of the basin is a convergence zone for these climatic front systems, particularly in the winter season period (Nitsche et al., 2019).

For the purpose of this study, we selected the hydroclimatic requirements of the studied species and weather data of annual, seasonal, monthly, and daily time series with clipping from 1976 to 2018. In order to analyze climate variability and produce the climate risk zoning, data from meteorological stations distributed around the basin were surveyed. The database comprises data from numerous weather stations, including six IAPAR—Instituto Agronomico do Paraná (Brazil) stations (data from 1976 to 2018), ten SIMEPAR—Sistema Meteorológico do Paraná (Brazil) stations (data from 2000 to 2018 were included to contribute to analyses, even though a short period of time), and 27 Águas Paraná (Brazil) stations (data from 1976 to 2018) (Figure 1). For this study, we used data from stations that had long term data series (1976–2018). The spatialization of these data was performed by interpolation, which is an effective method for spatial visualization of climate data. This was done using isohyets and/or by spatially filling the values through adjusted regression statistics, using the inverse distance weighted spatial interpolation algorithm (Lem et al., 2013). The maps were created using QGIS software.

To complement the rainfall variability analysis and to identify the best time for fruit planting and the detection of extremes, Box Plot graphs or box diagram were used. The main feature obtained from its use is to provide a quick view of data distribution. If the distribution is symmetrical the box is balanced with the median positioned in the center of it. For asymmetric distributions, there is an imbalance in the box with respect to the median. The graphics were created using Statistica® software.

Box plots represent five value classifications. Outliers are divided into outliers (values above the maximum, but not extreme) and extremes, with any values exceeding Q3 + 1.5 (Q3 - Q1) or less than Q1 - 1.5 (Q3 - Q1). The highs and lows are considered the highest values in the series, but they are not extreme or discrepant. Inside the box are classified three quartiles with 25% of the data each, in addition to the median value, equivalent to the second quartile, or 50% of the data (Lem et al., 2013).

The punctual data of the rainfall stations were entered into the Qgis *software* and transformed into a *raster* file, with aid of the IDW interpolator. This new file displays a regular surface adjusted to these point data of interest with spatial resolution pixel of 1 by 1 km. Subsequently, isohyet and their values were inserted for a better visualization of areas with similar precipitations and/or insolation and to regionalize them. We also evaluated the distribution of annual precipitations using one weather station by region: Missal (West), Cascavel (South) and Vera Cruz do Oeste (Center), Foz do Iguaçu (South) and Terra Roxa (North). The *Shuttle Radar Topography Mission* - SRTM base, at 30 m resolution was used together positioning to correct the influence of the topography on temperature. This method is needed to spatialize and regionalize data to areas that do not have temperature data with greater accuracy. Multiple linear regression equations were applied for the spatialization of the average temperature and frost data measured at the meteorological stations. The applied equation is given by:

$$y = a + b.lat + c.long + d.alt$$

where a, b, c, d are regression coefficients, and lat, long, and alt represent the latitude, longitude and altitude, respectively.

This mathematic formula was applied in Arcgis geoprocessing *software* over the SRTM file, making it possible to generate maps, with spatial resolution of 30 m. The method used for the probability of frost was based on the historical minimum temperature series recorded within the meteorological shelter. We determined the probabilities of values equal to or lower than 1.0° C and then also adjusted to the equation

$$y = a + b.lat + c.long + d.alt$$

Rainfall data (from the monthly totals of each year) and the monthly average temperature (from the monthly averages of the daily values of each year) were extracted. Then, potential evapotranspiration (PET) was calculated according to the Thornthwaite method. First, the standard potential evapotranspiration (PET, mm/month) was

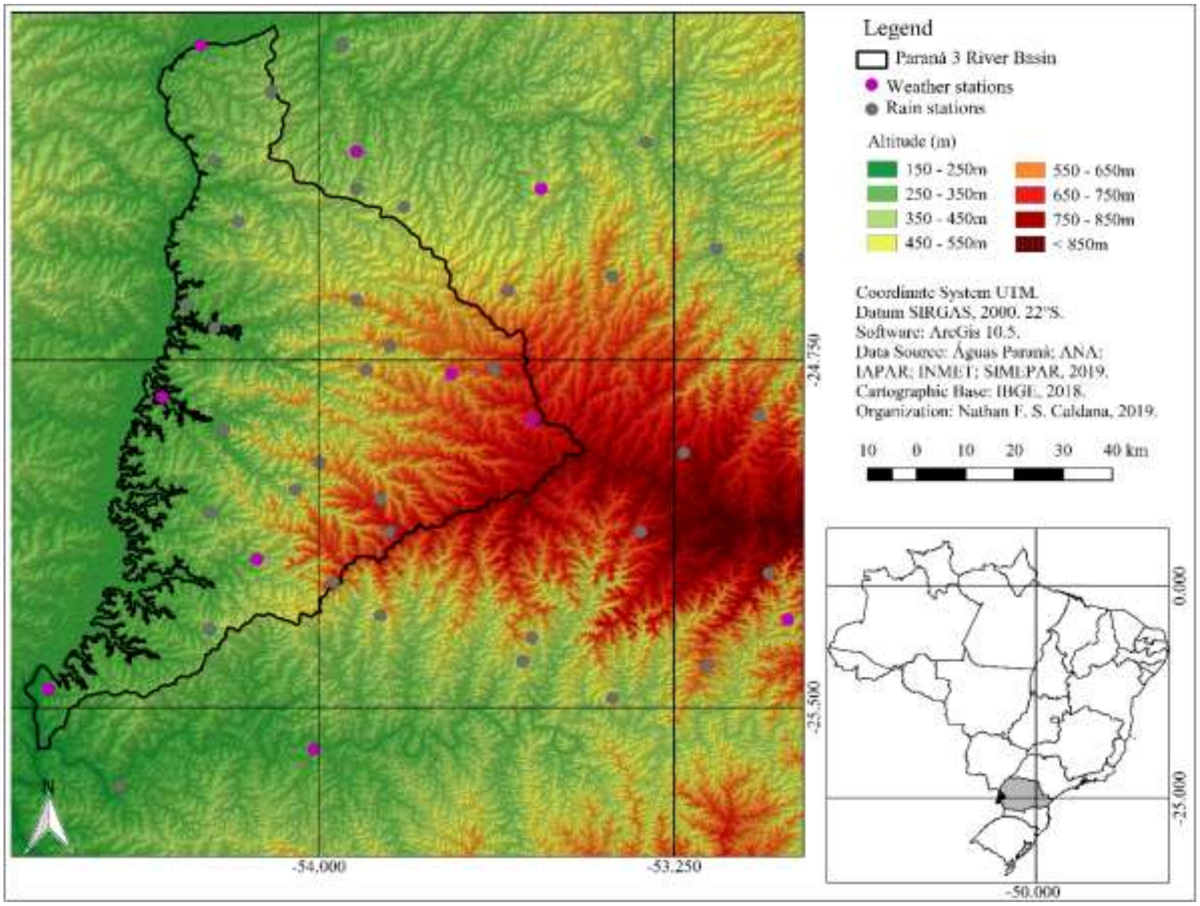

Figure 1. Hypsometry and locations of stations in the hydrographic basin of the Paraná River III.

calculated using the empirical formula:

$$\text{For: } 0 < \text{Tn} < 26.5°\text{C} \quad (1)$$

$$\text{PET} = 16\left(10\frac{\text{Tn}}{\text{I}}\right)^{\text{a}} \quad (2)$$

$$\text{For: Tn} \geq 26.5°\text{CTn}^2 \quad (3)$$

$$\text{PET} = -415\ 85, + 32\ 24, \text{Tn} - 43.0\ \text{Tn}^2 \quad (4)$$

Where Tn is the average temperature of month *n* (*n* = 1 is January, *n* = 2 is February, etc.) in °C, and I is an index that expresses the heat level of the region.

The value of I depends on the annual temperature cycle, integrating the thermal effect of each month, and is calculated using the formula,

$$\text{I} = 12(0.2\ \text{Ta})^{1514} \quad (5)$$

The exponent "a", being a function of I, is also a regional thermal index, and is calculated using the expression

$$a = 0.49239 + 1.7912 \text{ x } 10^{-2}\, I - 7.71 \text{ x } 10^{-5}\, I^2 + 6.75 \text{ x } 10^{-7}\, I^3 \quad (6)$$

The PET value represents the total monthly potential evapotranspiration that would occur under the thermal conditions of a standard 30 day month, and with a 12 h photoperiod (N) each day. Therefore, PET should be corrected for N and the number of days in the period.

$$COR = \left(\frac{N}{12}\right)\left(\frac{NDP}{31}\right) \quad (7)$$

Agroclimatic risk zoning

The risk factors selected for agricultural zoning of climatic risk were:

i) Average annual precipitation: data on monthly and annual precipitation from meteorological series of 27 stations in the basin were selected. The results obtained were interpolated in a geographic information system for the generation of maps with the regionalization of data through the IDW. It was considered: High Risk: annual rainfall less than 1,500 mm and as low risk greater than 1,500 and less than 1,900 mm annual distributed during the year (Mouco, 2010; Moura et al., 2015).

ii) Average Annual Temperature (Ta): We used meteorological data from historical series of average temperatures observed inside meteorological stations to estimate the average annual temperature. Using the Ta value, regression was applied as a function of latitude, longitude, and altitude for the whole basin. The risk classes defined for Ta were as follows: high risk – less than 20°C and low risk: greater than 20°C (Mouco, 2010; Moura et al., 2015).

iii) Annual Water Deficiency (AWD): This was estimated using the method of Thornthwaite and Matter (1955), and obtained by calculating the normal climatological water balance for the meteorological stations. We used a value of 100 mm for the available water capacity in the soil, considering that the avocado root system explores the soil profile to a depth of more than 1.50 m (Coelho et al., 2001). The results obtained were interpolated using the ArcGIS 10.0 geographic information system to generate the annual water deficit maps. (High Risk: AWD in two consecutive months > 10 mm, and Low Risk: AWD <10 mm in less than two consecutive months (Pereira et al., 2005; Mouco, 2010).

(iv) Frost risk: We used meteorological data from the thirteen-season historical series, taking into account occurrences of temperatures of 1 °C or below as observed within the meteorological shelters, to calculate the risk of frost. The probabilities of annual frost occurrence were calculated and correlated with altitude and latitude, obtaining a regression equation for the risk of frost. Using adjusted regressions, values greater than 20% were considered to be high risk (Pereira et al., 2005; Mouco, 2010).

For the creation of thematic maps and the final zoning map, ArcGIS software was used. Firstly, the numerical values from the meteorological stations were transformed into points, according to their geographical coordinates. We then used the edaphoclimatic requirements of the avocado species to produce data spatialization, which was used for the delimitation of the representative bands of the avocado climate requirements. Thus, the station values were replaced by “1. Apt” or “2. Restricted”, according to the physiological requirements for each meteorological variable analyzed. The next step was to combine the matrix images. Each pixel was assigned with the values “1” or “2”, as already described. If the combination for a point was filled only with values “1”, the region was classified as fit. If it had a value of “2” it was restricted by a given variable. If two or more “2” values were assigned, the location was classified as unfit. Then, standardization of the pixels using classifications was performed by dissolving the vector classes. In this way, the agroclimatic zoning classes were grouped, thus defining regions of suitability for the studied species. The final map showing the agroclimatic zoning of each crop will provide an estimate of the representative area of each risk class, ensuring its suitability for the site.

RESULTS AND DISCUSSION

In terms of water requirements, the mango is significantly resistant to drought, thanks to its root system that is capable of reaching depths into the soil, surviving up to 8 months without precipitation. Cultivation regions include areas that present low rainfall and high evapotranspiratory demand impose vegetal water supply through the irrigation. In these conditions, even when irrigated, the mango is into certain of water deficiency. Excessive precipitation, on the other hand, combined with high temperatures, makes the mango susceptible to fungal diseases and pests, and it is convenient that no precipitation occurs during the developing phase.

A dry period preceding flowering favors production, however, the mango requires edaphic moisture from the beginning of fruiting to maturation, which also influences the promotion of new vegetative growth (Mouco, 2010). In regions with low precipitation, irrigation is recommended based on the water requirements (Pereira et al., 2005). The estimated precipitation for the complete cycle development of the species in the region ranges from 1,500 to 1,900 mm, with annual values higher than the latter, favoring the proliferation of fungal pathologies (Figure 2).

Precipitation in the basin of Paraná River III was restricted only in the eastern portion, for mango production. The highlighted variable does not guarantee inaptitude. In addition, the mango needs a droughts period for better development during the flowering season. The precipitation occurrence at the time of flowering causes a series of damages such as: the removal of the pollen grain deposited in the stigma; dilutes stigmatic fluid favors loss of viscosity and non-retention of pollen; contributes to the fall of flowers and fruits; harms insect pollination and it also favors the proliferation of diseases such as powdery mildew and anthracnose (Mouco, 2010) (Figure 3). The region has no defined dry season; the driest month by the monthly average was August in municipality of Terra Roxa, with 56 mm. There is a significant discrepancy between the wettest and driest months, as in municipality of Matelândia, October has a median of 213 mm and August 65 mm. This difference between monthly rainfall during summer and winter may favor mango production. Mango is a drought-resistant species. This vegetation and fruit are found in regions of the Brazilian semiarid where the rainfall reaches 240 mm (Pereira et al., 2005). However, for the commercial success, it is recommended that the species does not spend more than two consecutive months under water stress; therefore, it is established that for zoning, the limit of two months under deficiency greater than 10 mm is restrictive for cultivation. Although summer is the rainiest season in the region (Figure 4), it is in this period that the highest temperature and evapotranspiration records occur (Nitsche et al., 2019); so even though winter is the driest season, the summer exhibits water deficiency in the region of the study. As identified, none of the analyzed stations presented AWD in two consecutive months, presenting no risk to production. Even in the Guaíra station, in the driest portion of the region, the annual deficit is no more than 60 mm. The spring months are the ones with the highest surplus volume, mainly in October.

Temperature is the most important climatic factor for mango cultivation, mainly due to the influence on flowering. The low temperatures paralyze the growth of the mango, of fundamental importance for the occurrence of flowering. Plants tend to grow, in vegetative phase and bloom irregularly in high temperature conditions (> 30°C day / 25°C night). At 15°C the growth of the branch

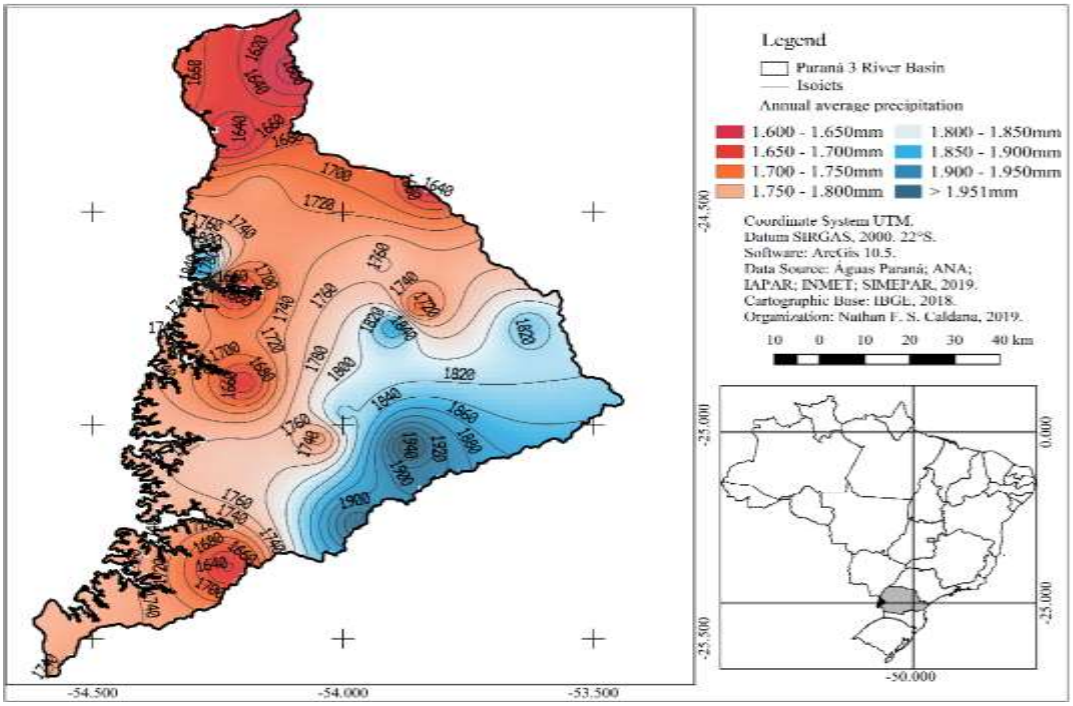

Figure 2. Annual rainfall average in the hydrographic basin of Paraná River III.

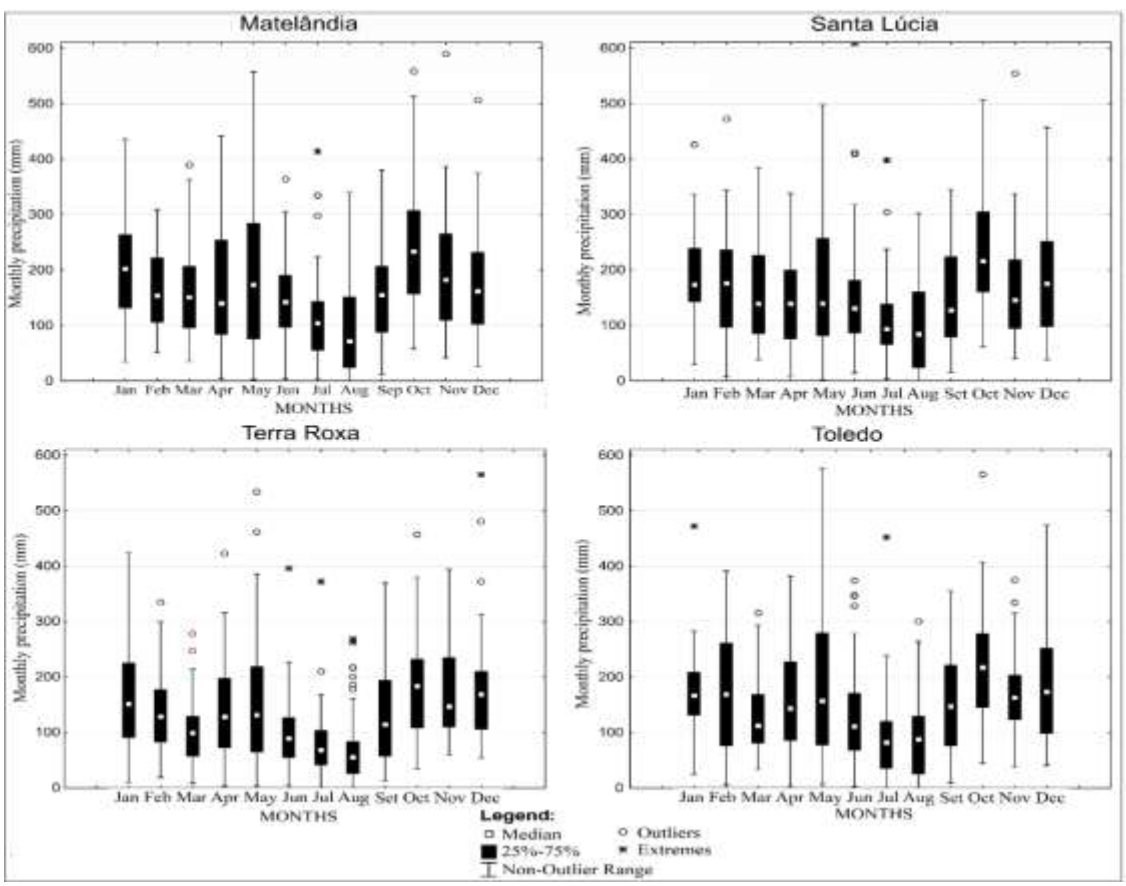

Figure 3. Annual rainfall variability in the hydrographic basin of Paraná River III.

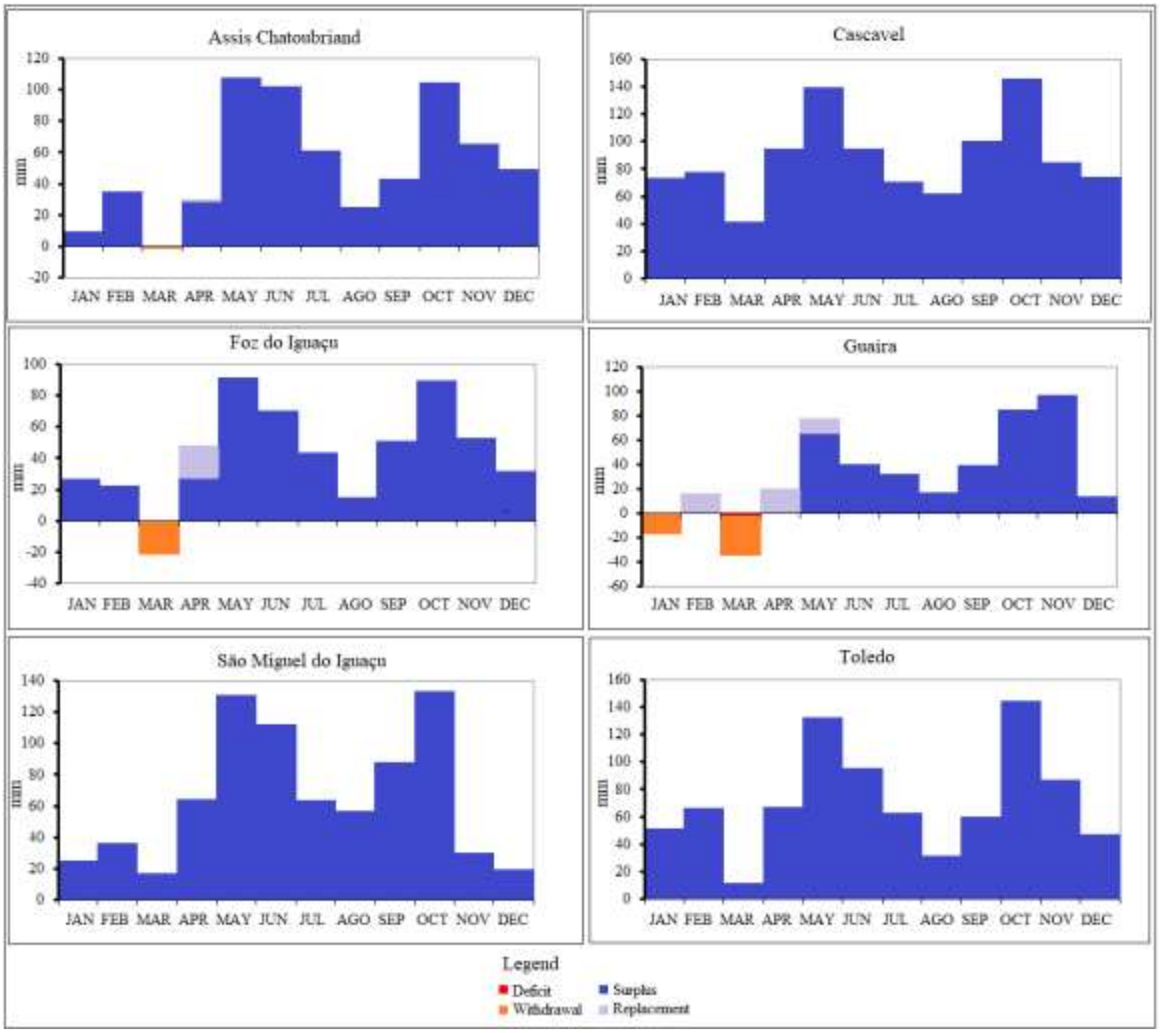

Figure 4. Water balance for avocado crop in the hydrographic basin of Paraná River III.

already stops, stimulating intense flowering. The initiation of flower buds depends on the cold days that occur from June to October, in the Southern Hemisphere (Pereira et al., 2005). The temperature showed no restrictions for the mango cultivation (Figure 5). The lowest records occurred in the portion with the highest altitudes (Figure 1) with an average temperature around 20.5°C; as the restriction evaluated was 20°C, there was no risk. In the western direction of the basin, the average values exceed 23°C.

In subtropical conditions, fruticulture management becomes relatively easy due to low temperatures facilitating flowering induction, although fruit growth and quality can be compromised by these temperatures (Sarkhosh et al., 2018). The sleeve cannot withstand temperatures below 10ºC. For this reason, the Southeast and Northeast regions of the country account for more than 90% of national production. Thus, the occurrence of frost becomes extremely harmful to production, since it leads to senescence, even if the tree survives, thus making production unfeasible (Mouco, 2010). It was identified that the region presents a risk of frost throughout its area (Figure 6). However it presents great regional variation. In the eastern portion of the basin, close to municipality of Cascavel, the probability is more than 25% of the occurrence of frost per year. While in the west direction, towards the Paraná River channel, the risk is reduced to less than 5%.

The cultivation of mango is not recommended in areas that present frost risk more than 10%, representing more than one strong frost every five years. The only area capable of presenting a lower risk is at the edge of the Paraná River, where the altitudes do not exceed 300 m, as presented in Figure 1. The final map of the agroclimatic risk zoning of the mango (Figure 7) presents the union of the agroclimatic maps presented in this study to determine the aptitude in the basin of Paraná River III. As noted that mango is a sensitive frost specie, the occurrence and frequency of frost was the key variable that restricted the cultivation of mango in the region,

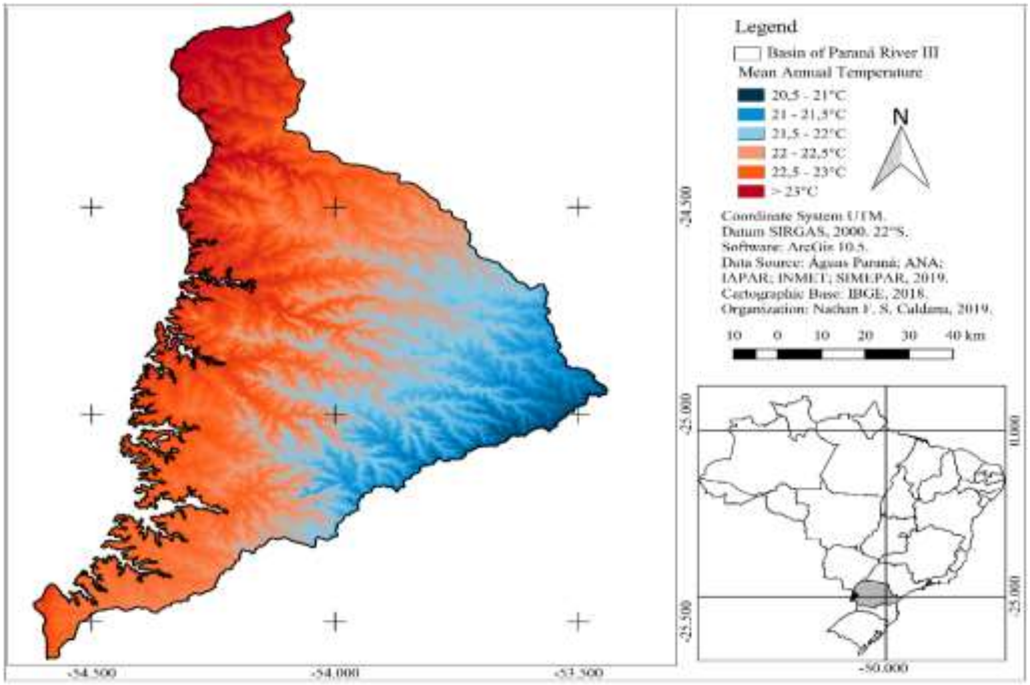

Figure 5. Annual average temperature in the hydrographic basin of Paraná River III.

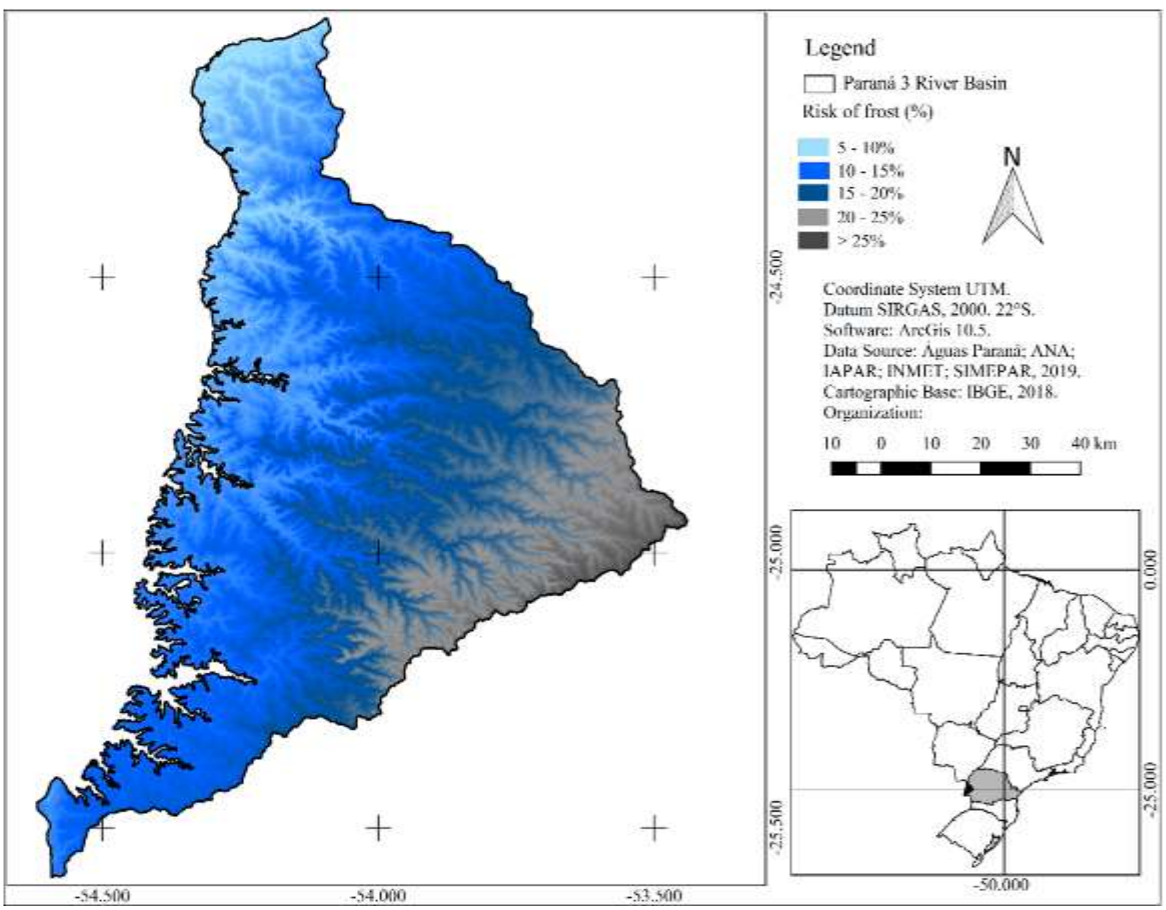

Figure 6. Frost risk in the hydrographic basin of Paraná River III.

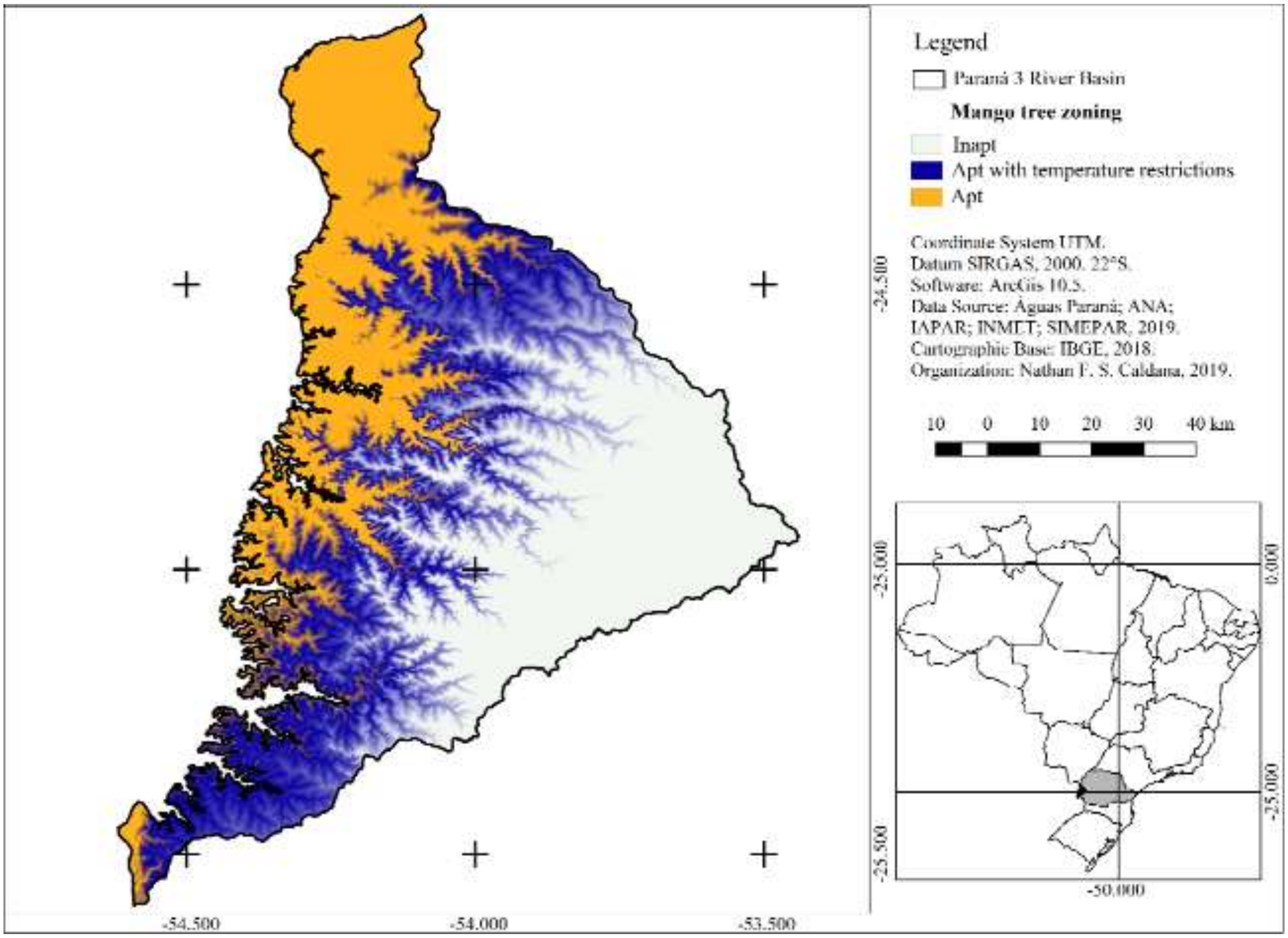

Figure 7. Agroclimatic risk zoning of mango (*Mangifera indica*) in the basin of Paraná River III.

making only the extreme west portion of the basin apt for cultivation.

In addition, the region is a small area, on the blue strip of the zoning map, where the risk of frost ranges from 10 to 15 %. Management agricultural practices must be taken to protect the orchards and avoid harm. Even in suitable regions, the risk of frost remains, so the farmer should avoid valley bottoms, at the end of the slopes, and give preference in areas that are not very sloping, to facilitate the displacement of cold air. Preferably, the top of the spike and half slope should be used, mainly on the faces facing north, since, as highlighted, the cold front has preferential displacement in the south / southwest direction, northeast direction (Caldana et al., 2019a, b). It should be noted that zoning does not eliminate the risks, but only presents more favorable conditions for the development of mango orchards. As agriculture is a risky activity, all activities are susceptible to climate extreme events, which may or may not cause harm for the farmer. In the context of sustainable agriculture, agroclimatic zoning provides greater security in decision-making, agricultural planning, and climate change scenarios, in the hydrographic basin of Paraná State III.

Conclusions

(i) The Hydrographic basin of Paraná River III has a small region with low climatic risk for mango cultivation, especially in areas with lower altitudes.
(ii) Mango is extremely sensitive to low temperatures and frost. The cultivation is restricted to a significant part of the basin. Even in suitable areas, the farmer must avoid cultivating in lowland areas with slopes facing the South side, thanks to the entry of cold air masses in the Paraná State.
(iii) Precipitation and water balance present sufficient values in all scenarios studied, however, during droughts periods, the farmer can use irrigation system.
(iv) Agricultural management techniques can be taken to avoid the risk of frost and to avoid areas with a higher incidence of the phenomenon can guarantee success in the cultivation of mango in the basin of Paraná River III.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Relative costs and benefits of implementing desiccant bead drying/hermetic storage and alternative drying and storage technologies for vegetable seeds in Kenya and Tanzania

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This paper assesses the relative costs and benefits of desiccant beads drying/hermetic storage and alternative drying and storage technologies. The study was conducted in Kenya and Tanzania in areas producing and trading vegetable seeds using a sample size of 280 respondents. The study revealed that costs of desiccant bead drying/hermetic storage are relatively higher for smaller quantities of seeds compared to alternative technologies. No storage losses are incurred with hermetic storage but high losses occur for ordinary storage. Using a combination of desiccant bead drying and hermetic storage is relatively more economical compared to using desiccant drying alone. There are economies of scale in the use of desiccant bead drying/hermetic storage compared to alternative technologies. Quantities of seeds that generate equal net benefits for both desiccant bead/hermetic storage and sun drying/ordinary storage range from 120 to 900 kg for African night shade and Amaranthus, and 300 to 1500 kg for beans. Efficiency in production and marketing is likely to encourage the use of desiccant bead drying/hermetic storage, which would be beneficial to farmers. Taking 15 kg of African night shade seeds and 18 kg of Amaranthus seeds, price premiums that would be necessary for farmers to receive for there to be an economic incentive for them to use the beads are approximately 35% for Amaranthus and 20% for the African night shade. Given efficiency of desiccant bead drying/hermetic storage it is likely to offer more benefits to farmers and traders compared to sun drying and other storage technologies.

Key words: Drying, storage, desiccant beads, moisture content, costs and benefits.

INTRODUCTION

High-yielding, high-quality seeds are a key technology input for the growth of the horticulture sector. Good quality seed alone can contribute 20-30% yield increase in vegetables (SSG, 2019; Poonia, 2013). However, a critical limitation to seed quality in warm and humid tropical regions is the inability to dry seeds to safe storage moisture content (MC). In general, seed longevity is reduced by half for every 1% increase in seed MC (percent of fresh weight) or 5°C increase in temperature, as inferred by Harrington's rule.

The combination of high MC and high temperature is particularly deadly for seeds (Ndung'u and Kimiti, 2017;

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Thomsen, 2000; Ellis and Roberts, 1981), so optimal storage recommendations include both low MC and low temperature. However, seed drying and cold storage facilities are generally unavailable or unreliable in many developing countries, particularly at the farm level. Seeds are much more resistant to high storage temperatures when their MC is low. Thus, drying to low MC and storage in hermetic containers to prevent rehydration from ambient air is the most realistic strategy for effective storage of seeds in warm tropical climates (Bradford et al., 2017; Ellis, 1988). A major impediment to this strategy is the difficulty of drying seeds to low MC under conditions of high ambient relative humidity (RH).

Desiccant ceramic beads can absorb water and reduce the RH to very low values in closed spaces, drying seeds to the optimum MC. After drying the seeds can be stored in hermetic containers/bags. Hermetic storage bags are made of woven polypropylene tapes of virgin resin. Drying products to levels low enough to reduce or prevent insect activity (~35% ERH) and maintaining dryness using hermetic packaging is a complementary strategy for controlling storage insects when adequate drying is possible (Kunusoth et al., 2012). Hermetic bags prevent insect damage by suffocating the insects and also by inhibiting penetration (Murdock et al., 2003). In this regard, hermetic bags would be good given that storage insects account for up to 40% of the total physical and nutritional loss of grain and dry food products in the developing world (Kumar and Kalita, 2017; Chomchalow, 2003; FAO, 1994). A key question is whether the technology would be economically beneficial for users. This paper assesses the relative costs and benefits of different seed drying and storage methods including the desiccant beads/hermetic bags, to determine under what circumstances the beads might be cost effective. The paper addresses three objectives, which are to: estimate the costs and returns using the current drying and storage methods; compare costs and returns of different drying and storage methods with the use of the desiccant bead technology; and identify possible scenarios under which the returns for using the beads could be enhanced. A specific question in this context is, “what price premium would be necessary for farmers to receive in order for there to be an economic incentive for them to use the beads?” Use of the beads becomes more economical with larger volumes of seeds, so a related question is “at what scale of seed production does use of the beads become economically attractive?”

MATERIALS AND METHODS

The study was conducted in Kenya and Tanzania in areas where farmers were involved in vegetable seed production using different approaches and there was seed trade. The seed production systems farmers used were contract, informal and quality declared seed. Vegetables used in the study included African night shade, amaranthus, beans, shelled groundnuts, onions, tomatoes and kale.

Two regions, Arusha and Dodoma, were covered in Tanzania. Respondents in the Arusha Region provided data for the contract and informal seed systems. Dodoma Region in Tanzania is where vegetable seed producers operate under the Quality Declared Seed (QDS) production system. In the case of Kenya data were collected from Bungoma for the contract seed growers, while Busia, Kinale and Yala areas provided data for informal seed growers. The seed producers were selected from each of the study areas using systematic sampling from lists of producers provided by the seed companies for the contract system, and from lists provided by local agricultural extension officers for the informal and QDS systems.

Data were also collected from seed traders including seed collectors, traders in the local market, wholesalers and agro-vets. Vegetable seed traders also provided data on costs and benefits as well as the activities involving drying, storage, distribution and marketing of the vegetable seeds in their respective areas of operation. Vegetable seed traders were randomly selected in local markets in each of the study areas. The distribution of the respondents from each of the data source categories is indicated in Table 1. A total of 280 respondents were selected for the study. Data were collected using structured questionnaires administered through face-to-face interviews. Data were collected for a range of different vegetables on the methods and costs for different drying and storage practices. Information was also collected on the selling prices for the seeds of the different vegetables with or without storage. As seed may deteriorate in storage for a range of reasons, estimates were also made of the amount of seed lost during storage by farmers before sale, which is effectively an additional cost of storage. Similar estimates were made from interviews with seed traders. In each case the volumes of seed involved were also recorded. As well as costs associated with drying and storage, an overall estimate was made of other production costs. This allows an estimate of actual returns to be made, as well as an estimate of the costs of drying and storage relative to other costs. To compare the use of desiccant beads with other drying and storage methods, a simple model specified below was used:

Returns = Selling price × Weight of seeds – Costs (production, drying, storage)

The parameters used in the computation of costs for comparison are included in Table 2. In the case of the seed traders the costs involved included the purchase price from the seed producers and the logistics costs consisting of the transportation costs and cess in the market places as well as labour costs. To make the comparison, the model was evaluated for the different vegetables using either the current or new drying and storage methods, and the difference in net returns calculated.

A sensitivity analysis was conducted for specific parameters in the above model. To examine the price premium that would be required, the selling price of the seeds varied while holding the other parameters constant. To establish the economies of scale, the model was evaluated for a range of values for the weight of seed, again while holding other values constant for the particular vegetable and production system. In each case, the benefit of using the desiccant bead technology is expressed as a per kg difference in returns when the beads are used and not used.

RESULTS AND DISCUSSION

Costs and income from the current drying and storage methods

Production costs for the different vegetable seeds

The types of production costs considered were seed,

Table 1. Distribution of respondents involved in the study.

Region	Informal seed producers	Contract seed producers	QDS seed producers	Traders
Bungoma		15	0	35
Busia	20	0	0	40
Kinale	10	0	0	10
Yala	15	0	0	25
Arusha	14	35	0	21
Dodoma	0	0	20	20

Table 2. Description of the parameters used in the model.

Parameter	Description
Production costs	A fixed cost per kg. The average production costs for different crops under the different production systems were determined and used in the model.
Drying costs: Current method	A fixed cost per kg. The actual values for drying by different methods under the different production systems were determined and are presented. For the model an average for each crop and production system combination is used.
Drying costs: Desiccant beads	Cost per kg, calculated from the existing model (see section 3.2.1). Inputs for this model are: (i) Species of crop (ii) Starting moisture content of the wet seeds (iii) Target moisture content of the dry seeds (iv) Weight of seeds to be dried (v) Cost of the equipment (drying beads) Values for starting and target moisture content were estimated by key informants, and are used as fixed values in the model.
Storage costs: Current method	A fixed cost per kg. The actual values for different storage methods under the different production systems were determined, but for the model an average for each crop and production system combination is used. Storage cost is assumed to be independent of storage duration.
Storage costs: Desiccant beads	Cost per kg, calculated with the drying costs as above.
Storage losses	Percentage loss. The actual values were obtained from the survey, assumed to be for a 3 month period. Percent loss using the new method is zero. The percentage loss thus reduces the amount of seed available for sale.
Selling price	Price per kg. Prices for the seeds were determined during the survey, for immediate sale following drying, and after storage for 3 months, when prices are generally higher.
Weight of seed	Because the cost per kg using the desiccant beads reduces with increasing weight dried/stored, actual weights of seed have to be used. The survey established the amounts of seed that farmers were drying and storing for the different crops and under the different systems, so for the basic comparison we use standard weights for the different crops.

fertilizer, pesticide and labour cost. Total production costs per kg of vegetable were relatively different for the vegetable seeds under different production systems (Table 3). The costs were similar for Kenya and Tanzania, which means that similar storage and drying methods could be used for the two countries. In fact,

Table 3. Production costs for the vegetable seeds (US$/kg).

Seed production system	Type of vegetable	Production cost (Kenya)	Production cost (Tanzania)
Contract (formal)	African night shade	1.80	1.78
	Amaranthus	0.68	0.71
	Beans	0.99	1.10
Informal	African night shade	1.22	1.22
	Amaranthus	3.27	3.26
	Beans	0.63	0.59
	Groundnuts	0.93	0.96
	Kale	1.74	1.72
Quality Declared Seed (QDS)	African night shade	QDS Not used in Kenya	1.56
	Amaranthus	QDS Not used in Kenya	0.89
	Beans	QDS Not used in Kenya	0.63
	Groundnuts	QDS Not used in Kenya	0.94

Table 4. Seed growers' average sun drying costs per kg.

Seed drying system	Vegetable	Kenya (US$/kg)	Tanzania (US$/Kg)
Contract seed system	African night shade	0.08	0.50
	Amaranthus	0.02	0.04
	Beans	0.03	0.01
Informal seed system	African night shade	0.59	0.56
	Amaranthus	0.77	0.38
	Beans	0.32	0.19
	Groundnuts	0.70	0.44
	Kale	0.43	0.16
Quality Declared Seed (QDS) System	African night shade	QDS Not used in Kenya	0.53
	Amaranthus	QDS Not used in Kenya	0.30
	Beans	QDS Not used in Kenya	0.10
	Groundnuts	QDS Not used in Kenya	0.39

some of the seed companies in Tanzania such as Simlaw seeds originally operated in Kenya and still have branches in Kenya.

Drying costs for the vegetable seeds

In all the project areas in both Kenya and Tanzania, the method that farmers and traders used for drying vegetable seeds was sun drying. Under the sun drying method the growers harvest the seeds and after harvesting the seeds are placed at the front of the houses on canvas, bags, mats, sacks or polythene papers on the ground or in a few instances on raised tables. The preferred method was drying on polythene paper. There was more diversity in the seed drying materials used in Kenya compared to Tanzania. No standard methods were used for checking moisture except visual inspection. The cost of drying was an aggregation of the cost of the various materials used for drying. The drying costs per kg for the different crops under the different production systems were variable but on average the costs were higher under the informal system (Table 4). The informal seed growers incurred more costs possibly due to the limited technical know-how. The technical skills required for the actual drying of the seeds are also relatively low among the informal seed growers. The quality declared seed producers have relatively more skills compared to the informal seed growers possibly because of the training that they receive from the Tanzania Official Seed

Table 5. Average storage costs incurred by the seed growers for 3 months.

Seed production system	Vegetable	Kenya (US$/kg)	Tanzania (US$/kg)
Informal	African night shade	0.46	0.23
	Amaranthus	0.05	0.13
	Beans	0.09	0.08
	Groundnuts	0.23	0.16
	Kale	0.03	0.02
Quality Declared Seed (QDS)	African night shade	QDS Not used in Kenya	0.26
	Amaranthus	QDS Not used in Kenya	0.06
	Beans	QDS Not used in Kenya	0.07
	Groundnuts	QDS Not used in Kenya	0.12

Table 6. Storage losses (%).

Production system	African night shade	Amaranthus	Beans	Groundnuts	Kale
Informal	22.0	25.0	14.0	10.2	16.0
QDS	8.5	10.5	10.0	7.50	

Certification Institute (TOSCI). The contract seed growers spend relatively less on drying compared to all the other categories of seed producers, possibly because they have adequate technical know-how relating to the proper physiological age of harvesting, the harvesting approaches and the techniques for drying the seeds. The findings suggest the need for capacity building for the informal seed growers with respect to post-harvest handling especially drying of seeds.

Storage costs for the vegetable seeds

After drying seeds were packed in different containers for storage. The packing materials included sisal sacks/bags, polythene bags/plastic containers, bottles and khaki papers. The seeds in any of the packing formats were then placed in the house or in some store pending sale and/ or use as appropriate. The main packing facilities were sisal sacks/bags. No special efforts were undertaken to ensure that the moisture content was maintained at the desired levels. The costs associated with each of the storage methods vary depending on the vegetable crop involved and the system of production (Table 5). Contract seed growers reported no storage costs because the seeds were collected by the seed companies immediately after drying. The computation of the storage costs involved adding together the costs incurred in purchasing equipment/materials and the labour costs incurred during storage of the seeds. The total costs were then divided by the quantity of seeds dried to arrive at the storage cost per kg of the seed stored by the different seed growers.

Some storage losses were incurred and an assessment was conducted for the key crops under the different seed production systems (Table 6). The storage losses were higher in the informal seed system compared to the quality declared seed system. This may be because the seed growers under QDS receive training on production and post-harvest handling practices. As such they are able to undertake storage in a more efficient manner that lowers the losses. This is also an indication that there is need to reduce storage losses given the corresponding monetary losses to the producers.

Selling prices for the vegetable seeds

The prices paid per kg for the different vegetables seeds after drying and storage were variable indicating the values the seed users attach to the different vegetable seeds (Table 7). The prices paid depended on whether the seeds were sold immediately after drying or after storage for some time. There were very few instances where seeds were stored for 6 months or longer. As a consequence, the analysis in subsequent sections is based on storage for 3 months. Prices after storage were relatively higher because selling was undertaken during times when seed supply was relatively lower compared to demand. Some losses were incurred during storage and hence prices after 3 months relate to the marketable seed that was left after storage losses. This suggests that better storage methods that reduce storage losses are likely to benefit the producers more. As a consequence, investment in better storage methods is warranted. No prices were reported for storage by the contract growers

Table 7. Seed sale price (US$/kg) by the seed growers after drying and storage.

Seed production system	Vegetable	Kenya (US$/kg)		Tanzania (US$/kg)	
		Immediate sale	Sale after 3 months	Immediate sale	Sale after 3 months
Contract (formal)	African night shade	5.81	No storage	3.75	No storage
	Amaranthus	2.33	No storage	3.13	No storage
	Beans	1.05	No storage	1.00	No storage
Informal	African night shade	7.19	11.05	6.25	7.19
	Amaranthus	6.98	11.63	2.50	3.75
	Beans	1.16	2.56	1.00	1.38
	Groundnuts	1.98	2.91	1.56	2.03
	Kale	2.91	3.49	1.25	1.31
Quality Declared Seed (QDS)	African night shade			6.09	6.88
	Amaranthus	No QDS	No QDS	2.63	3.38
	Beans	No QDS	No QDS	1.15	1.40
	Groundnuts	No QDS	No QDS	1.60	2.25

Table 8. Drying, storage and transaction costs of the traders.

Vegetable	Buying price from suppliers (US$/kg)	logistics costs (US$/ kg)	Drying costs (US$/kg)	Storage costs (US$/kg)	Selling price to the final users [no storage] (US$/kg)	Selling price to users after 3 months (US$/kg)
African night shade	7.19	0.06	0.22	0.07	11.05	16.40
Amaranthus	4.03	0.02	0.35	0.05	7.91	8.25
Beans	1.16	0.11	0.10	0.08	2.56	3.00
Groundnuts	1.98	0.12	0.13	0.03	2.91	6.24
Kale	2.91	0.07	0.18	0.19	3.49	7.79

because they sold seeds to the seed companies immediately after drying. QDS system is found in Tanzania alone and not Kenya.

Trader costs and selling prices

The drying costs incurred by the seed traders were not related to the time that harvesting was done but instead on the extent to which the seed had been dried by the seed growers or the seed collectors that eventually sold to the seed traders. There would be no need for the seed traders to dry the seeds in instances where the seeds had been dried to the correct moisture content by the seed growers and the seed collectors in the various places. However, all the seed traders that provided information stated that they dried the seeds before selling.

In both Kenya and Tanzania, the seed traders used the same methods and equipment for drying and storage of the seeds as the seed growers in the two countries. The costs and selling prices are shown in Table 8. Some losses were incurred during storage. The losses were attributed to pests and spillage during the transfers. For the key traded crops, the losses incurred were 10.2, 8.0 and 5.0% for beans, African night shade and amaranthus respectively. For the traders involved in sales and purchases of groundnuts and kale the losses reported were 6.4 and 10.5% respectively. It emerged that the prices paid by the buyers were relatively high in case seeds had been stored for some time. This is because it is possible to sell at relatively high prices after storage. Traders who do have storage facilities are able to set market prices and take advantage of higher prices when incoming supplies dwindle (RSA, 2015). The value of any surplus crop tends to rise during the off-season period, provided that it is in a marketable condition. Therefore, the principal aim of any storage system must be to maintain the crop in prime condition for as long as possible. This is in line with the understanding that correct design of storage after proper drying is a key to business success (Cromarty et al., 1982; Jones et al.,

Table 9. Moisture content and seed oil for the different vegetable seeds.

Name of vegetable		Starting MC	Desired MC	Seed Oil
Common name	**Botanical names**			
African night shade	*Solanum vilosum*	24.0	9.0	*27.2
Amaranthus	*Amaranthus tricolor*	29.0	9.0	6.0
Beans	*Phaseolus vulgaris*	45.5	12	21.0
Groundnuts	*Arachis hypogaea*	17.0	8.0	47.3
Kale	*Brassica oleracea var. acephala*	56.0	10.0	25.9

* The value used is for *Solanum nigram.*

2014). Seed traders are therefore likely to benefit more given good storage facilities.

Comparison of the current methods with the use of desiccant beads

Costs of using the desiccant beads

The materials needed for using zeolite desiccant beads to dry seeds are the beads themselves, baking oven, deep baking pan and sturdy gloves, funnel, plastic baskets, moisture-proof metal or plastic containers, temperature/humidity metre and small packets of silica gel (optional).

To determine the costs of using the desiccant beads for drying and the hermetic containers for storage it was necessary to specify values for the initial moisture content (MC) of the seed and the final/desired MC for storage. For long-term storage, seeds should be in equilibrium with 20-30% RH. Once dry the seeds should be stored in a room under prevailing environmental conditions in a moisture proof container. The initial and target moisture content used for the different species is given in Table 9. The target or desired moisture content is what is recommended for good storage of the seeds as per the standards of the seed companies. The initial/starting moisture content for the different seeds was obtained from consultations with experts in the seed industry and particularly those dealing with seeds at the farm level. The desired/safe moisture content for seed storage was obtained from Simlaw Seed Company. The costs of the desiccant beads were generated using the bead economic calculator from Rhino Research using the values reported above. The computation used US$ 22 as the price per kg of beads and assumed 7 days between batches which is the most acceptable duration by over 75% of the seed growers and traders. The temperature used was 25°C, which is the average from the areas based on information from the Meteorological Department. The period of storage is taken as 90 days.

Using the economic bead calculator and the necessary conditions documented in Table 9, which are consistent with Ahuja et al. (1987), CEAPRED (2010) and Ellis (1988), the costs of drying and storage for 3 months using the desiccant beads were calculated and documented in Table 10. The costs are computed on a per kg basis and compared to the costs of sun drying and ordinary storage. The costs of drying and storage decrease as the quantity of seeds involved increases (Figure 1) in the case of using the beads. For sun drying and ordinary storage the costs are assumed to remain constant per kg of seeds dried. The results suggest that it would necessary to increase productivity to ensure efficient use of desiccant beads and hermetic bags.

Returns using the current methods and beads

In the computation of returns standard values are used, which are the average quantities of the seeds that the seed growers reported in the survey. Average prices and production costs were also used in the computation to generate the returns (Table 11). In the case of traders, logistics costs and the buying price from the seed suppliers were used. The costs are computed on a per kg basis and the corresponding net income is obtained as the difference between price per kg and the costs per kg. The same table also provides comparable net income using the sun drying method.

A comparison of the usage of beads for drying and hermetic containers for storage with sun drying and ordinary storage showed that at the current small scale seed production beads drying is less lucrative (Table 12). However, the gains are much higher compared to using the beads for drying only. The volume of seeds from sun drying and ordinary storage is reduced by the storage losses (Table 6) while no storage loss is assumed when beads/hermetic containers are used. This assumption is based on a previous study which established that when compared with ordinary bags, the losses when hermetic bags are used are less than two percent (Murdock and Baoua, 2014).

Net income is obtained as the difference between the price per kg and the cost of drying per kg or the price per kg and the drying and storage cost per kg. Tables 11 and 12 indicate that the current individual production is insufficient to support the use of beads. The use of beads

Table 10. Comparison of the costs of drying and storage using the beads and hermetic containers with sun drying and ordinary storage.

Name of vegetable	Costs of bead drying (USD/kg)	Costs of sun drying (USD/kg)	Costs of Bead drying and hermetic storage (USD/kg)	Costs of sun drying and ordinary storage (USD/kg)
Informal seed system				
African night shade (15 kg)	3.92	0.59	4.51	1.05
Amaranthus (18 kg)	4.00	0.77	4.24	0.82
Beans (246 kg)	0.38	0.32	0.78	0.41
Groundnuts (10 kg)	5.44	0.70	6.32	0.93
Kale (40 kg)	2.57	0.43	3.01	0.46
Contract seed system				
African night shade (33 kg)	2.18	0.08	No storage	No storage
Amaranthus (450 kg)	0.21	0.02	No storage	No storage
Beans (488 kg)	0.19	0.03	No storage	No storage
QDS system				
African night shade (40 kg)	1.80	0.53	2.35	0.79
Amaranthus (50 kg)	1.88	0.30	2.32	0.36
Beans (70 kg)	1.34	0.10	1.97	0.17
Groundnuts (20 kg)	2.72	0.39	3.16	0.51
Traders				
African night shade (50 kg)	1.35	0.22	1.79	0.29
Amaranthus (100 kg)	0.94	0.35	1.58	0.40
Beans (940 kg)	0.10	0.10	0.86	0.18
Groundnuts (475kg)	0.15	0.13	0.94	0.16
Kale (100 kg)	1.16	0.18	1.58	0.37

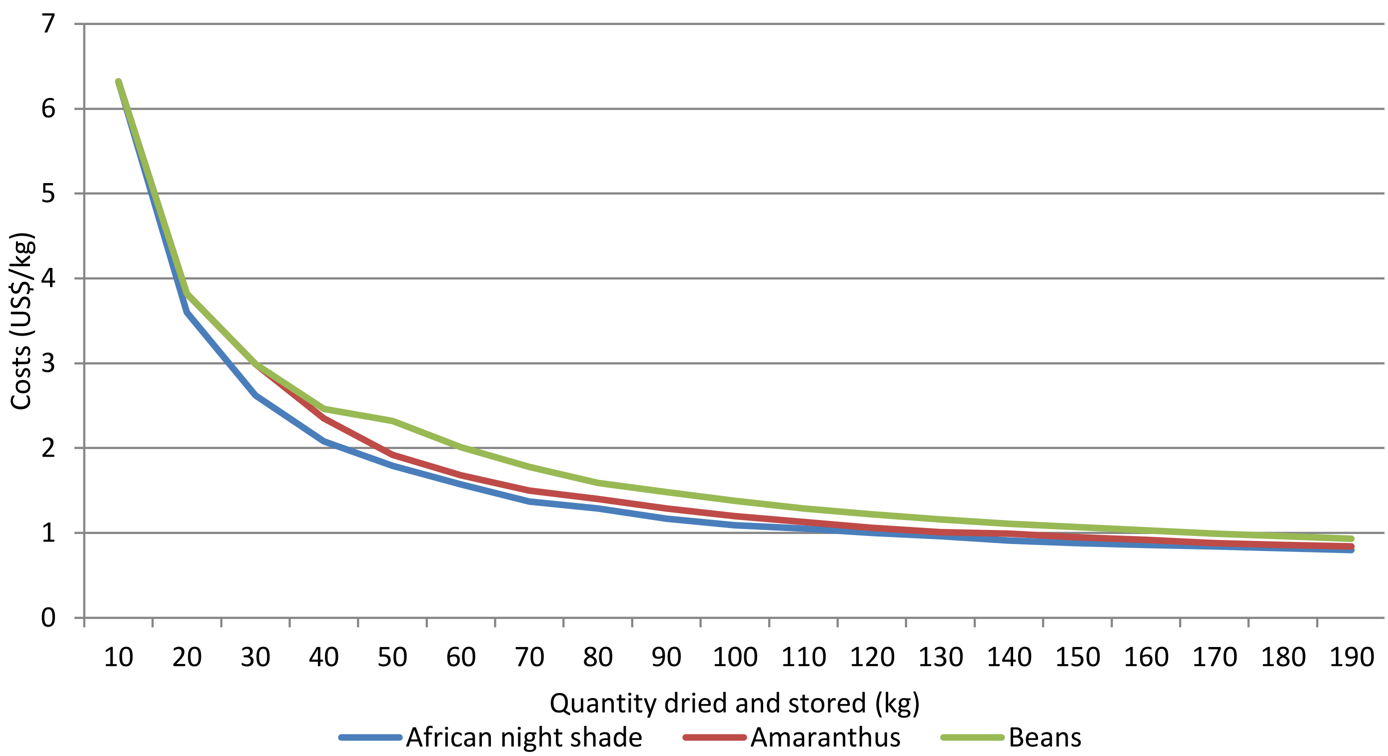

Figure 1. Costs of drying and storage of selected vegetable seeds using beads.

Table 11. Comparison of income from the different drying methods and beads for immediate sale.

Name of vegetable	Net income from sun drying (USD/kg)	Net income from desiccant beads drying (USD/kg)
	Informal seed system	
African night shade (15 kg)	5.38	2.05
Amaranthus (18 kg)	2.94	-0.29
Beans (246 kg)	0.21	0.15
Groundnuts (10 kg)	0.35	-4.39
Kale (40 kg)	0.74	-1.40
	Contract seed system	
African night shade (33 kg)	3.93	1.83
Amaranthus (450 kg)	1.63	1.44
Beans (488 kg)	0.03	-0.13
	QDS system	
African night shade (40 kg)	4.00	2.73
Amaranthus (50 kg)	1.44	-0.14
Beans (70 kg)	0.42	-0.82
Groundnuts (20 kg)	0.27	-2.06
	Traders	
African night shade (50 kg)	3.58	2.45
Amaranthus (100 kg)	3.51	2.92
Beans (940 kg)	1.19	1.19
Groundnuts (475 kg)	0.68	0.66
Kale (100 kg)	0.33	-0.65

Table 12. Comparison of income from sun drying and ordinary storage with bead drying and hermetic storage for 3 months.

Name of vegetable	Net income from sun drying and ordinary storage (USD/kg)	Net income from desiccant beads/hermetic storage (USD/kg)
Informal seed system		
African night shade (15 kg)	6.65	4.46
Amaranthus (18 kg)	5.42	2.65
Beans (246 kg)	1.31	1.10
Groundnuts (10 kg)	0.94	-4.34
Kale (40 kg)	1.08	-1.26
QDS system		
African night shade (40 kg)	3.82	2.49
Amaranthus (50 kg)	2.45	0.93
Beans (70 kg)	0.54	-1.2
Groundnuts (20 kg)	0.72	-1.85
Traders		
African night shade (50 kg)	8.15	7.36
Amaranthus (100 kg)	3.35	2.62
Beans (940 kg)	1.39	0.87
Groundnuts (475 kg)	3.73	3.20
Kale (100 kg)	3.97	3.23

Table 13. Quantities (kg) at which drying with beads gives equal returns to sun drying.

Vegetable	Contract seed system	Quality declared seed system	Informal seed system	Traders
African night shade	850	325	120	200
Amaranthus	900	600	120	380
Beans	1500	1000	300	900

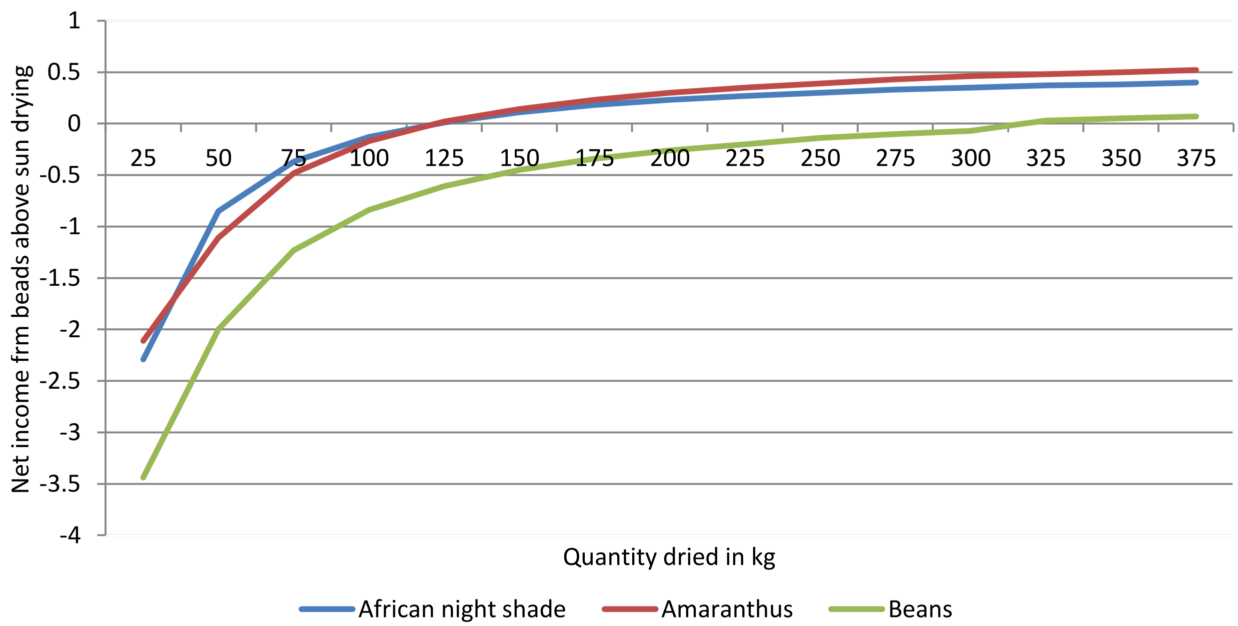

Figure 2. Net income from beads drying minus income from sun drying (US$/kg) for immediate sale in the informal seed system.

will require more production or pooled production from groups of farmers or large scale production of seeds. Given the potential of small scale production there is opportunity for using beads as efficiency in production of seeds increases. In addition, large scale seed production is likely to benefit more from use of the beads for drying and hermetic storage.

Situations under which using the beads is beneficial

A key driving factor in the use of any technology is the financial returns although there are also other benefits and costs that are more difficult to quantify. All the producers that provided information use sun drying as the method of choice. As a consequence, analysis is based on comparison of sun drying and ordinary storage with desiccant bead drying and hermetic storage. In the above comparisons with the 'standard' values, use of the beads/hermetic storage was not economically beneficial. However, under different circumstances this would change, so we investigated whether the returns become positive with greater volumes stored, or if there was a price premium for seeds stored properly.

Economies of scale

The use of beads at the current seed production level by the small scale seed growers was less profitable. However, as the per kg cost of using the beads decreases with increasing volume of seeds (Figure 1), the question then is at what quantity of seeds does use of beads become attractive? We assume that use of the beads would be economically attractive once the returns are greater than with traditional methods. Table 13 shows the seed volumes at which the returns in the two systems are equal.

Figure 2 shows how returns increase with increasing quantities of seed, for the informal seed growers. Although at different points use of the beads does become economically beneficial, the curves level off at a low level of return. Storage using hermetic containers also becomes more attractive when larger quantities are involved. The corresponding incomes increase and are relatively higher than using the beads for drying only. As

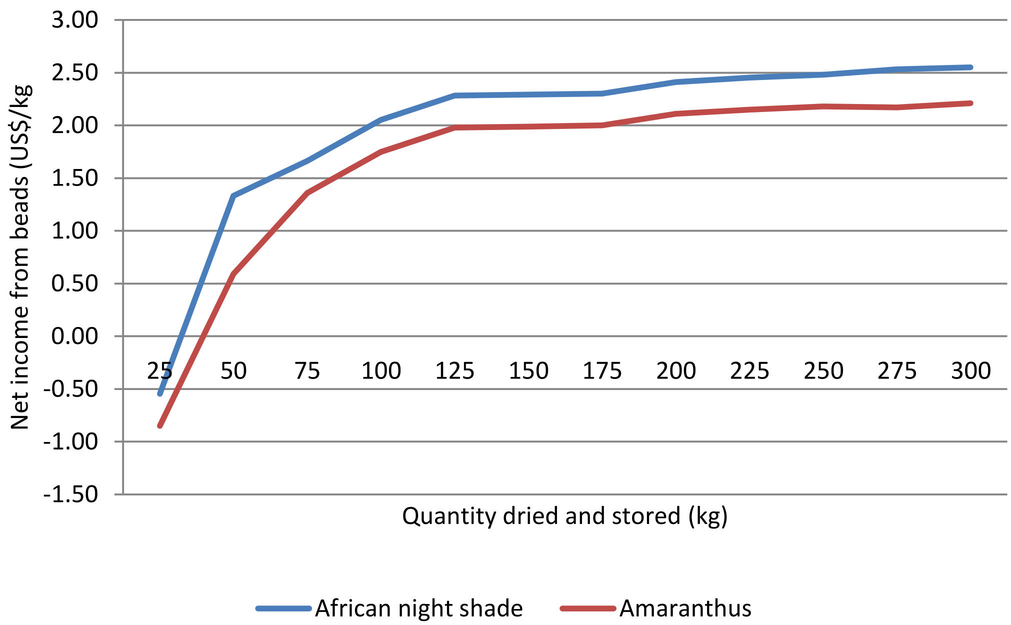

Figure 3. Net income from beads drying and storage minus income from sun drying in the informal seed system.

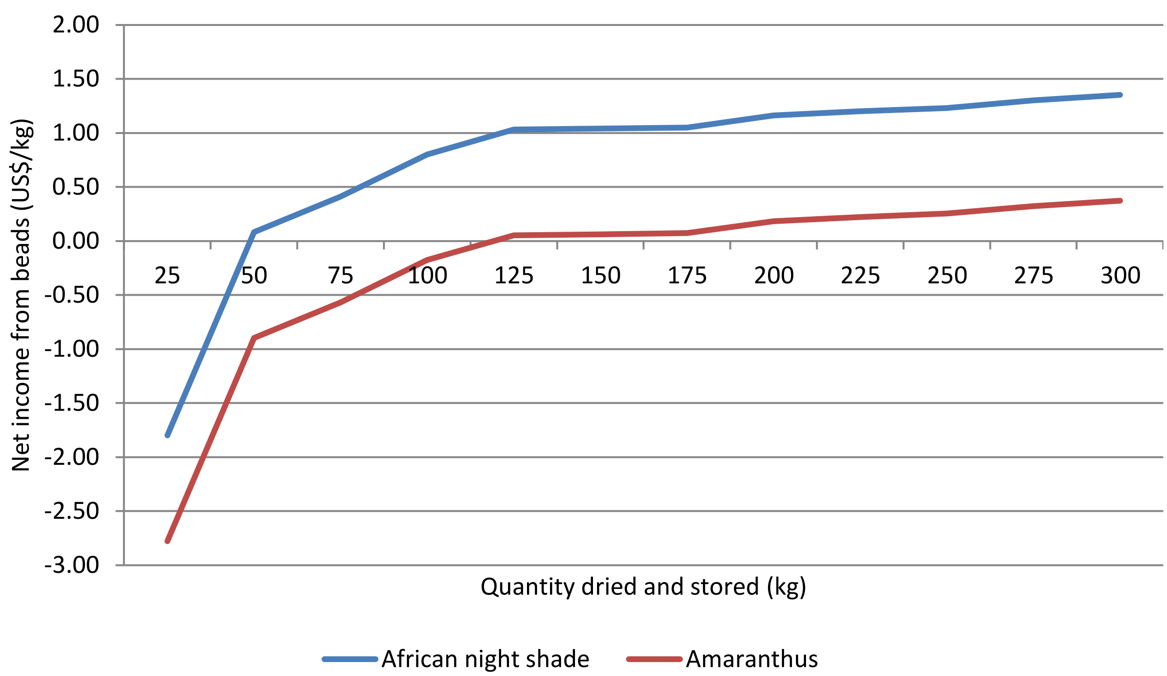

Figure 4. Net income from beads drying and storage minus income from sun drying in the quality declared seed system.

before, losses are assumed to be non-existent in the case of drying with beads and hermetic storage but sun drying and ordinary storage incur losses. Figures 3 and 4 show the difference in returns between the traditional and new methods for drying and storage as volumes increase for African night shade and Amaranthus, in the informal seed production system and the quality declared seed system respectively. The economies of scale apply to the traders as well. As the quantity of seeds dried and stored by the traders increases the net income associated with the use of desiccant beads/hermetic containers for drying starts increasing (Figure 5).

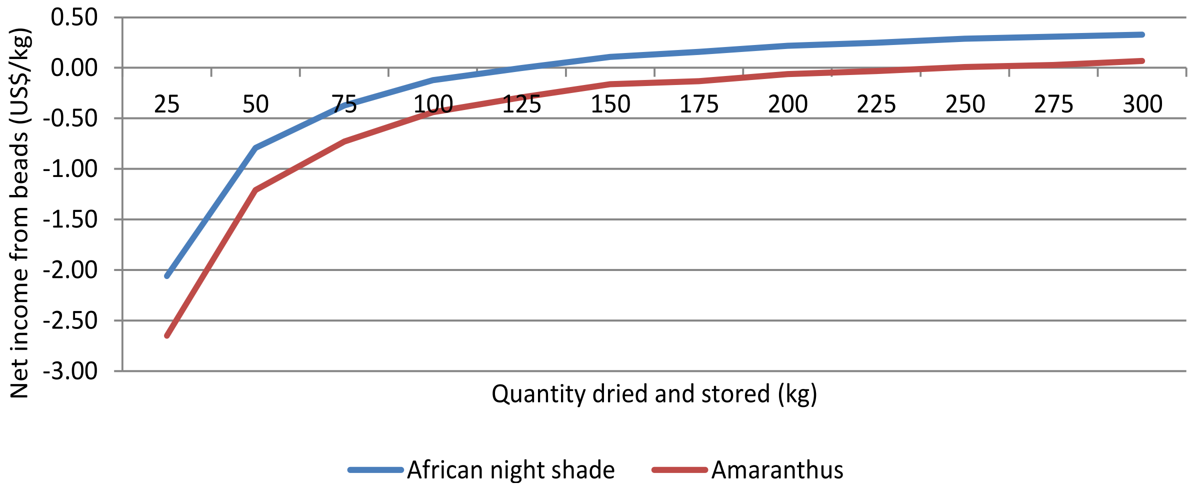

Figure 5. Net income from beads drying and storage minus income from sun drying for the traders.

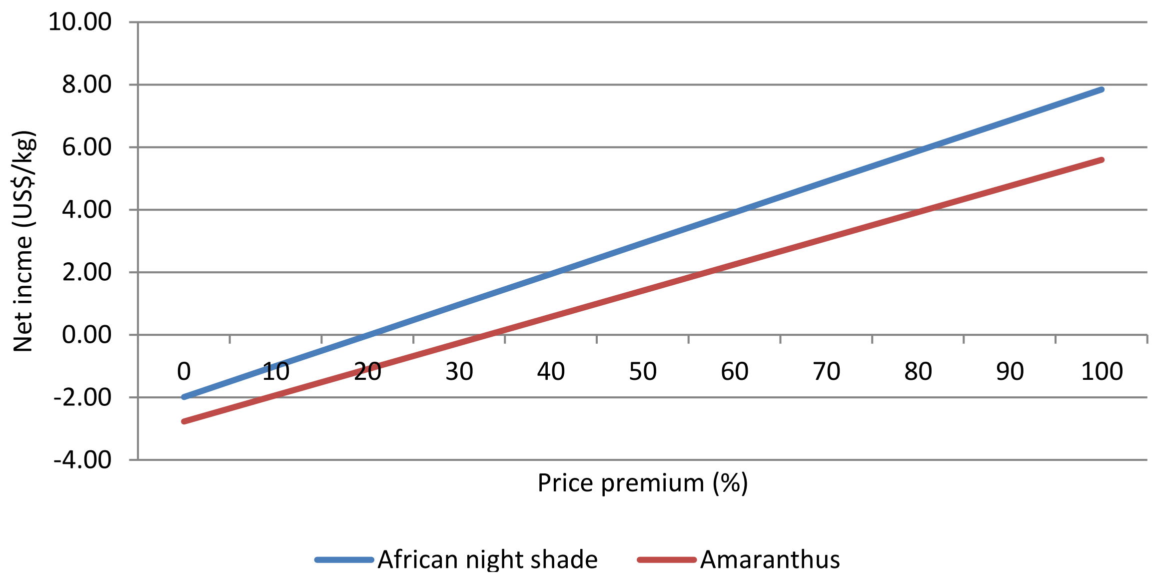

Figure 6. Effect of price premiums on net income from bead drying and storage in the informal seed system.

Price premiums

Price premiums for well dried and stored seeds would encourage efforts towards quality improvements as well as diversification of the drying and storage processes particularly given that efficient processes like bead drying appear expensive for smaller quantities. Starting with a zero premium which is the current price and adjusting the premium to 100% it was possible to establish the price premium at which the returns for the two methods were equal. Using the two preferred vegetables and the quantities of seeds currently produced in the informal seed system the premium is calculated. Taking 15 kg of African night shade seeds and 18 kg of amaranthus seeds, and the corresponding selling prices from Table 7, the net returns are as shown in Figure 6. The price premiums that would be necessary for the farmers to receive in order for there to be an economic incentive for them to use the beads are approximately 35% for Amaranthus and 20% for the African night shade.

For the quality declared seed system the quantity produced and used as base were 40 kg for African night shade and 50 kg for amaranthus. The baseline (0% premium) seed selling prices are again as in Table 7. Figure 7 provides the incomes adjusted by the price premiums for the two crops. The price premiums required are about 25% for African night shade and 60% for Amaranthus.

In the case of traders, the quantity produced and used as base were 50 kg for African night shade and 100 kg

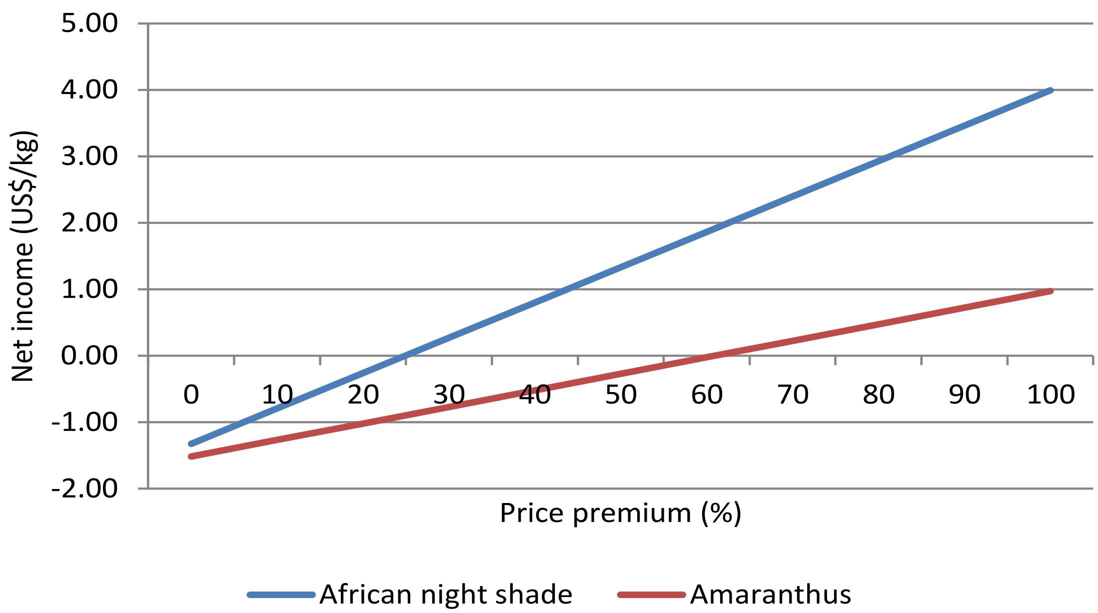

Figure 7. Effect of price premiums on net income from bead drying and storage in the QDS seed system.

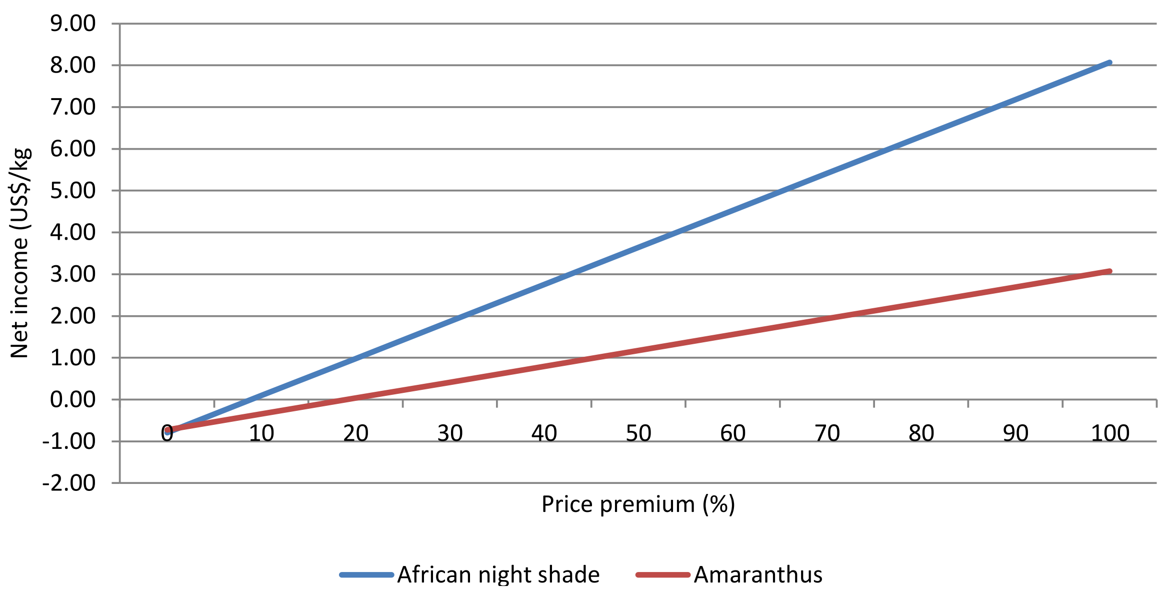

Figure 8. Effect of price premiums on net income from bead drying and storage by the traders.

for amaranthus. The seed selling prices were US$ 16.40/kg and US$ 8.25/kg for the African night shade and amaranthus respectively. Figure 8 provides the incomes adjusted by the price premiums for the two crops. The breakeven price premiums required are 7% for African night shade and 20% for Amaranthus.

Conclusions

Many different approaches to drying and storage are used, with widely varying estimates of costs. This suggests there may be at least some scope for improving the implementation of the traditional methods. The wide variability also suggests that in many cases farmers do not have a very good idea of their actual costs. The costs of desiccant drying/hermetic storage were relatively high compared to traditional methods under current production levels. The losses incurred in the traditional methods and improved production efficiency can offset the costs thereby justifying the use of desiccant bead drying/hermetic storage.

Using the values obtained from the field for current drying practices, use of the beads was less profitable. Extrapolation to relatively large quantities including production potential revealed that desiccant bead drying/hermetic storage can be profitable. Comparing the different seed systems is difficult, because the "standard" weight of seeds used in the model varied according to what was recorded in the field. However as larger amounts of seed are usually produced and sold by farmers under the contract system, the new technology is feasible.

When comparing the returns from drying and storage using the current methods with those from use of the beads and hermetic containers, the new methods were only profitable in case of larger quantities. The benefits would increase when a combination of bead drying and hermetic storage is used. This is because the storage costs using hermetic containers would be more than offset by the reduction in loss during storage.

Using larger volumes of seed is more cost effective because the cost per kg of using the beads and hermetic containers falls quite sharply as volume increases. Of interest here is the seed volume at which the traditional and new methods give equal returns, effectively the breakeven point on investing in the new technology. But the rate at which returns increase with higher volumes above the break-even point is also of interest, as technology users would want to see better than break even. When looking at drying alone, although break-even points (for the informal seed system) were at around 120 kg for Amaranthus and African night shade, above that point the graphs were flat, with returns from larger volumes only increasing slightly. Thus, for drying only, such as farmers in the contract system would use, the drying beads do not appear to offer economic benefits. When drying and storing using the new methods, there do appear to be economies of scale that could make the use of the technology attractive.

Given that individual farmers are usually drying and storing small volumes, this supports the suggestion that use of the beads is more likely to be appropriate in organisations such as farmer groups or cooperatives, as well as seed traders and companies. Gene banks are another organisation where larger volumes of seed might be stored, but this is only a very small potential market. The new methods would be more appropriate for seed species for which larger volumes are produced and traded. More widely grown species (such as beans) might therefore be a more successful entry point.

A price premium of around 20-30% would be needed to offset the higher costs of using the new methods and a higher premium would be needed to make the investment positively attractive. Price premiums are more likely to be sustainable in a more regulated and controlled market, where buyers can be confident that the higher price paid will actually ensure higher quality. This is likely to be effective under the QDS and contract seed systems. Sustainability of a price premium would also require farmers to be more aware of the value of buying good seed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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A cluster analysis of variables essential for climate change adaptation of smallholder dairy farmers of Nandi County, Kenya

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Smallholder dairy farmers occupy high potential areas of Kenya and are a source of manure, crops and milk. There is need to use other means of characterising smallholder dairy farmers as they mostly practice mixed farming. The objective of this paper is to use cluster analysis method to characterize the smallholder dairy farmers with added farmer and activity data variables. Clusters of 336 farmers in this study were derived using 28 key variables. This paper demonstrates how to conduct farmer assessments for climate change adaptation activities, climate smart technologies implementation using knowledge of key farmer variables and their distribution in the smallholder dairy farmers of Nandi County, Kenya. This paper demonstrates the importance of integrating agricultural information for smallholder dairy farmers to machine models to characterize the groups and observe the natural groupings. This allows for policy managers to know the key characteristics and how to use them in policy implementation especially in designing climate change adaptation programs factoring education and training of farmers as demonstrated in this paper that they are practicing many activities on their farms.

Key words: Cluster analysis, smallholder dairy farmers, farm utilisation, climate change adaptation.

INTRODUCTION

Sub-Saharan Africa (SSA) has the fastest growth in agriculture and the greatest level of agricultural imports compared to other global regions (Livingston et al., 2011). This growth follows huge demand for food and thus the importance of smallholder agriculture to the food security is cemented for this SSA (Bellarby et al., 2014).

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Smallholder farmers play a key role in development in Africa especially in recent years (Hammond et al., 2015; Livingston et al., 2011; Salami et al., 2010). Smallholder farmers are always characterised in many studies based on land size (Bebe et al., 2002; Herrero et al., 2014; van Averbeke and Mohamed, 2006).

Climate change adverse impacts are heavily felt by the smallholder farmers such as changes on climate variables of rainfall and temperature (Altieri and Koohafkan, 2008; Koohafkan et al., 2012). There exists great diversity in smallholder farmers despite the key variable used for characterizing smallholder farmers, that is farm size (Bebe et al., 2002; Brandt et al., 2018). This diversity is observed as smallholders farmers do mix livestock and crop production and such diversity is seen in smallholder dairy farmers in SSA (Bebe et al., 2002; Oborn et al., 2017; Staal et al., 2002). One of the main reasons climate change affects smallholder farmers is the extra mining of nutrients on their farms, which leads to lower production and also higher susceptibility to climate change effects (Bationo et al., 2004; Castellanos-Navarrete et al., 2015; Rufino et al., 2007).

Smallholder dairy farmers' adaptation to climate change would need the characterization of these farmers with more variables other than farm size as the only limiting factor (Auburger et al., 2015; Herrero et al., 2014; van Averbeke and Mohamed, 2006; Vrieling et al., 2011). There is need for the characterisation of smallholder dairy farmers with additional variables such as land use sizes of the farms, labour, type of livestock housing and other key variables that define smallholders' enterprise (Nyambo et al., 2019; Staal et al., 2002; Waithaka et al., 2007; Zake et al., 2010). These characterisation should use robust unsupervised models and integrated systems research to show natural groupings of smallholder dairy farmers to allow the policy makers to promote climate change adaptation practices (Nyambo et al., 2019; Oborn et al., 2017; Thompson, 2016). The lack of a characterisation of smallholder farmer with robust inclusion of key variables based on land survey limits options for policy makers as farm size reduces over time (Bebe et al., 2003). This paper seeks to use cluster analysis to characterize smallholder dairy farmers of Nandi County Kenya.

MATERIALS AND METHODS

Study area

The field study was conducted within Nandi County, Kenya (0.565°N, 34.736°E, 0.565°N, 35.437°E, 35.437°E, 0.118°S, 34.736°E, 0.118°S). Mean annual temperatures ranges from 18-22°C, with temperatures at lower elevations (< 1400 m) going as high as 26°C. Altitude ranges from approximately 600 m a.s.l. in the South to over 2200 m a.s.l. in the North east of the county. The highlands are recognized for their high agricultural potential (GOK, 2015; Mudavadi et al., 2001). Nevertheless, livestock and crop farming is mainly subsistence with average land sizes of approximately 4.5 ha per household. Dairy production is common throughout the county, with tea as a major cash crop, and maize as the primary staple crop (GOK, 2015).

Experimental design

Site classification

Agro-ecological zones (AEZ) were identified on the basis of altitude, rainfall, temperature and predominant land use (GOK, 2015). This resulted in three major AEZs: lower highland 1 (LH1: 1900-2400 m a.s.l., area of 934.3 km2, high seasonal variation in rainfall and thus having distinct long and short rains, main crops tea and maize). Lower highland 2 (LH2: 1400-1900 m a.s.l., area 1100.7 km2, low seasonal variation in rainfall characterized by bimodal rainfall – November-January as the short rains and May-July as the long rains, main crops tea and maize); upper midlands (UM: 1200-1400 m a.s.l. and an area of 364.7 km^2 with high seasonal variation in rainfall, main crops Sugarcane and maize). A participatory mapping exercise was conducted using experts' knowledge of personnel from the International Livestock Research Institute (ILRI) and Nandi county government to predict whether there were differences in dairy production systems across the AEZs. Thirty-six sampling points were generated with QGIS based on nearness to road infrastructure and masked away from forested areas with the assumption of no households on roads or in forests. The sampling points were kept away from forests since forests are legally gazetted by section 64 (1) of the Forest Conservation and Management Act, number 34 of 2016, prohibiting grazing (Republic of Kenya, 2016). The number of sampling points assigned to each of the three AEZ was weighted by the area of each individual AEZ (cluster), resulting in 15 sites each being located in LH1 and LH2 and six sites being located in the UM (Figure 1). At each of the 36 randomly selected points nine farmers were interviewed to generate a sample size of 336 households.

Household surveys and questionnaire

The household surveys were done using a questionnaire tool customized from the Integrated Modelling Platform for mixed Animal Crop systems (IMPACTlite) (Rufino et al., 2013). IMPACTlite was modified from IMPACT (Herrero et al., 2007) to collect household-level data, which was detailed enough to capture within-site variability on key farm performance and livelihood indicators. It was initially developed to encourage data sharing through standard protocols, and allowing tools to be linked to facilitate evaluations of various farming systems (Rufino et al., 2013). The household questionnaire was completed through face-to-face interviews with the household head using the Open Data Kit (ODK) platform (ODK, 2017). In case of absence of the household head, the most senior member available or the household member responsible for the farm was interviewed. A determination of the primary income categories (crop, dairy, poultry and others) as well as farm size and other farmer demographic data on literacy, age and gender were collected. From this, four animal confinement systems were defined: 'fence only (F)', 'fence and floor (FF)', 'fence and roof (FR)' and 'fence, roof and floor (FRF)'. The animal confinements formed the base for manure management systems so as to be able to relate the confinement with the manure management systems in use.

Manure management systems were classified according to Table

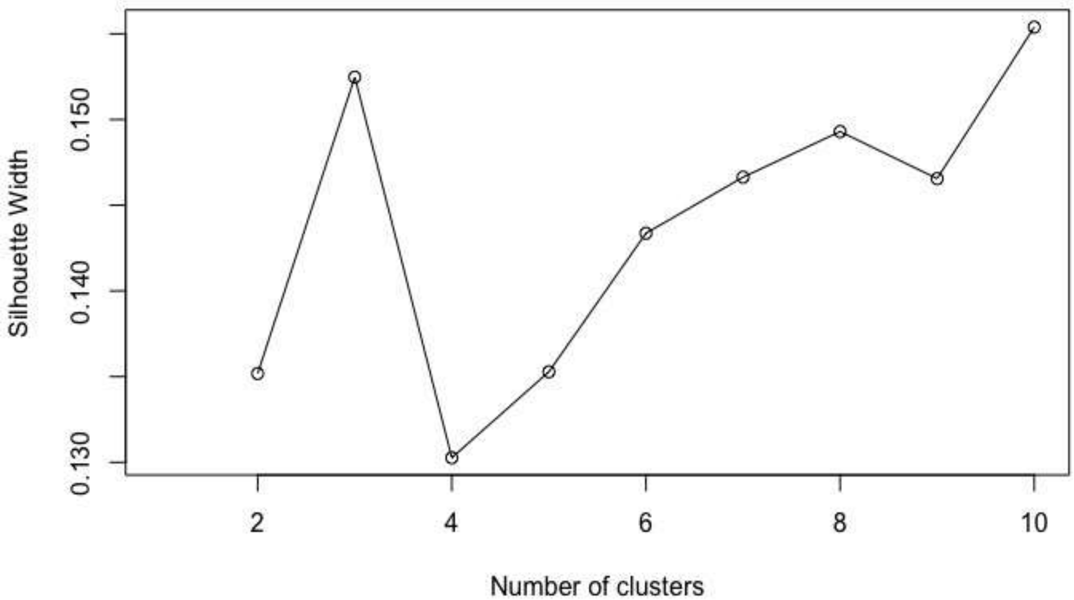

Figure 1. Results of silhouette plot analysis for the Nandi County dataset showing the optimal four clusters.

10.18 provided in the guidelines for GHG emission estimates (IPCC, 2006) and were characterized based on the state of manure being deposited, the location where the manure is stored as well as the duration of storage. The state of manure was either defined as 'fresh'- period less than 24 h from excretion, 'dry' - period more than 24 h from excretion, or 'bioslurry' – that is from biodigesters or farms with pit or lagoon, where liquid manure is collected. Manure handling and storage was characterized as: 'heap for composting', 'pit for fresh or dry manure', 'heap of either fresh or dry manure' and 'pit/lagoon for slurry'. The duration of manure storage before utilization on farm is a proxy for manure quality. Therefore, classification of manure storage was done according to three periods: less than 1 month equalling good quality, 3-4 months meaning reduced quality, and greater than four months equalling least manure quality.

Cluster analysis

Unsupervised learning algorithm was used for cluster analysis. This algorithms was K-means (Chibanda et al., 2009; Nyambo et al., 2019). In the analysis, the number of groups (K) represented how many farm typologies (clusters) could be defined for each dataset. The number of clusters that best represented the data was determined using the Elbow method (where a bend or elbow in a graph showing decline of within cluster sum of squares differences as the number of clusters increases provides the best solution) (Nyambo et al., 2019) The elbow method examines the percentage of variance explained by the clustering as a function of the number of clusters k (Kingrani et al., 2017; Syakur et al., 2018). The K-means algorithm has been widely used in non-hierarchical clustering and characterizing smallholder dairy farms (Kingrani et al., 2017; Nyambo et al., 2019; Tittonell et al., 2010). The algorithm uses Euclidean distance measures to estimate weights of data records. The algorithm is presented as Equation 1, with a segment of the Euclidean distance as in Equation 1.

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^j - c_j \right\|^2 \quad (1)$$

where $\left\| x_i^j - c_j \right\|$ computes the Euclidean distance as in Equation 1; k = number of clusters, n=number of observations, j=minimum number of clusters, i= minimum number of observations, x_i=Euclidean vector for any ith observation, and cj =cluster centre for any jth cluster. Production cluster outputted from the clustering algorithm was validated in three ways: (1) assessment of cluster robustness, (2) comparison of the cluster membership reallocation (differential allocation of households to clusters for training and testing datasets), and (3) evaluation of the proportion of variation explained by the clusters.

Feature selection

The top 28 features synthesised from literature on smallholder dairy farmers were tabulated (Table 1). These variables have been known to influence productivity in smallholder dairy farming based on experts' domain knowledge. These features and their amounts were Boolean, Discrete and continuous and derived from household survey of 336 smallholder dairy farmers in Nandi County. These variables would be used to identify 'natural groupings' of these 28 features to derive the number and type of clusters (Chibanda et al., 2009; Nyambo et al., 2019; Syakur et al., 2018). This was done by minimising the squared Euclidean distance within a decreasing number of clusters containing an increasing number of positively related variables and using Base R Package (RStudio V 1.1.442) within which dendrogram and plot showing optimal number of clusters using k means was generated (Chibanda et al., 2009). Each of the variables used in clustering was described as percentages (gender, education level, income

Table 1. Variables as features used in cluster analysis of smallholder dairy farmers of Nandi County, Kenya.

S/N	Feature name	Type	Range
1	Agro-ecological Zone	Discrete	1 (LH1), 2 (LH2)-3(UM)
2	Relationship to household head	Discrete	1 (Head), 2 (Spouse), 3 (Child)-4 (Others)
3	Gender	Boolean	1 (Male)- 2 (Female)
4	Age of farmer	Continuous	18-79
5	Education level	Discrete	1(No formal and illiterate), 2(No formal but literate),3 (Primary School), 4 (High school), 5 (College)-6 (University)
6	Total labour available	Continuous	1-13
7	Total time labour required	Continuous	0-26
8	Household area acreage (Hectares)	Continuous	0.05-15
9	Cash crop area acreage (Hectares)	Continuous	0-100
10	Horticulture acreage (Hectares)	Continuous	0-8
11	Grazing area acreage (Hectares)	Continuous	0-48.5
12	Acreage for trees (Hectares)	Continuous	0-180
13	Total farm acreage (Hectares)	Continuous	0.2-210
14	Main Income category	Discrete	1 (Crop), 2 (Pigs), 3 (Poultry), 4(Beef), 5(Dairy)-6 (Other)
15	Total number of dairy cattle	Continuous	1-223
16	Total number of beef cattle	Continuous	0-2
17	Total number of sheep/goats	Continuous	0-42
18	Total number of poultry	Continuous	0-740
19	Total number of other livestock	Continuous	0-8
20	Number of months milking	Continuous	0-12
21	Use of milk commercial/noncommercial	Discrete	1 (Use 100%), 2(Sell >25%), 3 (Sell 25%-75%) -4 (Sell >25%)
22	Number of hours livestock in confinement	Continuous	0-24
23	Number of hours livestock out confinement	Continuous	0-24
24	Livestock confinement system	Discrete	1(Fence Only), 2(Fence and Roof), 3 (Fence and Floor)-4 (Fence, Roof and Floor)
25	is water used in cleaning	Boolean	0(No) -1(Yes)
26	Is bedding removed during cleaning	Boolean	0(No) -1(Yes)
27	Number of manure management systems in use	Discrete	0-4
28	Do the farmers feed concentrates to livestock	Boolean	0(No) -1(Yes)

category) and means (age, acreage under grazing, total acreage, household labour numbers, household dairy numbers and number of manure management systems in use per household). Prediction accuracies were obtained by developing the clustering model in a training dataset (70% of all records) and the resulting model reapplied to a testing dataset (remaining 30%) (Nyambo et al., 2019). Rank analysis using the spearman correlation coefficient was used to evaluate the level of features reallocation between clusters. Hierarchical clustering was applied and it works in a bottom-up manner. That is, each variable object is initially considered as a single-element cluster (leaf). At each step of the algorithm, the two clusters that are the most similar are combined into a new bigger cluster (nodes). This procedure is iterated until all points are

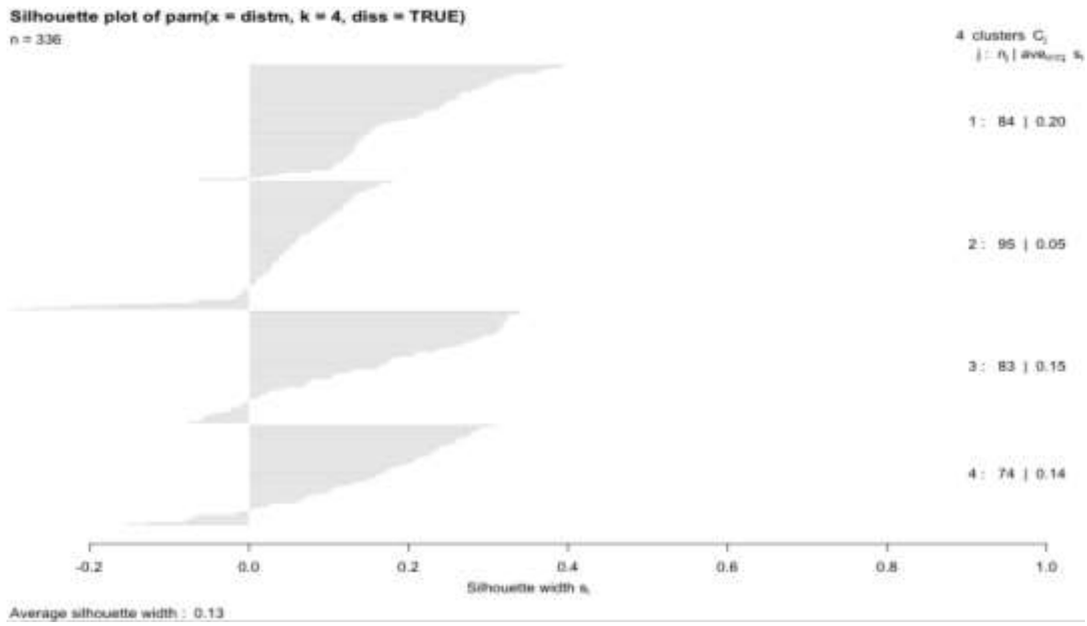

Figure 2. Cluster analysis results showing the four cluster of farmers in Nandi County derived from combining the variables (in column numbers).

member of just one single big cluster (root). Quality control was achieved by using cross clustering in a partial clustering algorithm that combines the Complete Linkage algorithms and Ward's minimum variance providing automatic estimation of a suitable number of clusters and identification of outlier elements (Tellaroli et al., 2016).

RESULTS AND DISCUSSION

Clustering

Based on the Elbow method, a four-cluster solution was found to be optimal for Nandi County dataset and was fitted in the clustering model (Figures 1 and 2). This was confirmed even by quality control using cross clustering and outliers. Cluster analysis was used to classify the smallholder farmers and examine how key variables of acreage for grazing, total acreage, education level, number of dairy cattle in the households and manure management affect their labour practices and major income categories and also classify them (Table 2). This agrees with observations from other studies on smallholders where such variables were enumerated (Nyambo et al., 2019). The study found that there are four classes split by gender and major income categories.

These clusters when using discrete variables showed focus areas such as the low education level of farmers and they were majorly male dominated. These clusters had total low acreage, as well as areas available for grazing, the farmers had less labour and high dairy livestock numbers. This finding agrees with Chibanda et al. (2009), Tittonell et al. (2010) and van Averbeke and Mohamed (2006) whose studies found that cluster analysis gave the key variables of note to define the components for practice change. There has been studies showing how farmer education can improve various farm practices and subsequently make climate change adaptation (Ausden, 2014; Boswell et al., 2010; Waithaka et al., 2007; Zake et al., 2010). The basic aim of cluster analysis is to find the "natural groupings", if any, of a set of individuals (cases or variables). This was an objective of this study and also agreed with other studies where the advantages of using cluster analysis were extolled (Adeyemo et al., 2019; Chibanda et al., 2009; Kwale, 2013). This study found that after running the analysis, the variables main income category, labour numbers, dairy livestock populations and grazing area acreage were key driving forces for the smallholder farmers. This leads to four clusters based on gender and education levels with differences occurring on the quantities for the other variables. Thus, this study's four clusters were the natural groupings of the smallholder dairy farmers.

CONCLUSION AND RECOMMENDATION

There are many ways to use cluster analysis. The kind of cluster analysis utilised in this study is how to form similar sets of variables. The purpose of this analysis in this study is, therefore, to draw inferences about natural

Table 2. Variables and their statistics in the four clusters of smallholder dairy farmers of Nandi County, Kenya.

Cluster number 1	**Variables from Table 1**	**1**		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**	
n=84		Mean	2	Mean	2	Mean	Male	Mean	44.94	Mean	High School	Mean	2.81	Mean	7.107	Mean	0.4387	Mean	3.206	Mean	0.3821
Cluster number 2	Variables from Table 1	1		2		3		4		5		6		7		8		9		10	
n=95		Mean	2	Mean	2	Mean	Male	Mean	43.94	Mean	High School	Mean	3.011	Mean	7.611	Mean	0.4079	Mean	5.158	Mean	0.3789
Cluster number 3	Variables from Table 1	1		2		3		4		5		6		7		8		9		10	
n=83		Mean	1	Mean	2	Mean	Female	Mean	42.05	Mean	Primary School	Mean	2.47	Mean	6.952	Mean	0.8482	Mean	3.128	Mean	0.462
Cluster number 4	Variables from Table 1	1		2		3		4		5		6		7		8		9		10	
n=74		Mean	2	Mean	2	Mean	Male	Mean	43.96	Mean	High School	Mean	3.203	Mean	9.297	Mean	0.6372	Mean	2.172	Mean	0.2014
Cluster number 1	Variables from Table 1			11		12		13		14		15		16		17		18		19	
n=84				Mean	3.885	Mean	2.774	Mean	10.685	Mean	Dairy	Mean	8.512	Mean	0.05952	Mean	3.119	Mean	13.51	Mean	0.1786
Cluster number 2	Variables from Table 1			11		12		13		14		15		16		17		18		19	
n=95				Mean	1.829	Mean	0.3516	Mean	8.127	Mean	Crop	Mean	11.41	Mean	0.01053	Mean	2.526	Mean	27.92	Mean	0.08511
Cluster number 3	Variables from Table 1			11		12		13		14		15		16		17		18		19	
n=83				Mean	3.814	Mean	2.558	Mean	9.106	Mean	Dairy	Mean	8.892	Mean	0.03614	Mean	2.422	Mean	19.24	Mean	0.1084
Cluster number 4	Variables from Table 1			11		12		13		14		15		16		17		18		19	
n=74				Mean	1.852	Mean	0.2905	Mean	5.153	Mean	Dairy	Mean	4.324	Mean	0.01351	Mean	1.541	Mean	9.689	Mean	0.1081
Cluster number 1	Variables from Table 1			20		21		22		23		24		25		26		27		28	
n=84				Mean	9.893	Mean	Sold >75%	Mean	22.33	Mean	1.667	Mean	Fence Only	Mean	0.05952	Mean	0.0119	Mean	1	Mean	Yes
Cluster number 2	Variables from Table 1			20		21		22		23		24		25		26		27		28	
n=95				Mean	8.2	Mean	Sold <25%	Mean	21.27	Mean	2.474	Mean	Fence Only	Mean	0.09474	Mean	0.02105	Mean	1	Mean	Yes
Cluster number 3	Variables from Table 1			20		21		22		23		24		25		26		27		28	
n=83				Mean	10.73	Mean	Sold >75%	Mean	13.96	Mean	10.33	Mean	Fence Only	Mean	0.04819	Mean	0.0241	Mean	1	Mean	Yes
Cluster number 4	Variables from Table 1			20		21		22		23		24		25		26		27		28	
n=74				Mean	9.135	Mean	Sold 25-75%	Mean	12.97	Mean	11.03	Mean	Fence Only	Mean	0	Mean	0	Mean	0	Mean	No

groupings of smallholder dairy farmers and the nature of the key variables used in these groupings. Hierarchical clustering was appropriate for and could also be applied to qualitative variables (Kwale, 2013; Nyambo et al., 2019). The major result of this study was that with as many as 28 variables the cluster analysis revealed only four distinct natural groupings. In this study, cluster analysis is used to test the proposition that there are simple natural groupings of smallholder dairy farmers and they are mirrors with realisation that the analysis yielded distinct groupings

(Chibanda et al., 2009; Condliffe et al., 2008). The study recommends there should be future research to give a detailed characterisation of other areas and types of farmers using cluster analysis to compare the counties and also scenarios if scaled to the region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of cowpea rust disease incidence and severity on selected cowpea genotypes in Western Kenya

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Cowpea production is common among smallholder subsistence farmers of Western Kenya due to its wide ecological adaptation. However, this crop is affected by cowpea rust *Uromyces phaseoli var vignae* (Baarel) Arth disease, causing economic yield losses with limited control measures. This study therefore, evaluated cowpea rust disease incidence (DI) and severity (DS) on growth of selected improved cowpea genotypes. A Randomized Complete Block Design (RCBD) in split plot arrangement experiment was conducted in Busia and Kakamega counties, Kenya during short rains of 2018 and long rains of 2019. Cowpea genotype: K80, KVU 27-1, Tumaini, Dakawa and local variety was the main factor and cropping system: pure stand cowpea and cowpea intercropped with maize was the sub plot-factor. Data were subjected to Mixed model ANOVA using SAS. The DI and DS were 41 and 39% respectively less in Dakawa and Tumaini with more cowpea leaf and grain yields compared to other genotypes. On the other hand, DI and DS were 35 and 56% respectively less in pure stand cowpea compared to intercrop cowpea. Pure stand cowpea also had more leaf and grain yields. The results indicate that Dakawa and Tumaini cowpea genotypes have potential resistance to cowpea rust and the conditions could be improved by planting cowpea in pure stand.

Key words: Cowpea genotype, cropping system, cowpea rust incidence, severity.

INTRODUCTION

The production of cowpea is more common among the subsistence smallholder farmers because of its wide ecological adaptation and tolerance to several biotic and abiotic stresses that include pests, diseases and drought. It is an important food source and is estimated to be the major protein source for more than 200 million people in sub-Saharan Africa. It is of major importance to the livelihoods of millions of relatively poor people in less developed countries of the tropics (FAO, 2013). Additionally, cowpea has many ecological benefits such as nitrogen fixation, heat and drought-tolerant crop, cover crop (Saidi et al., 2010). In addition, some cowpea varieties cause suicidal germination of the seed of *Striga hermonthica*, a parasitic plant that usually infests cereals

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with devastating effects in sub-Saharan Africa (Quin, 1997).

About a decade ago, world cowpea production was 5.72 million tons of which Africa produced 5.42 million tons; East Africa, 0.52 million tons and Kenya produced about 122,682 tons (FAO, 2013). In Kenya, cowpea grain production is estimated to be 0.53 tons/ha against the estimated production potential of 1.6 ton/ ha. The situation is worse for Western Kenya where yields are much lower than the average 0.53 tons/ ha. This scenario indicates that there is a huge yield gap in cowpea grain production in Kenya. There are a number of constraints that hinder sustainable cowpea production contributing to the production levels that are below production potential. Singh et al. (1997) reported that diseases, insect pests and parasitic weeds are the most important factors responsible for low cowpea yield in Nigeria and the same could explain the low cowpea yields in Kenya. One major disease that has been identified as a big threat to Cowpea production in East Africa particularly in Kenya and needs major attention is cowpea rust (Allen et al., 1998).

Cowpea rust caused by a fungus, *Uromyces phaseoli var vignae* (Baarel) Arth appeared in the late 1990s and occurs widely in Kenya. The disease interferes with normal root development and uptake of nutrients by plant roots resulting in reduced seed size and considerable yield loss. Many control measures that have been used against the disease have yielded limited impact. The most preferred control measure by many farmers is the chemical control using fungicides. The application of fungicides several times within a growing season by farmers to obtain a clean crop has been proofed not to be economical due to small land size in addition to negative environmental impacts as well as safety concerns (Mensah et al., 2018). Breeding and release of resistant cowpea cultivars has been found to be one of the cheap and most effective methods to control cowpea rust. Due to variations in genetic composition, significant differences have been found among cowpea genotypes on response to cowpea rust disease infestation (Mensah et al., 2018). Furthermore, new rust resistance cowpea genotypes released usually lose their resistance within a short period of time (Mensah et al., 2018). This means that new genotypes should be screened for their variability in response to rust infestation and those with high levels of resistance have to be bred constantly to replace the ones that are becoming or already susceptible.

Use of appropriate cropping system has been proven to provide numerous environmental benefits as well as contribute to pest and disease management (Ding et al., 2015). Cowpea is extensively grown in the low lands and mid altitude regions of Africa as either pure stand crop or are intercropped with cereals like sorghum, millet or maize. Research indicates that planting cowpea in pure stand yields more than intercrop (Francis, 1986). Despite the higher yields from pure stand cropping system, land is limited in western Kenya and this compels farmers to adopt alternative cropping systems like intercropping system.

Intercropping that entails growing two or more crops together on the same land during the same season is a traditional cropping system that is widespread among subsistence farming communities. Although many crops are intercropped, legume intercropping is common because legumes have the potential of biological nitrogen fixation (Vanlauwe et al., 2016). Other benefits of intercropping include: increase in yield per unit area and increase in economical returns as compared to pure stand crops. In addition, it is generally believed that one component of an intercropping system may act as a barrier or buffer against the spread of pests and disease causing pathogens within the intercropping system (Henrik and Peter, 1997). For instance intercropping maize-cowpea has been found to reduce the stem borer attack on maize (Henrik and Peter, 1997). In other instances, the canopy in the intercropping arrangement may create a favourable microclimate for the proliferation, infection and spread of disease causing pathogens. Thus, the effects of intercropping on the degree of infestation and spread of diseases have yielded varied results (Boudreau, 2013).

Sustainable cropping system is achieved when the cropping system design is based on the most important crops for particular region. Since maize is an importance staple food crop in many parts of Kenya especially western Kenya, development of sustainable cropping system for management of cowpea rust disease built around maize production is necessary. It is worth noting that at present, there is no single-cost efficient control measure to prevent rust infection particularly in different agro-ecological areas (Mensah et al., 2018). However, there is a need to bridge cowpea yield gap in order to improve households' food and nutrition, income as well as protecting the environment. In this regard, the study seeks to evaluate cowpea rust disease incidence and severity on growth of selected improved cowpea genotypes under two cropping systems in Western Kenya.

MATERIALS AND METHODS

Experimental sites

The experiment was conducted in Kakamega and Busia Counties of western Kenya. In Kakamega County, the experiment was conducted at Kenya Agricultural, Livestock Research Organisation (KALRO) Kakamega station (00°16.9' N, 034° 46.07'E). In Busia County, the experiment was conducted at KALRO Alupe station (00° 28.0'N, 34° 07.00'E). The soil in Kakamega is classified as Ferralic-orthic acrisol (Jaetzold et al., 2007), deep, well drained highly weathered soil with inherently moderate fertility whereas the soil in Busia is well drained, very deep, dark red Orthic ferralisols (Jaetzold et al., 2007). Both soils are poor in nutrients, thus require regular fertilization. Kakamega and Busia sites represent the Upper

Midlands 2 (UM 2) and Low Midlands 2 (LM 2) respectively with an altitude of approximately 1430 m and 1170 m a.s.l respectively (Jaetzold et al., 2007). The two counties have a generally cool wet climate receiving bimodal annual rainfall ranging between 1250-2000 mm in Kakamega and 760 -1750 mm in Busia and temperature range of between 14-27°C in Kakamega and 19-31°C in Busia (Jaetzold et al., 2007).

Experimental design

The experimental design was Randomized Complete Block Design (RCBD) in split plot arrangement. The main plot treatment was five cowpea genotypes namely K80, KVU27-1, Dakawa, Tumaini and local variety while sub-plot treatment was two cropping system namely pure stand and cowpea-maize intercrop resulting in a total of ten treatment combinations with three replications. The sub-plots measured 3 m wide and 5 m long and 0.5 m in between the subplots while the main plots were 1m apart. Two cowpea seeds were planted manually at recommended standard spacing of 0.6 m × 0.1 m in pure stand and 0.75 m x 0.3 m in intercrop respectively (KARI, 2000), resulting in 6 rows of cowpea plants in pure stand and 4 rows in intercrop. The plants were thinned to one plant per hole after emergence.

Parameters measured

All measurements were taken within the net area comprising two middle rows. Disease incidence was assessed using a quadrat measuring 1m by 1m which was thrown randomly within the sub-plot and the area under the quadrat analyzed. The incidence was described as the proportion of rust infected plants to the total number of plants in the quadrate and was scored using a scale of 0-9 (Mayee and Datar, 1986).

Disease severity was rated as a percentage of leaf area affected in the lower, mid and upper canopy of each of the plants under quadrat using a 0-8 visual scale score method in which a rating of 0 = no disease, 1 = disease severity up to 2.5%, 2 = disease severity 2.5-5%), 3 = disease severity 5-10%, 4 = disease severity 10-15%, 5 = disease severity 15-25%, 6 = disease severity 25-35%, 7= disease severity 35-67.5% and 8= disease severity 67.5-100%. Diseases incidences and severity were scored at an interval of three weeks starting from the first week after planting to the 15th week after planting marking the physiological maturity.

Numbers of leaves were determined by visual counting of all fully opened leaves on each of ten (10) randomly selected and tagged plants at an interval of three weeks starting from the first week after plant emergence up to the 15th week at physiological maturity (Agbogidi and Ofuoku, 2005). Leaf area measurements were taken at the same time with leaf count on the same plants. Leaf area (LA) was calculated as the product of the length and breadth at the broadest point of the longest leaf on the plant multiplied by 0.75, according to Abukutsa (2007). Leaf Area Index (LAI) was then calculated by dividing the LA by spacing.

Number of pods per plant was assessed in the field by visual counting of all pods on the ten (10) selected and tagged plants at physiological maturity. The numbers of pods were then divided by the number of cowpea plants to get number of pods per plant. Green leaf biomass was determined at physiological maturity. Leaf biomass samples were taken by plucking all fully opened mature leaves from each plant in the net area. Fresh weight was taken and recorded using an electronic balance (Woomer et al*.,* 2011). Pods were harvested within the net area at physiological maturity. Pods were harvested with hand and fresh weights of pods recorded. The pods were air dried to a constant weight and then shelled and the weight of grains recorded. Grain yield in kg ha^{-1} was standardized to 13 % storage moisture content.

Data analysis

Data collected were subjected to analysis of variance to determine the effect of cowpea genotype, cropping system and their interaction on plant height, number of leaves, Leaf area index, disease incidences and severity, number of pods per plant, leaf and grain weight using mixed model (Mixed procedure SAS Institute 2012). The means were compared using Least Significance Difference (LSD).

RESULTS

Number of leaves, leaf area index, and disease incidence and severity

The two experimental sites of Busia and Kakamega which represent different agroecosystems in western Kenya showed a wide variability on weather conditions and therefore data were analyzed separately for each site. There was no seasonal effect on variables measured and therefore data were average across the seasons for each site. The mixed model ANOVA showed that both the main effects of genotype and that of cropping system on the number of leaves, disease incidence (DI), disease severity (DS) and leaf area index (LAI) were significant ($P \leq 0.05$) at both sites. Generally DI, DS and LAI were higher in Kakamega than Busia for all the genotypes under study. In Busia, Dakawa cowpea genotype had significantly 8% more leaves than K80, KVU 27-1, Tumaini and local variety genotypes (Table 1). Though Dakawa had higher number of leaves in Kakamega, the difference was not significant (Table 2).

In assessing cowpea rust incidence, rust severity and leaf area index in Busia, Dakawa and Tumaini had comparable DI and DS which were 50 and 39% respectively low compared to K80, Local variety and KVU27-1 (Table 1). Similar trend was observed in Kakamega (Table 2).

In Busia, cowpea plants had 2 times more leaves in pure stand than intercrop cowpea (Table 3). Disease incidence and disease severity were 35 and 56% respectively less in pure stand cowpea compared to intercrop cowpea. While LAI was 36% significantly higher in pure stand cowpea compared to intercrop cowpea. A similar trend was observed in Kakamega where the number of leaves was 3 times more in pure stand compared to intercrop cowpea (Table 4). Disease incidence and severity were 12 and 10% respectively less in pure stand compared to intercrop cowpea and leaf area index was 13% more in pure stand cowpea.

Interaction effects of cowpea genotype and cropping system on disease incidence and severity

The mixed model ANOVA showed that the interaction effect of cowpea genotype and cropping system on disease incidence (DI) and severity (DS) was significant

Table 1. Influence of cowpea genotype on number of leaves, disease incidences, disease severity and Leaf Area Index in Busia.

Genotype	Number of leaves	Disease incidence	Disease severity	Leaf Area Index
K80	20.0[b]	1.8[a]	3.3[a]	0.99[b]
Local variety	19.0[b]	1.7[a]	3.0[a]	0.94[b]
Tumaini	19.0[b]	1.4[ab]	1.8[b]	1.06[b]
KVU 27-1	20.0[b]	1.2[ab]	3.1[a]	1.27[a]
Dakawa	23.0[a]	0.9[b]	1.7[b]	1.29[a]
LSD	2.3	0.51	0.32	0.12
CV%	24.6	29	23.9	22

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

Table 2. Influence of cowpea genotype on number of leaves, disease incidences, disease severity and Leaf Area Index in Kakamega.

Genotype	Number of Leaves	Disease incidences	Disease severity	Leaf area index
K80	21.[a]	6.9[a]	3.9[a]	1.51[ab]
Local variety	19.0[a]	7.1[a]	3.6[a]	1.66[a]
Tumaini	20.0[a]	4.9[c]	2.6[b]	1.46[b]
KVU 27-1	20.0[a]	6.2[b]	3.3[a]	1.56[ab]
Dakawa	22.0[a]	4.9[c]	2.4[b]	1.51[ab]
LSD	2.5	0.59	0.95	0.14
CV%	25.3	19.4	25	1.85

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

Table 3. Influence of cropping system on cowpea rust incidences, severity, Number of Leaves and Leaf Area Index at Busia.

Cropping system	Number of leaves	Disease incidence	Disease severity	Leaf area index
Pure stand	33.0[a]	1.5[a]	3.5[a]	1.5[b]
Intercrop	16.0[b]	2.3[b]	7.8[b]	1.1[a]
LSD	2.01	0.32	0.6	0.08
CV%	27.3	29	25	22

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05)

Table 4. Influence of cropping system on number of leaves, leaf area index cowpea rust incidences and severity at Kakamega.

Cropping system	Number of leaves	Disease incidences	Disease severity	Leaf area index
Pure stand	29.0[a]	5.6[b]	2.5[b]	2.8[b]
Intercrop	11.0[b]	6.4[a]	2.8[a]	2.5[a]
LSD	1.61	0.38	0.20	0.1
CV%	25.3	19.4	23.9	23.5

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

(P≤ 0.05). In Busia, both DI and DS were significantly lowest in Dakawa cowpea genotype planted as pure stand compared to other treatment combinations (Figure 1). Similar trend was observed in Kakamega (Figure 2).

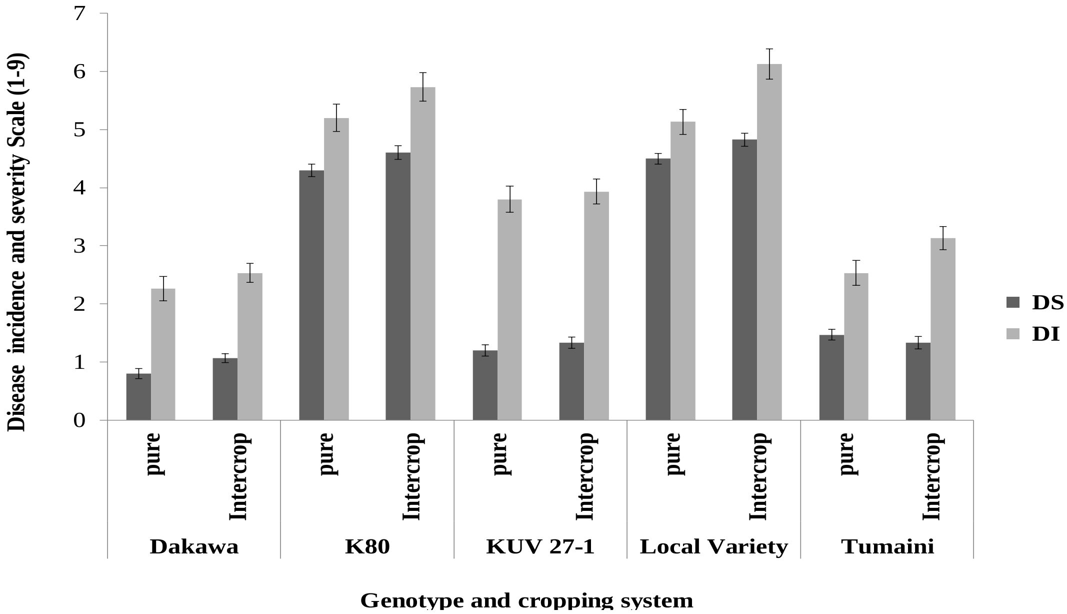

Figure 1. Influence of Interaction of genotype and cropping system on Disease incidence and severity in Busia

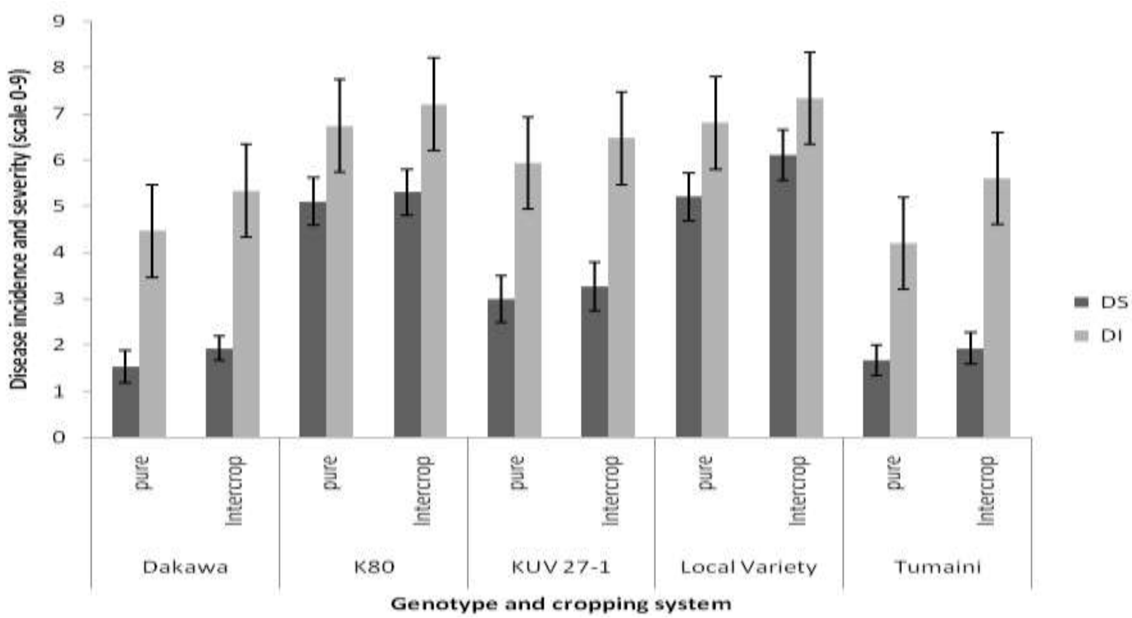

Figure 2. Influence of Interaction of genotype and cropping system on Disease incidence and severity in Kakamega.

Influence of cowpea genotype on yield and yield components

Main effect of genotype on number of pods per plant, leaf and grain yields was significant at both Busia and Kakamega ($P \leq 0.05$). In Busia, Dakawa and Tumaini were statistically similar and had 69, 49 and 70% more pods per plant, leaf yield and grain yield respectively compared to statistically similar K80, local variety and KVU 27-1 (Table 5). In Kakamega similar trends were observed in which Dakawa and Tumaini had 68, 43 and 50% more pods per plant, leaf yield and grain yield

Table 5. Influence of cowpea variety on number of pods per plant, leaf weight (kg ha^{-1}) and grain weight (kg ha^{-1}) in Busia.

Genotype	No. of pods per plant	Leaf weight (kg ha^{-1})	Grain Weight (kg ha^{-1})
K80	6.5[b]	2421.2[b]	216.7[b]
Local variety	7.0[b]	2441.7[b]	297.2[b]
Tumaini	16[a]	4741.7[a]	550.0[a]
KVU 27-1	7.5[b]	3080.6[b]	343.3[b]
Dakawa	15.1[a]	4151.7[a]	716.7[a]
LSD	4.2	1546.2	189
CV%	27	25	26

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

Table 6. Influence of cowpea variety on number of pods per plant, leaf weight (kg ha^{-1}) and grain weight (kg ha^{-1}) in Kakamega.

Genotype	No. of pods per plant	Leaf weight (kg ha^{-1})	Grain weight (kg ha^{-1})
K80	4.7[b]	1745.2[b]	285.6[b]
Local variety	4.8[b]	1729.5[b]	205.7[b]
Tumaini	12.7[a]	3462.4[a]	500.3[a]
KVU 27-1	7.7 [b]	2005.8[b]	289.7[b]
Dakawa	14.5[a]	3046.8[a]	567.2[a]
LSD	3.2	906.9	148.8
CV%	30.2	33	33

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

Table 7. Influence of cropping system on the number of pods per plant, leaf yield and grain yield in Busia.

Cropping system	No. of pods per plant	Leaf yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Pure stand	13.0[a]	2628.9[a]	429.9[a]
Intercrop	8.2 [b]	1886.9[b]	314.5[b]
LSD	4.2	573.6	94.1
CV%	30.2	33	33

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

respectively compared to other genotypes (Table 6).

Influence of cropping system on number of pods per plant, leaf and grain yields

The main effect of cropping system on number of pods per plant, leaf and grain yields was significant in both Busia and Kakamega (P ≤ 0.05). In Busia, pure stand cowpea had 58, 39 and 38% more pods per plant, leaf yield and grain yield respectively compared to intercrop cowpea (Table 7). A higher but insignificant number of pods per plant were observed in pure stand cowpea in Kakamega while leaf and grain yields were 60 and 40% respectively more in pure stand cowpea compared to intercrop cowpea (Table 8).

Cowpea rust disease incidence and severity progression over time

Disease incidence (DI)

There was a progressive increase in the intensity of DI with advancement in plant age both in Busia and Kakamega with Dakawa and Tumaini recording lower DI

Table 8. Influence of cropping system on the number of pods per plant, leaf yield and Grain yield in Kakamega.

Cropping System	No. of pods per plant	Leaf yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Pure stand	8.8[a]	5015.3[a]	495.1[a]
Intercrop	7.6[a]	3119.4[b]	354.4[b]
LSD	0.62	977.9	119.7
CV%	27	25	26

Means followed by the same lower case letter (s) within the column are not significantly different (P ≤ 0.05).

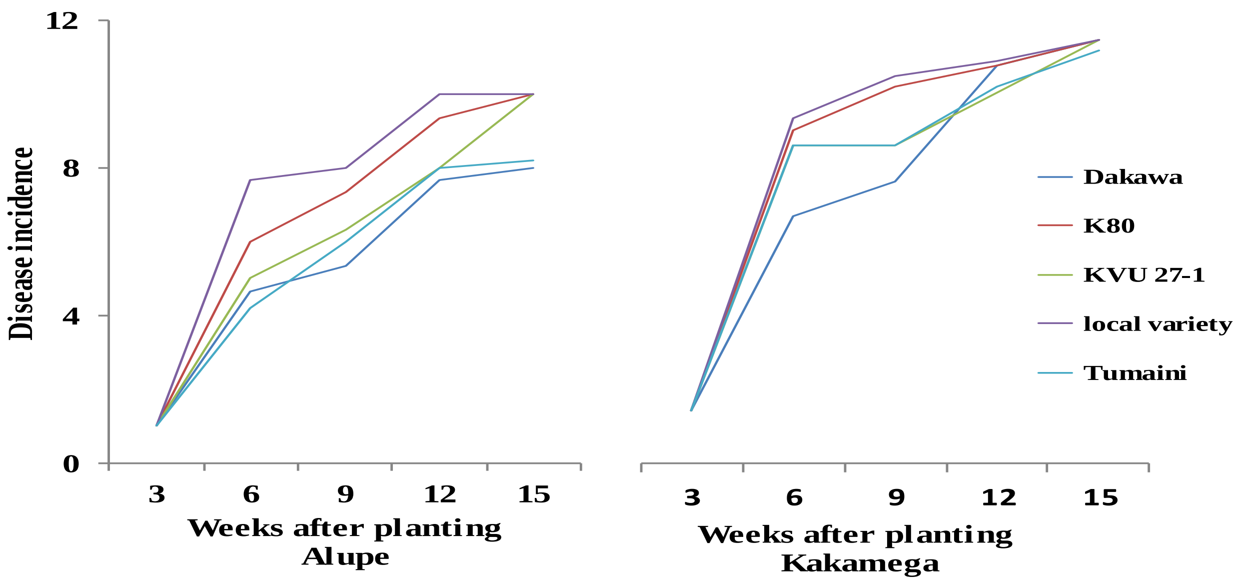

Figure 3. Progression of disease incidence on Cowpea genotypes in Busia and Kakamega.

at all growth stages (Figure 3). The intensity of DI tends to peak at week 9 (flowering stage) and levels off for the period of 12-15 weeks (podding and physiological maturity stages).

Disease severity (DS)

Disease severity increased with increase in plant age in all the cowpea genotypes in both Busia and Kakamega. Dakawa and Tumaini cowpea genotypes had lower DS at all growth stages compared with the local variety, K80, and KVU 27-1 genotypes (Figure 4). Disease severity rose steadily from vegetative (week 3 and 6), flowering (week 9) to podding (week 12) but slightly dropped at physiological maturity (week 15) in all the genotypes.

DISCUSSION

Cowpea rust was prevalent in both the two varied agroecosystem study locations of Busia and Kakamega. However, the disease was less prevalent in Busia, with low disease incidence and severity than in Kakamega. Though the data are not represented, rainfall was higher and temperature lower in Kakamega than in Busia. The higher rainfall and lower temperatures in Kakamega might have created higher relative humidity (Harrison et al., 1997; Lawrence, 2005) with low light intensities. This resulted in greater accumulation of cowpea rust fungi spores with high intensity of infestation and spread in Kakamega. High relative humidity implied long periods of leaf surface wetness which has been reported to favour the development and sporulation of fungal diseases (Dorrance et al., 2003; Gautam et al., 2013). The results are in line with the findings that environments in humid agro-ecological regions are more conducive for the growth and development of fungal disease-causing agents (Adegbite and Amusa, 2008). According to research done by Adandonon et al. (2003), disease incidence of cowpea stem rot was higher in the south and central zones of Benin Republic than its Northern zone as

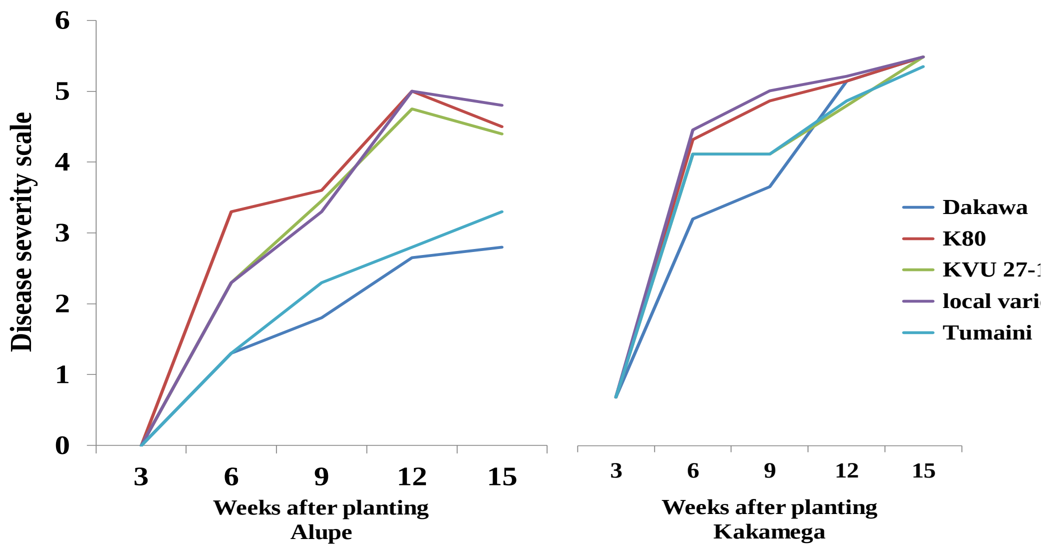

Figure 4. Progression of disease severity on cowpea genotypes in Alupe and Kakamega.

a result of different amount of rainfall received by the two zones. These results are in agreement with those of Mwang'ombe et al. (2007) who reported low prevalence of Angular Leaf Spot in beans at low altitude regions compared to those planted at high altitude regions.

The disease incidence and severity were lower in Dakawa and Tumaini genotypes and highest in local variety in both Busia and Kakamega. Cowpea genotypes that recorded low disease incidence rates also recorded low disease severity rates. Previous studies have also found a positive correlation between disease incidence and disease severity (Lawrence, 2005). The condition was more pronounced in the cropping system where pure stand cowpea exhibited significantly lower disease incidence rates and subsequently low disease severity scores compared to intercrop cowpea. Although this result contradicts the earlier findings that intercropping combinations result in decreased disease incidence and severity (Ihejirika, 2007; Boudreau, 2013), the intensified high relative humidity due to large plant canopy under intercropping environment has been found to increase fungal spore growth and development (Harrison et al., 1997). This could have resulted in high DI and DS in cowpea intercropped with maize in our study. Additionally, the microclimate created under cowpea-maize intercrop canopy could have reduced wind velocity resulting in decreased air circulation hence prolonged aerial fungal spore accumulation and cowpea leaf wetness favouring cowpea disease incidence and severity. The results are in agreement with the findings of Rothrock et al. (1985) who found that the incidence and severity of Southern stem canker of soybean was more in double cropped soybean/wheat compared to soybean monoculture.

In terms of growth and yields, Dakawa and Tumaini cowpea genotypes had generally higher leaf area index, leaf and grain yields compared to K80, local variety and KVU 27-1. Larger leaves with high LAI are known to increase surface area for photosynthesis and amount of biomass a plant produces (Balemi, 2009). The same trend was reflected in the cropping system where cowpea under pure stand had more number of leaves, more pods per plant and hence higher leaf and grain yield than in the intercrop stand. Intercropping legume with cereal has been found to create micro-climate which favoured disease manifestation and development with concomitant yield reductions in the affected crops (Simbine, 2013). Furthermore, other factors that prevail under intercropping such as minimum exposure to light that is essential for photosynthesis hence low dry matter accumulation, logging on the ground due etiolation and weak stems (Yang et al., 2014) could also limit plant development and productivity. This finding is in agreement with previous research that found out that abiotic and biotic stresses can reduce yield of crops. For example moisture stress has been documented to reduce the yield benefit from narrow row spacing in Kansas by more than 20% (Heitholt et al., 2005). The low disease incidence and severity in pure stand cowpea could have prompted leaf growth and development as a result of proper cell division and elongation in the meristematic tissues hence greater yields.

An exponential progression of disease was observed upto week 9 after planting after which the disease incidence and severity tend to flatten in both Busia and Kakamega experimental sites. The intensity of progression was however low in Dakawa and Tumaini compared with local variety, K80 and KVU 27-1. The low disease incidence at the initial vegetative stage (week 3 and 6) could be attributed to low fungal spores count during disease infection phase and also due to the vigorous growth and high immunity of the cowpea plants fighting the fungus. However, as weeks progress the cowpea rust fungus multiplies faster due to prevailing canopy created microclimate. This finding is in agreement with research conducted by Kone et al. (2017), who found out that as disease progresses it suppresses plasticity and recovery rate of cowpea genotypes. McCain and Hennen (1984) also found that younger leaves are immune to infection due to absence of well-developed stomata. On such leaves, the fungus fails to recognize stomata for infection to take place (Coutinho et al., 1994). Besides, the hydrophobic nature of young leaf surface may hinder fungal spore germination and penetration processes. The significant differences of dsease incidences and severities in cowpea genotypes and growth indicated the existence of varying tolerance and susceptibility among cowpea genotypes with growth period. The finding is in agreement with Schneider et al. (1975), who showed that cowpea genotypes have varying tolarence and susceptibility levels as time progresses upon cowpea rust infestation. This study clearly illustrates that there is variability in cowpea rust disease incidence and severity among the recommended improved cowpea genotypes in western Kenya. The study further provides information on cowpea rust disease prevelence under major cropping systems in two contrasting agroecosystems in western kenya.

Conclusions

From the current study it is evident that there is significant effect of cowpea genotype and cropping system on disease incidence, severity, and yields. Disease intensity and severity affects growth and yields of the affected crop. The results indicated that Dakawa and Tumaini cowpea genotypes have potential resistance to cowpea rust disease resulting in greater yields. The resistance and performance of these genotypes could be improved by planting them in pure stand. The authors recommend comprehensive investigations to determine the effects of different cowpea-maize combinations patterns on the occurrence and intensity of cowpea rust disease among the promising genotypes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Review

Nitrate contamination of groundwater: An issue for livelihood in Jaffna Peninsula, Sri Lanka

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Groundwater stored in large cavities and channels of Miocene limestone is the only source of portable water in Jaffna Peninsula, Sri Lanka. It is increasingly exploited and polluted by various contaminants that results in less availability of potable water. Nitrate contamination in drinking water is one of the major concerns which causes severe health impacts, such as methemoglobinemia especially in infants and oesophageal and stomach cancers. The current nitrate levels in drinking water in Jaffna peninsula are much higher than the WHO and SLS levels. The nitrate-N content of groundwater in the Jaffna Peninsula ranges from 0.1 to 45 mg/L as per the literature though the permissible nitrate-N level in drinking water is 10 mg/L. Further, the nitrate concentration in groundwater varies seasonally and is found to be higher during the wet season than the dry season. Research studies carried out at different localities in the Peninsula from 1983 to 2018 have shown that nitrate content of groundwater has increased over this period. A recent investigation in the Chunnakam area revealed nitrate-N level of 45 ppm. Hence, nitrate contamination of groundwater in the Jaffna Peninsula is found to be the most challenging issue in the water management system.

Key words: Groundwater, nitrate, Jaffna Peninsula, contamination.

INTRODUCTION

Groundwater is the important natural source with high economic value and social significance for the livelihood in Jaffna peninsula (Torfs, 2015). It is the water under the earth's surface that flows freely through tiny pores and cracks in rock and soil and can be pumped from wells (Hidayathulla and Karunaratna, 2013). Jaffna peninsula has four main limestone aquifers such as Valikamam, Thenmarachi, Vadamarachi and Kayts. Those are unconfined aquifers which mean the aquifers have direct contact with the atmosphere. Except very little rainy season, extracted groundwater is the only source for irrigation, drinking water and other industrial purposes throughout the year. It is necessary to monitor the quantity and quality of water stored and extracted from these aquifers (Mikunthan et al., 2013). Due to intensive domestic usage (250 L/day per capita), higher inorganic fertilizer use, resettlement and urbanization deteriorate water quality (Nanthini et al., 2001). There should be a monitoring system in the water management to assist long term planning of water supply in Jaffna peninsula.

Although nitrogen is essential for all living things, excessive concentration of nitrogen can be hazardous to

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human health. Nitrogen occurs in the soil in organic form by decaying plants and animal residues. Large quantities of nitrogen enter the soil by addition of inorganic fertilizers. Nitrate is easily leachable with water through the soil profile and concentrates the content in groundwater sources.

This review provides the studies of he nitrate contamination in groundwater in Jaffna peninsula. Furthermore, it gives insights of the sources and negative effects of nitrate contamination and ground water system vulnerability in Jaffna peninsula. In addition, the study gives a broad overview of possible scientific and managerial methods that effectively reduces and mitigates the risk of groundwater nitrate contamination.

NITRATE HEALTH HAZARDS

Nitrate contamination in drinking water is a major crisis in Jaffna peninsula. Due to harmful biological impacts of nitrate concentrated water it causes methemoglobinemia (blue baby syndrome), tumours and gastro-intestinal cancers (Foley et al., 2012). Nitrate is converted into nitrite in the digestive system and nitrite oxidizes the iron in the haemoglobin and form methaemoglobin which reduce the oxygen carrying ability of haemoglobin. This condition is called blue baby syndrome. Fortunately, human over the age of one year can convert methaemoglobin back to oxyhaemoglobin. The high nitrate content in water can affect mainly babies under the age of one, elder people and pregnant women. The potential cancer-causing compound, nitrosamine, can be formed by nitrite react with amines, fortunately, there are no any reports of potential birth defects associated with high nitrate content consumption in Jaffna peninsula. Elevated nitrogen levels may be the reason for relatively higher incidence of oesophagus and stomach cancer in Jaffna (Dissanayake, 1988; Panabokke, 1984; Sivarajah, 2003). Level of risk is increased through irrigation for crops as well as addition of inorganic fertilizers and soakage pits (Torfs, 2015).

There is a great deal for finding effective treatment processes to reduce nitrate level to safe levels. Reducing the amount of fertilizers used in agriculture, proper management of soakage pits and slurry stores came from manure are supposed to reduce nitrate in groundwater in future.

SOURCES FOR NITRATE CONTAMINATION

In general, nitrate pollution sources are divided into non-point (diffuse) and point-source pollution. Agricultural fertilizers (mainly synthetic fertilizers) application is the largest non-point source (Chern et al., 1999).

Point sources may result in extremely high nitrate concentration in localized areas. Areas of concentrated livestock confinement, leaky sewerage systems and areas of chemical or manure storage are contributed as point sources. Point source pollution occurs from accidental spills of nitrogen rich compounds, absence of slurry storage tanks (Chern et al., 1999). Household waste water contains nitrogen release into the septic system.

Organic nitrogen cannot be used by plants directly. It should be converted into inorganic nitrogen. Plants do not necessarily use the entire nitrate from used fertilizers or organic matter decomposing. In the aerobic zone of soil organic forms of nitrogen is converted into nitrate and leached to the groundwater.

Nearly 80% of nitrate originates from agricultural sources of legumes, manure and inorganic fertilizer. Another 18% comes from atmospheric sources such as automobile gasoline and lightening. The remaining part of 2% comes from sludge disposal sources (Melvani and Pathmarajah, 2013).

SEASONAL VARIATION OF NITRATE CONCENTRATION

The efficiency of nitrogen usage may reduce the potential of nitrate leaching to the groundwater. The nitrate leaching potential depends on used nitrogen rate, type of nitrogen source, application time (large amount of nitrate is needed at growing plants so more leaching happens at this stage) and irrigation practices. Soil texture also affects the leaching of nitrogen to the groundwater. The major soils in the Peninsula are the calcic red-yellow latosols, which are shallow, fine-textured and well drained soils (Sutharsiny et al., 2014). This may contribute rapid infiltration of dissoluble nitrate into the groundwater.

GROUNDWATER USAGE IN JAFFNA PENINSULA

Nearly half of the population (Nanthini et al., 2001) in Jaffna peninsula depends with tube well water or dug well water for their drinking purposes. The average annual groundwater recharge was 569,624 m^3 from April 2007 to March 2008 and the average annual groundwater withdrawal was 661,635 m^3 resulting a negative water balance of 92,011 m^3 (Nanthini et al., 2001). There is an imbalance between extraction and recharge of groundwater. Sustainability of limestone aquifer was threatened due to the over exploitation of groundwater from well or pumping.

NITRATE CONTAMINATION IN GROUNDWATER - STATISTICS VIEW

65% of the population are involve in agricultural activities and 34.2% of land is used for cultivating high land crops

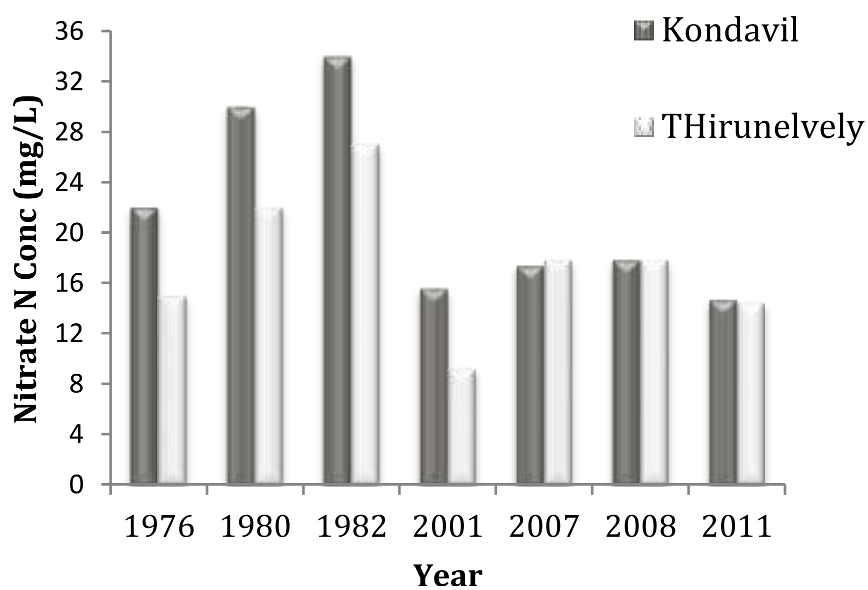

Figure 1. Nitrate-N concentration pattern in Kondavil and Thirunelvely.

such as onion, potato, chilies, tobacco and grapes (Mikunthan et al., 2013). The nitrate content exceeds greater than 10 ppm (WHO recommended level) in 60% of localized agricultural areas. In recent phenomenon, nitrate pollution is increasing and is correlated with the increasing use of nitrogen fertilizers over the last 30 to 40 years (Rajasooriyar et al., 2002; Melvani and Pathmarajah, 2013).

As an example, Figure 1 indicates nitrate concentration pattern from 1976 to 2011 in Thirunelvely and Kondavil areas. Thirunelvely is highly urbanized area and Kondavil is highly cultivated area. Therefore, soakage pit leakage and high fertilizer usage may be the reasons for high nitrate content. And also, those are nearby villages. Dissoluble nitrate can be distributed easily in the ground water.

In 2009, research findings contributes that the monthly average nitrate-N concentration ranged from 7.81 to 19.3 mg/l and 95% of the wells exceeded the drinking water standard of WHO in Jaffna peninsula (Jeyaruba and Thushyanthy, 2009). The Central Environmental Authority has adapted 10 mg/L nitrate-nitrogen as the maximum contaminant level and 1 mg/L for regulated public water systems. In the fields with intensified agriculture nitrate are excessively applied and leached into groundwater bodies (Jeyaruba and Thushyanthy, 2010).

The nitrate-N was ranging from 0.1 to 17.83 mg/l in Valikamam East and the agriculture intense village of Kondavil had the highest value of 17.83 mg/l in nitrate-N (Jeyaruba and Thushyanthy, 2009). In 2010, measured nitrate content in groundwater in Valikamam East within agricultural areas showed that 20% of well water was with nitrate-N content of less than 8 mg/l and 12% were within the critical range of 8 to 10 mg/l and 68% were with value of above 10 mg/l bodies (Jeyaruba and Thushyanthy, 2010). Dimuthu and Suvendran (2017) stated that nitrate-N content in many wells in Valikamam, was found below 8 mg/L. In most of information regarding nitrate content from Chunnakam and Valikamam areas, there are little data available for Thenmarachi and Vadamarachchi aquifers (Table 1).

Figure 2 shows that the places of Kodikamam and Madduvil where the tobacco, vegetables cultivation, indicated high nitrate content than the recommended level. Commonly farmers use 10 to 15 times higher than required amount of fertilizers to tobacco crop to get thick and high number of leaves. However, the tobacco cultivation will be banned in 2020 in Sri Lanka.

Figure 3 indicates some variation in nitrate content in Vadamarachi aquifer. Most of harmful fertilizers were banned during the war time in Jaffna peninsula and this may be the reason in low levels of nitrate in 2001.

The research on the impact of agriculture practices on quality of groundwater found that there was a good correlation between cropping and groundwater nitrate-N content. High nitrate content was observed at high land crops such as carrot than at mixed crops (Jeyaruba and Thushyanthy, 2009).

Figure 4 shows that nearly 75% of the wells exceed 10 ppm of nitrate-nitrogen compared to Sri Lankan standard in Chunnakam area. Similar study done by Dimuthu and Suvendran (2017) also indicated that 30% of wells exceeded the nitrate-nitrogen content. Those wells are used for agriculture as well as drinking purposes. There is a continuing cultivation done in Chunnakam with paddy, vegetables and tobacco.

Higher fertilizer usage may be the reason for the increase in nitrate content (Prabagar, 2015).

Table 1. Nitrate-N Concentration in different areas in Jaffna Peninsula from 1976 to 2019.

Study period	Nitrate-N conc (mg/L)	Study areas	Reference
1976	15	Thirunelvely	
	22	Kondavil	
1980	22	Thirunelvely	Mageswaran and Mahalingam (1983)
	30	Kondavil	
1982	27	Thirunelvely	
	34	Kondavil	
1988	6.1 - 13	Point pedtro	Kumuthini and Nadarajah (1988)
	16 - 10.5	Siththankerny	
	24 -17.5	Maviddapuram	
1992	4.97 - 6.77	Kokuvil	Baskaran and Mageswaran (1992)
	16.94 -33.9	Fort	
	22.58	Pointpedro	
	1.29 - 44.71	Velvettithurai	
	3.61 - 9.71	Vaddukkodai	
	4.51 - 36.12	Gurunagar	
2001	6.32 - 12.41	Velanai	Velauthamurthy and Mageswaran (2001)
	2.25 - 3.95	Kayts	
	2.03 - 4.11	Ponnalai	
	4.96 - 6.54	Araly	
	5.42 - 7.20	Koddady	
	7.90 - 9.39	Navatkuli	
	6.32 - 7.90	Kokouvil	
	13.77- 15.58	Kondavil	
	14.90- 18.39	Urumpirai	
	8.13 - 11.47	Chunnakam	
	9.94 - 21.75	Valvetithurai	
	1.94 - 4.44	Point pedtro	
	1.35- 2.86	Sarasalai	
	7.67 - 11.56	Madduvil	
	8.58 - 10.17	Kodikamam	
	4.06 - 6.18	Kachchai	
	2.71- 4.27	Mirusuvil	
	6.32 - 9.21	Thirunelvely	
2007	0.16 - 17.41	Kondavil	Jeyaruba and Thushyanthy (2009)
Jul 07 – Feb 2008	0.1 - 17.83	Kopay	Jeyaruba and Thushyanthy (2010)
	0.1- 17.83	Irupalai	
	0.1- 17.83	Thirunelvely	
	0.1 - 17.83	Neervely	
	17.83	Kondavil	
Jan 2011 to Dec 2011	0.1 -12.1	Chunnakam	Sutharsiny et al. (2014)
2011 Aug	1.73 - 26	Chavakachcheri	Kumara et al. (2013)
	1.73 - 26	Jaffna	
	1.73 - 26	Nallur	
	1.73 - 26	Pachchilaipallai	

Table 1. Contd.

2011	14.45	Thirunelvely	Aravinthan and Jasotha (2011)
	14.67	Kondavil	
	13.09	Nallur	
	12.65	Kalviyankadu	
	12.42	Kaithadi	
2012	0 -15.5	Kondavil	Hidayathulla and Karunaratna (2013)
	15-10	Chunnakam	
	15 -10	Thellipallai	
	1-2.5	Sandilipay	
	5 -10	Point pedtro	
	2.5- 5	Maruthankerny	
	10 -15	Kopay	
	5 - 10	Uduvil	
	5 - 10	Chankanai	
	5 - 10	Karaveddy	
2015	7-11	Neervely	Tharshana et al. (2015)
2016	8.2 - 29.8	Valikamam	Jeevaratnam et al., 2018)
2017	3.11 ± 40.1	Chunnakam	Dimuth et al. (2017)
	0.021 - 7.87	Valikamam	
2018	0.61 - 45.04	North east Valikamam	Navaranjan et al. (2018)
2019	10.0	Annaikoddai	Mahagamage et al. (2019)
	11.8	Kalviyankadu	
	15.8	Palai	

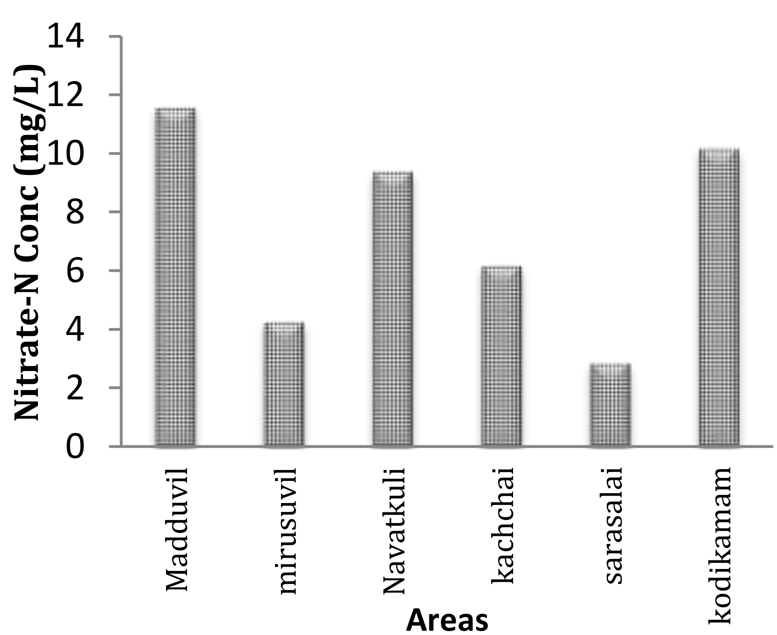

Figure 2. Nitrate-N concentration in Thenmarachchi aquifer in 2001.

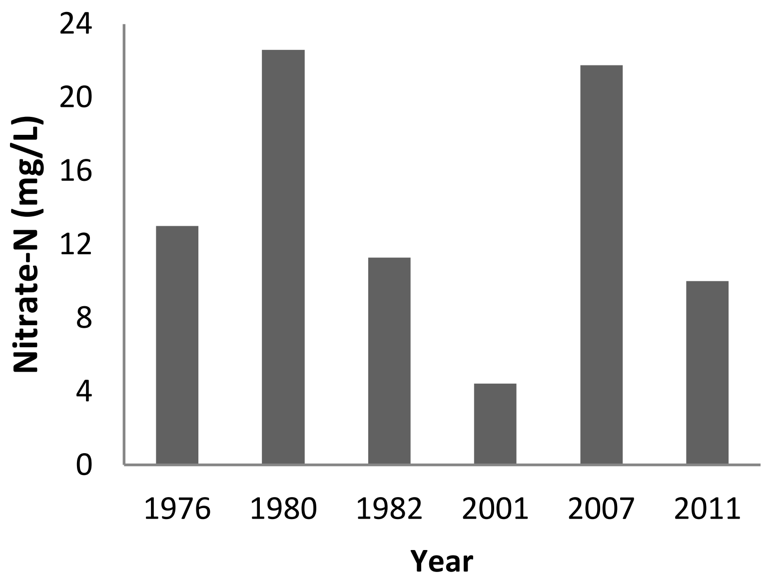

Figure 3. Nitrate-N Concentration pattern in Vadamarachchi aquifer.

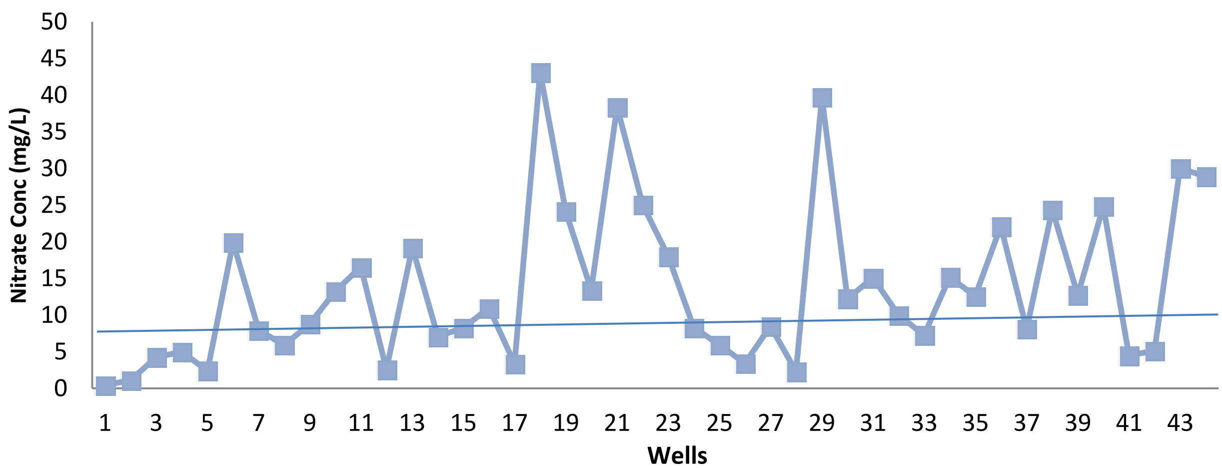

Figure 4. Nitrate-N concentration pattern in Chunnakam aquifer in 2015.

RECOMMENDATION/SUGGESTION

University and other research institutions can provide research findings and educational program on groundwater management on nitrate pollution. Soil fertility, soil type and crop type are considered for reducing nitrate in ground water. Best management practices have to be done to protect water quality by reducing nitrate content from urban and rural areas water sources. Restoring and protecting land and water resources can preserve environment.

Waste water management regulation, discharge of municipal and industrial waste to treatment system and municipal sludges, and biosolids liquids removal in proper way can reduce the nitrate content in the environment. Impacts of leakage should be avoided. Removal of manure, animal waste management practices and feed technology should be implemented. Septic tank design, placement, standards and maintenance should be controlled by the suitable authority.

Nitrate intensified places in Jaffna peninsula within the four aquifers should be identified properly. Mapping need to be done according to the agriculture and non-agriculture areas. With the help of municipal council and water board, household well intensity and agricultural wells will be monitored to reduce the nitrate content in Jaffna peninsula. Management of household waste, industries and buildings sludge disposals need to be done immediately with assurance.

Awareness program for peoples living in Jaffna especially for farmers could be conducted to educate them on the consequences of over application of fertilizers and its impact on groundwater quantity and quality.

Removal of nitrate

Water treatment processes for reducing nitrate concentrations in ground water could be commenced. However, the feasibility of non-treatment alternatives should always be considered first. Possible non-treatment options include drilling a new well, connecting to an adjacent system, removing sources of nitrate contamination, and blending with a low nitrate source. Blending is typically more cost-effective than installing treatment plant. In some cases, it will not be feasible to implement a non-treatment alternative, so treatment process must be considered. There are number of methods to remove nitrate from the contaminated water such as ion exchange, reverse osmosis, and electrodialysis while biological denitrification and chemical denitrification transform nitrate to other nitrogen species through reduction.

Ion exchange

The most commonly used nitrate treatment method is anion exchange and nitrate removed from the treatment stream by displacing chloride on an anion exchange resin. Subsequently, regeneration of the resin is necessary to remove the nitrate from the resin. Regeneration is done by using a highly concentrated salt solution resulting in the displacement of nitrate by chloride. Concentrated waste brine solution contains high in nitrate content and that requires disposal which is very costly.

Reverse osmosis

It is the common nitrate treatment alternative. Most of the nitrate is removed, along with other dissolved ions (desalination).

Electrodialysis

It is an electrochemical process in which ions migrate through ion selective membranes due to their attraction to oppositely charged electrodes.

CONCLUSION

The quality of water for any use is determined by the total amount and the type of contaminants present in the water. Water quality is judged on the potential severity of problems expected to develop over the long term. It is, therefore, essential to establish easily accessible information on water quality and availability that is required for future studies or project planning in Jaffna peninsula. Although several studies have been undertaken on groundwater quality in the Peninsula, no systematic studies have been carried out to characterize the water quality and recharge potentials of aquifers in the Jaffna peninsula. Without any consideration on nitrate reduction from groundwater in Jaffna peninsula, nitrate pollution will affect larger areas and water scarcity occurs for the livelihood in Jaffna.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Determinants of ecosystem-based adaptation to drought in the central cattle corridor of Uganda

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Ecosystem-based Adaptation (EbA) is widely recognised as an important strategy for strengthening climate change resilience. Nevertheless, there is limited evidence on the factors that facilitate or impede EbA for ecosystem services, adaptation benefits and livelihood improvement. In this study, the determinants of EbA to drought were assessed. A mixed quantitative and qualitative cross-sectional survey among 183 farmer households was undertaken in the central cattle corridor of Uganda. The majority of the interviewed respondents were female (60.1%) who mainly carried out agro-pastoral farming (63.4%), a practice 83.2% of them learned through indigenous knowledge transfer. A multinomial logit (MNL) model based analysis was used to establish the determinants of EbA to drought. Ecosystem services, adaptation benefits and livelihood improvement were each made a base category thus yielding three MNL models. The significant (p<0.05) factors from all the three MNL models for EbA to drought were access to extension services, time (hours) spent daily on farm by farmers, land size under crop farming, type of major agricultural activity, average annual income, membership to farmer organisation and use of indigenous knowledge. These factors provide a vital knowledge base for fostering EbA policy formulation and implementation among agro-pastoral farmers to increase their resilience to drought. Climate change adaptation initiatives, institutions and governments should support education and information dissemination about EbA to farmers particularly in rangeland areas.

Key words: Determinants, drought, ecosystem-based adaptation, multinomial Logit model, Rangeland, Uganda.

INTRODUCTION

Natural resource dependent communities especially those found in developing countries are highly vulnerable to climate variability and change due to their dependence on ecosystems for livestock and crop production (Westerman et al., 2012; IPCC, 2012, Deressa et al., 2009). The impacts impose challenges such as forage and water scarcity, which are perceived drought impacts experienced by agro-pastoral farmers in west Africa (Ndamani and Watanabe, 2016). Climate variability and change impacts manifested through recurrent droughts for example, have resulted into reduction in farm productivity (Kgosikoma et al., 2018). Drought, a climate change hazard has heavily and negatively affected the livelihood of local people who depend on ecosystems and

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biodiversity (Phuong, 2011). It is projected that the livelihoods of the poorest communities in arid and semi-arid areas are more likely to be negatively affected by drought through effects like crop withering, increased pest and disease invasion (Adger et al., 2003; FAO, 2013, 2014; Hisali et al., 2011). Rangelands, which are characterised by arid or semi-arid conditions such as high evapotranspiration, make agro-pastoralism a risky economic activity (Phuong, 2011). It is therefore of paramount importance that the agro-pastoral farmers in rangeland regions develop appropriate adaptation strategies to respond to the projected climatic changes especially the recurrent droughts and irregular rainfall patterns (Mavhura et al., 2015).

The heavy dependence on ecosystems for livestock and crop farming in Uganda increases the agro-pastoral farmers' vulnerability to drought because of unpredictable access to water and pasture (Zake, 2015; Waiswa et al., 2019). This is further exacerbated by the weak policy environment and implementation portrayed through inaccessibility to land and climate change adaptation information, limited extension support, poor natural resource management and weak institutional arrangements (National Development Plan, 2010). Agro-pastoral farming communities try out various measures to enhance their adaptive capacity to drought impacts (Kgosikoma et al., 2018). It is currently well recognised that communities and households utilise ecosystem services and biodiversity as one of the comprehensive adaptation strategies. Ecosystem-based drought adaptation involves the use of biodiversity and ecosystem services to help people adapt to the adverse rainfall variability and drought effects (Scarano, 2017). Ecosystem-based Adaptation (EbA) not only entails utilisation of ecosystem services; it also includes the management, restoration and/or conservation of biodiversity, ecological functions and processes (Convention on Biological Diversity, 2009; Vignola et al., 2015; Scarano, 2017). The Convention on Biological Diversity (2009) reports that EbA should most importantly entail exploiting the potential of ecosystem services to improve the well-being of communities and households in the face of a changing climate.

Studies on EbA have proved it to be the most effectual and sustainable climate change adaptation strategy for agro-pastoral farmers (Vignola et al., 2015; Munang et al., 2014, 2013; Harvey et al., 2017). Results from these studies reveal the opportunities of EbA which include biodiversity conservation, improvement and/or maintenance of farm productivity, buffering of biophysical impacts of climate change, securing food and livelihood diversification. In light of these, it is noticeable that EbA is not only ecosystem based, but it is also a provider of climate change adaptation benefits and livelihood improvement of agro-pastoral farmers (Vignola et al., 2015). Despite EbA's significance, there is insufficient knowledge of what influences or affects agro-pastoral farmers' utilisation of EbA as a response to climate change in their farming systems during long dry spells (Vignola et al., 2009). This study therefore sought to fill this gap by analysing the determinants of EbA in the central cattle corridor of Uganda. More so, the study obtained these determinants using a multinomial logit (MNL) model where three categories (Ecosystem services, adaptation benefits to drought and livelihood improvement) comprised the dependent EbA variable and the characteristics of the agro-pastoral farmers comprised the independent variables. The knowledge of determinants of EbA is paramount in assisting policymakers during policy formulation and implementation of EbA among agro-pastoral farmers (Vignola et al., 2009). In addition, these determinants could be useful in climate change adaptation initiatives to enhance agro-pastoral famers' resilience to drought especially those found in semi-arid areas and other farming systems.

MATERIALS AND METHODS

Description of study area

The study was conducted in the central cattle corridor of Uganda where climate changes and variability have been reported (National Environment Management Authority, 2010). The central cattle corridor of Uganda which originally had two dry seasons annually is currently experiencing prolonged droughts due to varying rainfall patterns (Nimusiima et al., 2018). Furthermore, the fluctuating temperature patterns in the central cattle corridor have been associated with drought and consequent increase in cattle deaths (The Republic of Uganda, 2015). There is also low ground water supply in the central cattle corridor which is exacerbated by drought thus affecting agricultural production (Centre for Resource Analysis Limited, 2006). The population growth in the central cattle corridor leads to farm insecurity as people struggle for land as well as put pressure on the existing ecosystems thereby increasing their vulnerability to climate change and variability (Kiboga District Local Government, 2012). The cattle corridor is majorly a rangeland ecosystem with an assortment of habitats and land uses such as livestock forage, wildlife habitat, water, wood products, recreation and natural beauty (Rugadya, 2006). The cattle corridor is customarily a communal livestock grazing area characterised by varying intensity of pastoralism depending on the culture. There is a variety of socio-economic activities that have sprout up due to population increment and these have brought about some changes in the cattle corridor, such as opening up more land including marginal areas for crop farming thus increasing the fragility of the rangeland ecosystem with low, unreliable rainfall coupled with sparse vegetation cover (Rugadya, 2006). Crop diversification has been adopted as an adaptation strategy to climate change in the central cattle corridor (Nimusiima et al., 2018).

Ddwaniro and Lwamata sub counties located in a rural district called Kiboga (Figure 1), in the central cattle corridor of Uganda were purposively selected for the study. Firstly, because they were the mostly drought stricken areas at the time of the study. Secondly, they were predominantly occupied by livestock and crop farmers, respectively (FAO, 2016). Kiboga is originally a pastoral region but upon a reconnaissance study it was discovered that there were some crop farming activities dominating Lwamata. In the study area's pastoral production system, mobility in search of water

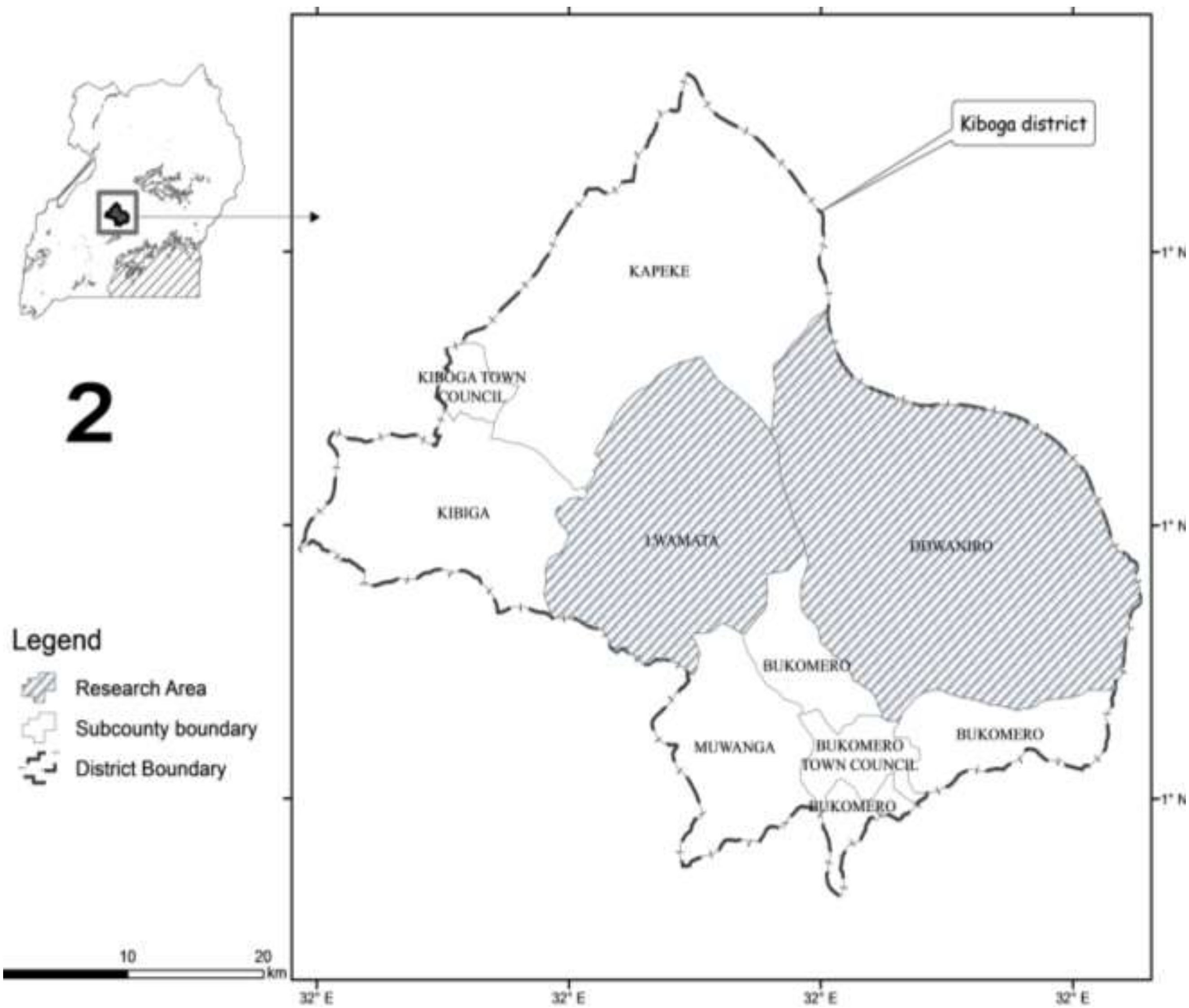

Figure 1. Map of Kiboga district showing the study area.

and fodder was initially an exclusive survival strategy for the farmers and their livestock (Ruhangawebare, 2010). However, most pastoralists have settled and started growing crops though livestock farming remains their major source of basic needs of milk, meat, income and savings. The agro-pastoral farmers not only graze their livestock on communal land in the rangeland but also give them crop residues. Nevertheless, they move the livestock in the dry season in search of fodder and water (Ruhangawebare, 2010). This history of agro-pastoralism reveals the relevance of ecosystems to such natural resource dependent communities. The study area's selection therefore was based on aforementioned farming predominance which would help to obtain information about the ecosystem-based drought adaptation from both livestock and crop farming.

Sampling and data collection

The study was based on a cross-sectional survey to collect data among randomly selected households using a semi-structured questionnaire. The survey covered a proportionate sample of 183 agro-pastoral farmer respondents (Roscoe, 1975). Since the cross-sectional survey was conducted among communities with very low literacy levels, guided and structured interviews using the questionnaire were undertaken to validate the questionnaire based responses (Morton, 2007). The use of semi-structured questionnaires allowed for some discretion about the order in which questions were asked, hence obtaining detailed information in a somewhat conversational style (Zake, 2015). Information on the agro-pastoral farmers' demographics, both on farm and off farm, was captured. The farmers' socio economic characteristics were important in examining the determinants of EbA to drought by agro-pastoral farmers. The respondents were interviewed from their randomly sampled homesteads so as not to interfere with their work. The household head was the major target of the interview although the spouse offered the immediate alternative in the event that the former was absent. The questionnaires were administered to the randomly selected households using the local language of the region. In case of language barrier, a field guide known in the area was used as an interpreter.

In addition, four focus group discussions were conducted to obtain broader context and understanding for interpretation of quantitative data from the questionnaire. The four focus group discussions were gender specific to allow free sharing of information, that is, two for females and two for males. For each sub county (Ddwaniro and Lwamata) there was a representative group for males and another for females. The membership to the focus group discussions was guided by the sub county veterinary (Ddwaniro) or agricultural (Lwamata) officer and comprised five to ten participants.

There were five key informants that were also interviewed. These were purposively selected basing on their farming expertise, on EbA and leadership position in Ddwaniro and Lwamata sub counties (Marshall, 1996). They included the Kiboga district environment officer, two local government council leaders (one from Ddwaniro and another from Lwamata), one veterinary officer from Ddwaniro and one agricultural officer from Lwamata.

Data analysis

The quantitative information collected through semi structured questionnaires during the survey was entered in SPSS software and then transferred to STATA software. Data on socio-economic characteristics was obtained and presented in Table 4. A multinomial logit model (MNL) was used to find out the degree of relationship between the dependent and independent variables to obtain the determinants of EbA to drought by agro-pastoral farmers in the central cattle corridor. The dependent variable comprises three categories, that is, ecosystem services, adaptation benefits to drought and livelihood improvement. The independent variables comprising majorly the characteristics of the agro-pastoral farmers were used to obtain the major determinants of EbA to drought. The qualitative information obtained through focus group discussions and key informant interviews was manually processed and used to complement the quantitative data in the analysis.

Estimation of the variables (dependent and independent) used to obtain determinants of EbA to drought by agro-pastoral farmers

The Multinomial logit (MNL) model used to obtain determinants of EbA by agro-pastoral farmers requires estimation of a relationship between a dependent variable and a set of independent variables. In this study, the dependent variable denotes EbA based on three EbA categories, that is, ecosystem services, adaptation benefits to drought and livelihood improvement. These aforementioned three categories are components of EbA as recommended by Vignola et al. (2015) that EbA should not only be based on ecosystem services and adaptation benefits but should also improve livelihoods of agro-pastoral farmers. In the MNL models run in STATA software during data analysis, these three categories (ecosystem services, adaptation benefits to drought and livelihood improvement) of this dependent variable was abbreviated as CAT_3. The three categories that make up CAT_3 were one at a time made a base category by the MNL analysis.

The agro-pastoral farmers' demographics provided a set of independent variables which were used in explaining the determinants of EbA to drought by agro-pastoral households. The choice of these independent variables was dictated by data availability, theoretical behavioural hypotheses and empirical literature. The variables considered in this study consist of socio-economic and institutional factors. Kgosikoma et al. (2018) report that resources, infrastructure institutions and household characteristics influence agro-pastoral farmers' ability to adapt to climate change. The independent variables that were used in this study have been summarised in Table 1.

Development of MNL model used to obtain determinants of EbA to drought by agro-pastoral farmers

Prior to the MNL analysis, the independent variables (from which the determinants of EbA were obtained) were tested for multicollinearity to ascertain that there were no two or more independent variables that are were highly correlated (Greene, 2000). Correction for possible multicollinearity problems between the independent variables in the MNL analysis was carried out using the estimated Variance Inflation Factors test (VIF). The VIF estimates (Table 2) were less than 10 for all the independent variables used in the MNL analysis of this study, thus indicating that the level of multicollinearity was not severe (Gujarati and Porter, 2009).

The MNL involved analysis of categorical placement on a dependent EbA variable (CAT_3) based on multiple independent variables (Table 1). The MNL analysis, provided calculations of choice probabilities expressed in analytical form with no need of multivariate integration (Tse, 1987; Deressa et al., 2009). The analysis also resulted in estimated binary logits for all comparisons among the three dependent categories of the EbA variable which are ecosystem services, adaptation benefits to drought and livelihood improvement (Long and Freese, 2001).

To describe the MNL model, let CAT_3 denote a nominal outcome representing EbA in any farming household and has three categories that is, based on ecosystem services E, adaptation benefits to drought, A and livelihood improvement, L. Each agro-pastoral farmer is assumed to face a set of discrete, mutually exclusive choices of EbA. EbA is assumed to depend on a number of factors (as explained in Table 2). Assume that there is a single independent variable ik measuring indigenous knowledge, examining the effect of ik on CAT_3 by estimating three binary logits:

$$\ln\big(p(L\,|\,x)\big)\big|p(E\,|\,x)\big) = \beta 0, L\,|\,E + \beta 1, L\,|\,Eik$$
$$\ln\big(p(A\,|\,x)\big)\big|p(E\,|\,x)\big) = \beta 0, A\,|\,E + \beta 1, A\,|\,Eik$$
$$\ln\big(p(L\,|\,x)\big)\big|p(A\,|\,x)\big) = \beta 0, L\,|\,A + \beta 1, L\,|\,Aik$$

where the subscripts to the β's indicate which comparison is being made (e.g., $\beta 1, L\,|\,E$ is the coefficient for the first independent variable for the comparison of L and E).

The three binary logits include redundant information. Since ln x/y =ln x − ln y, the following equality must hold:

$$\ln\big(p(L\,|\,x)\big)\big|p(E\,|\,x)\big) - \ln\big(p(A\,|\,x)\big)\big|p(E\,|\,x)\big) = \ln\big(p(L\,|\,x)\big)\big|p(A\,|\,x)\big)$$

This implies that:

$$\beta 0, L\,|\,E - \beta 0, A\,|\,E = \beta 0, L\,|\,A \quad (1)$$
$$\beta 1, L\,|\,E - \beta 1, A\,|\,E = \beta 1, L\,|\,A$$

In general, with J outcomes, only $J - 1$ binary logits need to be estimated. Estimates for the remaining coefficients can be computed using equalities of the sort shown in Equation 1.

The MNL analysis, estimates binary logits of two categories while dropping the third (Long and Freese, 2001). For example if comparing ecosystem services, E and adaptation benefits to drought, A, then livelihood improvement, L is dropped. The dropped

Table 1. Description of independent variables as used in the MNL analysis.

Variable label	Variable name	Description	Measurement
Gender	Gender of farmer respondent	Discrete, dummy takes the value of 1 if male and 2 if female	1=Male, 2= Female
Agric	Major agricultural activity of the household	Discrete, Dummy takes the value 1= Crop farming, 2= Livestock farming, 3= Both crop and livestock farming	1= Crop farming, 2= Livestock farming, 3= Both crop and livestock farming
Extservices	Access to extension services	Discrete , Dummy takes the value 1 if yes and 0 if otherwise	1= Yes, 0= No
Policyaware	Awareness of policy related to farmers	Discrete, Dummy takes the value 1 if yes and 0 if otherwise	1= Yes, 0= No
HH_No	Household number	Continuous	People
farming_yrs	Number of farming years of farmer	Continuous	Years
Mgttime	Time (hours) spent on farm daily by the farmer	Continuous	Hours
Annualincom	Average annual Income of the farmer	Continuous	Uganda shillings converted to USD
Cropacreage	Acreage occupied by crops	Continuous	Acres
Livestkacre	Acreage occupied by livestock	Continuous	Acres
Familyonfarm	Number of family members working on farm	Continuous	People
Hiredlabour	Number of hired farm labourers	Continuous	People
farmer_org	Membership to farmer organisation	Discrete, Dummy takes the value 1 if yes and 0 if otherwise	1= Yes, 0= No
Ik	Use of Indigenous Knowledge as major source of farming knowledge	1= Yes 0= No	1= Yes, 0= No
Altincome	Having an alternative source of income	Continuous	Uganda shillings to USD

category, *L* becomes the base category and the comparison category. In such a scenario, the first comparison is made between coefficients from binary logit for *E* and *L*, then the second between *A* and *L*. In this study, three comparisons were made, that is, firstly ecosystem services, *E* and adaptation benefits to drought, *A* with livelihood improvement, *L* as base (comparison) category; secondly adaptation benefits to drought, *A* and livelihood improvement, *L* with ecosystem services, *E* as base category; thirdly ecosystem services, *E* and livelihood improvement, *L* with adaptation benefits to drought, *A* as the base category.

Formally, the MNL can be written as:

$$\ln\Omega_{m|b}(x) = ln\frac{P(y=m|x)}{P(y=b|x)} = x\,\beta_{m|b} \text{ for } m = 1 \text{ to } J$$

where *b* is the base category, which is also referred to as the comparison group. Since $\ln\Omega b|b(x) = \ln 1 = 0$, it must hold that $\beta b|b = 0$. That is, the log odds of an outcome compared to itself is always 0, and thus the effects of any independent variables must also be 0. These *J* equations can be solved to compute the predicted probabilities:

$$P\left(y = \frac{m}{x}\right) = \frac{\exp(x\,\beta m\,/b)}{[1+\sum_{h=1}^{j}[\exp(x\beta j/\,b)]} \quad (2)$$

The MNL assumes the independence of irrelevant alternatives (IIA) property. This IIA property, specifically, states that the probability of a given household using EbA basing on ecosystem services, adaptation benefits to drought or livelihood improvement should be independent of each other. This IIA property helps to minimize biases and ensures consistent parameter estimates of the MNL model in Equation 2.

The parameter estimates of the MNL model give only the direction of the effect of the independent variables on the dependent variable, but estimates do not represent either the actual degree of change nor probabilities (Deressa et al., 2009). For instance, if the estimated values of these independent variables are

Table 2. Table showing VIF test for multicollinearity among independent variables included in the MNL analysis.

Variable name	Variable label	VIF	1/VIF
Number of family members working on farm	Familyonfarm	2.08	0.481021
Household number	HH_No	2.04	0.489793
Major agricultural activity of the household	Agric	1.3	0.767428
Awareness of policy related to farmers	Policyaware	1.24	0.804505
Acreage occupied by livestock	Livestkacre	1.22	0.817132
Membership to farmer organisation	farmer_org	1.22	0.820623
Number of hired farm labourers	Hiredlabour	1.21	0.829168
Gender of respondent	Gender	1.19	0.843614
Acreage occupied by crops	Cropacreage	1.18	0.847886
Use of indigenous knowledge as major source of farming knowledge	Ik	1.18	0.848007
Number of farming years	farming_yrs	1.17	0.853763
Average annual income of the farmer	Annualincom	1.16	0.863615
Hours spent on farm daily by the farmer	Mgttime	1.12	0.895894
Access to extension services	Extservices	1.12	0.896243
Having an alternative income	Altincome	1.09	0.918699
	Mean VIF	1.3	-

positive and significant ($p< 0.05$), it infers that the farmers are more likely to use EbA. To determine the effect of a unit change in any of the variables in Table 2 on the probability that a given household will use EbA is given by the marginal effect equation (Greene, 2000):

$$\left(\frac{\partial Pj}{\partial Xk}\right) = Pj(\beta jk - \sum_{j-1}^{j-1} Pj\beta jk \quad (3)$$

RESULTS

Socio-economic characteristics of agro-pastoral farmers

The results reveal that the majority of the interviewed respondents were female (60.1%) who mainly carried out both crop and livestock farming (63.4%), a practice 83.2% of them learned through indigenous knowledge transfer. On average, a household had 6.0 ± 3.3 persons with an average crop and livestock acreage of 3.63±8.51and 5 .91 ± 18.29, respectively (Table 3).

Determinants of EbA to drought by agro-pastoral farmers

Tables 4 to 6 present the significant coefficients at 5% of the estimated determinants obtained from the multinomial logit model. Three models were run which displayed three tables as each EbA category was one at a time made as a reference (base) category. In all the three models, access to extension services, average annual income of the farmer, the major agricultural activity of the household, acreage occupied by crops, spending more time on farm, use of indigenous knowledge and membership to farmer organisations were the most significant factors at 5%. The Chi-square results showed that the likelihood ratio statistics were highly significant (χ^2= 79.21, p=0.0000, pseudo R^2 =0.258) which suggested that the model was fit and had a strong explanatory power.

According to Model 1 (Table 4), the major agricultural activity, average annual income, and membership to farmer organisation were less likely to influence EbA based on ecosystem services compared to livelihood improvement whereas access to extension services had significant positive influence on EbA for the same. Acreage occupied by crops was less likely to influence EbA for adaptation benefits to drought compared to livelihood improvement.

With reference to Model 2 (Table 5), the hours spent on farm daily were more likely to influence EbA based on adaptation benefits compared to ecosystem services whereas acreage occupied by crops and use of indigenous knowledge as major source of farming knowledge were less likely to influence EbA for the same. Major agricultural activity, average annual income and membership to farmer organisation were more likely to influence EbA based on livelihood improvement compared to ecosystem services whereas access to extension services was less likely to influence EbA for the same.

In Model 3 (Table 6), acreage occupied by crops and use of indigenous knowledge as major source of farming knowledge were more likely to influence EbA based on ecosystem services compared to adaptation benefits to drought whereas the hours spent on farm daily were less likely to influence EbA based for the same. Acreage

Table 3. Socio-economic characteristics of agro-pastoral farmers.

Variable	Mean ± SD	Percentage
Gender of household head	-	Female 60.1% Male 39.9%
Major agricultural activity of household	-	Livestock farming only 2.7%, Crop farming only 33.9% Both crop and Livestock farming 63.4%
Use of indigenous knowledge as major source of farming knowledge	-	83.2
Alternative source of income		44.8
Access to extension services		21.3
Awareness of policy related to EbA		8.2
Membership to farmer organisation		24
Household number	6.02 ± 3.31	-
Number of farming years of household	25.37 ± 17.88	-
Time spent on farm daily by famers (hours)	4.69 ± 2.16	-
Average annual income of the farmer	*UG 1,445,658.39 ± 2,871,007.967	-
Land size under crop farming	3.63±8.51	-
Land size under livestock farming	5.91 ± 18.29	-
Number of family members working on farm	3.16 ± 2.836	-
Number of hired farm labourers	2.04 ± 1.18	-

***USD rate 3655 (USD 396 ± 786).

Table 4. Coefficients of significant determinants of MNL model run with livelihood improvement as the base outcome (Model 1).

Determinants	Based on ecosystem services (Coefficients)	Based on adaptation benefits to drought impacts (Coefficients)
Major agricultural activity	-0.7941351*	-0.3385913
Average annual income	-5.48E-07*	-4.42E-07
Access to extension services	1.058011*	-0.3815853
Membership to farmer organisation	-1.463593*	-0.7242587
Land size under crop farming	0.0377693	-0.4086709*
Constant	1.252623	-2.901506

Multinomial logistic regression, Number of obs = 183LR, $Chi^2(30)=79.21$, Prob > Chi^2 = 0.0000, Log likelihood = -113.88037, Pseudo R^2= 0.258. *indicate statistical significance at 5%.

occupied by crops was more likely to influence EbA based on livelihood improvement compared to drought adaptation benefits whereas the hours spent on farm daily were less likely to influence EbA for the same.

DISCUSSION

The socio-economic characteristics of the agro-pastoral farmers in the central cattle corridor reveal their vulnerability and adaptive capacity at household level. All the sampled households were highly dependent on farming. Despite the study area being an originally pastoral region, the majority of the agro-pastoral farmers practiced both crop and livestock farming mainly using indigenous knowledge transferred to them by their ancestors. This indicates that there has been a shift from pastoral to agro-pastoralism in the central cattle corridor of Uganda. The standard deviation of land size under livestock farming was very far from the mean which implies that the farmers have varying land sizes on which they keep their livestock. There could be a possibility of them diversifying the land into other activities like crop farming. Crop diversification plays a significant role in increasing household income and food security of pastoral farmers thus reducing their vulnerability to climate change including drought (Tiwari et al., 2014; Waiswa et al., 2019).

Table 5. Coefficients of significant determinants of MNL model run with Ecosystem services as the base outcome (Model 2).

Determinants	Based on adaptation benefits to drought (Coefficients)	Based on livelihood improvement (Coefficients)
Land size under crop farming	-0.4464402*	-0.0377693
Time spent daily on farm (hours)	0.6350912*	0.0910715
Use of Indigenous Knowledge as major source of farming knowledge	-2.309535*	-1.001454
Major agricultural activity	0.4555438	0.7941351*
Average annual income	1.06E-07	5.48E-07*
Access to extension services	-1.439596	-1.058011*
Membership to farmer organisation	0.7393346	1.463593*
Constant	-4.154129	-1.252623

Multinomial logistic regression, Number of obs = 183LR, $Chi^2(30)=79.21$, Prob > Chi^2 = 0.0000, Log likelihood = -113.88037, Pseudo R^2= 0.258. *indicate statistical significance at 5%.

Table 6. Coefficients of significant determinants of MNL model run with Adaptation benefits to drought as the base outcome (Model 3).

Determinants	Based on Ecosystem services (Coefficients)	Based on Livelihood improvement (Coefficients)
Land size under crop farming	0.4464402*	0.4086709*
Time spent daily on farm (hours)	-0.6350912*	-0.5440196*
Use of Indigenous Knowledge as major source of farming knowledge	2.309535*	1.308081
Constant	4.154129	2.901506

Multinomial logistic regression Number of obs = 183LR, $Chi^2(30)=79.21$, Prob > Chi^2 = 0.0000, Log likelihood = -113.88037, Pseudo R^2= 0.258. *indicate statistical significance at 5%.

There were more female respondents than males. This could be probably because the males have to traverse the cattle corridor in search for water for the livestock. As they camp near the water reservoirs (water dams) which could be far from their pastoral households, they establish dry thatched tents for shelter during their stay. The females that are left home to fend for the rest of the household members have to devise means to fend for their household members usually children. They therefore tend to establish kitchen gardens. Establishment of kitchen gardens is one of the climate change adaptation responses in the Uganda central cattle corridor (Mfitumukiza et al., 2017).

The MNL analysis showed different determinants of EbA to drought in the central cattle corridor of Uganda. The analysis used the socio-economic characteristics as the factors from which determinants of EbA to drought were obtained. The determinants were specific to each of the three EbA categories (ecosystem services, adaptation benefits to drought and livelihood improvement) in comparison with each other. The estimation involved normalising one category as the base category. Moreover, the most common factors which significantly influenced EbA during drought included access to extension services, average annual income of the farmer, the major agricultural activity of the household, land size under crop farming, time spent on farm daily (hours), use of indigenous knowledge and membership to farmer organisations.

The access to extension services had a significant positive influence on EbA to drought although the majority of the respondents were found to have had minimal access to the same. The results reveal that if the agro-pastoral farmers in the study area have access to extension services, then there is a greater likelihood of EbA to drought because of the ecosystem services that it offers to their farming systems. Access to extension services increases agro-pastoral farmers' knowledge and skills in regard to the ecosystem services derived from the existing ecosystems. This in turn enhances their likelihood to conserve the ecosystems in order to sustainably obtain services from them during long dry spells. A study by Bandyopadhyay et al. (2011) reveals that access to extension services increases the farmers' knowledge and information concerning sustainable utilisation of ecosystems which are a sole source of services that boost their agricultural productivity. A study by Harvey et al. (2017) estimated extension training to be an important determinant of some EbA measures that are knowledge intensive.

The use of indigenous knowledge as a major source of farming knowledge is more likely to influence EbA during long dry spells. The agro-pastoral farmers are more likely to use indigenous knowledge as a major source of farming knowledge during drought to derive ecosystem services from EbA strategy. The availability of ecosystem services in the central cattle corridor of Uganda is influenced by the use of locally available knowledge. Agro-pastoral farming depends on availability of ecosystem services such as pollination, water provision, nutrient recycling and biological pest control (Vignola et al., 2015). Agro-pastoral farmers in the central cattle corridor use drought resistant fodder crops to provide fodder for livestock and mulch for crops to maintain soil moisture during drought thus maintaining farm production. Elephant or Napier grass is the major fodder crop used by these farmers. Napier grass (*Pennisetum purpureum*) has low water and nutrient requirements therefore can easily survive uncultivated lands and long dry spells. Establishment of Napier grass is not only for fodder but also has the potential of attracting stem borer moths away from maize, a strategy that is more sustainably affordable for agro-pastoral farmers than insecticide (Khan et al., 2007). Indigenous knowledge has been depicted as simple, static and primitive yet it is essential for provision of ecosystem services and biodiversity (Nyong et al., 2007). According to a study done by Egeru (2012), in another agro-pastoral region of Uganda, indigenous knowledge plays a significant role in climate change adaptation through availing sustainable provisioning services. Since EbA entails sustainable management of biodiversity and ecological functions, the agro-pastoral farmers that possess and utilise traditional knowledge will more likely conserve those ecosystems on which they are traditionally dependent (Phuong, 2011).

Average annual income had a significant positive influence on EbA for the improvement of the agro-pastoral farmers' livelihoods. Increase in annual income potentially widens the opportunities for agro-pastoral farmers to opt for ecosystem based livelihood improvement options. For instance with increased income, the agro-pastoral farmers are able to diversify their agricultural systems to maintain food provision. In addition, with increased income still they could be able to restore riparian areas to ensure supply of water during long dry spells. On the other hand, with low average annual income the agro-pastoral farmers may not be able to meet the costs associated with sustainable establishment and maintenance of ecosystem based adaptation measures. A study by Mulwa et al. (2017) reveals that famers with higher income usually have off-farm income sources which allows them not to be fully reliant on agricultural income thus are less exposed to production risks. Therefore, with constrained income levels, the agro-pastoral farmers may find it difficult to adapt to drought effects using EbA even when provided with the right information.

Furthermore, the major agricultural activity of a household, land size under crop farming and membership to farmer organisations were found to have a positive influence on EbA to drought because of their ability to improve livelihoods. In the central cattle corridor of Uganda, the culture and economic status especially in Ddwaniro, is oriented towards livestock. Households depend on livestock for a significant part of their basic needs, typically characteristics of farmers in rangelands. Large herds guarantee subsistence, income, status and insurance against drought impacts on agriculture (Ruhangawebare, 2010). However, the initially pastoral famers that diversified their livestock herds with crops had a greater likelihood of coping with climate change risks like drought than those that did not (Mulwa et al., 2017). Crop diversification by farmers in the central cattle corridor regions such as those in the study area, increases food security and income during long dry spells (Nimusiima et al., 2018). Through discovery learning and sharing of experiences using existing ecosystems and biodiversity, the agro-pastoral farmers in Uganda's central cattle corridor learn crop diversification and other adaptation strategies in farmer organisations, commonly known as farmer field schools (Mfitumukiza et al., 2017). Establishment of kitchen gardens, use of water reservoirs and live fences are some of the ecosystem based adaptation measures that farmers learn in farmer field schools. Through such avenues, the uptake of EbA could be accelerated.

It was interesting to note that the amount of time (hours) the farmers in the central cattle corridor spent on farm daily was significantly less likely to increase availability of ecosystem services and improving their livelihoods during drought from EbA utilisation. This implies that the more time they spent on farm, the less possibility of obtaining available ecosystem services and having improved livelihoods, which are the cost-effective benefits arising from EbA. The reverse could be true; that sustainable supply of ecosystem services could promote spending less time on farm as well as have improved livelihoods. Therefore, there could be probable depletion of ecosystem services as a result of the drought. Considerably, insufficient knowledge about Ecosystem-based drought Adaptation could lead to increased time on farm so as to obtain enough produce for the household. Despite the drought, the agro-pastoral farmers in central cattle corridor have to continue providing for their households with basic needs from their farming activities. Agriculture in Uganda's central cattle corridor is constrained by the long dry spells. In addition, drought decreases ability of ecosystems to provide services sustainably. Therefore the agro-pastoral farmers have to spend more time working on their farms using the scarce ecosystem services in order to adapt to drought. The spending of more time on farm seems to contradict the benefits of EbA as it is supposed to decrease on farmers' workability which seems to be different in this case. EbA is aimed at reducing the considerable amount of time that agro-pastoral farmers spend on farm through continuous provision of ecosystem services even during periods of change in climate. This in turn will help to maintain or improve crop, animal or farm productivity, reduce the biophysical impacts of extreme drought events on crops, animals or farming systems and also reduce pest and disease outbreaks (Vignola et al., 2015).

Conclusion

In rural agro-pastoral farming communities, it is of paramount importance that their vulnerability to climate change is decreased and adaptive capacity to drought enhanced. The major determinants of EbA to drought in this study were access to extension services, time (hours) spent daily on farm by farmers, land size under crop farming, type of major agricultural activity, average annual income, membership to farmer organisation and use of indigenous knowledge. With this study, EbA not only improves the farmers' livelihoods but also increases their resilience to drought. Therefore, there is need to use the significant determinants of EbA in farmers' education and training, policy formulation and implementation to strengthen drought adaptation as well as improve the livelihoods of the agro-pastoral farmers. Access to extension services should be fostered, alternative income generating activities and crop diversification encouraged. Membership to farmer organisations like farmer field schools should be encouraged and supported by extension service providers. Indigenous knowledge use should be encouraged and incorporated in drought adaptation measures. The aforementioned recommendations will in turn minimise the time spent by agro-pastoralists on farm daily (hours) during drought. These determinants of EbA unveiled by this study could also be transformed into indicators of monitoring climate change adaptation in rangeland or semi-arid areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Cracking and breaking response in four rice varieties as influenced by fertilization regime and storage duration

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In Northern Ghana, harvesting of the bulk of paddy, which is cultivated under rain-fed conditions, coincides with the harmattan season. This season is characterized by low relative humidity and dry weather conditions which hasten drying and increase the tendency of the paddy to crack during milling. The farmers also store paddy for longer periods in anticipation of higher price in the open market, thus the paddy may deteriorate as a result of fluctuations in seasonal temperature and relative humidity. This study assessed the effects of fertilizer application regimes and storage duration on cracking and breaking during milling in 4 aromatic rice varieties. Across the varieties, grains that showed signs of cracks will eventually break during milling, and grain susceptibility to cracking significantly ($P<0.05$) increased when stored beyond 30 days. Gbewaa rice recorded significantly ($P<0.05$) higher cracking (49.2%) followed by Amankwatia (43.9%), CSIR-AGRA (40.4%) and Exbaika (40.3%). Fertilization regime of 2 basal applications and 2 topdressings at panicle initiation and booting-heading stages resulted in grains that were well-filled and thick to resist drying and cracking.

Key words: Aromatic varieties, nitrogen fertilizer, straight-milling, paddy cracking, consumer taste.

INTRODUCTION

In Ghana, straight-milled aromatic rice varieties are preferred by majority of rice consumers (Angelucci et al., 2013; Danso-Abbeam et al., 2014; Addison et al., 2015). However, straight milling is difficult to achieve due to a number of factors attributable to harvest maturity, and environmental conditions at harvest and during storage (Faraji et al., 2013). As a result, rice millers, especially in northern Ghana, are not able to conduct straight-milling at the required volume as there is a large percentage of cracked grains in the paddy supplied to the mills (Asuming-Brempong et al., 2011). The mills, therefore, resort to parboiling, a hydrothermal process that seals and cements the cracks, thus reducing breakages and improving head rice yield. Though the parboiling process is costly and time consuming, parboiled rice sells at a relatively lower price as compared to straight-milled rice

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on the Ghanaian market. This accounts for the large volumes of straight-milled rice imported into the country, which has negative consequences on the local rice industry.

In northern Ghana, harvesting of the bulk of paddy, which is cultivated under rain-fed conditions, coincides with the harmattan season. This season is characterized by low relative humidity and dry weather conditions. This condition hastens drying and increases the tendency of the paddy to crack during milling. In addition, smallholder farmers tend to store paddy for longer periods in anticipation of higher prices in the open market. Thus, the paddy may deteriorate during storage as a result of the seasonal fluctuation of temperature and relative humidity.

Rice cracking was known as sun-cracking by earlier researchers, latter research led to the observation that rice cracking was due to moisture absorption of dried rice (Schluterman and Siebenmorgen, 2007; Akowuah et al., 2012). Some studies in different varieties found that rice cracking begins at moisture content below 14.2 and 18.3% for crack resistant and crack susceptible varieties, respectively (Kumoro et al., 2019). Another factor that may cause paddy to crack before harvest is nonsynchronous blooming which leads to uneven grain maturity (Schluterman and Siebenmorgen, 2007; Akowuah et al., 2012; Kumoro et al., 2019). In bulk storage of paddy, moisture migration causes low-moisture grains to absorb moisture from the high-moisture grains and crack when the high-moisture grains had only 4 to 5% more moisture than the low-moisture grains (Akowuah et al., 2012). Thus, grains can crack before harvesting, during threshing, in bulk storage, and during transportation. The study assessed the relationship between rice cracking and breakage during milling and the effect of storage duration on cracking. Furthermore, the effect of three fertilizer application regimes on grain filling and cracking was evaluated.

MATERIALS AND METHODS

Field experiment

The study was conducted in partnership with three rice aggregators, namely Excel bit Com, Karaga Busaka ABC and Avnash Rice mill, all located in northern Ghana. The study was conducted at 9 paddy field sites (3 sites for each rice aggregator). Four (4) aromatic rice varieties: Gbewaa (Jasmine), CSIR-AGRA, Exbaika and Amankwatia were used. These varieties were planted from 22nd to 26th of July, 2016 at 9 study sites. Three fertilizer application regimes were used namely: FR1 = 1 basal + 1 topdressing at maximum tiller stage; FR2 = 2 basal + 1 topdressings at panicle initiation and FR3 = 2 basal + 2 topdressings at panicle initiation and booting-heading. For several decades now, treatment FR1 has been the farmer practice in the northern Ghana. However, due to continuous cropping leading to loss of soil fertility, this rate appears to be inadequate to achieve economic yield and optimum grain quality. Studies in India and the Philippines, suggest that two to three applications of nitrogen per crop cycle gives the highest nitrogen efficiency, and that more split applications are needed for long duration varieties and for lighter soils (Faraji et al., 2013; Rehman et al., 2013). The study modified the fertilizer application rate to enhance both yield and milling quality; although the effect on grain yield is captured in another study.

Harvesting and storage of samples

Freshly harvested paddy samples were sent to the CSIR-SARI Rice laboratory and threshed manually. Samples were transferred into Ziploc bags (©2014 S.C Johnson and Son Inc. Racine. W1 53403-22360 U.S.A) and stored in a cold room at the Institute (4°C, 30% RH) to minimize temperature fluctuation and adsorption of moisture. When the analysis began, samples were stored in sacks and on shelves to mimic the storage conditions of aggregators and farmers.

Determination of grain moisture content

Moisture content of the paddy was determined using a rice moisture meter Riceter f501 Series (KETT Electric Laboratory, 1-8-1 Minami-Magome Ota-Ku, Tokyo, 143-8507 Japan). Three sample readings were conducted and the average recorded. Cracking test on samples was conducted once every two weeks in the first month, followed by monthly test in other 5 months. Analysis of cracks in the harvested paddy was carried out at both Avnash Rice Mills and the CSIR-SARI Rice Laboratories. After thoroughly mixing, a sample of 2 kg was collected and spread thinly on a table. Nine sub-samples (weighing 30 g) were picked and mixed thoroughly. The sub-samples were then spread on a table and subdivided again into 4 equal parts using the coning and quartering method to obtain working samples. The working samples were then gently manually dehusked and the brown rice gently placed into a Petri dish. For any grain that breaks during the process, one piece is put into the Petri dish and the other(s) discarded. Units of 100 grains were dehusked and spread thinly on Petri dish and placed on a crack detector. Cracked and broken grains were separated, counted and percent cracked grains computed using the following equation. The procedure was repeated three times and the average percent cracked grains recorded.

$$\%\ Cracked\ grains = \frac{No\ of\ cracked\ grains}{100\ grains} \times 100$$

Determination of milling parameters

The paddy in sack was thoroughly mixed and winnowed, and a sample of 10 kg weighed and dehusked in a Satake Laboratory dehusker. The weights of husk and brown rice were recorded and the percent husk determined. Then 1 kg sample was dehusked and cleaned. Then 3 replicates of 200 g samples of the cleaned brown rice were milled in a Satake Laboratory Mill. After milling, the weight of the bran was recorded and the percent bran determined. The milled rice was cleaned, spread on a table and sub-samples were obtained. Broken grains were manually separated from whole lot and their respective percentages calculated. This process was replicated 3 times at each location.

Laboratory analysis

The following parameters were determined in the laboratory:

(1) Number of days at storage before milling
(2) % Paddy dryness over time
(3) % Cracking during milling at 0, 30 and 60 days after storage
(4) % Moisture content
(5) Milling recovery (Total milling yield, brown rice yield and head

Table 1. Milling parameters of four aromatic rice varieties cultivated in northern Ghana.

Variety	% Husk	% Bran	% Broken	% Head whole grain	% Crack
CSIR-AGRA	26.8	9.9	4.7	29.4	11.3
Amankwatia	31.6	10.0	6.2	58.5	12.9
Exbaika	27.5	11.1	4.6	21.6	14.7
Gbewaa	28.9	12.2	1.1	19.1	13.6
LSD	4.5	3.8	9.1	44.1	1.8
CV (%)	10.7	24.0	15.7	10.5	8.7
Se	3.0	2.6	6.2	30.02	1.2
P<5%	ns	ns	ns	ns	ns

Table 2. Pearson correlation coefficients between milling parameters of four aromatic rice varieties.

Correlation	AV % MC	AV % Cracks	% whole grain	% Broken	% Bran	% Husk
AV % MC	1	-0.150	-0.356	0.370	0.170	-0.191
AV % Crack	-0.150	1	-0.123	0.242	0.062	-0242
% whole grain	-0.356	-0.123	1	-0.878**	-0.114	0.092
% Broken	0.370	0.242	-0.878**	1	0.196	-0.482*
% Bran	0.170	0.062	-0.114	0.196	1	-0.703**
% Husk	-0.191	-0.242	0.092	-0.482*	-0.703**	1

"*" = Significant at 5%, "**" = Significant at 1%.

rice yield)

Statistical analysis

The data sets collected were subjected to analysis of variance, and treatment means separated using Least Significant Difference at 5% significance level. Correlation and regression relations between cracking and other parameters (% moisture content, duration of storage, days to milling, etc.) were computed.

RESULTS AND DISCUSSION

Response of varieties to milling

Most rice varieties are composed of roughly 20% rice hull or husk, 11% bran layers, and 69% starchy endosperm, also referred to as the total milled rice. In an ideal milling process this will results into the following fractions: 20% husk, 8 to 12% bran depending on the milling degree and 68 to 72% milled rice or white rice depending on the variety. In this study, Amankwatia, recorded the highest head rice yield of 58.5% while Gbewaa recorded the lowest of 19.1%. Percentage broken was relatively low, ranging from 1.1 to 6.2% (Table 1). This may be due to the fact that the paddy was dried to the desired moisture content and milled immediately. Low percent cracking was observed in CSIR-AGRA (11.3%) and Amankwatia (12.9%) as compared to Gbewaa (13.6%) and Exbaika (14.7%). In general, the recommended moisture content to mill rice is 14%, at this moisture content, rice has the maximum mechanical strength. Above this moisture, the grain is soft and would crush during milling. At moisture contents less than 14%, the grain becomes brittle and cracks or break during milling. Both instances lead to reduction in head rice yield (Schluterman and Siebenmorgen, 2007; Akowuah et al., 2012; Kumoro et al., 2019). Generally, a good quality paddy constitutes about 55% head rice, 15% broken, 20% husk, and 10% bran.

The results in Table 2 establish no significant relations between grain cracking and breaking during milling. Thus, all cracked grains will eventually break during milling. This may be due to the fact that some cracks may not go through the entire grain, while other cracks may be at the extreme tip of the grain. Although, there was no significant difference among the varieties in relation to percent crack and percent breakage, relatively higher percent breakages were observed in Exbaika (14.9%) and Gbewaa (16.5%) compared to CSIR-AGRA (13.2%) and Amankwatia (11.2%) (Figure 1). Figure 2 depicts the effect of variety on grain cracking across locations over a period of storage time. It can be observed that CSIR-AGRA (40.4%) and Exbaika (40.3%) showed relatively lower mean percentage cracking as compared to the other two varieties. Gbewaa rice recorded the highest percent cracking (49.2%).

Effect of length of storage on cracking

Figure 3 shows the effect of length of storage on percent cracking. Generally, percent cracking ranged from about

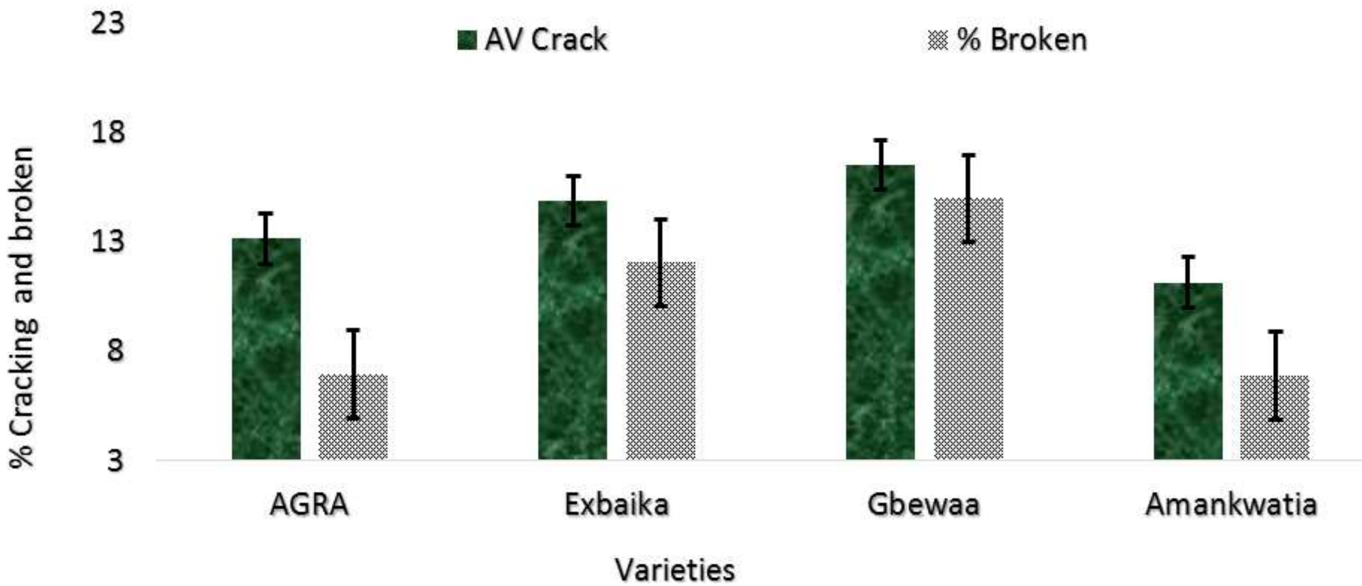

Figure 1. Relative susceptibility of four aromatic rice varieties to cracking and breakage during milling.

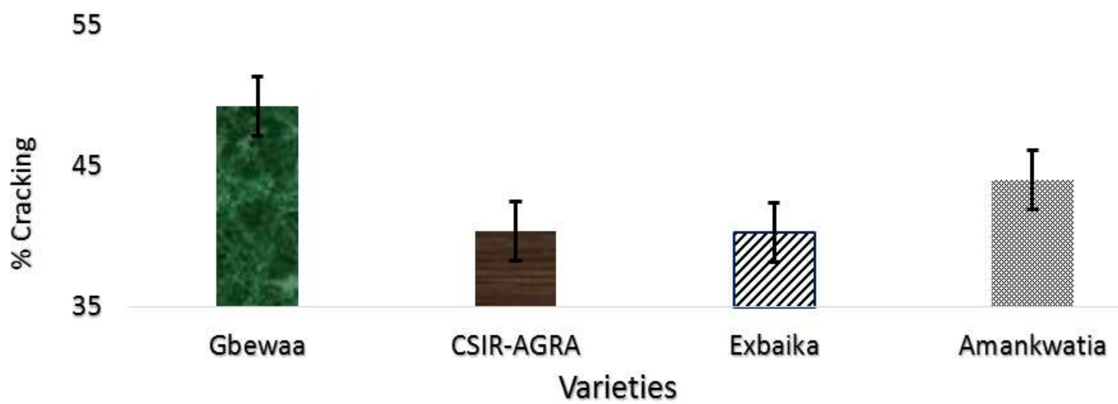

Figure 2. Relative susceptibility of four aromatic rice varieties to cracking.

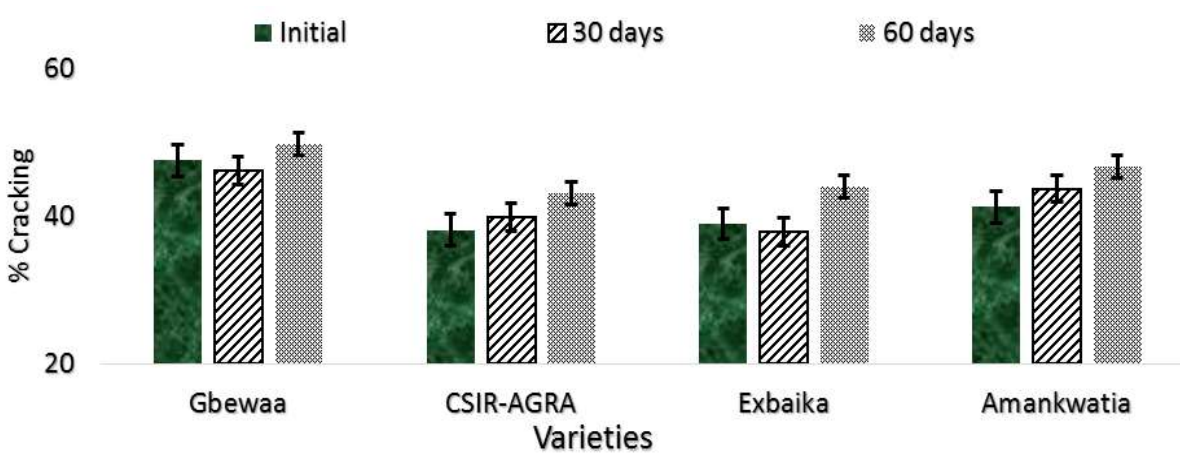

Figure 3. Effect of storage duration on percent cracks in four aromatic rice varieties in northern Ghana.

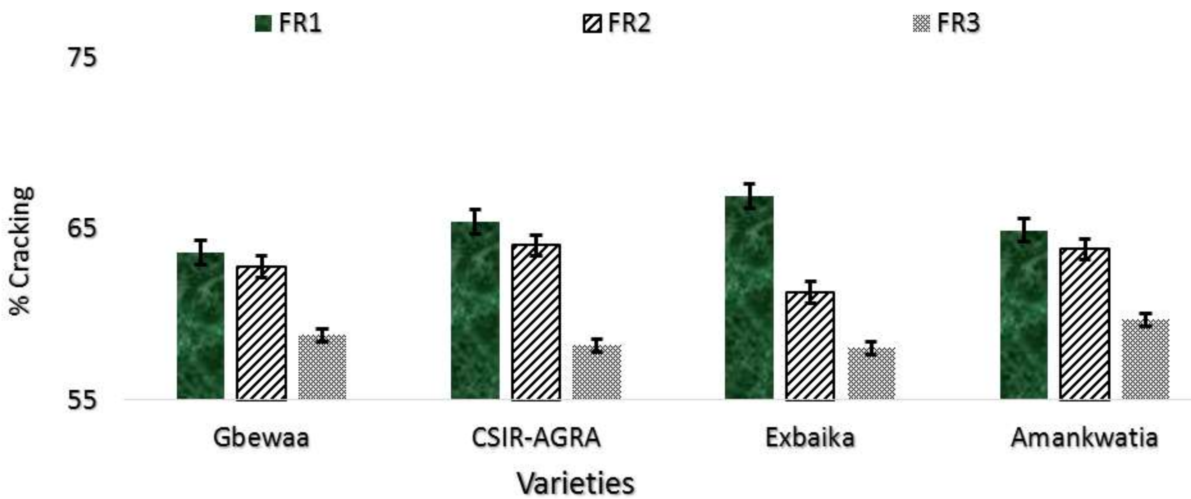

Figure 4. Effect of fertilizer management on percent cracking in four aromatic rice varieties after two months of storage. (FR1 = 1 basal + 1 topdressing at maximum tiller stage; FR2 = 2 basal + 1 topdressings at panicle initiation; and FR3 = 2 basal + 2 topdressings at panicle initiation and booting-heading).

38 to 54%. Depending on the storage duration and prevailing ambient conditions, the quality of grain will remain same or deteriorate in storage. There was no significant difference in cracking across the varieties at 0 and 30 days after storage. However, by 60 days after storage, Gbewaa rice showed significantly higher cracking percentage compared to three other varieties.

Effect of fertilizer management on cracking

Use of appropriate nitrogen application regimes has been postulated to enhance hardness and reduce breakages in rice (Rehman et al., 2013; Faraji et al., 2013; Tari and Amiri, 2015). Current practice of two split applications of the recommended rate has been found to result in inefficient use of N. In this case, most of the N applied is not available at the grain filling stage when presumably; the plants require lots of nutrients to accelerate grain filling (Tari and Amiri, 2015). Such grains are thin, dry-out readily and susceptible to cracking. Finding adequate nitrogen management regime in rice production could result in the production of grains that are well filled, thick to resist drying and resistant to cracking.

Figure 4 shows the effect of fertilizer treatment on grain cracking after three months of storage in northern Ghana. There was no significant difference between the first two splits, FR1 (1 basal + 1 topdressing at maximum tiller stage) and FR2 (2 basal + 1 topdressings at panicle initiation) except in Exbaika, where there was a significant differences. However, significantly lower percent cracking was observed in all four varieties at FR3 (2 basal + 2 topdressings at panicle initiation and booting-heading). This indicates that all four varieties responded significantly to increased split fertilizer rates. The higher the split fertilizer application, the more resistant the paddy is to cracking. These results correspond well with several earlier findings (Faraji et al., 2013; Rehman et al., 2013).

Conclusion

Cracks in paddy can occur before harvest, during threshing, drying, storage and even transportation depending on the ambient conditions. In this study, there was no direct relationship between paddy moisture content and percent cracking across the varieties. Overall, CSIR-AGRA Rice showed lower susceptibility to cracking compared to other 3 varieties. Fertilization regime of 2 basal applications and 2 topdressings at panicle initiation and booting-heading stages resulted in grains that were well-filled and thick to resist drying and cracking. Across the varieties, grains that showed signs of cracks will eventually break during milling, and grain susceptibility to cracking significantly increased when stored beyond 30 days. It is therefore recommended that farmers and aggregators do not keep their paddy for too long as that could affect milling quality. Where storage is inevitable, the environment should minimize possible exposure of the paddy to absorb moisture.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of growth and yield modelling on forest regulation and earnings

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The elaboration of a forest schedule involves constructing and solving a forest regulation model. The regulated structure is not easy to obtain, considering the fluctuations in the effective planting area during the planning horizon, technological advances, and changes in annual demand. Nevertheless, the establishment and implementation of a regulation model often results in an improvement of the forest, in terms of the distribution of age classes. The successful use of regulation models and consequent definition of a forest management plan depends on the quality of data from forest inventory plots and prediction accuracy of stand wood stock. This study evaluated the effect of different alternatives of growth and yield modelling on the regulation of a eucalyptus even-aged forest. Each alternative was used to create yield tables, which were used as inputs in a linear programming model. In this model, restrictions of area, demand, and regulation were included, with the goal of maximising the total net present value. The most consistent forest schedule was obtained with a total stand model.

Key words: Forest management, forestry planning, scheduling, growth, yield models.

INTRODUCTION

Forest management is the application of analytical techniques in the selection of management alternatives to meet the objectives of a company or forestry organisation (Bettinger et al., 2017; Araujo et al., 2018). The best choice among these alternatives depends on the accuracy of information on forest resources (both data and models used to estimate and predict population variables, like wood volume), (Carvalho et al., 2016) and the intensity of interventions during the planning horizon (Clutter et al., 1983; Duvemo and Lämas, 2006). Due to the substantial investments required for management of timber production, highly accurate models of tree

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attributes and stand development are required (Burkhart and Tomé, 2012).

To develop a management plan for an even forest requires knowledge of the three essential elements of management: land classification, establishment of prescriptions, and prediction or projection of growth and harvest stock. According to Campos and Leite (2017), modelling growth and stand production is related to the first and third of these elements.

Data from inventory can be used to construct site index curves and map stand production capacity. This information together with the forest historic and physiographic maps of soils and roads, results in a detailed description of each forest compartment and growth and production models can be adjusted and employed to examine forestry and logging options, to determine sustainable production, to examine the impacts of management options and guide forest policy (Davis and Johnson, 1987).

Growth and yield models looking for describe precisely how a forest population grows, providing information for decision making (Peng, 2000; Fahlvik et al., 2014), help managers to exploit forest resources in a sustainable way (Vanclay, 1994) and can be used as input for models to regulate the forest production (Casas et al., 2018). Choosing the appropriate approach for growth and yield modelling depends on the management's purpose, the stratification of the forest, and on the size, quality, and representativeness of the data from the permanent plots or stem analysis (Campos and Leite, 2017). These models can be divided according to the level of detailed: total stand, diameter distribution and trees (Palahí et al., 2003; Castro et al., 2013).

Considering the competitiveness of the increasingly forest-based market, regulating a forest also means maintaining a sustainable production that meets fluctuating market specifications and demand and satisfies capital and operational constraints. It also ensures regular employment (Bachmatiuk et al., 2015; Troncoso et al., 2011) and presents minimum costs and maximum returns within a planning horizon (Heinonen, 2007; Mäkinen et al., 2012; Pereira et al., 2015; Martin et al., 2016).

The regulation of forest production consists of obtaining continually forest products of the same volume, size, and quality. To regulate a forest, managers must determine where, how, and when to sustainably produce goods and services from the forest, to better achieve the objectives of the owner (Pukkala, 2002; Heinonen, 2007; Bouchard et al., 2007). Forestry regulation can ensure continuous production of various products and use of forests regarding sustainability.

The two main models used for the forest production regulation are known as Models I and II (Johnson and Scheurman, 1977). In this classical approach, each management unit should be assigned to one prescription. The basis for this formulation is the initial subdivision of the forest into homogeneous age classes, prescribing a set of requirements for each class (Carvalho et al., 2015). The difference between these two models is that in Model I, the prescriptions assigned to a management unit remained in place until the end of the planning horizon (Buongiorno and Gilles, 2003).

The influence of the growth and yield model on the forest schedule is straightforward because this model generates future information on the expected harvest (Siipilehto and Rajala, 2019). Managers usually select the best model based on its statistical performance, without considering its effect on the management plan (Castro et al., 2016).

The objective of this study is demonstrating the effect of the growth and yield models on the regulation of a eucalyptus even-aged stand.

MATERIALS AND METHODS

Data

For the regulation models, we built yield tables using five growth and yield models. These models were adjusted using data from a continuous forest inventory of a eucalyptus stand located in northern Minas Gerais, Brazil in an area of about 17,000 ha. The area is used for producing wood for charcoal and contains 13 different clones of *Eucalyptus* spp in a 3.0 x 3.0 m spatial arrangement.

2700 permanent plots of 600 m^2 were installed in the stand and the trees had their height and diameter at the breast height (*dbh*) measured in four different years (2005 thru 2008). Tables 1 and 2 show the statistics information of all measurement.

The data was used to adjust the whole-stand and the diameter-distribution models. When possible, we adjusted the models after arranging the data according to genetical material (clone) *stratrum*. The plots were grouped in bigger groups, called management units (m.u.), by having the same genetic material, age class and productivity capacity.

Site index

To determine the productive capacity of the stands, we defined site indexes using the guide-curve method (Clutter et al., 1983) with an index age of 60 months. The guide-curve method was adjusted for each genetic material using the logistic model (Draper and Smith, 1998):

$$Hd = \beta_0 (1 + \beta_1 e^{-\beta_2 Age})^{-1} + \varepsilon \tag{1}$$

where *Hd* denotes the dominant height, in meters; *Age* denotes the age in months; β_0, β_1 e β_2 are the model parameters, and ε is the random error $\varepsilon \sim NID(0, \sigma^2)$.

Yield tables and costs

The yield tables used in this study were built using five growth and yield modelling alternatives: four whole-stand (Models 1 to 4) and one diameter-distribution model (Model 5) as shown in Table 3.

Table 1. Number of trees per hectare of each clone.

Clone	2005	2006	2007	2008
A	1312	1294	1145	1053
B		1147	1086	1080
C		1214	1103	
D		1190	1091	
E	1131	1161	1100	1048
F		1137	1127	1083
G	1125	1156	1118	1061
H		1156	1104	1076
I	1103	1134	1068	1022
J	1306	1313	1222	1234
K	1138	1138	1087	1098
L	1115	1119	1099	1099
M	1179	1190	1139	1135
N	1308	1313	1226	1189

Table 2. Statistics for Dbh and height for each year.

Year	Min Dbh	Average Dbh	Max Dbh	Dbh standard deviation	Dbh variance	Min height	Average height	Max height	Height standard deviation	Height variance
2005	3.47	8.96	16.27	2.57	2.89	3.77	10.87	19.00	1.70	6.58
2006	4.04	9.74	20.05	4.58	4.08	3.63	11.67	24.00	2.02	21.01
2007	0.16	10.67	24.19	5.17	7.67	1.68	15.39	31.00	2.77	26.67
2008	3.28	10.77	25.24	6.37	8.45	3.00	15.79	47.20	2.91	40.55

The models were adjusted for each genetic material stratum, except those that contained insufficient data to fit a specific model; in this case, the models were fitted using all the data without stratification. The yield tables for each management unit were constructed using the results from the last inventory as the input. Five yield tables were obtained for each of the 341 management units using the fitted models. Productive capacity was used as an input in alternatives 2 and 4. The simulated costs were based on Melido (2012) study and timber price was set as €25.00/m^3. Brazilian currency (R$) values were converted to euros (€) using the conversion factor of 2.436 (€1.00 = R$ 2.436), as on 1 August, 2008 (European Central Bank, 2019), the last year that the plots were measured.

Projection errors

We used the correlation coefficients to evaluate the models' goodness of fit, bias, relative bias (bias%), and error variance to assess the estimation precision of timber stocks (Islam et al., 2009):

$$r_{y\hat{y}} = \frac{n^{-1}\sum_{i=1}^{n}(\hat{Y}_i - \hat{Y}_m)(Y_i - \bar{Y})}{\sqrt{n^{-1}\sum_{i=1}^{n}(\hat{Y}_i - \hat{Y}_m)^2 \, n^{-1}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}};$$

$$bias = \frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)}{n}; \quad Bias\% = 100\frac{\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)}{n}}{\frac{\sum_{i=1}^{n}(Y_i)}{n}}$$

$$Variance(\hat{Y}_i - Y_i) = \frac{\left[bias - (\hat{Y}_i - Y_i)\right]^2}{n-1}; \quad RSME = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{n}};$$

$$RSME\% = \frac{100\sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2}{n}}}{\frac{\sum_{i=1}^{n}(Y_i)}{n}}$$

where $\hat{Y}_i$ and Y_i are the estimated and observed production values and n is the number of permanent plots.

The models were categorised into four groups according to the magnitude and variance of relative bias (Figure 1). The groups are named: LBLV (low bias % and low variance), LBHV (low bias % and high variance), HBLV (high bias % and low variance), and HBHV (high bias % and high variance) (Islam et al., 2009).

Table 3. Models adjusted as alternatives to analyse their effects on the regulation of the production of eucalyptus stands.

Alternative	Statistical model
1 - Exponential	$V = \theta_0 + e^{\theta_1/AS} + \varepsilon$
2 – Logistic (1961)	$V = \dfrac{\theta_0}{1+\theta_1 e^{-\theta_2 AS}} + \varepsilon$
3 - Clutter (1963)	$LnB_2 = LnB_1\left(\dfrac{A_1}{A_2}\right) + \theta_0\left(1-\dfrac{A_1}{A_2}\right) + \theta_1\left(1-\dfrac{A_1}{A_2}\right)S + \varepsilon$ $LnV_2 = \beta_0 + \dfrac{\beta_1}{A_2} + \beta_2 S + \beta_3 LnB_2 + \varepsilon$
4 - Buckman (1962)	$V = \beta_0 + \beta_1 BHd + \varepsilon$ $LnICAB = \beta_0 + \beta_1 S + \beta_2 \dfrac{1}{A} + \beta_3 B_1 + \varepsilon$
5 - Nogueira (2003)	$d\min_2 = d\min_1 e^{-\theta_1 (A_2^{\theta_2} - A_1^{\theta_3})} + \varepsilon$ $Ln\gamma_2 = Ln\gamma_1 e^{-\theta_1 (A_2^{\theta_2} - A_1^{\theta_3})} + \varepsilon$ $d\max_2 = d\max_1\left(\dfrac{A_1}{A_2}\right) + \theta_1\left(1-\dfrac{A_1}{A_2}\right)\theta_2 + \varepsilon$ $\beta_2 = \beta_1\left(\dfrac{A_1}{A_2}\right) + \theta_1\left(1-\dfrac{A_1}{A_2}\right) d\max_2 + \varepsilon$ $N_2 = N_1 e^{\theta_1 (A_2^{\theta_2} - A_1^{\theta 2})} + \varepsilon$

V: volume in m³ha^{-1}; *A*: age, in years; *S*: site index (m) in the index age of 60 months, B: basal area, m²ha^{-1}; *ΔB*: basal area increase, m²ha^{-1} per year; *c*: constant of relative approximation on the sum of the maximum and minimum rates of basal area growth; *γ*: shape parameter of Weibull function, *β*: scale parameter of Weibull function; *dbh*: diameter at 1.3 m height (in cm); *dmax*: maximum diameter in cm; *dmin*: minimum diameter in cm, *N*: number of trees per hectare; *Δdbh*: diameter increment, cm per year; *BAL*: competition index measured by the sum of sectional area of trees with diameter greater than the evaluated tree, m², *H*: total height in m; *Hd*: dominant height in m; *Ddom*: the diameter of the dominant tree in cm, *D*: Square root of the diameter in cm, *Ln*: Napierian logarithm; *β0, β1, β2, β3e* θ_0: model parameters.

Forest production regulation

For the yield tables, cost worksheet, price of wood, and definition of regulatory rotation (6 years), planning horizon (18 years), and management prescriptions, we formulated the forest regulation model using linear programming (LP) model I (Leuschner, 1984; Dykstra, 1984), so named by Johnson and Scheurman (1977). The only difference between the five management plans was the yield table employed. We used the 12% annual interest rate. The management prescription was clear cut with 6 years followed by replanting. We consider that the genetic materials and yield of a plot does not change from one cutting cycle to another.

The objective function defined to maximise the total net present value (NPV) of the stand is as follows:

$$Maximize = \sum_{i=1}^{M}\sum_{j=1}^{N} C_{ij} X_{ij} \quad (2)$$

where,
C_{ij} denotes the NPV of management unit *i* assigned to prescription *j*;
X_{ij} denotes the area (ha) of management unit *i* assigned to prescription *j*;
M denotes the number of management units, M = 341; and
N denotes the number of alternative prescriptions.

The net present value (NPV) is calculated as Equation 3:

$$C_{ij} = \sum_{k=0}^{n} R_k (1+w)^{-k} - \sum_{k=0}^{n} C_k (1+w)^{-k} \quad (3)$$

where,
C_{ij} denotes the NPV management unit *i* assigned to prescription;
R_k denotes revenue at the end of period *k*, k = 0, 1, ..., 17;
C_k denotes final cost in period *k*, k = 0, 1, ..., 17;
w denotes interest rate = 0.12;
n denotes the max(k) = the horizon planning (18); and
k denotes period in years.

The area (4), production (5 and 6), and regulatory constraints (7)

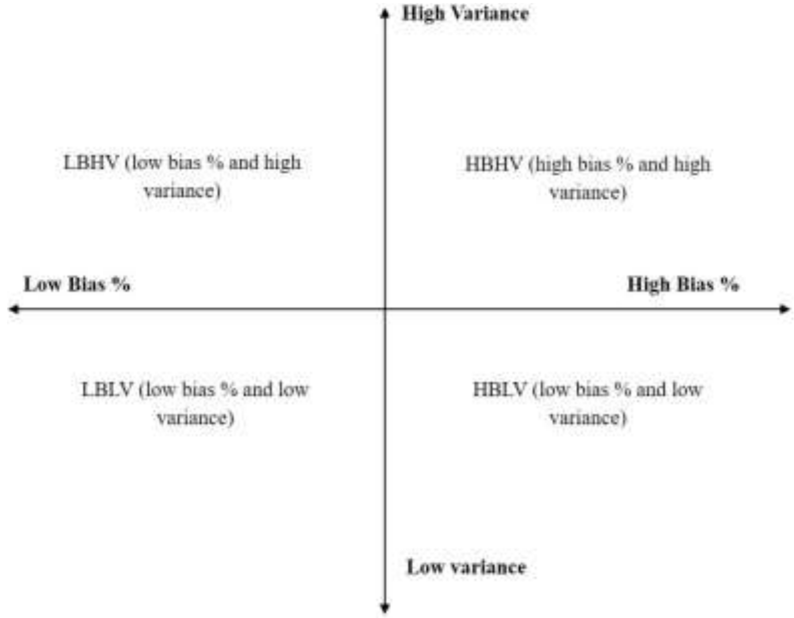

Figure 1. Categorization of measures of accuracy bias% and error variance of the volume estimations of the seven growth and yield modeling alternatives, with bias % and error variance crossing their medians.

are shown below:

$$\sum_{i=1}^{M} \sum_{j=1}^{N} X_{ij} \leq A_i \forall i = (1...m) \quad (4)$$

$$\sum_{i=1}^{M} \sum_{j=1}^{N} V_{ijk} X_{ij} \geq D\min \forall k = (0...h-1) \quad (5)$$

$$\sum_{i=1}^{M} \sum_{j=1}^{N} V_{ijk} X_{ij} \leq D\max \forall k = (0...h-1) \quad (6)$$

$$\sum_{i=1}^{M} \sum_{j=1}^{N} X_{ijt} \geq \frac{A_t}{r} \forall k = (1...r) \quad (7)$$

where,
A_i = Area of the *i*th management unit (i = 1, 2, ..., 341);
V_{ijk} = Volume (m^3) of management unit *i* assigned to prescription *j* at year k;
D_{min} *and* D_{max} = Minimum and maximum demand for timber in year *k;*
X_{ij} = area of the *i*th management unit in the *j*th prescription;
X_{ijt} = area of the *i*th management unit in the *j*th prescription, where trees have *t* years during the final period of the planning horizon; and
r = number of age class, equal to 6 years (regulatory rotation).

Five different management plans were generated using the yield tables resulted from the five growth and yield models tested. The results from the LP problems were compared in terms of their prognosis errors to detect their effect on the prescribed management plan. Additionally, the standard deviations of the costs and harvesting were considered to verify their uniformity during the planning horizon. The LP models were solved using Lindo Systems Inc. (http://www.lindo.com).

RESULTS

All models had satisfactory results, with correlation coefficients above 0.7. The whole-stand models better describe the volume yield, especially the Clutter et al. (1983) model, for the different clone *strata* with correlation coefficients from 0.87 to 0.98, indicating that the independent variables contributed effectively to explain the production variations. The results for each model are presented in Tables 4 and 5.

The categories defined for bias and variance values show that Model 3 is both most accurate and precise. From a comparison of the prognosis errors (bias), we verified that there is a direct relationship between the error categories and the total NPV from the optimization (Table 6). That is, the models with lower biases and variances yield a higher overall NPV. The obtained NPV has high amplitude, ranging from about € 50 (Model 5) to € 94 million (46.5% difference) (Model 3).

The complete formulation of the LP problem for yield regulation resulted in 16,401 decision variables (X_{ij}), with 341 area constraints. As only one restriction is required for each management unit, 18 demand constraints, one

Table 4. Estimates of the parameters of the growth and production models at the settlement level of alternatives 1, 2, 3, and 4 adjusted for each stratum and respective correlation coefficients genetic material.

GM	Alternative 1			Alternative 2				Alternative 3							Alternative 4			
	Exponential (V=f(*I*,*S*))			Logistic (V=f(*I*))				Clutter (1963)							Buckman (1962)			
	β_0	β_1	$r_{\hat{y}y}$	β_0	β_1	β_2	$r_{\hat{y}y}$	α_0	$r_{\hat{y}y}$	β_0	β_1	β_2	β_3	$r_{\hat{y}y}$	β_0	β_1	β_2	$r_{\hat{y}y}$
A	514.711	-1629.962	0.91	211.366	42.202	0.096	0.90	3.418	0.93	2.259	-9.211	0.015	1.125	0.96	17.402	3.017	4.051	0.87
B	841.612	-2111.571	0.82	105.942	297.489	0.172	0.82	3.617	0.79	1.294	-4.042	-	1.385	0.93	17.548	3.122	4.479	0.45
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	743.944	-1746.733	0.78	209.246	65.843	0.111	0.69	-	-	-	-	-	-	-	18.386	2.876	4.348	0.83
E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.988	2.722	5.431	0.88
G	670.872	-1918.402	0.85	171.197	236.906	0.167	0.85	3.824	0.50	0.427	-1.161	-	1.675	0.87	-	-	-	-
H	649.951	-1826.501	0.95	206.132	65.028	0.112	0.94	3.749	0.95	0.840	-4.008	0.001	1.529	0.98	20.164	2.527	4.723	0.86
I	521.662	-1666.443	0.84	209.246	65.843	0.111	0.82	3.681	0.94	0.864	-13.639	-	1.649	0.97	25.327	3.096	5.608	0.74
J	816.143	-1957.544	0.95	241.114	79.370	0.120	0.93	3.731	0.87	1.336	-13.132	0.004	1.385	0.98	15.623	3.269	4.661	0.80
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L	211.104	-1079.423	0.95	100.214	67.464	0.106	0.94	-	-	-	-	-	-	-	15.875	4.378	5.000	0.80
M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
General	635.010	-1740.821	0.91	209.246	65.843	0.111	0.89	3.707	0.95	0.965	-8.203	0.002	1.509	0.98	21.703	3.155	4.861	0.87

*($r_{\hat{v}v}$)= correlation coefficient; *GM*= genetic material.

Table 5. Estimates of the parameters of the stratified non-linear equations of alternative 5 and their respective correlation coefficients ($r_{\hat{v}v}$).

GM	Minimum diameter			Beta		Number of trees			Maximum diameter		Gama		
	θ_1	θ_2	$r_{\hat{y}y}$	θ_1	$r_{\hat{y}y}$	θ_1	θ_2	$r_{\hat{y}y}$	θ_1	$r_{\hat{y}y}$	θ_1	θ_2	$r_{\hat{y}y}$
A	1.2310	-1.0480	0.8000	-	-	-	-	-	-	-	-	-	-
B	1.0430	-1.0880	0.8610	-	-	-	-	-	-	-	-	-	-
C	-	-	-	0.8000	0.0630	-	-	-	-	-	-	-	-
D	-	-	-	0.8610	0.8280	0.0002	4.4240	0.5600	-	-	-	-	-
E	-	-	-	1.2200	0.9590	-	-	-	-	-	-	-	-
F	1.2980	-1.0630	0.4090	1.3180	0.2140	0.0100	3.0920	-0.0180	-	-	-	-	-
G	-	-	-	1.2930	0.9170	-	-	-	-	-	-	-	-
H	1.3930	-1.2450	0.8120	1.2490	0.8320	-	-	-	-	-	-	-	-
I	1.7060	-0.6420	0.8780	1.3110	0.9320	-	-	-	-	-	-	-	-

Table 5. Contd.

J	1.3760	-1.8450	0.7250	1.2290	0.8600	0.0050	3.0810	0.7320	-	-	-	-	-
K	-	-	-	-	-	0.0001	4.6250	0.6010	-	-	-	-	-
L	-	-	-	1.2410	0.2060	0.0020	3.2310	0.3810	-	-	-	-	-
M	-	-	-	1.1200	0.7940	-	-	-	-	-	-	-	-
N	-	-	-	1.0750	0.2540	-	-	-	-	-	-	-	-
General	1.3210	-1.1520	0.6570	0.8700	0.9590	0.9590	1.9770	0.7300	2.1550	0.9120	0.0020	2.1570	0.8860

*GM= genetic material.

Table 6. Categorisation of error measures of growth modelling and production alternatives.

Alternative	Model	|Bias%|	Variance	Category	RSME	RSME%	e%	Total NPV (€)
1	Exponential	1.92	3,421.94	LBLV	21.01	4.08	-2.24	87,075,185.81
2	Logistic (1961)	9.39	3,237.26	HBLV	28.46	7.04	-9.8	58,824,087.38
3	Clutter (1963)	2.72	3,021.99	LBLV	20.00	3.53	3.72	94,682,749.56
4	Buckman Mod (1962)	9.32	4,492.54	HBHV	30.67	4.12	-9.32	61,239,149.18
5	Nogueira (2003)	4.27	5,536.63	HBHV	39.43	5.31	2.95	50,643,657.87
Medium		4.27	3,421.94		28.46	4.12	-2.24	61,239,149.18

for each year of the planning horizon, and six regulatory restrictions were defined by the regulating age. For all five management plans, restrictions were met, but with differences in overall NPV, annual costs, and annual cutting area during the planning horizon (Table 7 and Figure 2).

In this study, the best model was a whole-stand model (Model 3) for both the overall NPV and evenness of harvested areas within the planning horizon. This model had the lowest standard deviation for annual harvested areas. Although Model 5 had the lowest standard deviation for annual costs, followed by Models 1, 4, and 3 (Table 7), it performed poorly on forest regulation and had the lowest NPV.

The differences in costs between Model 3 and Models 4, 5, 2, and 1 were -41.3, -7, 5, -6.2, and -5.0%, respectively. Conversely, the corresponding percentage differences in the total NPV were -35.3, 46.5, 37.9 and -8.0%, respectively. Therefore, even with fluctuating costs over the years, the profitability was at least 8% greater in Model 3.

By adopting the second-best modelling alternative (Model 1), based on the measures of precision, accuracy, the forest manager would have a reduction in the updated cost for the zero year of 5%. However, there would be an 8% reduction in return on investment (NPV). This and the results in Table 7 show the consequences of using inefficient modelling alternatives.

The use of a poor modelling alternative, such as alternative 4, would result in great chances of not reaching the objectives established when formulating the regulation model. Alternative 4 had resulted in a strong bias, with underestimation of production. Thus, the use of this alternative would result in a great chance of not meeting the management objectives over the planning horizon.

DISCUSSION

The Clutter et al. (1983) model was the most representative for the volume data used in this study. Whole-stand models are explicit, less complex, require less information and, therefore, have fewer errors (Soares et al., 2004; Oliveira et al., 2009; Scolforo et al., 2019). In relation to the

Table 7. Solution of the Linear Programming model using yield data for the 5 growth and yield model alternatives, where NPV is the maximization of the objective function, Area (ha) is the annual harvested area, and Cost (€ 103) is the cost during each period of the planning horizon.

PH	Model 1		Model 2		Model 3		Model 4		Model 5	
	Exponential		Logistic		Clutter (1963)		Buckman (1962)		Nogueira (2003)	
	NPV: 87,075,185.81		NPV: 58,824,087.38		NPV: 94,682,749.56		NPV: 61,239,149.18		NPV: 50,643,657.87	
	Area	Cost	Area	Cost	Area	Cost	Area	Cost	Area	Cost
0	2,062.50	210,404.02	2,054.10	99,519.32	2,679.90	145,286.49	2,315.50	459,600.87	1,506.80	302,172.34
1	2,451.60	160,036.46	2,791.10	135,230.36	3,041.90	235,369.28	1,500.00	615.94	2,981.00	384,036.30
2	3,147.40	447,142.61	2,785.40	242,421.71	2,941.70	370,347.35	2,628.80	381,679.11	2,279.10	335,843.72
3	1,751.40	343,860.76	3,177.10	588,114.85	2,530.70	434,858.33	2,457.20	119,052.68	2,934.50	142,176.90
4	2,548.30	329,184.33	2,784.90	516,292.20	3,083.00	482,830.94	2,507.50	121,489.18	2,298.60	171,960.91
5	3,111.60	177,116.17	2,474.10	119,867.61	3,292.00	159,498.75	3,500.00	1,437.19	2,575.90	140,293.11
6	2,829.60	144,263.46	2,722.90	136,929.74	2,578.30	124,918.41	2.31,3	263,161.79	2,392.40	309,606.78
7	2,732.40	173,640.13	2,799.10	136,774.57	2,494.80	155,927.77	2.89,6	137,770.66	2,923.60	296,318.73
8	2,474.90	362,285.47	2,794.00	244,094.69	2,503.30	254,728.49	1,800.00	739.13	1,181.20	224,999.96
9	2,822.00	434,486.39	3,011.20	588,235.00	2,618.20	509,998.03	2,102.50	409,545.11	1,579.10	310,245.14
10	2,120.80	425,290.81	2,507.50	502,853.45	2,832.90	568,113.54	1,445.20	289,810.91	1,427.70	286,309.20
11	2,800.00	135,659.67	2,800.00	135,659.67	2,934.50	142,176.90	2,934.50	142,176.94	2,934.50	142,176.90
12	2,800.00	135,659.67	2,800.00	135,659.67	2,934.50	142,176.90	2,934.50	142,176.90	2,934.50	142,176.90
13	2,800.00	135,659.67	2,800.00	135,659.67	2,934.50	142,176.90	2,934.50	142,176.94	2,934.50	142,176.90
14	2,800.00	237,528.03	2,800.00	237,528.03	2,934.50	248,939.15	2,934.50	248,939.10	2,934.50	248,939.10
15	2,800.00	545,409.60	2,807.70	546,917.26	2,934.50	571,611.67	2,934.50	571,611.66	2,934.50	571,611.67
16	2,800.00	561,506.18	2,800.00	561,506.26	2,934.50	588,481.58	2,934.50	588,481.54	2,934.50	588,481.54
17	3,531.80	171,117.73	2,800.00	135,659.67	2,934.50	142,176.90	2,595.20	125,735.15	2,342.90	113,511.23
SD	415.1	147,754.6	229.8	195,918.2	223.4	177,079.8	574	168,856.49	620	140,098.1

*SD= Standard Deviation.

other whole-stand models, the Clutter et al. (1983) model uses more explanatory variables other than age and site-index, making it more precise. Usually, models that consider only age as an independent variable do not explain yield variations properly (Silva et al., 2003; Nascimento et al., 2015; Novaes et al., 2017) and need maximum data classification. In this study, we have stratified data by genetic material, making these models specific and efficient for volume estimation. However, we would not recommend using this model for areas with no stratification.

The differences in NPV are associated with the predicted volume in each model. In some cases, the future volume of a stand is underestimated resulting in significant losses. In this study, the best model is a whole-stand model (Model 3) based on the yielded NPV. The same result may not be the same in different types of forests, especially if they do not have homogeneity in even-aged eucalyptus forests (Härkönen et al., 2010; McCullagh et al., 2017).

The lowest standard deviations for harvest and cost were obtained in Models 3 and 5, respectively. This is important because one of the benefits of regulation is maintaining regular employment, and lower standard deviations indicate a greater possibility of achieving this goal. For managers, less variation in annual harvest and annual costs facilitates the planting, harvesting, and replanting activities and workforce and equipment scheduling to perform those activities during the planning horizon (Rode et al.,

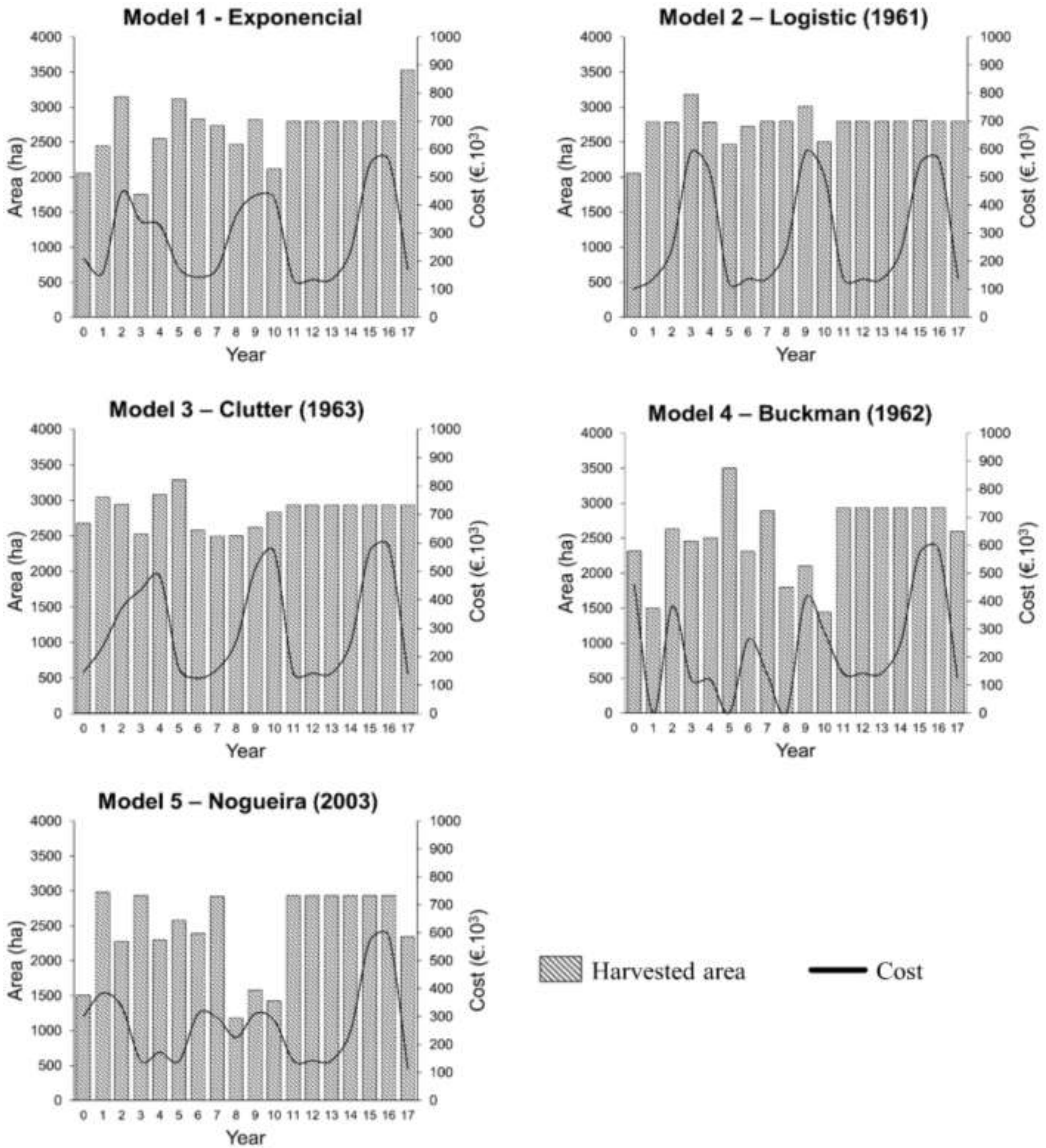

Figure 2. Linear programming model results using data from the five growth and yield models, where: Area (ha) is the annual cut area, represented as bars and Cost (€.10³) is the total cost in that year, represented as the smoothed lines.

2014; Oliveira Neto et al., 2020).

These results demonstrate the consequences of inefficient modelling alternatives. Poor modelling, as shown in Model 4, results to differences in cost, total

NPV, and annual harvesting areas, with similar results found in Silva et al. (2003). Since Model 4 resulted in a strong bias with a yield underestimation, using it would result in a higher probability of failing to meet management objectives during the planning horizon, with a possibility of producing excess wood in the annual cutting.

Conclusions

Choosing an inefficient modelling alternative, results in profound changes and uncertainties in the forest management plan. That is, the successful implementation of a management plan is dependent on the quality of the yield tables used. In this study, the management plan is more consistent when using the Clutter et al. (1983) model, fitted using the genetic material strata.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Relationship between leaf rolling and some physiological parameters in durum wheat under water stress

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Durum wheat is an important staple food in Morocco. Wheat and barley are mostly grown in drought prone areas in this country. Drought is the most limiting factor under Mediterranean climate. Leaf rolling ability has been identified as a potential selection criterion for drought tolerance in cereals. The objective of this study is to test this hypothesis. The role of leaf rolling in water stress tolerance was assessed in eleven Moroccan wheat cultivars. Trials were conducted under greenhouse conditions and three watering regimes simulating different drought levels were applied. Leaf rolling, leaf area, leaf specific weight and relative water content were recorded. The results indicated that the studied cultivars have shown significant differences in their leaf rolling (LR) under water deficit. The varieties *2777* and *Irden* showed the highest LR scored under these constraints. The variety *Marjana* showed the lowest LR score and expressed no LR ability under non limited irrigation treatment. Strong correlation have been observed between LR and relative water content (RWC) (r=0.923), and negative correlation was observed between LR and leaf area (LA, r=-0.783). Cultivars with high LR scores showed their capacity to control the negative impacts of water stress by keeping their physiological traits to adequate levels in order to maintain the main physiological activities of the plants. This result showed the important role of LR in water stress tolerance in the studied durum wheat cultivars.

Key words: Water stress, agro physiological traits, drought tolerance, leaf rolling, Morocco.

INTRODUCTION

In Morocco, durum wheat is one of the oldest cultivated cereal species. It is highly appreciated by Moroccan consumers, mainly for the preparation of bread and traditional products with an average consumption of

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around 90 kg/person/year (Taghouti et al., 2017). Morocco is ranked third in the Mediterranean region and first in the North Africa and Middle East region in terms of durum wheat acreage (Nsarellah et al., 2011). This crop is sown over 1.0 million hectares annually and 45% of which are in the arid and semi-arid regions. However, water availability for agriculture in these regions is an issue of growing concern because of the high evaporative demand (about 1500 mm/year) and the low and irregular rainfall (200-300 mm/year) (Bouizgaren et al., 2013). Furthermore, climate change is expected to increase the extents of drought and temporal climatic variation in the Mediterranean region (IPCC, 2007). Water stress limits wheat productivity in the drought-prone areas of Morocco where the average grain yield is low and variable, ranging from 0.5 to 1.2 t/ha (Jouve, 1988). Drought is the most important stress factor.

A viable solution for crop production in these areas is to develop drought tolerant varieties. In this respect, selection of durum wheat is mainly aimed at the creation of new genotypes with adaptive morphological and physiological characteristics, which could provide protection against drought (Sarieva et al., 2010). Leaf rolling is among morphological traits envisaged to maintain yield under water-limited conditions. It is considered as an important drought avoidance mechanism (Richards, 1996). Leaf rolling allows the plant under water stress to reduce its exposed leaf area and to reduce transpiration and gas exchange through the stomata. In addition, it is hypothesized that optimal operation of photosynthesis under drought could be sustained by changes of the rolling of the leaf blade (Price et al., 2002). Selection of cultivars with a capability for leaf rolling, which provides and increased drought tolerance, was used for rice (Dingkuhn et al., 1989), maize (Premachandra et al., 1993), sorghum (Corlett et al., 1994) and wheat (Omarova et al., 1995). In Morocco, durum wheat breeding program has been undertaken since the beginning of the twentieth century. Genetic improvement has led to the development of multiple modern durum wheat cultivars that are highly productive (Nsarellah et al., 2005). However, more information related to drought tolerance of these new cultivars is needed, in particular, the physiological role of leaf rolling which remains insufficiently studied.

The present study aims to assess water deficit effects on leaf rolling and some physiological parameters in eleven Moroccan durum wheat cultivars (*Triticum durum Desf*.), and to determine the relationship between several morphological and physiological traits under water deficit conditions.

MATERIALS AND METHODS

Plant material

The experiment was conducted on 11 cultivars of *Triticum durum* (*Irden*, 2777, *Sebou*, *Yassmine*, *Oumrabiaa*, *Isly*, *Marouane*, *Massa*, *Jawhar*, *Marjana*, *Korifla*). Ten varieties were selected and provided by the durum wheat breeding program at the National Institute for Agricultural Research of Morocco (INRA). One variety was selected by the International Center for Agricultural Studies in the Dry Areas (ICARDA) (Table 1).

Experimental conditions and design

Seeds of the studied durum wheat cultivars were surface disinfected with 5% sodium hypochlorite for 5 min and rinsed with deionized water several times, and then germinated at 25°C and total darkness in Petri dishes containing two imbibed layers of filter paper. Seedlings that were 6 to 7 days old were transferred to plastic pots that were 12 cm high and with a 6 cm diameter. The pots were previously filled with 5.0 kg of sterilized clay-loam soil and peat with a proportion of 3:1 (on dry weight basis). Pots were then placed in the greenhouse with a temperature of 27/20° (day/night), 49 to 70% of relative humidity and 16 h photoperiod (21 Klux).

A total of 66 pots containing 8 plants each were subjected to two irrigation treatments: the first treatments is a non-limiting water condition and at soil field capacity (FC) with a frequency of twice a week. The second treatment consists of water stressed conditions through stopping irrigation for one week from the end of the stem extension to the beginning of heading stages. The experiment was conducted during 5 weeks in three replications under homogeneous conditions. The plants at three leaves growth stage were harvested and several parameters were assessed.

Parameters assessed

Leaf rolling

Leaf rolling (LR) was assed visually in stressed and non-stressed plants using 0 to 7 scales (Table 2): 0 = no leaf rolling, 1 to 3= low rolling, 4 to 5 = intermediate rolling and 6 to 7 = complete rolling (Figure 1).

Leaf area

Leaf area (LA) was measured by using an area meter (LI-3100C AREA METER) and expressed in cm². The measurements were performed at the beginning of the heading stage on flag leaf.

Specific leaf weight

The specific leaf weight (SLW, $mgcm^{-2}$) is the ratio between the leaf dry weight (LDW) and the leaf area (LA). This is an indicator of leaf thickness or of leaf weight per unit leaf area, it is calculated as follows (Figure 1):

$$SLW = LDW\ A^{-1}$$

Relative water content (RWC)

Relative water content (RWC) was determined in 0.1 g of fresh leaflets weight (FW) from separate plants. The turgid weight (TW) of the samples were measured after keeping them for 4 h in deionized water, followed by complete drying in a hot air oven until a constant weight was reached then their dry weight (DW) were determined. RWC was calculated by using the following equation:

$$RWC\ (\%) = [(FW - DW) / (TW - DW)] \times 100.$$

Table 1. The studied wheat varieties and their main characteristics and adaptation zone.

Cultivar	Adaptation zone	Hessian fly resistance (S: Sensitive; R: Resistant)
Irden	Semi-arid, drought tolerant	R
2777	Favorable	S
Sebou	Semi-arid + favorable	S
Yassmine	Large	S
Oum rabiaa	Semi-arid	S
Isly	Large	S
Marouane	Semi-arid, drought tolerant	R
Massa	Large, rainfed	S
Jawhar	Large, Irrigated	S
Marjana	Large	S
Korifla (selected by ICARDA)	Large – Drought tolerant	S

Table 2. Leaf rolling scores utilized in this study.

Rolling class	Rolling index	Description
No rolling	0	Absence of rolling
Weak rolling	1	The tip of the leaf rolls up
	2	A quarter of the leaf rolls up
	3	One third of the leaf rolls up
Medium rolling	4	Half of the leaf rolls up
	5	More than half of the leaf rolls up
High rolling	6	Two third of the leaf rolls up
	7	Thorn shape of leaf fully rolled

Statistical analysis

Statistical analysis consists of a two-way analysis of variance (ANOVA II) and Tukey's grouping test. It was performed by using the SPSS 21.0 software (SPSS, Chicago, Illinois, USA 2012). Significant differences were determined at 0.05 probability level ($P < 0.05$), 0.01 probability level ($P < 0.01$) and at 0.001 probability level ($P < 0.001$).

RESULTS

Effect of water deficit on leaf rolling (LR)

Under non limited water conditions, none of the studied wheat cultivars have shown any leaf rolling. A wide variation in LR scores has been noted among all of the studied cultivars in response to limited water conditions (Figure 2). *Marjana* cultivar showed the lowest LR score (LR = 1). The maximum LR scores were reached by *2777* and *Irden* cultivars. In contrast, *Massa, Oum rabiaa, Marouane, Jawhar* and *Isly* cultivars showed low or moderate leaf-rolling abilities under stressed conditions.

Effect on leaf area (LA)

The results showed that water deficit has significantly ($P<0.001$) reduced the leaf area of flag leaves in all of the studied wheat cultivars with significant variations among them (Table 3). Under non water limited conditions, Irden and Oum Rabiaa cultivars showed the highest LA values of 15.3 ± 0.73 and 14.4 ± 0.82 cm^2, respectively. The lowest LA score, of 10.9 ± 0.68 cm^2 have been recorded on the variety *Marjana* under water limited conditions. This variety showed the lowest LA reduction rate (10.3%). The LA reduction rates were more pronounced in *Irden* and *2777* cultivars and were as high as 57.2 and 49.7%, respectively.

Effect on specific leaf weight (SLW)

The SLW was significantly ($P<0.001$) reduced under water stressed treatments in all of the studied cultivars (Table 3). *Isly* cultivar showed the highest SLW values of 2.62 ± 0.02 and 2.04 ± 0.03 mg cm^{-2} under well-watered

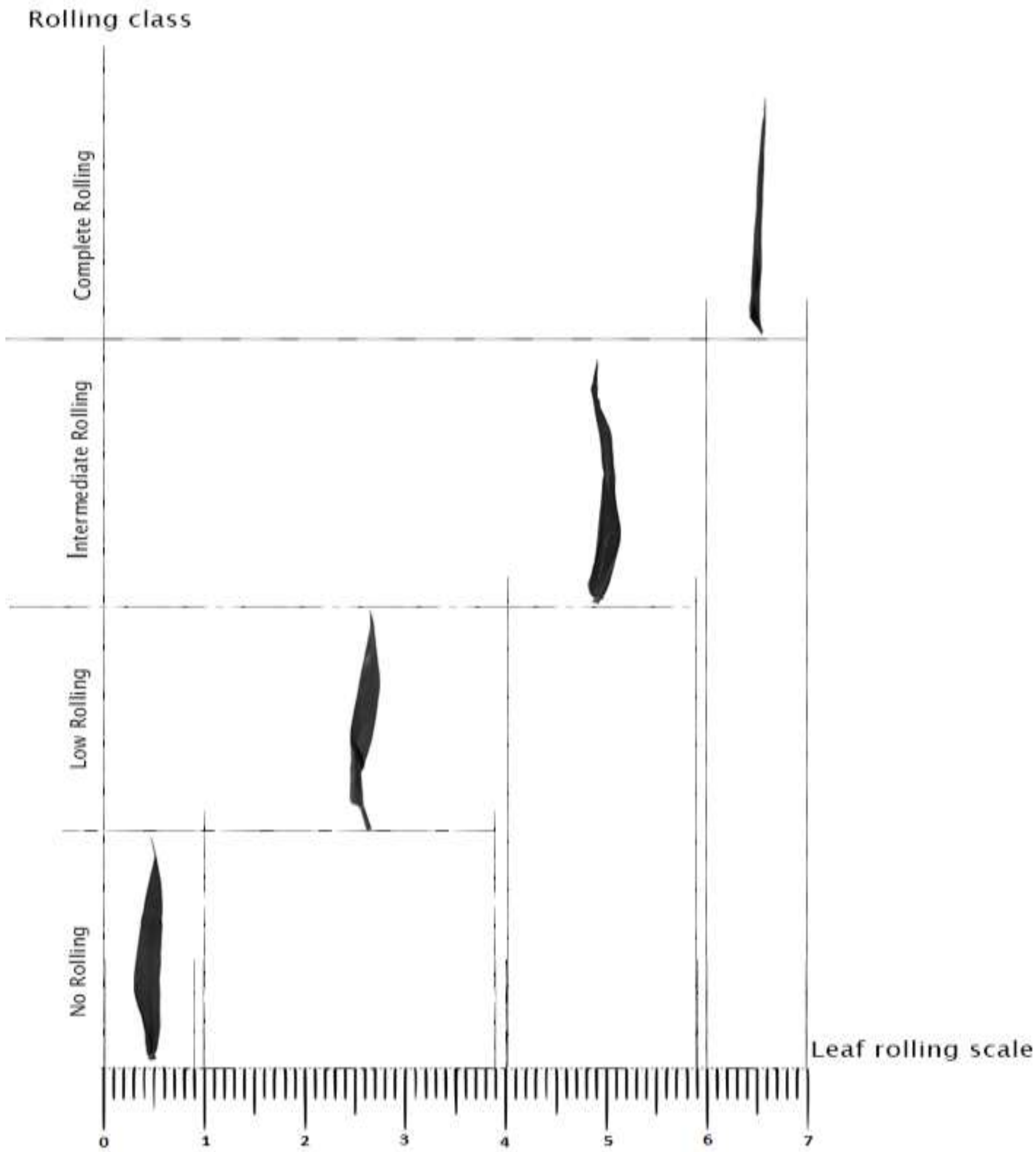

Figure 1. Visual leaf rolling ranking.

and stressed conditions, respectively. However, in terms of reductions under stress conditions, *2777* and *Irden* cultivars presented the lowest values (6.8 and 10.3%, respectively) while, Marjane variety has shown the highest reduction rate (33.1%).

Effect of drought stress on relative water content (RWC)

Water stress has exerted a negative effect on RWC in all of the studied cultivars under water deficit (Tables 3). Significant differences have been noted in the behavior of each studied cultivar. The highest RWC values of 81.8 ± 5.5 and 79.2 ± 2.2% were recorded for Irden and 2777 cultivars under water stress, respectively. Meanwhile, the lowest RWC values of 21.3 ± 4.4 and 45.8 ± 2.3% were recorded for Marjana and Isly cultivars under the same conditions.

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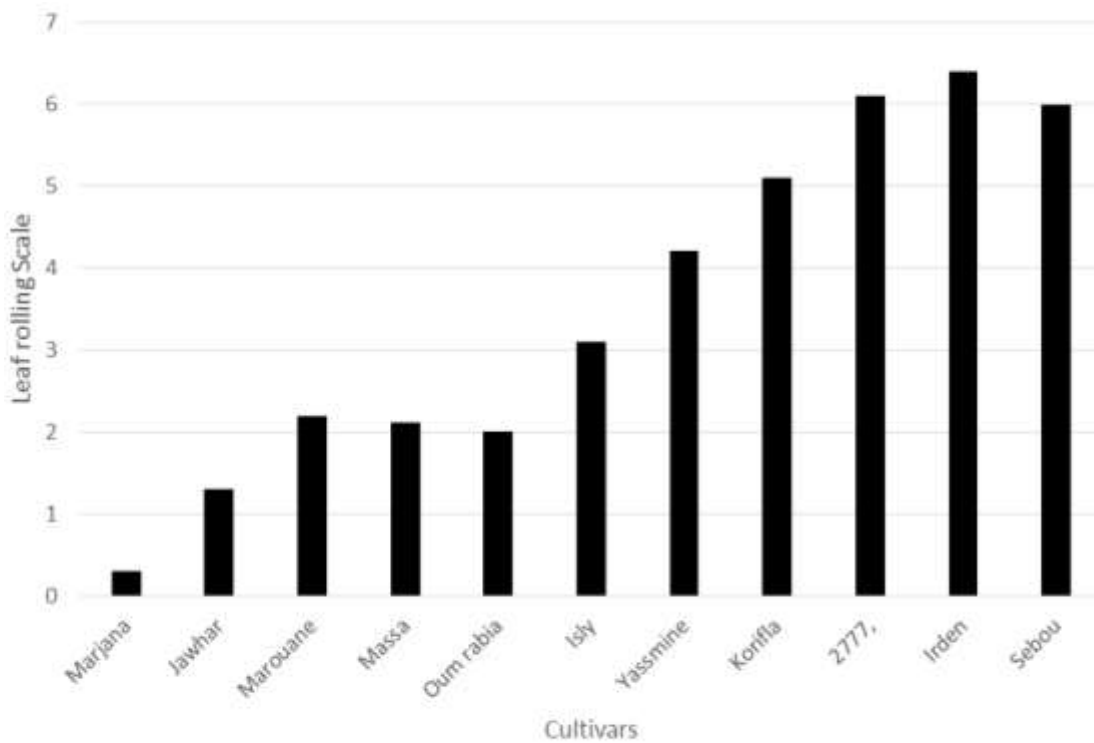

Figure 2. Leaf rolling score of studied durum wheat cultivars noted under water stress in greenhouse experiments.

Correlations between leaf rolling (LR) and agrophysiological traits and preservation of their performance under water stress

The correlations between leaf rolling and studied agro-physiological traits are shown in Table 4. A strong positive correlation is observed between LR and RWC (r=0.923, P<0.001). Strong negative correlations are shown between LR and LA (r= -0.783, P<0.001), and between LR and SLW (r= -0.407, P<0.001).

DISCUSSION

The irregular occurrence of drought periods influences the growth and yields of wheat cultivars grown in drought-prone regions of Morocco. Cultivation of drought adapted cultivars is the best approach to avoid yield loss under water deficit conditions. One of the essential defense adaptation mechanisms in plants to avoid drought damage is the maintenance of osmotic adjustment in the cells. This can be achieved by acting on some plant attributes such as the reduction of leaf size, or leaf rolling under a short-term water deficiency (Nemeskéri et al., 2012). In our experiment, the eleven wheat cultivars were visually assessed for leaf rolling ability under drought stress conditions as an indicator of plant water status. There was a marked variation among cultivars for this trait, and two cultivars *2777* and *Irden* were highly scored. This increased leaf rolling under drought stress would have the advantage of preventing water loss, respiratory losses, and of promoting a cooler leaf temperature and avoiding radiation damage (Pandey and Shukla, 2015). It may be considered as drought adaptive mechanism in wheat (Sarieva et al., 2010). Bogale et al. (2011) reported that genotypes with high LR presented more grain yield and high-water productivity in comparison with those of lower scores. This may lead to the conclusion that leaf rolling has positive effects on controlling the leaf expansion and stomatal water loss under water limited conditions. In this study, *Marjana* cultivar presented low LR score and expressed no ability of leaf rolling under both water treatments. This may lead to classify it as a sensitive cultivar to drought stress. According to the leaf rolling scores presented in Figure 2, the other cultivars were classified as moderately tolerant or moderately sensitive to drought stress.

The results showed that leaf area (LA) was negatively correlated to LR trait (r= -0.783, p<0.001) and to RWC (r=-0.580, P<0.001). Larbi and Mekliche (2004) reported that genotypes possessing the ability to maintain green leaf area duration "stay green" and high RWC traits throughout grain filling are potential candidates to assure yield in semi-arid regions. The importance of flag leaf in grain filling is well recognized. For grain filling to occur under drought, either a relatively uncompromised or a

Table 3. Effect of water limited conditions on leaf area (LA), specific leaf weight (SLW) and relative water content (RWC) of the Moroccan durum wheat cultivars.

Cultivar	Leaf area (LA) (cm^2)			Specific leaf weight (SLW) (mg cm^{-2})			Relative water content (RWC) (%)		
	Treatments			Treatments			Treatments		
	Non-limited water	Water stress	Reduction (%)	Non-limited water	Water stress	Reduction (%)	Non-limited water	Water stress	Reduction (%)
Marjana	10.9 ± 0.68^{a}	9.81 ± 0.79^{de}	10.3	2.49 ± 0.05^{g}	1.66 ± 0.03^{f}	33.1	84.8 ± 9.3^{a}	21.3 ± 4.4^{de}	75.0
Massa	13.1 ± 0.45^{bc}	10.77 ± 0.28^{ef}	18.2	1.94 ± 0.02^{d}	1.50 ± 0.03^{de}	22.3	91.5 ± 0.8^{cd}	52.5 ± 8.2^{ef}	42.5
Oum Rabiaa	14.4 ± 0.82^{c}	11.78 ± 0.43^{f}	18.3	$2.04 \pm 0\ .09^{e}$	1.57 ± 0.08^{e}	23.1	98.8 ± 0.4^{de}	53.5 ± 5.2^{f}	45.9
Marouane	12.1 ± 0.36^{ab}	9.49 ± 0.41^{cd}	21.2	1.69 ± 0.01^{c}	1.30 ± 0.01^{b}	23.5	86.5 ± 3.0^{ab}	47.8 ± 1.5^{cd}	44.5
Isly	13.7 ± 0.81^{c}	10.81 ± 0.75^{ef}	21.5	2.62 ± 0.02^{h}	2.04 ± 0.03^{h}	22.1	93.5 ± 2.4^{d}	45.8 ± 2.3^{ef}	50.7
Jawhar	13.2 ± 0.78^{bc}	10.44 ± 0.81^{de}	21.5	2.14 ± 0.05^{f}	1.68 ± 0.04^{g}	21.0	95.7 ± 1.4^{cd}	56.5 ± 4.2^{de}	41.0
Yassmine	11.3 ± 0.74^{a}	8.67 ± 0.60^{c}	23.8	1.68 ± 0.04^{bc}	1.42 ± 0.04^{c}	15.6	85.7 ± 4.8^{a}	66.0 ± 6.2^{c}	23.3
Korifla	13.6 ± 0.77^{c}	9.66 ± 0.68^{cd}	29.3	1.27 ± 0.03^{a}	1.08 ± 0.02^{a}	15.1	93.7 ± 3.1^{d}	69.0 ± 5.9^{cd}	26.5
Sebou	13.6 ± 0.17^{c}	7.19 ± 0.05^{b}	47.5	1.63 ± 0.05^{bc}	1.38 ± 0.07^{c}	15.5	91.0 ± 3.2^{d}	69.3 ± 4.8^{b}	23.8
2777	12.0 ± 0.72^{ab}	6.05 ± 0.43^{a}	49.7	1.62 ± 0.02^{bc}	1.50 ± 0.03^{de}	6.8	89.2 ± 2.1^{ab}	79.2 ± 2.2^{a}	11.2
Irden	15.3 ± 0.73^{d}	6.60 ± 0.51^{ab}	57.2	1.60 ± 0.01^{b}	1.44 ± 0.01^{cd}	10.3	90.7 ± 3.9^{e}	81.8 ± 5.5^{ab}	10.0
	df	**F**		**df**	**F**		**df**	**F**	
Irrigation	1	1267,8***		1	2618,35***		1	1760,15***	
Cultivar	10	42,2***		10	687,86***		10	52.03***	
Interactions	11	39,6***		11	43,61***		11	43.61***	

*Significance at 0.05 probability level. **Significance at 0.01 probability level. ***Significance at 0.001 probability level; NS: not significant at 0.05. Values are means of six replicates ± standard errors and superscript letters represent significance of Tukey's test at 0.05 probability level.

favorably reprogrammed function of flag leaf is required to maintain synthesis and transport of photo-assimilates (Pandey and Shukla, 2015).

Significant variation in specific leaf weight (SLW) has been observed in the studied wheat cultivars subjected to non-limited and deficit water conditions. Similar results were reported by Singh and Rajan (2009). Also, Semcheddine and Hafsi (2014) conducted an experiment on 10 durum wheat (*Triticum durum* Desf.) genotypes under rainfed conditions of Eastern Algeria and observed that SLW significantly differed among water treatments at heading and grain filling stages suggesting the possibility of selecting tolerant genotypes for drought tolerance under semi-arid condition. They reported that the variation in SLW was due to enhanced photosynthate translocation efficiency which is a function of leaf dry matter content. In this study and in relation with rolling leaf trait, low reduction in SLW was recorded under drought stress for *2777* and *Irden* cultivars which are characterized by their high leaf rolling ability. The two parameters were significantly and negatively correlated (r= -0.407, P=0.001) showing the role of LR in maintaining SLW under water limited conditions. A previous study indicated that flag leaf area and its active duration during grain filling has been considered as an essential trait in determining the grain yield (Khaliq et al., 2008). Richards et al. (2002), Wu (2009), and Zhang et al. (2009) reported that leaf rolling in rice (*Oryza sativa* L.) reduces LA, improves photosynthetic efficiency and delays senescence by reducing water loss via the regulation of transpiration through stomata and optimizing light transmission and by consequence increasing grain yield.

Water stress has produced a negative effect on RWC; thus, under stress conditions, all cultivars lost much more water than under normally irrigated treatment. Water deficit caused 10 to 75% RWC reductions of the leaves.

The studied cultivars were significantly varied in maintaining a stable RWC under both water stress and non-limited water conditions. This reduction

Table 4. Correlations between agro-physiological traits and rolling leaf measured under drought stress treatment in the 11 assessed durum wheat cultivars.

Correlation	Relative water content	Leaf area	Specific leaf weight	Rolling leaf
Relative water content	1			
Leaf area	-0,580** (P<0.001)	1,000		
Specific leaf weight	-0,414** (P=0.01)	0.334** (P=0.006)	1,000	
Rolling leaf	0.923** (P<0.001)	-0.783** (P<0.001)	-0.407** (P=0.001)	1,000

**Significant at P<0.05

under stress was also reported by Kumar et al. (2014). The reduction might be due to rapid decline in cell division and leaf elongation under drought. This result confirms the findings of a previous study on durum wheat (Mekliche et al., 1992), showing the effect of water stress on RWC in wheat plants. Under stressed conditions, cultivars with high leaf rolling ability (*2777* and *Irden)* showed their ability to restrict water loss. Significant positive correlation was observed between leaf rolling and RWC (*r*= 0.923, P<0.001). According to El Jaafari (2000), the ability of the plant to survive severe water deficit depends on its ability to restrict water loss through the leaf epidermis after the stomata have reached minimum aperture. During drought stress, plant water balance is disrupted and as a result, the RWC and water potential of leaves decreases (Bajjii et al., 2001). Changes in the RWC of leaves are considered to be a sensitive indicator of drought stress and to be a more useful integrator of plant water balance than the leaf water potential (Strauss and Agenbag, 2000). It has been reported also that highly leaf rolling rice genotypes presented high osmolyte accumulation and leaf RWC under drought stress (Swapna and Shylaraj, 2017). In addition to morphological responses, tolerant genotypes may accumulate more osmolytes in order to preserve the structural and the functional integrity of their cells (Mouradi et al., 2016). By using more than 200 rice genotypes, Cal et al. (2019) reported that several genotypes continue transpiration when rolling. They demonstrated that this mechanical response by bulliform cells to drought stress is not directly related to physiological process in rice. It could be useful to understand in detail of the LR relations by comparing large number of wheat genotypes in terms of several other physiological and biochemical traits before these traits could be used in drought tolerant genotypes selection.

Conclusion

Drought tolerance is a complex phenomenon involving many adaptation mechanisms. Among these mechanisms, leaf rolling induces a significant positive effect on RWC and on photosynthetic activity under stress conditions. Therefore, it is an important drought-avoidance mechanism and represents an important tool to be used in wheat-breeding program to select cultivars adapted to drought-affected environments.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment of the effects of water stress on seed yield of common bean genotypes

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Drought stress is among the most important abiotic factors that contribute to the significant yield reduction of common bean (*Phaseolus vulgaris* L.). Due to unreliable and poor distribution of rainfall, drought tolerance has become the important train in common bean in bean growing areas. The objective of this study was to evaluate 16 common bean genotypes for drought tolerance under three moisture regimes and identify genotypes with specific traits that improved tolerance to drought that could be recommended for released and become useful parents in the breeding programs. The experiment was conducted in Maruku, Bukoba under screen- house. Based on the drought stress indices which includes drought tolerance index (DTI), Harvest Index (HI) SMC 162, DAB 602, SSIN 1128, DAB 378, DAB 362 and SMR 101 had performed better than other tested genotypes. Also, the results showed that genotypes DAB 582, SRC 59, DAB 602, SSIN 1240, SMC 24, SMR 101 and DAB 362 were drought tolerant with lower and high value of the DSI and YSI respectively. Therefore, the later genotypes can be used in the future breeding programs as the parent for drought tolerance and also can used as a new varieties by farmers.

Key words: Moisture stress, common bean, seed yield, drought.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the main grain legume grown in Tanzania, where they are often intercropped with maize. Cultivation of beans can be seen in most areas of farming communities (Kilasi, 2012), with a great potential for improving human nutrition due to its high protein content (Manjeru et al., 2007), but the crop does not tolerate prolonged periods without rainfall, and to obtain a reliable yield in the drier areas a supplementary irrigation is required (Hillocks et al., 2006). Low yields are undoubtedly due in part to the direct effect of drought, and in part to the fact that dry areas are also hot spots where there is less capital investment (Beebe et al., 2013).

Maintaining crop yields under adverse environmental conditions is probably the major challenge facing the modern agriculture. To meet this challenge it is

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necessary to understand the contrasting adaptations of plants to grow in stressed and non- stressed conditions, and the compromises and trade-offs between them (Lizana et al., 2006). Given the high consumption rates of water by agriculture, constraints on water resources can be mitigated by the genetic improvement for drought stress (DS) tolerance by crop species (Porch et al., 2009).

Germplasm development of common bean has resulted in the release of a number of lines tolerant to DS and has led to a better understanding of the genetics of this trait. Drought tolerance, measured as seed yield, is an additive and quantitative trait with significant interaction with the environment. The presence of large genetic variability for drought tolerance is fundamental since it allows for selection of best varieties for breeding programs (Gustavo et al., 2003). Some studies indicate that grain yield of different common bean cultivars is not intrinsically associated with vegetative vigor at flowering and that mechanisms during pod filling can strongly influence the final crop yield. The establishment of a profuse root system during pod setting, associated with the continuous N and P acquisition during early pod filling, seems to be relevant for higher grain yields of common bean (Araujo and Teixeira, 2008).

Improved photosynthate acquisition, accumulation, and then remobilization have been observed as important mechanisms for adaptation to drought stress (Asfaw et al., 2012), which is considered one of the most important causes of yield reductions (Gustavo et al., 2003). Better remobilization of photosynthates to grain production is needed for the success of superior genotypes under stress (Polania et al., 2017). The stress tolerance index (STI) is defined as a useful marker to determine the potential of tolerance and yield under stress of the evaluated genotypes (Fernandez, 1992). Several studies have been conducted on drought stress indices (STI, MP, GMP, YI, HM and YSI) for screening genotypes under drought conditions (Sánchez-Reinoso and Gustavo, 2019), (Farshadfar, 2014). Other alternative indices useful for the identification of tolerant genotypes to water stresses have been proposed, such as drought susceptibility index (DSI) (Fischer and Maurer, 1978), Pod harvest index (PHI) (Stephanie, 2012), Harvest index (HI) (Monneveux et al. 2014). According to the study of Fernandez (1992), a suitable index or criterion is an index that is able to identify genotypes with a steady superiority that have a high correlation with yield in both stress and non-stress environments.

Drought susceptibility index (DSI) was found to be the most reliable index to identify drought tolerant genotypes, while drought intensity index (DII) and stability index (SI) were better suited to identifying intensity of drought at a location and grouping of drought tolerant genotypes, respectively (Kilasi, 2012). The genotypes that had DSI value lower than unit were selected as drought tolerant genotypes and those whose DSI values were higher than a unit, were selected as drought sensitive genotypes (Salyula, 2013).

Due to the importance of reproductive development in the drought stress (DS) response, germplasm evaluation of common bean is commonly conducted through the application of DS between pre-flowering and physiological maturity (Porch et al., 2009). Two dry matter partitioning indices have been shown to be relevant for improved drought resistance: pod partitioning index (PPI) which indicates the extent of mobilization of assimilates from the vegetative structures to pod formation, and pod harvest index (PHI) which indicates the plant efficiency in partition of photosynthates from vegetative shoot structures to pods and from pod wall to grain, which varies with the genotypes and is affected by drought. The ability of genotypes to partition stored vegetative biomass to reproductive organs to a large extent determines sink establishment and economic yield under drought stress (Chaves et al., 2002) which reduce biomass and seed yield (Muñoz-Perea et al., 2006).

The main objective of this study was to evaluate genotypes from 13 lines developed with specific traits to improve tolerance to drought and to be recommended as parents in breeding programs.

MATERIALS AND METHODS

Experimental site and materials

The study was conducted in screen house for two consecutive seasons; October – January 2017/2018 and February – May 2018 at TARI Maruku station which is located in Bukoba District, Kagera Region. During the experimental period, the minimum, mean and maximum temperatures were 14, 22 and 31°C respectively. A total of 16 common bean genotypes, 13 were introduced genotypes evaluated for drought tolerance from the International Center for Tropical Agriculture, CIAT, two released varieties (Lyamungu 90 and JESCA as drought check) and one landrace (Ibwera as local check) were used in the experiment (Table 1).

Experimental layout

The two – factors experiment was used in this study in layout in split – plot arrangement with three replications. The main – plot factor was water level/regimes with three levels and sub – plot factor completely randomized was common bean genotypes with 16 levels. The three levels of water were as follows: 75, 200 and 400 ml of water applied for treatment I (T1), II (T2) and III (T3) respectively, water was applied to the topsoil every day; the treatment III was considered as control.

A sandy clay loam soil was sieved through a 6 mm mesh sieve to remove large fragments and steam boiled at 100°C for three hours as a treatment measure against soil borne pathogens. Treated soil mixture containing soil, sand and farm yard manure in ratio of 1:1:1 was filled in the plastic pot (Nair and Bharathi, 2019). Each pot was filled with 5 kg of air-dried soil mixture and watered to field capacity. Four seeds were sown in each pot and one week after germination, seedlings were thinned to two seedlings per pot. All pots were well watered to field capacity in order to establish the trial until plants had three trifoliate leaves when the water stress was imposed.

Table 1. Characteristics of the common bean genotypes used under experimentation.

Genotype	Seed size	SCP[1]	SCS[2]	SBS[3]	GH
DAB 378	Large	R	2	3	Type I
DAB 219	Large	M	6	2	Type I
DAB 291	Large	M	6	3	Type I
SAB 659	Large	M	6	1	Type I
SCR 59	Medium	O	6		Type II
SSIN 1128	Medium	O	2	1	Type III
SSIN 1240	Medium	M	6	1	Type III
IBWERA	Medium	R	2	1	Type I
JESCA	Large	O	2	1	Type I
Lyamungu 90	Large	M	2	2	Type I
SMC 162	Medium	O	1	1	Type II
SMC 24	Medium	O	1	2	Type III
SMR 101	Large	O	1	1	Type I
DAB 602	Large	M	2	1	Type I
DAB 582	Large	R	2	1	Type I
DAB 362	Large	R	2	3	Type I

GH, Growth habit.
[1]CIAT Seed color Pattern: O – No pattern, M – Mottled, R – Striped, J – speckle, P – pinto, B – bicolor,
[2]CIAT Seed color Scale: 1 – white, 2 – Cream-beige, 3 – yellow, 4 – brown maroon, 5 – pink, 6 – Red
[3]CIAT Seed Brilliance Scale: 1 – Dull, 2 – Semi-Shine, 3 – Shiny.
Type I: Determinate habit, Type II: Indeterminate bush habits, erect stem and branches, Type III: Indeterminate bush habit with weak and prostrate stem and branches.

Data collection

Days to flowering and days to maturity were recorded as the number of days from planting to when 50% of plants in a pot had at least one open flower and when 75% of plants in a pot had at least 90% of their pods dried, respectively (Rezene et al., 2012).

The destructive sampling was done at mid – pod filling and harvest. At mid – pod filling, one plant per pot of each genotype were sampled from both moisture stress and non – stress treatments (Polania et al., 2016). Plants were cut above the soil surface and then separated into leaves (without petioles), stems and the remaining (pods and reproductive structures) plant parts. Those plant parts were oven dried for 48 h at 80°C and dry weight of each sample was measured to determine total dry matter production and dry matter distribution in the different plant parts (Asfaw and Blair, 2014). These data were used to determine dry matter partitioning indices:

Pod partitioning index (PPI), pod harvest index (PHI) and harvest index (HI).

At the time of harvest, a plant from each pot was cut and dry weights of stem, pod, seed, and pod wall, seed number per plant (SPP) and pod number per plant (PPP) were recorded. Data were also recorded for dry weights of stem biomass, pod biomass, seed biomass, and pod wall biomass (pod without seeds). The severity of drought stress on plant traits was estimated as follows:

Drought Intensity Index (DII) = $1 – X_{ds}/X_{ns}$,

Where X_{ds} and X_{ns} are the mean of all genotypes under Drought Stress (DS) and Non-Stress (NS) environments, respectively.

Drought susceptibility index (DSI) = $(1 – Y_{ds}/Y_{ns})$/DII

where Y_{ds} and Y_{ns} are mean yields of a given genotype under DS and NS conditions, respectively (Fischer and Maurer, 1978).

DII and DSI were derived from the grain yield data under the three moisture regime treatments (Kilasi, 2012).

Drought tolerance index (Fischer and Maurer, 1978):

$$\text{Drought tolerance index} = \frac{\textbf{Grain yield under stress}}{\textbf{Grain yield under normal irrigation}} \quad 1$$

Under such conditions, common bean genotypes with higher mean yields in NS and DS environments and lower DSI values are desirable (Terán and Singh, 2002). The geometric mean (GM), harvest index (HI), pod harvest index (PHI), pod wall biomass proportion (PWBP), pod partitioning index (PPI) were determined as described by Beebe et al. (2013).

(i) Geometric mean Productivity (GMP): this was determined for economic yield,

GMP = (Yns × Yds) 1/2

where ns is non-stress and ds is drought stress (Monneveux et al., 2014).
(ii) Harvest index (HI): seed biomass dry weight at harvest / total shoot biomass dry weight at pod – filing × 100 (Monneveux et al., 2014).
(iii) Pod harvest index (PHI): The PHI for each genotype is determined by seed biomass dry weight at harvest / pod biomass dry weight at harvest × 100 (Stephanie, 2012).
(iv) Pod wall biomass proportion (PWP) (%): pod wall biomass dry weight at harvest / pod biomass dry weight at harvest × 100 (Monneveux et al., 2014).
(v) Pod partitioning index: Pod (PPI) biomass dry weight (without

seeds) at harvest/total shoot biomass dry weight at mid – pod filling × 100 (Stephanie, 2012)

(vi) Yield Stability Index (YSi): Grain yield under drought stress /grain yield under non-stress (Kwabena et al., 2013).

(vii) Percentage Yield Reduction Rate (%YRR) was determined using formulae described by Fischer and Maurer (1978). YRR due to drought stress was calculated as [(mean value non-stress traits) - (mean value of drought stress trait)]/mean value of non-stress (Rezene and Zelleke, 2012).

Data analysis

Analysis of variance of the variables was done using GenStat Discovery Version edition 13 Computer program and means separation test was done using a Duncan's New Multiple Range Test (DNMRT). Relationships between selected parameters were determined using the Pearson's simple correlation test.

RESULTS AND DISCUSSION

Analysis of variance

Results of analysis of variance, including the interactions were always significantly affected by treatments (Table 2). However, genotypes x treatment interaction for all traits showed significant variation except for seed biomass and pod wall biomass. The genotype x treatment had no significant differences on root weight and number of pod per plant at 0.05 level of significance.

As it was reported by Kilasi (2012) that DSI was found to be the most reliable index to identify drought tolerant genotypes. The genotypes that had DSI value lower than unit were selected as drought tolerant genotypes and those with DSI values higher than a unit, were selected as drought sensitive genotypes (Salyula, 2013). Based on the DSI, results revealed that only genotype DAB 582, performed better because it had lower values of DSI which were – 1.00, while genotypes DAB 219, DAB 291, SSIN 1128 and SAB 659 were the least performed based on the DSI which were 1.4, 1.4, 1.6 and 2.2 respectively, as shown in Table 3.

Furthermore, the genotypes responded differently to the level of moisture stress imposed during the experiment, based on the percentage yield reduction rate (YRR). The genotypes with the lowest YRR values were DAB 582, SCR 59, IBWERA, and DAB 602, respectively 45, 0.0, 3.2 and 3.8. This means that these genotypes were drought tolerant, while the last four genotypes with the highest YRR values were SAB 659, SSIN 1128, DAB 291 and DAB 219 (Table 3). The genotypes with the lowest YRR values also had the highest values of yield stability index (YSI) as shown on the Table 3.

Association among traits

The study shows that number of pod per plant (NPP), pod wall weight (without seeds) (PWW), number of seeds per pod (NSPP), seed weight per plant (SWPP) and total pod weight (TPW) were positively correlated to each other in both stress and non – stress moisture condition as shown in the Table 5. The SWPP of the tested genotypes under moisture stress (T2) had shown a highly positive correlation with TPW (r = 0.99) and TSW (r = 0.87) while in non-moisture stress (T3) the association of the SWPP and TSW was increased by 0.11 to r = 0.98 this revealed that during the moisture stress the association of seed weight and total shoot weight is decreased to make sure that photosynthetic materials were relocated to economic part of the plant during moisture stress.

The NSPP was highly positive correlated with RL (r = 0.62) and RW (r = 0.59) in the moisture stress condition but in non-moisture stress condition the association of NSPP with RL was decreased by 0.20 to r = 0.42 with no significance while its association with RW was increased to r = 0.63, this means during the non-moisture stress condition plant gets enough water therefore there were no effect of extending root length. Exposure to drought affects total biomass and seed yield, photosynthates translocation and partitioning, root length and mass (Table 4).

As suggested, by Fernandez (1992), that a suitable index or criterion is an index that is able to identify genotypes with a steady superiority that have a high correlation with yield in both stress and non-stress environments. Thus, drought indices which provide a measure of drought based on yield loss under drought condition in comparison to normal condition have been used for screening drought-tolerant genotypes (Mitra, 2001). This study revealed that harvest index (HI), drought tolerance index (DTI), mean productivity (MP) and geometric mean productivity (GMP) were significantly difference with grain yield in both stress and non – stress moisture conditions. Therefore, the best indices to select common bean genotypes were HI, DTI, MP and GMP (Table 4).

Also, the study revealed a positive and significant correlation between grain yield and dry matter partition indices (PPI and PHI) in moisture stress condition (Table 4). This positive relationship indicates that genotypes with higher values of grain yield under drought stress are physiologically responsive to drought stress. (Zare, 2012; Sánchez-Reinoso et al. 2019; Farshadfar, 2014; Polania et al., 2016) have suggested that the drought resistance in common bean is associated with a more efficient dry matter partitioning to pod formation and grain production.

In this regards PHI could serve as a useful selection criterion for improving drought resistance because of its simplicity in measurement and its significant correlation with grain yield under both drought stress and non – stress conditions (Assefa et al., 2013). The genotypes Lyamungu 90, SSIN 1128, IBWERA SMR 101, SSIN 1240 were superior in their ability to partition greater proportion of biomass to pod while genotypes IBWERA,

Table 2. Analysis of variance.

Trait	PPP	SPP	EY	TSB	PBM	PWB	RL	RW	PWP	PPI	RSR
T	**	**	**	**	**	**	**	**	**	**	**
G	**	**	**	**	**	**	**	**	ns	**	**
G x T	ns	**	**	**	**	**	**	ns	*	**	*
CV%	4.0	16.6	15.9	12.8	15.0	14.6	3.8	14.2	4.0	5.7	20.3
S.E	0.2	1.2	0.3	1.2	0.8	0.5	0.3	0.2	1.9	2.9	2.65

T, Treatment: G, Genotype, G x T, genotype x treatment interaction: EY, Economic yield biomass (g $plant^{-1}$): TSB, Total Stem Biomass: PBM, Pod Biomass(g $plant^{-1}$): PWB, Pod wall biomass (g $plant^{-1}$g): SB, Seed biomass (g $plant^{-1}$): RL, Root length (cm): RW, Root biomass (g $plant^{-1}$): PPP, Pod per plant: SPP, Seed per pod: PWP, Pod wall proportion: PPI, pod partition index: RSR, Root shoot ratio: HI Harvest Index
*significant at P≤ 0.05: ** significant at P≤ 0.01: ns, no significant difference

Table 3. Selection indices for drought tolerance in response to grain yield under stress and non-moisture stress conditions of the 16 tested common bean genotypes.

Genotype	T2	T3	HI	PHI	DSI	DTI	MP	GMP	YRR	YSI	PPI
DAB 219	1.5	3.8	4.2	33.6	1.4	0.4	2.7	2.4	61.7	0.4	70.2
DAB 291	0.8	2.0	2.5	36.3	1.4	0.1	1.4	1.2	61.7	0.4	64.4
DAB 362	2.9	5.2	9.4	30.3	1.0	1.0	4.0	3.9	44.9	0.6	65.8
DAB 378	2.5	6.4	10.4	43.2	1.3	1.1	4.5	4.0	60.9	0.4	73.2
DAB 582	3.0	2.1	3.4	35.5	-1.0	0.4	2.5	2.5	-45.1	1.5	67.3
DAB 602	4.2	4.4	8.5	27.8	0.1	1.3	4.3	4.3	3.8	1.0	65.5
IBWERA	2.0	2.1	10.9	46.7	0.1	0.3	2.1	2.1	3.2	1.0	77.4
JESCA	2.1	3.8	6.9	29.5	1.0	0.6	3.0	2.8	44.7	0.6	68.2
LYAMUNGU 90	0.9	1.3	5.9	54.1	0.6	0.1	1.1	1.1	26.4	0.7	59.2
SAB 659	0.0	3.9	4.5	19.5	2.2	0.0	2.0	0.0	100.0	0.0	69.5
SCR 59	2.1	2.1	8.6	43.5	0.0	0.3	2.1	2.1	0.0	1.0	71.0
SMC 162	3.1	7.3	11.1	43.1	1.2	1.6	5.2	4.8	56.9	0.4	66.1
SMC 24	1.0	1.5	1.8	20.1	0.7	0.1	1.3	1.2	31.1	0.7	36.5
SMR 101	2.6	4.3	9.9	45.5	0.9	0.8	3.5	3.4	38.8	0.6	67.6
SSIN 1128	2.0	8.1	13.9	48.0	1.6	1.1	5.1	4.1	74.8	0.3	64.9
SSIN 1240	2.3	2.7	4.9	43.9	0.4	0.4	2.5	2.5	17.1	0.8	62.2

DSI, Drought Susceptibility Index; DTI, Drought Tolerance Index; MP, Mean Productivity; GMP, Geometric Mean Productivity; YRR, Yield Reduction Rate %; YSI, Yield Stability Index

Table 4. Correlation among seven indices with respect to grain yield of the 16tested common bean genotypes performances at moisture stress (T2) and non-moisture stress (T3) regimes.

Indices	Grain yield (T3)	Grain yield (T3)	PPI	PHI	HI	DSI	DTI	MP	GMP
T2	-								
T3	0.2^{ns}	-							
PPI	0.3*	0.1^{ns}	-						
PHI	0.2*	0.0	0.1^{ns}	-					
HI	0.2*	0.6**	0.3*	0.36*	-				
DSI	0.2^{ns}	0.3*	0.1^{ns}	0.0	0.0	-			
DTI	0.6***	0.7***	0.2^{ns}	0.0	0.5*	0.0	-		
MP	0.5*	0.9***	0.1^{ns}	0.0	0.6**	0.0	0.9***	-	
GMP	0.8***	0.6*	0.4*	0.1^{ns}	0.5*	0.0	0.9***	0.8***	-

PPI, Pod Partition Index; PHI, Pod Harvest Index; HI, Harvest Index; DSI, Drought Susceptibility Index ; DTI, Drought Tolerance Index ; MP, Mean Productivity ; GMP, Geometric Mean Productivity, *significant at P≤ 0.05: ** significant at P≤ 0.01: ns, no significant difference.

Table 5. Pearson's correlation coefficients, r, of the grain yield and other traits of the tested 16 genotypes under moisture stress (T2) (lower diagonal) and non-stress (T3) (upper diagonal) conditions.

Trait	NPP	PWW	NSPP	SWPP	TPW	SW	RL	RW	TSW
NPP	-	0.79**	0.97**	0.86**	0.82**	0.31^{ns}	0.39 ^{ns}	0.60*	0.84**
PWW	0.80**	-	0.75**	0.98**	0.99**	0.20^{ns}	0.13 ^{ns}	0.50*	0.97**
NSPP	0.86**	0.77**	-	0.83**	0.78**	0.31^{ns}	0.42 ^{ns}	0.63**	0.80**
SWPP	0.78**	0.96**	0.76**	-	0.99**	0.23^{ns}	0.16 ^{ns}	0.51*	0.98**
TPW	0.79**	0.99**	0.77**	0.99**	-	0.21^{ns}	0.14 ^{ns}	0.51*	0.98**
SW	0.07 ^{ns}	0.25 ^{ns}	0.11^{ns}	0.19 ^{ns}	0.22 ^{ns}	-	0.00 ^{ns}	0.03 ^{ns}	0.40 ^{ns}
RL	0.41^{ns}	0.42 ^{ns}	0.62**	0.31 ^{ns}	0.38 ^{ns}	0.42^{ns}	-	0.69**	0.13 ^{ns}
RW	0.45 ^{ns}	0.28 ^{ns}	0.59*	0.32 ^{ns}	0.29 ^{ns}	0.13^{ns}	0.69**	-	0.49 ^{ns}
T SW	0.66 ^{ns}	0.90**	0.64**	0.87**	0.89**	0.61**	0.49 ^{ns}	0.30 ^{ns}	-

NPP: Number of pod per plant, PWW: Pod wall weight (without seeds), NSPP: Number of seeds per plant, SWPP: Seed weight per plant, TPW: Total pod weight, SW: Stem weight, RL: Root length (Tap root), RW: Root weight, TSW: Total shoot weight.
*significant at P≤ 0.05: ** significant at P≤ 0.01: ns, no significant difference.

Table 6. Average, minimum, maximum and percentage reduced of four selected traits 16 common bean genotypes at three different moisture regime levels.

Trait	Average			Minimum			Maximum			Percentage reduced	
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2
Economic yield (EY)	0.50	2.07	3.81	0.00	0.60	1.27	1.13	4.20	8.07	86.88	45.67
Number of pod per plant (PPP)	1.08	5.19	8.19	0.00	1.50	2.00	3.33	8.67	13.00	86.81	36.63
Number of seed per pod (SPP)	1.40	3.42	4.63	0.00	1.00	3.00	3.00	5.00	6.00	69.76	26.13
Root length (RL)	4.73	12.43	11.94	0.00	7.30	8.17	12.00	18.17	20.17	60.39	-4.10

T1, Treatment 1: T2, Treatment 2: T3, Treatment 3:

DAB 378, SCR 59, DAB 219 and SAB 659 were superior in partitioning its biomass to grain production after being exposed to moisture stress environment (Table 3). As showed in the Table 5, NPP, PWW, NSPP, SWPP and TPW were highly positive and significant to each other in both moisture stress (T2) and non-moisture stress (T3) environment, also the results revealed that the RW had a positive and significant association with most of the traits except TPW in non-moisture stress but it was observed that RW had positive and significant association with NSPP only in moisture stress environment.

Root length (RL) had a positive significant effect on NSPP in moisture stress environment while had no significant in non-moisture stress environment, this means that during the moisture stress plants had potential to extend its tap roots deeper to extract more water from the soil; the previous study by Ndimbo (2015) reported the same result (Table 6). The yield and yield components economic yield (EY), number of pod per plant (PPP), number of seeds per pod (SPP) together with root length were used to assess the responses of the genotypes to different level of the water regime. The genotypes responded differently against moisture level, the T1 reduces economic yield, number of pod per plant, number of seed per pod and root length of the genotypes by 86.88, 86.81, 81.00 and 60.39% respectively, while the T2 had reduction of the same by 45, 36.63, 41.25 and -4.10% of the reduces economic yield, number of pod per plant, number of seed per pod and root length respectively as shown on Table 7. The reduction in economic yield of the genotypes after imposition of the moisture stress was associated with the decrease in photosynthate assimilation and poor carbohydrate partitioning to the developing grain while reduction in number of pods per plant in drought – stress as compared to the non-stress condition, may have been due to a reduction in flower fertilization under drought-stress conditions. Darkwa et al. (2016) suggests that common bean responds to drought stress by increasing root growth. Yield-component traits are generally good indicators of overall drought stress (Darkwa et al., 2016). This study revealed the significant reductions of the number of PPP and SPP under moisture stress similar as reported by Darkwa et al. (2016), Asfaw and Blair (2014) and Lizana et al. (2006).

The average yield effects of all tested genotypes were 0.5 and 2.06 g plant $^{-1}$ treatment 1 and 2 respectively which give a yield reduction rate of 86.88 and 45.67% respectively, while the non-stress treatment had an average of 3.81 g plant^{-1}. The study revealed two

Table 7. Mean economic yield (g/plant) of the 16 tested genotypes under three moisture regime treatments.

Genotype	Yield (g plant $^{-1}$)				RSR		PWP%		PPI		PHI	
	T1	T2	T3	Mean	T2	T3	T2	T3	T2	T3	T2	T3
DAB 219	0.0	1.5	3.8	1.8	7.5	8.7	61.8	60.7	37.7	70.2	56.3	44.6
DAB 291	0.7	0.8	2.0	1.2	12.7	15.3	40.7	60.3	47.9	64.4	37.3	50.0
DAB 362	0.0	2.9	5.2	2.7	6.4	10.0	59.7	61.2	74.5	65.8	47.8	43.0
DAB 378	0.9	2.5	6.4	3.3	18.5	10.1	53.8	64.3	64.6	73.2	55.9	39.0
DAB 582	0.3	3.0	2.1	1.8	4.4	25.8	38.9	60.8	43.2	67.3	31.3	50.5
DAB 602	0.0	4.2	4.4	2.9	6.4	9.9	62.6	63.0	63.1	65.5	42.1	41.4
IBWERA	0.5	2.0	2.1	1.5	15.4	17.5	65.0	61.9	57.8	77.4	52.3	50.8
JESCA	0.0	2.1	3.8	2.0	9.5	11.0	66.0	61.1	73.3	68.2	44.2	44.3
LYAMUNGU 90	1.0	0.9	1.3	1.1	36.7	22.4	62.4	62.2	72.7	59.2	57.7	50.3
SAB 659	0.2	0.0	3.9	1.4	0.0	9.3	0.0	62.0	0.0	69.5	0.0	43.1
SCR 59	0.9	2.1	2.1	1.7	32.0	32.1	61.1	65.5	67.0	71.0	50.0	43.9
SMC 162	1.1	3.1	7.3	3.8	16.3	7.4	57.1	57.2	67.2	66.1	50.1	45.8
SMC 24	0.0	1.0	1.5	0.8	13.0	7.5	45.9	42.0	45.3	36.5	29.8	30.6
SMR 101	1.1	2.6	4.3	2.7	25.7	14.5	58.6	57.4	73.6	67.6	51.1	47.7
SSIN 1128	1.1	2.0	8.1	3.7	22.5	10.2	63.3	59.5	60.5	64.9	45.9	43.7
SSIN 1240	0.1	2.3	2.7	1.7	34.8	13.3	54.7	60.3	72.2	62.2	60.7	48.7
AVERAGE	0.5	2.1	3.8	2.1	16.4	14.1	53.2	59.9	57.5	65.6	44.5	44.8

RSR, Root – Shoot ratio: PWP, Pod wall proportion: PPI, Pod partition index, T1, Treatment 1; T2, Treatment 2; T3, Treatment 3.

genotypes DAB 582 and SCR 59 were able to increase its yield by 45.1% under moisture stress (T2) and maintaining the yield regardless of the stress respectively. DAB 582 performed well under moisture stress during its ability to reduced root to shoot ratio and pod wall proportional by 83% and 36.0% respectively.

Genotype SAB 659 did not performed at all in moisture stress (T2) because all plants wilted.

The effects of moisture stress on dry matter distribution

Two dry matter partitioning indices have been shown to be relevant to improved drought resistance: pod partitioning index (PPI) which indicates the extent of mobilization of assimilates from the vegetative structures to pod formation (Rao et al., 2013). The study revealed that the dry matter distribution of the 16 genotypes responded significantly to the moisture stress. Drought stress caused the significant reduction of the average pod partitioning index by 8% from 65.56 in no stress treatment (T3) to 57.55 in stress treatment (T2) (Table 7).

Root shoot ratio (w/w)

The ratio of the root biomass and the total shoot biomass revealed that DAB 582, DAB 362, DAB 602 and DAB 219 genotypes had lower ratio when subjected to the moisture stress (T2) compared to other genotypes with the average scores of 4.36, 6.4, 6.44 and 7.54% respectively while Lyamungu 90, SCR 59, SMR 101, DAB 378 had higher ratios of 36.68, 31.97, 25.74, 18.51 respectively (Table 7). In non-moisture stress treatment (T3) SMC 162, SMC 24, DAB 219 and DAB 659 were the first four genotypes which had lower ratio of the root to shoot biomass with the values of 7.42, 7.51, 8.67 and 9.26% respectively. While SCR 59, DAB 582, Lyamungu 90 and IBWERA genotypes had higher percent of the root biomass to total shoot biomass.

Pod wall proportion

Pod wall proportions (PWP) of the tested genotypes

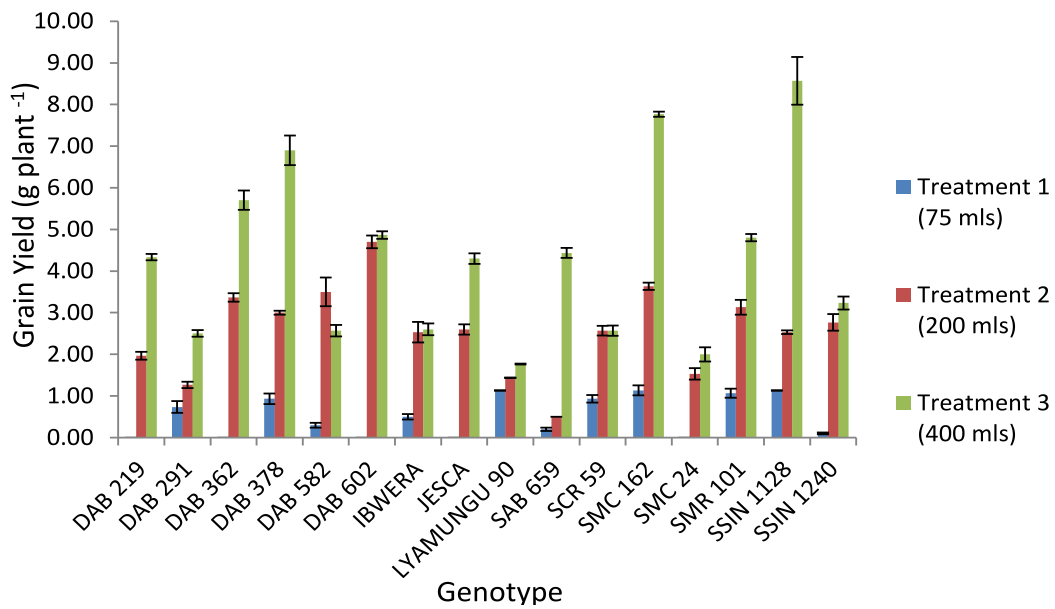

Figure 1. Mean economic yield of the 16 tested genotypes under different moisture regime treatments.

were also differed significantly with respect to the moisture stress treatments. It was observed that the average pod wall proportion of the tested genotypes was dropped from 59.94% in no stress treatment to 53.20% in stress II treatment. The study also revealed that DAB 582, DAB 291, SMC 24 and DAB 378 were the genotypes that had lower contribution to pod wall biomass when subjected to the moisture stress (T2) compared to other tested genotypes with 38.88, 40.65, 45.9 and 53.83% of the pod wall biomass in the pod biomass respectively. While the last four genotypes JESCA, IBWERA, DAB 602, Lyamungu 90 had higher contribution of the pod wall biomass to the pod biomass of 65.97%, 64.96%, 62.60%, 62.43% respectively. In the non-moisture stress treatment (T3), the SMC 24 had lower contribution of the pod wall biomass of 41.97% to the pod biomass compared to other genotypes as shown in the Table 7.

Pod partitioning Index

The pod dry matter partition index revealed that DAB 362, SMR 101, JESCA and Lyamungu 90 were the genotypes which had higher PPI values of 74.48, 73.59, 73.28 and 72.73% respectively for the T2 but in T3, IBWERA, DAB 378, SCR 59 and DAB 219 had performed better than other genotypes as shown in the Table 7.

Effect of drought stress on seed yield and yield components

Figure 1 reveals that in treatment 1 genotypes SMC 162, SSIN 1128, SMR 101 and Lyamungu 90 were the ones which perform best among the tested with the mean economic yield of 1.13, 1.13, 1.07 and 1.00 g plant^{-1} respectively, while in the treatment 3 genotypes DAB 602, SMC 162, DAB 582, DAB 362 and SMR 101 were performed better than others with the mean yield of 4.37, 3.13, 3.00, 2.88 and 2.63 g plant $^{-1}$. For the case of the treatment 3 the mean performances of the genotypes SSIN 1128, SMC 162, DAB 378, DAB 362 and DAB 602 were higher compared to others which were 8.07, 7.27, 6.4, 5.2, 4.37 g plant $^{-1}$. Genotypes SSIN 1128 and SMC 162 had performed better under non-moisture stress condition compared to others but were highly sensitive to moisture stress as it reduced its seed yield by 74.8 and 56.9% respectively under moisture stress (T2) which was different to other genotypes such as DAB 602, DAB 362 which reduced its yield by 3.8 and 44.9% respectively under the same condition. Also the results revealed that genotype DAB 582 had performed better under moisture stress (T2) by increased yield of 45.1% this genotypes was able to remobilize the photosynthates to economic part of the plant while the genotype SCR 59 stabilized its yield regardless of the moisture stress condition (Table 3).

Conclusion

The current study revealed that there were a positive and significant association between the grain yield of the tested genotypes and the dry matter partitioning indices; PPI, PHI, HI, and DTI in moisture stress environment, this meant during the drought stress, plants had ability to partition its photosynthates from the vegetative structures to pods and grain production. It was also observed that there were a positive association (r = 0.62 **) of the tap root length and the number of seeds per pod during the moisture stress environment. Genotypes SMC 162, DAB 602, SSIN 1128, DAB 378, DAB 362 and SMR 101 had expressed their superiority in tolerating moisture stress with higher values of HI and DTI Harvest index (HI) has proved to be an important trait to breeders in identifying genotypes that are adapted to drought stress through better photosynthates mobilization.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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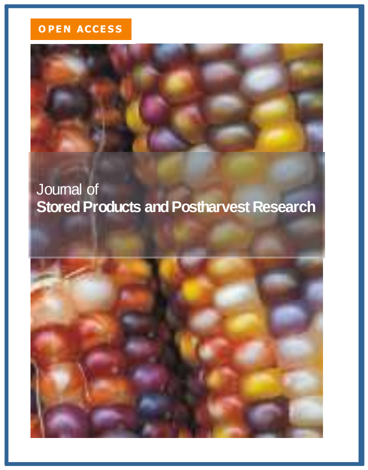

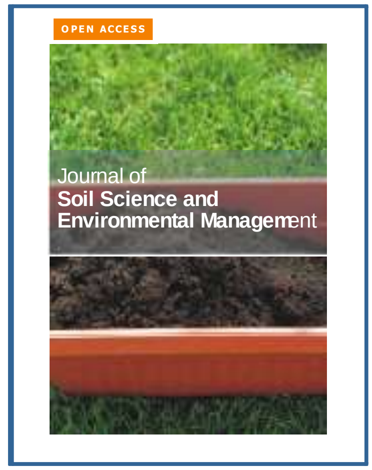

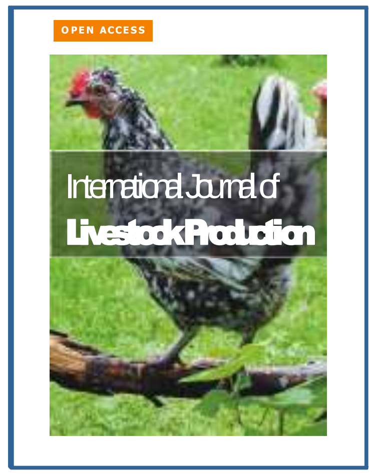

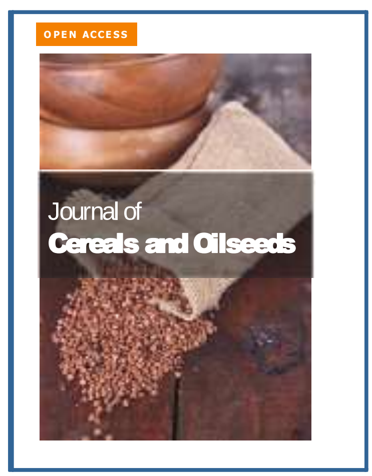

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