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Full Length Research Paper

Phenotypic variability and association of traits among yield and yield-related traits in Castor (*Ricinus communis* L.) accessions at Melkassa, Central Rift Valley of Ethiopia

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A field experiment was conducted to study the genetic variability and association of characters among yield and yield-related traits in castor accessions at Melkassa, central rift valley of Ethiopia during the off season of the 2013/2014. A total of 48 castor accessions were evaluated by using randomized complete block design with three replications. Analysis of variance revealed that there was highly significant difference among the accessions for most of the characters studied. For all traits, phenotypic coefficient of variation was highly higher than genotypic coefficient of variation; this indicates that there was environmental influence on these traits. Those characters which brought high heritability and genetic advance including the moderate one indicate that these characters could be improved through selection easily. Seed yield had positive and significant phenotypic and genotypic association with number of capsules per plant (NCP), number of seeds per plant (SP), number of primary branches per plant (PB), number of secondary branches per plant (SB), length of inter node (LIN), and number of inflorescence per plant (NIP). Oil content (OC) had positive and significant genotypic correlation with seed yield.

Key words: Ethiopia, castor (*Ricinus communis* L.), correlation, genetic variability, oil content.

INTRODUCTION

Castor (*Ricinus communis* L.) belongs to the family of Euphorbiaceae and genus *Ricinus*. It is a diploid plant with chromosome number of 2n=20 (Goodarzi et al., 2012) adapted from lowlands to highlands. It is indigenous to Eastern Africa probably Ethiopia (Anjani, 2012). The plant tolerates moisture stress but not saline or poorly drained soils and requires 600 to 700 mm of rainfall or supplemental irrigation during the growing season (Weiss, 2000). Castor oil is non-edible and has been used almost entirely for pharmaceutical and industrial applications. Castor is a valuable oilseed crop that provides almost the entire world's supply of hydroxy

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fatty acids. It is used in varnish, paints, detergent, pharmaceuticals, and synthetic polymers industries. Its oil does not freeze even at high altitudes and it is one the best lubricants for jet engines (Hafiz et al., 2012).

Knowledge of genetic and phenotypic diversity in a germplasm is important for the genetic improvement of crop plants. The objective of any breeding program is to develop desirable genotypes with high yield potential and better quality. Selection is an integral part of breeding program by which genotypes with high productivity in a given environment are selected (Blessing et al., 2012). However, selection for high yield is made difficult by the complex nature of this trait. The polygenic inheritance of yield components makes selection more difficult (Singh et al., 2011).

Most of the time, traits are correlated and knowledge of the relationships among various quantitative and qualitative traits is an essential aid to the choice of appropriate parameters to be used as selection indices (Abimiku et al., 2012). The breeding strategy to derive high yielding cultivar depends upon the nature and magnitude of variation for different yield components, the assessment of genetic parameters like phenotypic coefficient of variation, genotypic coefficient of variation, heritability and genetic advance is a pre-requisite for making effective selection.

There exists quite abundant castor germplasm available in Ethiopia (Abebe et al., 1992). However, the country has not benefited from the available plant genetic wealth as a result of poor research and development. Nevertheless, there exists breeding and agronomy research in a limited scale (Getinet et al., 2011). However there has never been scientifically planned study on the variability of castor germplasm. Therefore, Considering the importance of genetic variability as a basic breeding tool for improvement, this study was conducted to evaluate the genetic variability and selection of suitable diverse parents for yield and related traits in future breeding programme.

MATERIALS AND METHODS

Description of the study area

Forty eight accessions of castor were planted at the experimental farm of Melkassa Research Center, situated in Central Rift Valley of Oromiya region, Ethiopia during the off season under irrigation. Melkasa is located at 8° 24'N, 39° 12'E, 1550 masl in the hot to warm sub-moist rift valley in the central part of the country and receives an average annual rainfall of 680 mm.

Plot size was four rows spaced at 80 cm apart, 60 cm between plants and 6 m long. The design of the experiment was randomized complete block design (RCBD) with three replications. The experimental plots were plowed twice and harrowed once and ridges were made at 80 cm using tractor. Seeds were planted at two seeds per hill and thinned to a single plant after growth. No fertilizer or pesticide was applied. All plots received the required irrigation every 7 days until maturity. Data was collected based on an average of five randomly selected plants and plot basis. Five representative plants per plot were randomly selected from the central rows excluding the two border rows and tagged for observations.

Statistical analysis

Analysis of variance

The plot mean values were subjected to statistical analysis according to the procedure of randomized complete block design for each trait as shown on Table 2 (Gomez and Gomez, 1984). Data were subjected to Analysis of Variance (ANOVA) using GLM procedure in SAS statistical software (SAS, 2002) (Table 1).

Estimation of genetic parameters

The phenotypic and genotypic coefficients of variation were estimated according to the method suggested by Burton and de Vane (1953) as follows:

Environmental variance ($\sigma 2e$) = MSE (mean square)

Genotypic variance ($\sigma^2 g$) = MSg – Mse / r

Phenotypic variance ($\sigma^2 p$) = $\sigma^2 g + \sigma^2 e$

PCV (%) = √Phenotypic variance / Population mean for the trait × 100

GCV (%) = √Genotypic variance of genotypes / Population mean for the trait × 100

Broad-Sense heritability

Broad sense heritability h^2 (bs) expressed as the percentage of the ratio of the genotypic variance ($g\ \sigma^2$) to the phenotypic variance ($\sigma^2 p$) and was estimated on genotype mean basis as described by Allard (1960) as:

$$h^2_{(bs)} = (g\sigma^2) / (\sigma^2 p) \times 100$$

where $h^2_{(bs)}$ = heritability in board sense, $\sigma^2 p$ = phenotypic variance, and $\sigma^2 g$ = genotypic variance.

Genetic advance under selection (GA)

Genetic advance is the improvement over the base population that can potentially be made from selection for a given character (Falconer, 1981). Expected genetic advance (GA) is calculated as:

$$GA = (k)\ (б_p)\ (h^2_{bs})$$

where GA = expected genetic advance; K = constant based on selection intensity (2.06), $б_p$ = phenotypic standard deviation, and h^2 = heritability in broad sense.

Genetic advance as a percent of mean (GAM) which is used to compare the extent of predicted genetic advance of different traits under selection, was computed using the following formula:

GA (%) = Genetic advance / Population mean for the trait × 100

Association of traits

Correlation coefficient (r): Phenotypic and genotypic correlation coefficients were estimated using the standard procedure as

Table 1. The procedure for the ANOVA.

Source of variation	Degree of freedom	Mean of square	Expected mean
Replication	r-1	MSr (M1)	$\sigma^2e + r\,\sigma^2g$
Genotype	g-1	MSg (M2)	$\sigma^2e + \sigma^2g$
Error	(r-1) (g-1)	MSe (M3)	σ^2e
Total	(rg-1)	-	-

r = Number of replications, g= Number of genotypes, MSr= Mean of squares due to replication, MSg= Mean of squares due to genotypes, MSe = Mean of squares due to error, σ^2e = Error variance, σ^2g = Genotypic variance.

Table 2. Minimum, maximum, range, mean and SE of the 15 quantitative traits of the Castor accessions.

Traits	Minimum		Maximum		Range	Mean	SE±
	Score	Accession	Score	Accession			
PH	105	106550	158	200354	105-158	130	1.49
LMI	22	208619	65.00	200355	22-65	31	0.60
CP	45	212989	70	203645	45-70	53	0.72
PB	1.40	212871	2.68	106559	1.45-2.68	2.05	0.04
SB	0.10	Abaro	0.95	200371	0.1-0.95	0.39	0.02
LIN	6.52	219684	10.33	200354	6.5-10.33	8.00	0.10
IP	1.60	219684	3.82	106595	1.6-3.82	2.63	0.06
DFF	57	219637	125	208950	57-125	86	1.28
DSF	89	219637	137	219640	89-137	113	1.43
DFM	128	208630	152	212989	128-152	143	0.73
DSM	149	106595	180	106594	149-180	164	0.62
SP	131	106501	164	106578	131-164	156	1.94
HSW	30	212772	60	219618	30-60	40	0.00
SY	288.33	219689	570.00	219619	188-470	373.24	7.16
OC	42.40	106595	53.53	219640	42-53	49.69	0.28

PH: Plant height, LMI: length of main inflorescence, CP: number of capsules per plant, PB: number of primary branches per plant, SB: number of secondary branches per plant, LIN: length of inter node, IP: number of inflorescence per plant, DFF: days to 50% first flowering, DSF: days to 50% second flowering, DFM: days to first maturity 50%, DSM: days to second maturity 50%, SP: number of seeds per plant, HSW: hundred seed weight, SY: seed yield per plot, OC: oil content, SE: standard error of the mean.

suggested by Miller et al. (1958) from corresponding variance and covariance components as:

Phenotypic correlation = $r_p\,(xy) = Cov_p\,(_{xy}) / \sqrt{}Vp\,(x) \times \sqrt{}Vp\,(Y)$

Genotypic correlation= $r_g\,(xy) = Cov_g\,(xy) / \sqrt{}Vg\,(x) \times\sqrt{}\,Vg\,(Y)$

where COVp (xy) and COVg (xy) are phenotypic and genotypic covariance between x and y traits, while VP (x) and Vg (x) represent variances of X trait and Vp (Y) and Vg (Y) denote variances of Y trait at phenotypic and genotypic level, respectively.

RESULTS AND DISCUSSION

Mean, range and analysis of variance

The highest values for oil content (53.53) were obtained from accession 219640 and the lowest (42.4) for accession 106595. Accession 106595 showed the minimum value (149) for days to second maturity and accession 106594 revealed maximum values (180) (Table 2). This was supported by the study of Patel et al. (2010) with the range of oil content 42.50 to 54.86 and 110.00 to 183.33 days to maturity.

The variability for agronomic traits observed in this study is sufficient to develop early, short and high yielding variety of castor containing high oil in its seed.

Analysis of variance (ANOVA)

The results of the analysis of variance of 15 quantitative traits indicated that, the mean square due to accession were highly significant ($p<0.01$) for traits length of main inflorescence, number of capsules per plant, days to first flowering, days to first maturity, days to second maturity, hundred seed weight and plot seed weight (Table 3) indicating sufficient genetic variability for these traits. Days to second flower and number of seeds per plant were significant at ($p<0.05$). The mean square was non-significant for all other traits.

Table 3. Morphological and agronomic traits of 105 castor accessions grown at Melkassa, Ethiopia, 2011 (MARC 2012).

Trait	Range	Mean	SE±
Days to first flowering	52-93	72	8.5
Days to second flowering	73-105	86	6.4
Days to first harvest	144-177	154	11.6
Days to second harvest	154-205	175	20.1
Number of node/plant	8.2-22.4	13.5	2.7
No. of Inflorescence/plant	1.2-15.2	4.7	2.7
Plant height in cm	211-342	271	26.0
No. of branches/plant	1.6-11.75	4.5	1.7
No. of capsules/plant	35-242.6	102.2	44.2
Seed weight/100 seeds in g	19.6-85.4	50.3	16.4
Seed weight per plot g	320-2915	1225	467.7
Oil content	39.3-55.5	49.0	2.7

Estimates of genetic parameters

Estimates of variance components

Environmental and phenotypic variances were highest for plot seed weight followed by plant height and days to flowering indicating that these traits are more influenced by environment. The lowest environmental and phenotypic variances were recorded for number of capsules per plant, number of seeds per plant, number of primary branches per plant, number of secondary branches per plant and length of main inflorescence. The magnitude of phenotypic variation was highest as it is a product of environmental and genetic variability. The genetic variance was highest only for first and second days to flowering next to plot seed weight (Table 4).

Estimates of phenotypic and genotypic coefficient of variation

There is little difference between genotypic coefficient of variation and phenotypic coefficient of variation for 100-seed weight and days to second maturity 50%, this implies that the environmental effect was small for the expression of this trait. However, for all the other traits, phenotypic coefficient of variation was greater than genotypic coefficient of variation. This indicated the presence of environmental influence on these traits. Halilu et al. (2013) reported similar PCV (16.14) and nearly similar results GCV (8.5) for number of capsules per plant (Table 4).

Estimates of heritability in a broad sense and genetic advance

Moderate heritability coupled with moderate GA were observed for days to 50% first flowering and moderate heritability with high GA for days to 50% second flowering indicating that these traits are mainly controlled by additive type of genes and that direct selection for these traits could be effective. However, moderate heritability coupled with low GA was observed for 100-seed weight (Table 4). Thus, this trait is controlled by non-additive genes (dominance and epistasis). Low heritability with low GA observed for most of the traits indicates environmental control on the expression of these traits and their improvement could be achieved through heterosis breeding. Obviously, the length of internodes in non-dwarf castor genotypes is highly influenced by soil fertility and availability of moisture. Similarly, oil content is influenced by soil fertility, moisture and temperature (Weiss, 2000). Therefore, the low heritability of internode length and oil content is not surprising. In this study, the heritability was 23% for number of capsules per plant. In a similar study by Halilu et al. (2013) consisting of 30 genotypes, heritability was 32% for number of capsules per plant. The heritability value for number of secondary branches in this study was 11% as compared to 32% in Halilu et al. (2013). This could be probably due to the differences in materials studied (30 in his and 48 in the present study). In addition, the present study was carried out under off season that may have limited expression of the traits fully.

Association of agronomic traits

Seed yield is the result of many traits and is the complex trait. Breeders always look for genetic variation among traits to select desirable types. In this study, yield related traits were investigated for their relationship with yield as well as among themselves using genotypic and phenotypic correlation analysis.

Phenotypic correlation

Phenotypic correlation indicated that seed yield

Table 4. Analysis of variance of 15 quantitative traits in 48 Castor (*Ricinus communis*) accessions grown at Melkassa in 2014 during off season.

Source of variation	DF	PH	LMI	CP	SP	PB	SB	LIN	IP	DFF	DSF	DFM	DSM	HSW	SY	OC
Rep	2	72.55	166.94*	0.45	25.98	0.05	0.004	0.04	0.003	138.59	13.02	33.36	5.69	0.00006	8.5	68.31**
Access	47	329.86	68.98**	107.29**	591.96*	0.26	0.096	1.7	0.64	453.74**	415.59*	109.58**	115**	0.0003**	10562**	11.67
Error	94	317.53	39.88	58.78	0.21	0.21	0.01	1.4	0.49	127.31	237.89	61.94	27.24	0.0006	5942	9.77
CV%	-	13.64	20.04	14.28	14.75	22.49	27.66	14.76	26.54	12.99	13.61	5.49	3.17	17.61	17.01	6.29

**and* indicate significant differences at 1 and 5%, respectively. PH: Plant height, LMI: length of main inflorescence, CP: number of capsules per plant, PB: number of primary branches per plant, SB: number of secondary branches per plant, LIN: length of inter node, IP: number of inflorescence per plant, DFF: days to 50% first flowering, DSF: days to 50% second flowering, DFM: Days to first maturity 50%, DSM: Days to second maturity 50%, SP: Number of seeds per plant, HSW: hundred seed weight, SY: seed yield per plot, OC: oil content.

Table 5. Estimates of error mean square, genetic component of variance, heritability and genetic advance of 48 castor accessions grown at Melkassa in 2014 during the off season.

Traits	$\sigma^2 e$	$\sigma^2 g$	$\sigma^2 p$	PCV%	GCV%	H%	GA	GAM%
PH	317.53	4.17	321.52	15.10	1.56	1.00	0.37	0.28
LMI	39.88	9.70	48.59	22.34	9.87	20.00	2.90	9.20
CP	58.78	16.17	74.95	16.14	7.49	23.00	17.25	32.00
SP	0.21	0.02	0.23	0.31	0.09	9.00	0.09	3.00
PB	0.21	0.02	0.23	23.48	6.83	9.00	0.09	3.00
SB	0.01	0.01	0.09	76.92	17.95	11.00	0.07	17.43
LIN	1.40	0.10	1.50	15.25	1.50	7.00	0.18	2.25
IP	0.49	0.05	0.54	27.76	0.76	9.00	0.14	5.32
DFF	127.31	108.10	236.12	17.69	11.96	46.00	14.56	17.00
DSF	237.89	217.83	455.72	18.83	13.02	48.00	21.11	18.63
DFM	61.94	15.88	77.82	6.16	2.77	20.40	3.63	3.00
DSM	27.24	87.79	115.04	6.52	5.32	76.31	16.78	10.20
HSW	0.00006	0.00008	0.00014	25.00	23.00	57.00	0.01	25.00
SY	5942.00	1540.00	7482.00	23.17	10.51	21.00	37.42	10.00
OC	9.77	0.62	10.39	23.41	1.59	6.00	0.40	0.80

was highly positively and significantly correlated with number of seeds per plant (r=0.413), number of primary branches per plant (r=0.488), number of secondary branches per plant (r=0.376) and length of inter node (r=0.279), and weakly positively correlated with number of inflorescence per plant (r=0.180) and number of capsules per plant (r=0.318) (Table 5). Hence, more importance should be given to these traits at the time of selection to improve seed yield. In castor, late maturing genotypes had longer main inflorescence, more capsules and seeds per plant and consequently higher yield (MARC, 2011, 2012). This was supported by the positive and highly significantly correlation of plant height with length of main inflorescence (r=0.295), number of capsules per plant (r=0.230), number of primary branches per plant (r=0.357) and number of secondary branches per plant (r=0.122) and positively non-significant correlation with seed yield (r=0.105), oil content (r=0.060) and number

Table 6. Genotypic correlation coefficient of yield and yield related 15 quantitative traits of 48 castor accessions grown at Melkassa in 2014 during the off season.

Correlation	PH	LMI	CP	SP	PB	SB	IP	LIN	DFF	DSF	DFM	DSM	HSW	SY	OC
PH	1.000	0.402**	0.469**	0.578**	0.429 **	0.122	0.244	0.697**	-0.114	-0.226	-0.054	-0.219	-0.178	0.313**	0.188
LMI		1.000	0.149	0.062	0.236	0.106	0.355**	0.380**	0.206	-0.276	-0.198	-0.264	-0.187	0.123	0.022
CP			1.000	0.669**	0.350*	0.430**	0.372**	0.540**	0.015	-0.090	-0.133	-0.294*	-0.102	0.304**	0.370**
SP				1.000	0.495**	0.370**	0.227	0.471**	-0.192	-0.234	-0.195	-0.314*	-0.299*	0.355*	0.377**
PB					1.000	0.514**	0.376**	0.317*	-0.337*	-0.303*	-0.056	-0.302*	-0.244	0.654**	0.185
SB						1.000	0.176	0.331*	-0.174	-0.152	-0.119	-0.223	0.045	0.366*	0.327*
IP							1.000	0.241	-0.185	-0.357*	-0.285*	-0.315	-0.005	0.143	0.160
LIN								1.000	0.192	-0.320*	-0.191	-0.363*	-0.138	0.414**	0.176
DFF									1.000	0.831**	0.659**	0.766**	0.492**	-0.342*	0.101
DSF										1.000	0.743**	0.778**	0.449**	-0.392**	0.185
DFM											1.000	0.755**	0.344*	-0.308*	0.130
DSM												1.000	0.360**	-0.376**	0.133
HSW													1.000	-0.147	0.068
PW														1.000	0.304*
OC															1.000

**and*Indicate significant differences at 1 and 5%, respectively. PH: Plant height, LMI: length of main inflorescence, CP: number of capsules per plant, PB: number of primary branches per plant, SB: number of secondary branches per plant, LIN: length of inter node, IP: number of inflorescence per plant, DFF: Days to 50% first flowering, DSF: days to 50% second flowering, DFM: days to first maturity 50%, DSM: days to second maturity 50%, SP: number of seeds per plant, HSW: hundred seed weight, SY: seed yield per plot, OC: oil content.

of inflorescence per plant (r=0.194) (Table 5). The positive correlation of number of seeds per plant and seed yield is very clear and as yield is a sum of number of seeds. Similarly, the correlation of number of primary branches with secondary branches is also obvious. The negative correlation of number of seeds per plant with flowering and maturity dates shows that earlier genotypes had lower seed number.

Number of inflorescence per plant had positive significant correlation with seed yield (r=0.180) and strongly negative correlation with oil content and days to second flowering, respectively. However, it was negatively non-significantly correlated with the rest of the traits. When castor genotypes are taller and branchy they would have more number of inflorescences and capsules as well as number of seeds per plant and consequently higher seed yield. However, the seeds that are born on the main inflorescence have higher oil content than seeds born on the secondary branches. Similarly, Getinet et al. (2013) reported that the seeds born on the main inflorescence of the variety Hiruy had higher oil content than seeds born on secondary branches. Therefore maximizing the length of main raceme and number of capsules on main raceme is the primary target for increasing oil content per plant. The correlation among flowering and maturity traits was strong and positive. The correlation among flowering and maturity traits with seed yield was strong and negative indicating that early genotypes are low yielders. This is because most early castor genotypes are susceptible to leaf and root diseases while late genotypes mostly had escape/tolerance mechanism.

Genotypic correlation

The positive association of length of main inflorescence with length of inter node and plant height indicates that taller plants had longer inflorescence. However, the plant height can be reduced using dwarfing genes without affecting the nature of inflorescence. Number of capsules per plant exhibited a positive and highly significant correlation with number of seeds per plant (r=0.669), number of secondary branches per plant (r=0.430), number of inflorescence per plant (r=0.372), length of inter node (r=0.540), oil content (r=0.370), seed yield (r=0.304) and number of primary branches per plant (r=0.350) (Table 6). The positive association between seed yield and number of capsules per plant (0.304) was in agreement with the study of Patel et al.

(2010). The positive correlation of capsules per plant with number of branches and inflorescences shows that as castor genotypes have more branches it also bears more capsules and seeds. Number of seeds per plant had a positive and highly significant correlation with number of primary branches per plant (r=0.495), number of secondary branches (r=0.370), and length of internode (0.471). The positive correlation of primary branches with seed yield and secondary branches as well as inflorescence is straight forward. If a castor plants have more branches they are likely to bear more branches, capsules and seeds and consequently higher seed yield. Number of secondary branches per plant had positive and significant correlation with length of inter node (r=0.331), seed yield (r=0.366) and oil content (r=0.327). The positive correlation of number of secondary branches with length of inter node shows that taller plants would likely have more number of branches than shorter plants. While the positive correlation of number of secondary branches with seed yield indicates that as castor plants bear more number of secondary branches they would likely have more seeds and hence higher seed yield. Number of inflorescence per plant had negative and significant correlation with days to 50% second flowering (r=-0.357) and days to first maturity (r=-0.285) indicating that early genotypes have lower number of inflorescence. The negative correlation between length of inter node with days to mature indicates that earlier plants are shorter in height as long internode is associated with tall

Conclusions

The range and mean of agronomic traits obtained in this study indicated that there is sufficient variability in castor germplasm. The range of oil content observed 42.4 to 53.53 with a mean of 42.53% is quite high as compared to the level in other oil seeds such as noug, linseed and sunflower. The analysis of variance also revealed that there is sufficient variability among the 48 accessions. Oil content was negatively correlated with number of capsules and seeds per plant at the genotypic level. This is because as there are more seeds and capsules per plant there is higher competition or partition of photosynthetic product resulting in less oil content. Correlation analysis confirmed that the number of primary branch per plant was the key contributors of seed yield.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of long-term positioning of straw returning on the quality and yield of summer maize

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The aim of the work is to study the effects of different treatments: control, single application of organic manure, two seasons straw returning, a quarter of straw returning combined with nitrogen fertilizer, two seasons straw returning combined with nitrogen fertilizer on the quality index and yield of summer maize; protein, starch, fat content and the amino acid were analyzed using cluster analysis. The results showed that there are significant effects of different fertilization on the quality and yield of maize; the content of maize grain protein content of different straw returning treatments significantly increased by 0.90, 77.03 and 60.6% respectively which was higher than other test treatments. In addition, single organic fertilizer has the most prominent effect on total amino acids. However, the amounts of starch decreased and the less decreased treatment was a quarter of straw returning combined with nitrogen fertilizer treatment for 3.5%. The highest crude fat of grain of the single application of organic manure (M) significantly improved by 24.79%. The results show that different long-term straw and fertilizer affect summer maize in their quality characters; application of organic fertilizer can significantly improve the quality of summer maize, as well as its protein and amino acid content.

Key words: Long-term location experiment, straw returning, quality and yield, summer maize.

INTRODUCTION

With the continuous improvement of people's living standards, the requirement of quality of crop products is also increasing. The quality of crops is affected by the dual influence of genetic, ecology environment and cultivation technology (Sun et al., 2011). Fertilization is the most important factor affecting the quality of crops, because it is the most direct source of nutrients. Long term positioning of straw returning to field has great meaning in the study of fertilization, soil fertility, environmental evolution, variation of crop yield and quality, and is valued domestically and overseas (Zhao and Zhang, 2002; Gao et al., 2015; Belay et. al., 2002; Wang et al., 2015; Wang et al., 2001) . In the past, the research on the quality influence of crops is relatively weak, because the research fields of different fertilization systems on the long-term positioning mostly focused on the effects of soil fertility and yield. Previous researches mainly study the effect of short term fertilization on the

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Table 1. Experimental treatments.

Treatments	Straw	Straw	Organic fertilizer (kg/hm^2)	Nitrogenous fertilizer (kg/hm^2)
CK	0	0	0	0
M	0	0	60000	0
WN	+	0	0	276
WC	++	++	0	0
WCN	++	++	0	276

$^+$Quarterly wheat straw returned; $^{++}$Wheat and corn straw returned two seasons.

quality of maize (Gao et al., 2015; Bao, 2000; Li et al., 2017; Qu et al., 2002; Xiao et al., 2016; Montemurro et al., 2002). This experiment determines and analyzes the content of crude fat, protein, starch and amino acids of maize samples through long-term straw returning treatments. We studied the effect of the quality of corn straw returning treatments and provide a theoretical basis for rational fertilization (Lan et al., 2012; Li et al., 2017; Lu and Lu, 2017).

Long-term fertilization experiment of straw returning is a test method of "long term" and "positioning". It is secular and has the characteristics of repetition in the climate, abundant information, accurate and reliable, strong explanatory power and can provide decision-making basis for the development of agriculture. Therefore, it has inimitable advantages compared to routine testing (Gao et al., 2015; Xiao et al., 2016). So it can solve the scientific problems that cannot be solved by many short-term tests. At present, our country is facing the problem of "food security", which determines in the future, the influence of long-term fertilization on crop yield, quality and soil fertility and soil quality. It is still the main content of China's long-term fertilization trial (Gao et al., 2015; Huang et al., 2010). This paper built on the long-term orientation of straw returning to field experiment, the effects of different straw returning treatments on the quality of summer maize, and provided the basis for scientific and reasonable fertilization (Cui et al., 2017; Dickson et al., 2013; Hana et al., 2010).

MATERIALS AND METHODS

Experiment design

The experiment was built up in Laiyang Test Station (36.9°N, 120.7°E) of Qingdao Agricultural University in 2009. It is Gleyic Cambisols and the basic properties are as follows: 6.8 pH; 5.01 g/kg Soil Organic Matter (SOC); 0.60 g/kg Total Nitrogen (TN); 0.64 g/kg total phosphorus (total P); 16.34 mg/kg Olsen P; 72.00 mg/kg Available Potassium (AK) and 13.80 cmol/kg Cation Exchange Capacity (CEC). The rotation of wheat and maize were in the autumn and summer every year. There were five treatments in this study (Table 1): A quarter of straw returning combined with application of nitrogen fertilizer (WN), two seasons straw returning (WC), two seasons straw returning combined with nitrogen fertilizer (WCN), single organic manure (M) and blank control of no-fertilizer (CK). Each treatment has 3 replicates, with plot area of 33.3 m^2; the random group was arranged.

The rotation of winter wheat and summer corn was in autumn and summer every year. The type of wheat was Yanyou361. In addition, the type of corn was Luyu 16. Urea was used for inorganic fertilizer, and high amount of nitrogen fertilizer (276 kg/hm^2) was applied per year. Pig manure was used for organic fertilizer and nitrogen content of 2-3 g/kg; total phosphorus content of 0.5 to 2 g/kg, organic matter content of 20 to 50 g/kg. Corn and wheat straw returned to field totally. Organic fertilizer was used as basal fertilizer overall, and for tilling of the soil before wheat planting in winter. Nitrogen fertilizer is used for seed manure, topdressing of turning green and jointing stage of wheat, topdressing of jointing stage and bell stage of maize. 45 kg/hm^2 seed fertilizer of urea was applied per year. The rest is used as topdressing of turning green and jointing stage of wheat (furrow fertilization); topdressing of jointing stage and bell stage of summer maize (hole fertilization).

Experiment method

The summer maize samples were protected by paper bags in the field and samples in 2009 to 2014 were used in this study. In each plot, 30 samples were randomly collected and 25% samples were kept on average. All the samples were sieved to 0.25 mm. The contents of protein of the wheat were investigated Jiacheng Lao (Lao et al., 1998. Analysis of Soil Chemistry Handbook): “Micro kjeldahl determination”. The starch was determined by anthranone-H2SO4 and fat was tested by residue method, but the amino acid was analyzed by automatic amino-acid analyzer. Protein components were determined by coomassie brilliant blue G - 250 method. All the data were analyzed by SPSS 19.0.

RESULTS AND DISCUSSION

Effect of long term positioning of straw returning on the protein content of summer maize grain

The effect of long term positioning of straw returning on the protein content of maize grain was shown in Figure 1. Compared with the control, the content of maize grain protein content of different straw returning treatments (WC and WCN, WN) significantly increased by 0.90, 77.03 and 60.6% respectively; and compared to organic fertilizer, two seasons straw returning combined with nitrogen fertilizer made protein content of maize grain significantly increased by 7.22%. Under the same nitrogen fertilizer level, the protein content of maize grain of the two seasons straw returning treatment (WCN) was significantly higher than a quarter of straw returning

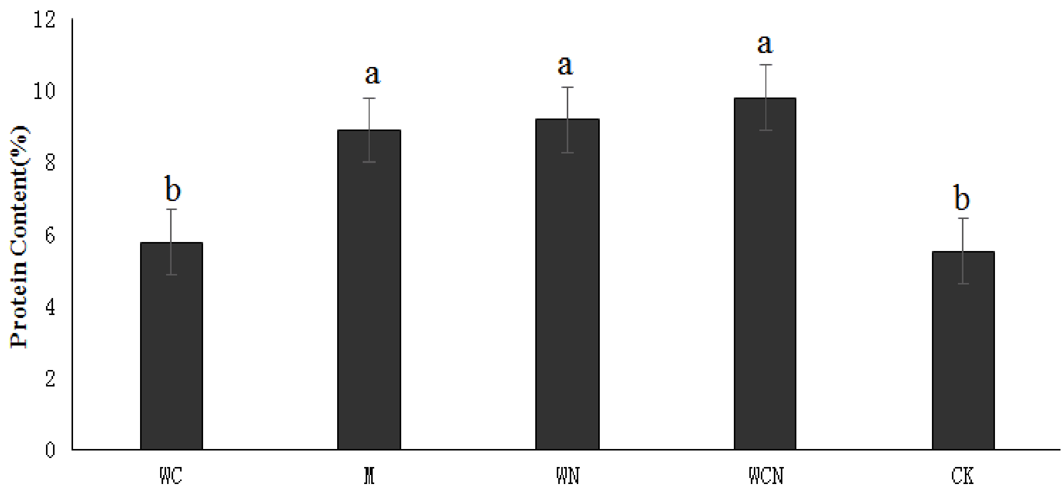

Figure 1. Effects of different fertilization treatments on protein content of corn grain. CK, Control; M, single application of organic manure; WC, two seasons straw returning; WN, a quarter of straw returning combined with nitrogen fertilizer; WCN. two seasons straw returning cooperated with nitrogen fertilizer.

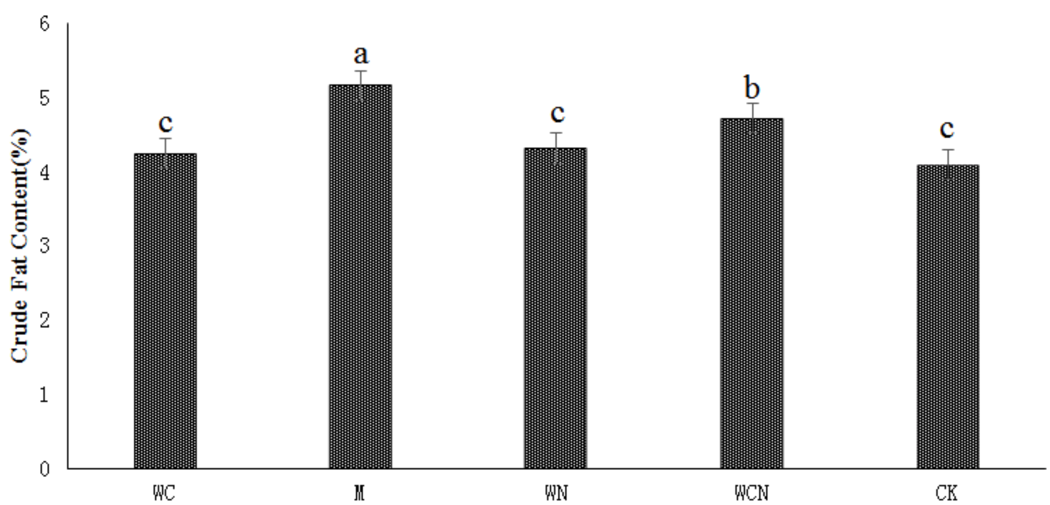

Figure 2. Effects of different straw returning treatments on crude fat content of corn.

(WN), WCN processing maize grain protein content significantly increased by 10.37%; under the same straw returning to the field level, the content of protein of maize grain of nitrogen fertilizer treatment (WCN) was significantly higher than straw returning treatment (WC) and WCN processing significantly increased by 72.44%. High proportion of nitrogen was beneficial to the increase of protein content in maize grain. With the increase of the amount of straw returning, the protein content increased within certain range, consistent with the Theory of Nutrient Returns. The results showed that the different fertilization treatments can affect the content of protein in summer maize. Single straw returning treatment had minor effect on protein content, two seasons straw returning combined with nitrogen fertilizer on corn protein content increased significantly. It showed that the straw fertilizer combined with nitrogen fertilizer could promote nitrogen uptake, thereby affecting protein synthesis and enhancing the corn quality through increasing protein content. Therefore, nitrogen fertilizer and organic fertilizer and straw returning can effectively improve the content of protein in maize grain, and effectively improve the quality of maize grain (Li et al., 2015).

Effect of long term positioning of straw returning on the crude fat content of summer maize grain

There are differences in crude fat content of corn grain between different straw returning treatments (Figure 2).

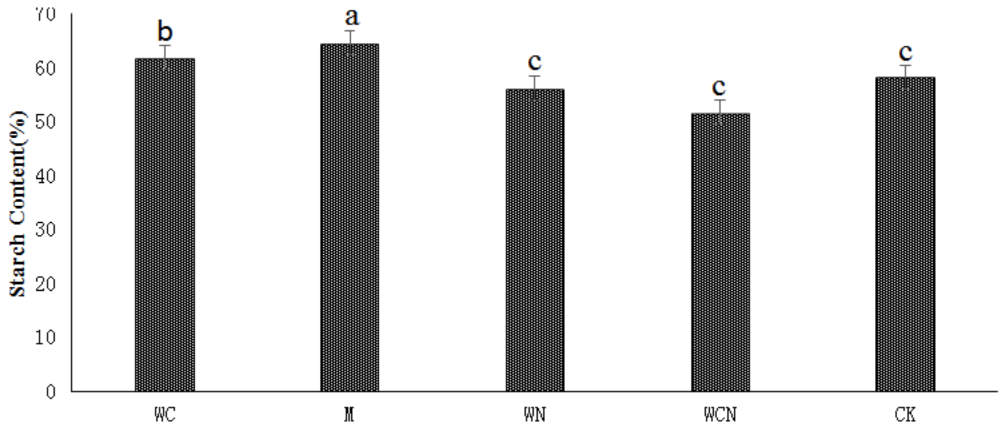

Figure 3. Effects of different straw returning treatments on corn starch content.

Compared with the control, the crude fat of grain of the single application of organic manure (M) significantly improved by 24.79%, the straw returning treatment combined with nitrogen fertilizer compared with organic fertilizer, summer maize grain crude fat content were significantly reduced by 8.51 and 16.44% of two seasons straw returning combined with nitrogen fertilizer (WCN) and a quarter of straw returning combined with nitrogen fertilizer (WN) respectively. Under the same nitrogen fertilizer level, straw returning in two seasons (WCN) crude fat content was significantly higher than a quarter of straw returning(WN) treatment and it significantly increased by 9.49%. It suggested that high proportion of straw returning can be beneficial to improve the crude fat content of corn grain. Overall results indicated that the effect of straw returning and fertilization on maize grain crude fat content was significant, single application of organic fertilizer could significantly increase the content of crude fat in corn, straw returning and nitrogen fertilizer combined application made the content of crude fat decreased slightly. It was possible because straw and nitrogen fertilizer combined application affects the synthesis and accumulation of crude fat; therefore, if we want to improve the content of crude fat of corn, we should increase the application of organic fertilizer, or straw and nitrogen and increase organic fertilizer (Chen et al., 2012).

Effect of long term positioning of straw returning on the starch fat content of summer maize grain

As Figure 3 shows, and compared with the control, the starch content of maize grain of single application of organic manure treatment (M) significantly increased by 10.67%; and compared to M treatment, straw returning combined with nitrogen fertilizer made corn starch content decreased significantly. Among them, the decreasing amplitude of two seasons straw returning combined with nitrogen fertilizer (WCN), and a quarter of straw returning combined with straw returning (WN) were 18.74 and 24.53% respectively; under the same nitrogen fertilizer level, starch content of one season of straw returning treatment (WN) was significantly higher than the two seasons straw (WCN) processing . The maize starch content of WN processing improved by 8.58% compared to the WCN processing. In the same amount of straw returning to field (WC and WCN), the WC treatment significantly improved by 19.52% compared to WCN treatment; high proportion of straw returning to field was more favorable to increase grain starch content. Test results show that there are significant differences between the different treatments. The content of starch in the control group was higher than straw returning and straw returning combined with nitrogen fertilizer application treatment. WCN and WN reduced by 11.1 and 3.5% than the control respectively. The starch content in the treatment reduction is possibly attributed to large planting density of blank processing, sunlight relatively strength, the plant carbohydrate synthesis increase, that results in increase of the starch content. Nitrogen fertilizer led to the imbalance of soil nutrient, which affected the synthesis of carbohydrate. So, the accumulation of starch in maize kernel is reduced, as well as the grain quality of maize.

Effect of long term positioning of straw returning on the amino acid content of summer maize grain

As Table 2 shows, amino acid content of five treatments and a quarter straw returning combined with nitrogen fertilizer treatment (WN) was 6.52% at most, followed by two seasons straw returning combined with nitrogen treatment (WCN) (6.34%). The control treatment (CK) has a minimum value of 4.10%; and in five experimental treatments, the content of glutamic acid was the highest among 14 kinds of amino acid. In the control treatment

Table 2. Effects of different straw returning on the amino acid content of the summer corn.

Amino acid (%)	CK	M	WC	WN	WCN	The 5% significant level
Threonine*	0.17	0.27	0.18	0.25	0.24	cdef
Valine*	0.21	0.34	0.23	0.31	0.30	f
Methionine*	0.09	0.16	0.12	0.16	0.16	ef
Isoleucine*	0.14	0.24	0.15	0.22	0.21	b
Leucine*	0.44	0.91	0.49	0.81	0.79	cde
Phenylalanine*	0.18	0.35	0.50	0.32	0.31	ef
lysine*	0.17	0.21	0.18	0.21	0.20	cd
Aspartate	0.28	0.47	0.32	0.43	0.40	def
Tyrosine	0.19	0.32	0.19	0.29	0.29	cdef
Serine	0.20	0.34	0.21	0.31	0.30	a
Glutamic acid	0.71	1.39	0.78	1.23	1.19	def
Glycine	0.19	0.27	0.21	0.25	0.25	c
Alanine	0.31	0.54	0.33	0.49	0.48	ef
Cysteine	0.14	0.21	0.15	0.19	0.19	def
Total amino acids	4.10	7.21	4.5	6.52	6.34	

*The essential amino acid.

(CK), single application of organic manure (M), two seasons straw returning (WC), a quarter straw returning combined with nitrogen (WN), two seasons straw returning combined with nitrogen fertilizer (WCN), the glutamic acid content of five treatments was 0.71, 1.39, 0.78, 1.23 and 1.19% respectively. Among these treatments, the glutamate content from single application of organic fertilizer processing(M) was the highest (1.39%), followed by a quarter of straw returning combined with nitrogen treatment (WN) (1.23%), and control group treatment with a minimum of 0.71%. Compared with the control, the glutamate levels of a quarter straw returning combined with nitrogen treatment (WN) and two seasons straw returning combined with nitrogen treatment (WCN) increased by 95.77 and 73.24% respectively; under the same nitrogen fertilizer input level, WC treatment compared with the WCN treatment, the content of glutamic acid reduced by 34.45%. Other kinds of amino acids in WC processing in respect to the WCN treatment also showed a downward trend. It suggests that nitrogen fertilizer with plenty of straw returning could significantly increase the content of amino acids of maize grains. There are increased total amino acids and essential amino acids in different straw returning treatments. Single organic fertilizer changed most significantly. It suggests that single organic fertilizer has the most effect on total amino acids; different long-term straw returning treatments have different effect on the contents of various amino acids in summer maize, a quarter straw returning combined with nitrogen treatment (WN) has remarkable influence on serine, glutamic acid, isoleucine, leucine, tyrosine, phenylalanine and proline of summer maize, and different treatments have different effects on the amino acid.

The effect of long-term straw returning on amino acid content of maize grain is shown in Figure 4. The change trend of total amino acid content is in line with the content of protein. Q clustering hierarchical of SPSS was used to analyzed amino acid content respectively. Individual distance used was squared Euclidean distance. The distance between classes adopts average linkage distance, and the clustering analysis tree was created finally. As shown in Figure 4, the contents of amino acid of a quarter of straw returning combined with nitrogen treatment (WN), two seasons straw returning combined with nitrogen treatment (WCN), single organic manure (M) have high similarity; they are first class. The amino acid content of control treatment (CK) and two seasons straw returning treatment (WC) have high similarity; they can be clustered into second class.

Effect of long term positioning of straw returning on the content of protein components of summer maize grain

As shown in Table 3, there were significant differences in the protein contents of maize kernel protein between different straw returning treatments. In the same application rate of nitrogen fertilizer level (WN, WCN), increasing the amount of straw returning can increase the content of HD protein, globulin, alcohol soluble protein and glutenin by 5.43, 5.64, 9.74 and 13.78%, respectively. With the increase of the amount of straw returning to the field, the histone proteins content increased significantly. In WCN processing compared to M, globulin, gliadin reduced by 24.00 and 7.14% respectively, and albumin and glutelin increased by 14.11

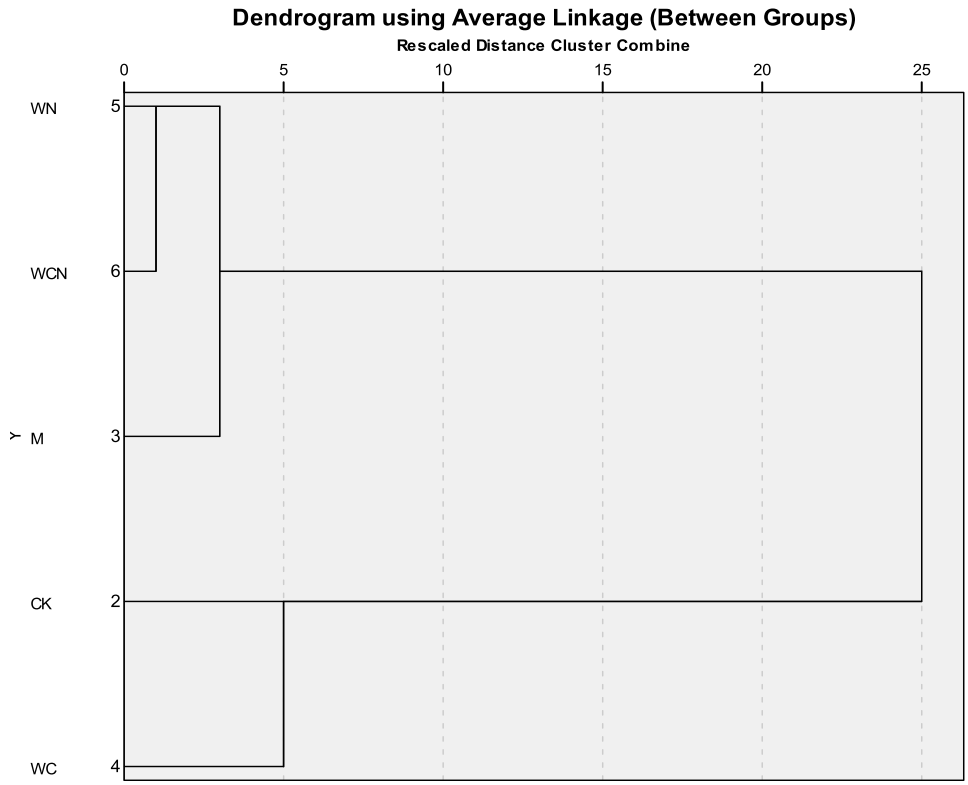

Figure 4. The result of hierarchical cluster analysis of the amino acid composition of summer corn in long-term location straw returning.

Table 3. Effects of different straw returning treatments on the contents of protein components in maize.

Treatments	Albumin (%)	Globulin (%)	Prolamine (%)	Glutenlin (%)	Gluten/alcohol ratio (%)
WC	0.51	0.52	3.22	1.93	60.04
M	0.85	0.93	4.95	2.58	52.12
WN	0.92	0.71	4.21	2.61	62.00
WCN	0.97	0.75	4.62	2.97	64.29
CK	0.47	0.62	2.45	1.74	71.17

and 15.12% separately. In straw returning (WC) compared to straw returning combined with nitrogen fertilizer (WCN), albumin, globulin, alcohol soluble protein and glutenin content increased significantly by 90.19, 44.23, 43.47 and 53.62% respectively. It suggests that long straw returning combined with nitrogen fertilizer and organic fertilizer could increase the content of protein composition of maize grain, improve the quantity of maize, organic fertilizer and straw and other organic substances to affect protein composition.

Effect of long term positioning of straw returning on the yield of summer maize grain

As seen fin Figure 5, the application of organic fertilizer and straw returning combined with nitrogen fertilizer treatments can significantly increase the yield of maize grain. The M treatment had the highest yield of corn grain (10572.6 kg/hm^2); compared to control, it increased by 210.23% and yield increase was extremely significantly. WCN processing had the second-highest yield (8442.0 kg/hm^2); and compared to control treatment it increased by 143.08%. When in the same nitrogen fertilizer level (WN, WCN), WN processing maize yield was 6522.6 kg/hm^2, and compared to WCN processing it decreased by 29.42%. It indicates that under the same nitrogen fertilizer level, increasing the amount of straw returning could increase the yield of maize; when in the same level of straw returning (WC and WCN), WC production was 3472.8 kg/hm^2, and it reduced by 143.72% compared to WCN treatment. Under the same straw returning to the

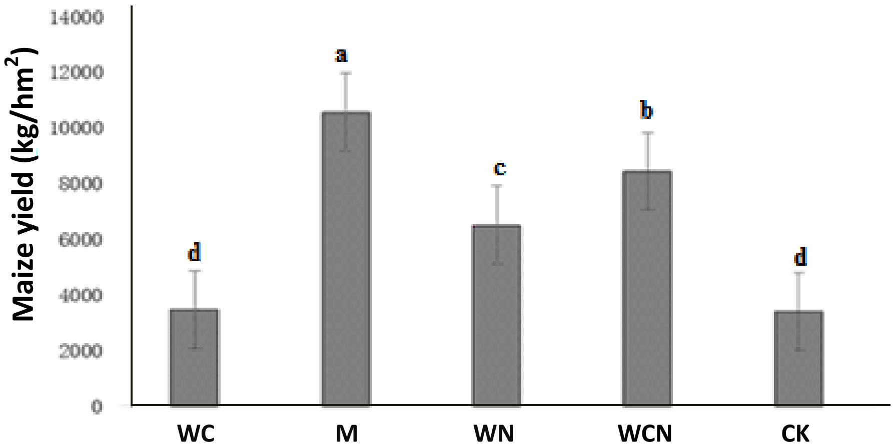

Figure 5. Effects of long-term fixed straw returning on the yield of corn.

field level, increasing nitrogen fertilizer application can increase the yield of maize.

Conclusion

This paper is focused on the research of the long-term location straw returning to field .The following conclusions can be drawn from this experiment:

(1) Long-term single application of organic manure, straw returning and combined with nitrogen fertilizer can increase the content of crude fat, starch, protein and amino acid of maize; scientific application of organic manure, straw returning and with nitrogen fertilizer can increase maize grain quality and improve quality of maize.
(2) Organic fertilizer and straw and other organic matter influence the composition of protein components, straw returning treatment, long term application of organic manure, straw and with nitrogen fertilizer decrease the ratio of glutelin to zein of maize, and increase the content of albumin, globulin, gliadin and glutenin. Long term application of nitrogen fertilizer and organic fertilizer could increase the content of protein and improve the quality of maize.
(3) The long-term scientific and rational application of organic fertilizer, straw returning combined with nitrogen fertilizer can significantly improve the yield of summer maize.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Efficacy of the association of cover crops with maize and direct sowing short-term effect on crops' yields in maize-cotton cropping system in Western Burkina Faso

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To improve the productivity and sustainability of cotton and cereals based system, direct sowing under mulch was tested for its efficacy on cotton and maize yields on the research station of Farako-Bâ, in Western Burkina Faso. The experimental design was a complete randomized blocks of Fisher with four replications. Conventional tillage by annual moldboard plowing (T7) was compared with direct sowing under mulch-based cropping system (DMC) using maize association with cover crops defined as: maize without cover crop (T1), maize + *Brachiaria ruziziensis* (T2), maize + *B. ruziziensis* + *Mucuna cochinchinensis* (T3), maize + *B. ruziziensis* + *Panicum maximum* (T4), maize + *B. ruziziensis* + *Stylosanthes hamata* (T5), and maize + *Crotalaria juncea* (T6). Cover crops were planted 21 days after maize emergence between the rows of this main crop. The biomass produced by the cover crops and maize straws were evaluated as well as maize and cotton yields, during the first 6 years of the study, from 2010 to 2015. Results showed that among cover crops, the biomass production was significantly lower with *C. juncea*. The associations of cover crops with maize increased significantly the production of total dry matter compared to plots without cover crops, in the conventional tillage. Association with cover crops did not influence significantly nitrogen, phosphorus and potassium contents of maize and the maize's yields even if the depressive effects were recorded. Compared to the conventional tillage, the DMC appeared also effective on seed cotton yields even without a significant improvement during the 6 first years of the study. These promising results, confirm the feasibility in tropical conditions of DMC which must be continued to better analyze its long-term effects on soil properties.

Key words: Cover crops, mulch-based cropping system (DMC), conventional tillage, biomass, yield.

INTRODUCTION

Conservation agriculture and cropping systems using direct sowing in crop residues mulch are agricultural management practices in full expansion in many regions of the world (Lu et al., 2000; Naudin et al., 2010;

Kulagowski et al., 2016; Nascimento et al., 2016). However, in African countries, these practices are unusual and the majority of cropping systems are characterized by a low productivity, accentuated by climatic variations (Barro et al., 2009; Nielsen and Reenberg, 2010). Conventional tillage, largely practiced, contributes to the degradation of cultivated soil fertility with inappropriate tillage techniques (Schneider et al., 2010; Pedroso et al., 2016). Soil tillage modifies the distribution of crops residues, soil structure and affects consequently the micro-organisms of the soil and therefore, the mineralization of organic matter (Vian et al., 2009; Fernandes de Sousa et al., 2015). Studies have shown that decomposition of organic matter is nearly five times faster under wet and hot conditions in the humid tropics than under temperate conditions (Corbeels et al., 2006; Lal et al., 2007; Wilson, 2015). Soil tillage also affects its physical, chemical and biological properties. The tillage system is considered as the most important soil management system for the sustainability of agroecosystems (Van Eerd et al., 2014; Luoa et al., 2017).

The practice of no-tillage increases the concentration of nutrients in the upper layers of the soil and provide agronomic and environmental benefits (Ducamp et al., 2012; Santos et al., 2014; Marcillo and Miguez, 2017). Luoa et al. (2017) reported that intensification of sustainable agricultural in cultivated lands is a key element of the global response to food security and environmental protection. Studies reported on the advantages of the use of no-tillage systems, particularly, direct sowing mulch-based cropping system (DMC) which is growing in all regions of Brazil, covering 25 million hectares (Nascente et al., 2015). In this system, it is important to assess the contributions of cover crops used in the management of soil fertility (Prabhakara et al., 2015). Using cover crops in the no-tillage system could be an important alternative to increase the sustainability of agricultural systems, which may favor the increasing of soil fertility and restoring considerable amounts of nutrients to crops. The use of cover crops provided a significant increase in the level of nutrients, soil organic matter, cation exchange capacity, and base saturation in the soil (Fernandes de Sousa et al., 2015; Nascente et al., 2015). In addition to reducing nutrient runoff, cover crops, provide protection from raindrop impact and increase soil aggregate stability, decrease wind and water erosion (Zuazo and Pleguezuelo, 2008; Ducamp et al., 2012, Chowaniak et al., 2016; Morton and Abendroth, 2017).

In the Cotton-4 countries (C4), namely Benin, Burkina Faso, Mali, and Chad, soil tillage and inappropriate management practices cause an accelerated degradation of soil fertility and a decrease of yields which can compromise the cotton production, however, very important in these countries. The rainfall irregularity which characterizes climate changes, involves unfavorable conditions for ploughing, with the consequences of sowing delays, and therefore, a decrease of crops yields (Ouattara et al., 2017). In this context, there is a need to explore DMC for a sustainable alternative of crop production in these countries. Scopel et al. (2005) reported that the amount of crop residues that is retained on the surface as a mulch depends on the residue availability, and hence on crop biomass production, and on the residues destinations. In the cotton growing zones of Burkina Faso, as well as many parts in the tropics, the low amount of crops residues in conventional systems are, in general, burned or removed from the fields for various domestic uses (Ogbodo, 2011; Autfray et al., 2012), while soil surface mulching provides many benefits in no tillage systems (Sombrero and Benito, 2010; Chowaniak et al., 2016).

This study was initiated by the “C4 + Togo” project, in collaboration with Brazil and the C4 countries, to improve the sustainability of cotton sector in Africa. The objective is to quantify the biomass production of cover crops cultivated in association with maize to ensure the DMC. Moreover, the study determines the effects of the DMC technique on the crop’s yields, in a maize and cotton rotation system. It was hypothesized that the introduction of cover crops associated with maize could improve the amount of biomass which is necessary for direct sowing in mulch-based cropping system and increased crops yields.

MATERIALS AND METHODS

The experiment was conducted in Farako-Bâ Research Station (4° 20 W Longitude, 11° 06 N Latitude, 405 m above sea level). The climate is of south-Sudanese type, with a rainy season ranging between May and October, and a dry season, from November to April. During the experiment carried out from 2010 to 2015, the mean annual rainfall was between 831 and 1289 mm, received on 62 to 79 days (Table 1). The rainfall distribution was characterized by frequent dry spells of 10 days or longer in June and July, followed by water excess in August and September.

The experiment was conducted on a tropical ferruginous soil (lixisol), after 4 years of natural fallow. Soil textures were sandy loam (0 to 20 and 20 to 40 cm depths) and clayey (40 to 60 cm), with important percentages of coarse elements unfavorable for moisture and nutrients retention on the surface layers. Soil chemical properties revealed low organic matter contents, total N, available P, and cation exchange capacity, while pH values (5.3 to 5.6) showed high acidity level (Brady and Weil, 2008). The soil hydrological parameters (moisture, bulk density) revealed a good

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Table 1. Sowing dates and rainfall at Farako-Bâ research station, 2010 to 2015.

Parameter	Years					
	2010	2011	2012	2013	2014	2015
Sowing dates of crops	Maize 17/07	Cotton 08/07	Maize 17/07	Cotton 09/07	Maize 26/06	Cotton 4/07
Sowing dates of cover crops	10/08	-	20/08	-	30/07	-
Rainfall (mm)	1289.5	831.0	1089.0	1126.0	1142.9	1050.9
Number of raining days	79	73	51	63	79	65

Table 2. General soil properties at the experiment site, Farako-Bâ station, 2010.

Characteristic	Depths		
	0-20 cm	20-40 cm	40-60 cm
Clay (%)	14.25 ± 0.35	18.63 ± 0.18	28.38 ± 0.18
Silt (%)	29.55 ± 2.02	28.69 ± 1.94	27.63 ± 4.74
Sand (%)	56.45 ± 2.37	52.81 ± 2.11	44.12 ± 4.92
Texture	Sandy loam	Sandy loam	Clayey
C (g kg^{-1})	5.60 ± 0.14	3.98 ± 0.07	3.61 ± 0.09
N (g kg^{-1})	0.43 ± 0.04	0.32 ± 0.07	0.28 ± 0.05
C/N	13.00 ± 0.70	12.50 ± 0.78	13.00 ± 1.43
P total (mg kg^{-1})	104.93 ±1.40	123.94 ± 33.15	171.38 ± 5.63
P available (mg kg^{-1})	6.95 ± 0.03	3.11 ± 0.06	0.67 ± 0.18
K total (mg kg^{-1})	879.76 ± 83.06	1131.06 ± 53.97	1943.49 ± 55.21
K available (mg kg^{-1})	133.87 ± 0.01	101.66 ± 0.00	90.52 ±1.75
CEC ($cmol^+$ kg^{-1})	3.22 ± 0.25	4.32 ± 0.17	7.88 ± 0.62
pH water	5.31 ± 0.15	5.37 ± 0.41	4.94 ± 0.02
Al^{3+} ($cmol^+$ kg^{-1})	0.10 ± 0.03	0.26 ± 0.03	0.42 ± 0.03
H^+ ($cmol^+$ kg^{-1})	0.04 ± 0.01	0.06 ± 0.02	0.04 ± 0.01
Bulk density	1.55 ± 0.01	1.51 ± 0.01	1.49 ± 0.02
Particles density	2.65 ± 0.01	2.68 ± 0.02	2.68 ± 0.02
pF 2.5	15.23 ± 0.09	16.25 ± 0.30	21.29 ± 0.47
pF 3	6.47 ± 0.30	7.82 ± 0.28	13.22 ± 0.12
pF 4.2	3.72 ± 0.74	4.42 ± 0.01	8.73 ± 0.04

Values after the sign ± represent standard deviation of means.

water infiltration within the soil profile. The detailed characteristics of the soil are given in Table 2.

Plant materials was maize (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) representing the two main crops in the cotton growing zones of Burkina Faso. Cotton variety used was FK37 with a cycle of 150 days and a potential yield of 3.5 t ha^{-1} of seed cotton. Maize variety SR 21 with 110 days cycle length, and 4.1 t ha^{-1} as potential yield, was also cultivated. In addition to these two crops, the five cover crops used were, *Brachiaria ruziziensis*, *Mucuna cochinchinensis*, *Panicum maximum*, *Crotalaria juncea* and *Stylosanthes hamata*.

This study was conducted in a complete randomized block design, with seven treatments and four replications. The treatments consisted of cover crops associated with maize, followed the next year, by direct sowing of cotton, according to a biennial maize and cotton rotation (Table 3). The experimental unit of 160 m² was a plot consisting of ten 20 m length rows, spaced 0.80 m apart. Each of the four replications was separated by an alley of 2 m, while the total surface of this experiment was 4480 m². In the first year of study carried out in 2010, soil was ploughed using a tractor at an average depth of 25 cm, and then harrowed.

From the second year of study (2011), animal traction was used for ploughing (15 cm depth) only, in conventional tillage plots (T7). The direct sowing was adopted both for maize and cotton, in no-tillage system for the other treatments (T1 to T6). Thus, from the third year of experimentation, direct sowing of maize was done without soil surface mulch after removing the cotton straws. In conventional tillage system, the moldboard plough was used to carry out ploughing in animal draw for soil preparation. Before the direct sowing of crops (maize and cotton), glyphosate (N-phosphonomethyl glycine) non selective herbicides, was used for weeds control at the rate of 720 to 1080 g ha^{-1}. Cotton was directly sown on the biomass produced by maize and the cover crops residues. Cotton and maize were sown in seed holes, drawn aside

Table 3. Treatments used.

Treatment	Years and crops	
	2010, 2012 and 2014	**2011, 2013 and 2015**
T1	Maize	Cotton in DMC*
T2	Maize + *Brachiaria ruziziensis*	Cotton in DMC (maize + *B. ruz*) mulch
T3	Maize + *B. ruz* + *Mucuna cochinchinensis*	Cotton in DMC (maize + *B. ruz* + *M. cochinchinensis*) mulch
T4	Maize + *B. ruz* + *Panicum maximum.*	Cotton in DMC (maize + *B. ruz* + *P. maximum*) mulch
T5	Maize + *B. ruz* + *Stylosanthes hamata*	Cotton in DMC (maize + *B. ruz* + *S. hamata*) mulch
T6	Maize + *Crotalaria juncea*	Cotton in DMC (maize + *C. juncea*) mulch
T7	Maize in conventional tillage (CT)	Cotton in conventional tillage (CT)

DMC*: Direct sowing under mulch-based cropping system.

by 0.40 m, then thinned out 15 days after emergence, at two plants per hole, to obtain a theoretical density of 62,500 plants per hectare. Crops were sown between June 26th and July 17th, depending on years (Table 1). The cover crops *B. ruziziensis*, *M. cochinchinensis*, *P. maximum*, *C. juncea* and *S. hamata* were sown between two rows of maize 0.40 m apart from each other, approximately three weeks after the maize sowing.

In the first year of the study (2010), 6 t ha^{-1} of compost was applied for soil amendment. The average composition of compost was 20.1, 2.2, 1.1, 1.7, 0.3, 2.14, and 0.19% for C, N, P, K, S, Ca, and Mg, respectively. Mineral fertilization of cotton and maize was done using 200 kg ha^{-1} of NPKSB (14-18-18-6S-1B) applied 15 days after emergence and 50 kg ha^{-1} of urea (46% N), at 40 days. Cover crops were not fertilized. Weeds control on the two main crops was done using the herbicides applications (800 g ha^{-1} of diuron for cotton and 1250 g ha^{-1} of pendimethalin for maize) supplemented by mechanical weeding. Cotton protection was ensured by applying the insecticides indoxacarb (150 g ha^{-1}) at 30 and 44 days after emergence, the association of zeta-cypermethrin (12 g ha^{-1}) and profenofos (200 g ha^{-1}) at 58 and 72th days, and cypermethrin (36 g ha^{-1}) associated with acetamiprid (8 g ha^{-1}) at the 86 and 100th days. After maize harvesting, maize straws and cover crops biomass were preserved as surface mulches for soil protection. Thus, in conventional tillage plots (T7), maize straws were completely exported out of the field, as well as the cotton straws removed from all treatments.

In the first year of experimentation, leaf samples of maize were collected at 60 days after plants emergence to determine nitrogen, phosphorus and potassium contents. Cotton and maize yields, as well as the dry matter of these two crops, were evaluated on eight central lines (128 m²) of each plot. Determination of the biomass produced by the cover crops (combined with maize) was done from four 1 m² spots in each plot.

Data were collected and subjected to an analysis of variance (ANOVA), using the GENSTAT 9.2 software. Student-Newman-Keuls test was used for means comparison when the analysis of variance reveals significant differences between treatments at 5% significance level.

RESULTS AND DISCUSSION

Contribution of cover crops to biomass production in DMC

The biomass production of cover crops associated with maize varied significantly (P < 0.05) according to the type of cover crops (Table 4). Measurements of biomass in 2010, 2012 and 2014 showed that *C. juncea* associated with maize (T6) gave significantly lower biomasses productions. This result confirms that the production of biomass was very dependent on used cover crops reported by various studies (Fageria et al., 2005; Ducamp et al., 2012; Santos et al., 2014). The use of *B. ruziziensis* alone (T2) or associated with *M. cochinchinensis* (T3), *P. maximum* (T4), and *S. hamata* (T5) gave no significant difference in biomass productions (2010 and 2012). However, in 2014, this biomass decreased significantly (P < 0.05) with *B. ruziziensis* + *Mucuna cochincinensis* (T3) due to the growing conditions. Santos et al. (2014) reported the interest of covers crops, particularly, grasses with a deep root system and high biomass production, which are essential for nutrient supply in the long term, mainly in the soil surface layers. The lowest biomass productions obtained with *C. juncea* (T6) could be attributed to low densities and vegetative growth of this cover crop which suffer from the competition of maize. Planting two cover crops between main crop (maize) rows, did not improve the biomass amount compared to the use of *B. ruziziensis* alone (T2) which can produce more than 3917 kg ha^{-1} of dry matter. The important biomass production of cover crops can also be affected by environmental conditions, soil fertility and crop management practices (Zuazo and Pleguezuelo, 2008; Basche et al., 2016)

The lowest quantities of total dry matter were produced in the control (T1) and conventional tillage system (T7) plots, without using the cover crops (Table 5). The productions of total dry matter were significantly improved by the associations of cover crops with maize, except *C. juncea* (T6). Using the cover crops, total biomass increase was +13% with *C. juncea* and +63 to +89% with *B. ruziziensis* alone or combined with the other cover crops, which gave better soil covering and the protection from water erosion (Santos et al., 2014; Prabhakara et al., 2015; Alvarez et al., 2017). In addition to the soil protection, the increase in total biomass would induce an improvement of soil organic and biological status (Wilson, 2015). The use of the leguminous *M. cochinchinensis* as cover crop in this study could contribute to nitrogen

Table 4. Productions of dry matter biomass by cover crops associated with maize during 3 years.

Treatment	2010	2012	2014
		kg ha^{-1}	
T1. Maize	-	-	-
T2. Maize + *B. ruziziensis*	3142^{a} ± 770	3442^{a} ± 863	3917^{ab} ± 412
T3. Maize + *B. ruz* + *M. cochinchinensis*	3421^{a} ± 871	3653^{a} ± 879	2500^{bc} ± 610
T4. Maize + *B. ruz* + *P. maximum*	3488^{a} ± 709	3435^{a} ± 1230	5317^{a} ± 1831
T5. Maize + *B. ruz* + *S. hamata*	2454^{a} ± 860	2538^{ab} ± 1118	4483^{a} ± 1502
T6. Maize + *Crotalaria juncea*	833^{b} ± 789	1729^{b} ± 698	1433^{c} ± 402
T7. Maize in conventional tillage (CT)	-	-	-
F	6.681	2.759	6.013
Probability (0.05)	< 0.0001	0.014	0.004

Values followed with the same letter in each column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability. Values after the sign ± represent standard deviation of means.

Table 5. Total biomass production by maize straws and cover crops.

Treatment	2010	2012	2014
		kg ha^{-1}	
T1. Maize	3932^{b} ± 1142	2258^{d} ± 664	5703^{d} ± 167
T2. Maize + *B. ruziziensis*	6698^{a} ± 704	5981^{a} ± 946	9229^{ab} ± 1030
T3. Maize + *B. ruz* + *M. cochinchinensis*	7314^{a} ± 1121	5551^{ab} ± 344	7786^{bc} ± 575
T4. Maize + *B. ruz* + *P. maximum*	7124^{a} ± 732	6114^{a} ± 518	9965^{a} ± 723
T5. Maize + *B. ruz* + *S. hamata*	6221^{a} ± 1028	5124^{ab} ± 1399	9314^{ab} ± 2221
T6. Maize + *Crotalaria juncea*	4373^{b} ± 1542	4253^{bc} ± 1019	6694^{cd} ± 637
T7. Maize in conventional tillage (CT)	3868^{b} ± 655	3336^{cd} ± 1175	6510^{d} ± 1044
F	8.838	9.607	9.085
Probability (0.05)	<0.0001	<0.0001	<0.0001

Values followed with the same letter in the same column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability. Values after the sign ± represent standard deviation of means.

fixation (Lu et al., 2000; Santos et al., 2014) and can reduce the use of nitrogenous fertilizers of subsequent crops (Tabaldi et al., 2012). The increase of biomass quantities by cover cropping and maintenance of maize straws on the field were favorable to cotton growing in DMC, which main limiting factor in tropical zone, is small amounts of surface residue for soil mulching (Zuazo and Pleguezuelo, 2008; Tabaldi et al., 2012; Prabhakara et al., 2015).

Nitrogen, phosphorus and potassium contents of maize associated with the cover crops

In the first year of experimentation, the use of cover crops associated with maize did not have significant effects on N, P and K contents of maize (Table 5). Cover crops are generally included in cropping systems as nutrient management tools (Ruffo and Bollero, 2003; Busari et al., 2015). According to Loué (1984), maize nutrition was correct for P and K with higher contents than their respective deficiency level of 0.25 and 1.75%. Thus, values of nitrogen were sometimes below the level considered to be adequate (2.75%) by Loué (1984), indicating a nitrogen deficiency on treatments associating maize with *B. ruziziensis* + *P. maximum* (T4) and *B. ruziziensis* + *S. hamata* (T5). Dinnes et al. (2002) and Luoa et al. (2017) reported that for the first several years after conversion to no-tillage, there is competition for nitrogen with soil productivity increases and more nitrogen is stored in the soil in the form of organic matter and humus. These results suggested that the use of cover crops, properly associated with maize may increase biomass production (Fageria et al., 2005) without affecting maize nutrition.

Effects of cover crops association on maize yields

Maize grain yields were not statistically influenced by

Table 6. Nitrogen, phosphorus and potassium contents of maize in 2010.

Treatment	N	P	K
	% Dry matter		
T1. Maize	2.97 ± 0.39	0.49 ± 0.13	2.52 ± 0.30
T2. Maize + *B. ruziziensis*	2.86 ± 0.64	0.38 ± 0.03	2.53 ± 0.01
T3. Maize + *B. ruz* + *M. cochinchinensis*	2.79 ± 0.10	0.38 ±0.05	2.63 ± 0.15
T4. Maize + *B. ruz* + *P. maximum*	2.74 ± 0.03	0.36 ± 0.02	2.73 ± 0.01
T5. Maize + *B. ruz* + *S. hamata*	2.56 ± 0.21	0.34 ± 0.08	2.63 ± 0.45
T6. Maize + *Crotalaria juncea*	3.17 ± 0.43	0.37 ± 0.01	2.84 ± 0.15
T7. Maize in conventional tillage (CT)	2.86 ± 0.21	0.35 ± 0.01	2.63 ± 0.14
F	0.442	1.215	0.500
Probability (0.05)	0.830	0.398	0.792

Values after the sign ± represent standard deviation of means.

Table 7. Yields of maize associated or not with cover crops.

Treatment	2010	2012	2014
	kg ha^{-1}		
T1. Maize	2973^{a} ± 577	2338^{ab} ± 469	3878^{ab} ± 331
T2. Maize + *B. ruziziensis*	2686^{a} ± 887	2441^{ab} ± 781	3782^{ab} ± 572
T3. Maize + *B. ruz* + *M. cochinchinensis*	2622^{a} ± 624	1931^{b} ± 1182	3795^{ab} ± 405
T4. Maize + *B. ruz* + *P. maximum*	2808^{a} ± 497	2527^{ab} ± 575	3362^{b} ± 866
T5. Maize + *B. ruz* + *S. hamata*	2619^{a} ± 590	2406^{ab} ± 109	3770^{ab} ± 582
T6. Maize + *Crotalaria juncea*	2696^{a} ± 528	2462^{ab} ± 658	4106^{ab} ± 113
T7. Maize in conventional tillage (CT)	3039^{a} ± 787	3138^{a} ± 761	4218^{a} ± 702
F	0.230	0.992	0.964
Probability (0.05)	0.962	0.027	0.473

Values followed with the same letter in the same column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability. Values after the sign ± represent standard deviation of means.

cover crops association in first year (2010), contrary to the third and fifth years (Tables 6 and 7). The best yields were obtained with maize cultivated without cover crops in conventional tillage (T7). Fageria et al. (2005) reported that planting cover crops between main crops can improve soil physical, chemical, and biological properties and consequently lead to improved soil health and yield of principal crops. During the first 6 years of this study, DMC did not show significant increase in maize yields reported by various studies (Scopel et al., 2005; Ducamp et al., 2012; Santos et al., 2014; Luoa et al., 2017). Results showed that cover crops associations led to depressive effects on maize yields mainly due to the competition for water and nutrients of cover crops with maize (Santos et al., 2014; Alvarez et al., 2017). The most significant decreases of maize yields were 13.8 and 38.5%, respectively in 2010 and 2012, with insertion of *B. ruziziensis* + *M. cochinchinensis* (T3) between maize rows. In the experiment, the most severe competition was induced by *M. cochinchinensis* cover cropping invading completely the maize plants whose potentials of production were also reduced. In short term study, after three years experiment, Nkongoloa and Harunab (2015) reported that maize yield was not significantly affected by tillage or cover crop which may have an impact on soybean yield. These results suggested a better choice and management of cover crops in order to avoid adverse effects of cover cropping reported by Dinnes et al. (2002).

Variations of seed cotton yields in DMC

No tillage in DMC (Table 8) did not affect significantly seed cotton yields compared with conventional tillage (T7) using moldboard plough, which is difficult to be done under irregular and unstable climatic conditions (Nielsen and Reenberg, 2010). In 2011, 2013, and 2015, the direct sowing of cotton under maize stems and cover crops biomasses, were as effective on yield conventional tillage system (T7) with annual plough causing soil erosion, compaction, and nutrient depletion (Ouattara et al., 2006;

Table 8. Seed cotton yields variations in conventional tillage and direct sowing with maize as precedent crop.

Treatment	2011	2013	2015
		Kg ha^{-1}	
T1. *DMC maize straws mulch	2214 ± 506	1248 ± 255	1082 ± 140
T2. DMC (maize + *B. ruziziensis)* mulch	2155 ± 264	1195 ± 219	1166 ± 320
T3. DMC (maize + *B. ruz* + *Mucuna c.*) mulch	2045 ± 413	1090 ± 242	1212 ± 234
T4. DMC (maize + *B. ruz* + *Panicum m*) mulch	2202 ± 253	1142 ± 161	1188 ± 286
T5. DMC (maize + *Brach ruz* + *S. hamata*) mulch	2059 ± 391	1204 ± 162	1173 ± 144
T6. DMC (maize + *C. juncea)* mulch	2146 ± 310	1049 ± 140	1015 ± 180
T7. Conventional tillage (CT)	2298 ± 177	1284 ± 334	1336 ± 380
F	0.262	0.616	0.628
Probability (0.05)	0.948	0.715	0.706

*DMC: Direct sowing under mulch-based cropping system. Values after the sign ± represent standard deviation of means.

Basche et al., 2016; Chowaniak et al., 2016; Morton and Abendroth, 2017). This result confirms the importance of DMC which can enhance profitability by lowering machinery and other costs and are more environmentally fit than the moldboard plough (Sombrero and Benito, 2010; Tabaldi et al., 2012; Luoa et al., 2017). Furthermore, yield increases depend on management of cover crops as well as subsequent crops (Fageria et al., 2005). During this study carried out from 2011 to 2015, probably due to climatic variations, the cover crops and no tillage in DMC did not gave the expected increase of crops yield reported by Oliveira et al. (2016). The higher seed cotton yields in 2011 could be attributed to the residual effects of 6 t ha^{-1} of compost previously applied for soil amendment at the beginning of the study in 2010. Long-term research reveals that seven to nine years of continuous no-till produces higher yields than conventionally tilled fields because it takes seven to nine years to improve soil health by getting the microbes and soil fauna back into balance and to start to restore the nutrients lost by tillage (Van Eerd et al., 2014; Kulagowski et al., 2016). The low effectiveness of DMC in improvement of cotton and maize yields, founded in this experiment, seems related to the insufficiency of soil mulching by the residues which are used for the animals feeding. But also, the number of years of experimentation seems insufficient to obtain positive effects of DMC.

Conclusion

This study pointed out the benefit of cover crops insertion between the main crops to improve biomass production which is necessary to undertake direct sowing under mulch-based cropping system. The association of various cover crops with maize did not influence maize plants nutrition in the first year of experimentation, but this practice could affect the maize yields compared to conventional tillage. Generally, even if the DMC did not produce improvements in cotton and maize yields, these practices appeared as effective as conventional tillage system which is more expensive for the requirement of soil plowing. These first results, suggested a better use of cover crops to avoid the risks of competition with the principal crop. Analyses of specific impact of each cover crop were needed to improve management of cover crops for appropriate recommendations to farmers regarding the diversification of agricultural productions. In addition, this study revealed a potential to be explored by direct sowing under mulch-based cropping system. Therefore, the DMC effects on soil properties, especially on soil hydrology and nutrients cycling, need to be determined for environmental sustainability of the production system in continuation of the study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Potassium forms of soils under *enset* farming systems and their relationships with some soil selected physico-chemical properties in Sidama zone, Southern Ethiopia

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Soil potassium is classified as unavailable, readily available and slowly available (fixed) K forms. A research was conducted to determine the distribution of forms of K (water soluble K, exchangeable K, non-exchangeable K and total K) and their relation with some soil properties under *enset* farming systems of Sidama zone in South Ethiopia. The soils were collected from 'Qola' (dry, hot tropical climate and moist to humid), 'Woinadega' (warm subtropical climate) and 'Dega' (wet and cool temperate climate). In the study, coefficient of variance (CV%) for sand, soil organic matter (SOM), total nitrogen (TN), available phosphorus, water soluble K, exchangeable K, non-exchangeable K and percent potassium saturation were high (>30%). The high, medium and low proportions of acidic reaction were determined in Hula, Dale and Hawassa-Zuriya districts, respectively. The concentrations of total K in the soils ranged from 1358.9 to 3181.5 (mg/kg) where the Hula district soil show the lowest value. Water soluble K and exchangeable K concentrations in the soils ranged from 14.7 to 110.5 mg/kg and 130.9 to 1134.9 mg/kg, respectively, where the lowest values were indicated by Hula district. The Hawassa-Zuriya district soils had the highest concentrations in both exchangeable and water soluble K. The non-exchangeable K concentrations varied from 241.5 to 1714.9 mg/kg. It constituted the highest proportion of the total K measured in the soils, while the proportion of water soluble K in the total K measured was the lowest. Nearly all soils of Hula and Dale districts indicated low ratio of K:Mg. Almost all of the Hula district soils and about 50% of the Dale district soils had potassium saturation percent (KSP) values below critical level. Significant indirect and direct associations existed among soil physico-chemical properties. All forms of soil K correlated significantly and positively with pH, PBS and silt, and negatively correlated with SOM and Al^{+3}.

Key words: Water soluble K, exchangeable K, non-exchangeable K, total K, organic matter, cation exchange capacity.

INTRODUCTION

Potassium (K) is a macro element in plant, animal and human nutrition (Simonsson et al., 2009). It is necessary for the functioning of all living cells, and is thus present in all plant and animal tissues. Potassium is required in large amounts by plants, animals and humans (Hamdallah, 2004) because it plays a critical role in plant nutrition and physiology. Many plants frequently absorb greater potassium than nitrogen and phosphorus. It is extracted in large quantities by intensive cropping systems (Panaullah et al., 2006) and hence regularly applied to agricultural lands in many areas (Rangel, 2008).

Soil potassium is classified (based on its availability to plants) into relatively unavailable, readily available and slowly available or exchangeable K forms. Water soluble and exchangeable (K held on soil colloid) forms are known to be readily available K pools constituting 1 to 2% of the soil total K (Brady and Weil, 2002). Over 95% of potassium in tropical soils occurs as relatively unavailable forms contained in primary and secondary minerals including feldspars, muscovites, biotites and illites (Olaitan and Lombin, 1984). Mineral (structural) K is unavailable form of potassium in the short-term periods and constitutes about 90-98% of all soil K (Hoeft et al., 2000). Defoer et al. (1998) noted that these minerals are quite resistant to weathering and so they release K very slowly. Non-exchangeable K is not readily available to plants. However it is in equilibrium with available forms and consequently acts as an important reservoir of slowly available K (Srinivasarao et al., 2010). Generally, the K held at inter-lattice positions is non-exchangeable K and it is not exchangeable by NH_4OAc (Lalitha and Dhakshinamoorthy, 2013).

Potassium forms distributed in the soil are in equilibrium with each other. The equilibrium between them determines the status of K in the soil and the potential of its supply to plants (Pavlov, 2007). It is affected by physical, chemical, biological and climatic factors (Barre et al., 2008). This could be related to clay mineralogy (Barre et al., 2008), moisture (Zeng and Brown, 2000) and texture (Pal et al., 2001). Furthermore, soil K forms and their equilibrium in soil could be related to cation exchange capacity (Sardi and Csitari, 1998), pH (Uribe and Cox, 1988), and concentrations of other ions (Zawartka et al., 1999) of the soil. In addition to these soil properties, fertilization and cropping system are the most important management factors that influence potassium equilibrium in soils (Simonsson et al., 2007). In this way, an exceeded tillage and the abandonment of soil erosion could destabilize this equilibrium between soil physical and chemical properties (Bogunovic et al., 2017; Martínez-Hernández et al., 2017; Rodrigo-Comino et al., 2017).

Readily available pools of K are slowly depleted after prolonged periods of agricultural production and during removal of the agricultural products. Though, the dependence of plants on the release of fixed K to recharge the readily available pools when these are exhausted, the size of the fixed potassium pool in many soils, or the rate at which it is released, is insufficient to meet plant demand. This is common where crop production is intensive and/or when high-yielding production systems are established (Mikkelsen, 2007). Therefore, a clearer understanding of the distribution of potassium forms and their relationships with other physico-chemical properties are required to enable effective management of potassium supply and use.

The main aim of the present study is to determine soil potassium forms, examine the relationships existing between the K forms and evaluate their relations with other soil physico-chemical properties under *enset* farming systems of Sidama zone, South Ethiopia. The results of this study are expected to shed light on the effects of some soil properties on the crop availability of potassium in the study area.

MATERIALS AND METHODS

Study area

The study was conducted in Awassa-Zuriya, Dale and Hula districts of Sidama zone, Southern Ethiopia (Figure 1) in 2016. Sidama administrative zone is located within 5°45'- 6°45'N latitude and 38°-39° E longitude, covering a total area of 6,538.17 sq km of which 97.71% is land and 2.29% is covered by water (SZPEDD, 2004). It is bordered by Gedeo administrative zone in the south, North Omo administrative zone in the west and Oromiya regional state in the north and southeast. Sidama zone lies in the area varying from flat land (warm to hot) to highland (warm to cold). The regional and zonal capital, Hawassa, which is located in the northern tip of Sidama zone, has a distance of 275 km from Addis Ababa. In the present study, sample districts from the zone were randomly selected because nearly all areas in the zone have good potential for *enset* production irrespective of productivity variation due to rainfall and altitude discrepancy. The sites are located between 038°20'7.8" - 038°32'36.5"E and 06°28'15.5" - 07°04'50.3"N. A total of nine 'Kebeles' (peasant associations) were selected, of which 3 were from Awassa-Zuria, 3 from Dale and 3 from Hula district.

Soil sampling

Eighty one composite samples were collected in November 2015 from the three randomly selected districts in Sidama zone. Then, three 'Kebeles' in each district were also selected randomly. After selecting representative farmers' *enset* farms in the 'Kebeles', each field was divided into three strata 12 m long in the direction from home vicinity to far located fields. Composite soil sample (12 cores) from each stratum was taken based on the method outlined by Hussen (2007). Twelve soil profiles of 50 cm depth were bored randomly using an auger and soils were collected in plastic pail. Samples collected from cores were placed on a plastic sheet with an area of 3 m^2 and thoroughly mixed. Then, about 1 kg sample was taken and kept in a polyethylene plastic bag and labeled. Undisturbed samples were taken with a core sampler that is 10 cm

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long and 7.2 cm in diameter for bulk density determination. Before laboratory analysis, samples were air-dried at room temperature, ground using mortar and pestle, homogenized, and passed through a 2 mm sieve. Finally, samples were stored in clean and dry area at room temperature until the time of use.

Physico-chemical analysis

Selected soil physical and chemical properties were analyzed at Horticoop Ethiopia (Horticultural) PLC in Addis Ababa and at Hawassa College of Teacher Education. Particle size analysis was performed using the Bouyoucous hydrometer method (Bouyoucos, 1951). Bulk density was determined by core method (Black, 1965). Maximum water holding capacity was measured according to procedures in Piper (1996). The pH was determined in 1:2.5 soil-water suspension using a glass electrode (Jackson, 1973). Electrical conductivity (EC) was determined from the saturation extract (1:5 soil water ratio) of soils (Gupta, 2009). Organic carbon was determined by wet oxidation method (Walkley and Black, 1934). Total nitrogen (N) was determined by Kjeldhal method. Mehlich III extractant was used to extract phosphorus (P), potassium, calcium (Ca), magnesium (Mg), sodium (Na) and sulfur (S) (Mehlich, 1984). The concentration of nutrients was determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). Cation exchange capacity (CEC) was determined using ammonium acetate method (Sumner and Miller, 1996).

Water soluble K was extracted with deionized water (1: 5 w/v) after shaking for 30 min on a mechanical shaker and later, the contents were centrifuged to separate clear extract (Jackson, 1973). The exchangeable potassium was determined using Mehlich III extractant (Mehlich, 1984). The non-exchangeable potassium was extracted by adding 25 ml of 1 M HNO_3 to 2.5 g of soil and boiling for 15 min (Helmke and Sparks, 1996). Total K was estimated by the digestion of soil samples (ground to pass through 0.17 mm sieve) in HF-$HClO_4$-HNO_3 acid mixture (McKeague, 1978). Potassium in different soil extracts was analyzed using the flame photometer. Soil organic matter (SOM) was estimated by multiplying the soil organic carbon by 1.72 (Baldock et al., 1999). The different values for the various soil fertility parameters were rated using the EthioSIS adopted critical levels (Ethiosis, 2014).

Statistical analysis

Data analyses were performed with the statistical analysis system (SAS Institute, 2012). The soil data generated were subjected to analysis of variance (ANOVA) using the general linear model procedure. Tukey's Studentized Range (HSD) test was used to determine the differences among soil samples from different districts based on the measured K forms and other soil properties at P = 0.05. The simple correlation analysis of data was computed in relation to the potassium amount with physico-chemical properties of soil under study.

RESULTS AND DISCUSSION

Soil physical properties

Selected physical and chemical properties determined in the soils are summarized in Tables 1 and 2. For all soil properties determined, Tukey's (HSD) means comparison test was employed to show means that indicate statistically significant differences. The proportions of sand, silt and clay varied from 14 to 56, 16 to 45 and 17 to 50% for Awassa-Zuriya, Dale and Hula districts, respectively. Based on Gomes and Garcia (2002), CV value of sand for all district soils was very high (>30%) indicating wide variability in sand proportion. The results indicate that most of the soils contained relatively higher proportion of clay as compared to silt and sand, but among the districts, Hula district had highest sand contents (Table 1). Percentage of clay soils in Dale and Hula districts was high (55.6%) while only 22.2% of the studied soils were clay in Awassa-Zuriya. Therefore, site specific K fertilizer recommendation is required to boost crop productivity since most soils of these areas are clay soils (Lelago et al., 2016) that could fix exchangeable K and reduce its availability for plants (http://www.ata.gov.et/highlighted-deliverables).

Bulk densities (g/cm^3) of the soils of Awassa-Zuriya, Dale and Hula districts varied from 0.71 to 0.94, 0.87 to 1.22 and 0.87 to 1.08, respectively. Mean bulk density of Awassa-Zuriya was lowest (P<0.01) and statistically different from that of Dale and Hula districts. The maximum percent water holding capacity (WHC) of the soils of Awassa-Zuriya, Dale and Hula districts varied from 53.3 to 70, 58.96 to 76.81 and 64.52 to 80.97, respectively. Among the districts, Awassa-Zuriya soils were found to hold less water (59.6%) as compared to Dale and Hula district soils (P<0.0001).

Soil chemical properties

The pH values of the soils of Awassa-Zuriya, Dale and Hula districts varied from 6.2 to 7.5, 6.3 to 7.6 and 4.7 to 5.4, respectively. According to EThiosis (2014), it indicated wide range of variation from strongly acidic to moderately alkaline and all of the soil samples of Hula district were strongly acidic in reaction. Percent SOM of the studied soils were very variable (CV>30%) and shows high significant difference among the districts (P<0.0001) (Table 1). It ranged from 2.1 to 7.1% and was observed to increase with decrease in pH. Exchangeable Ca^{2+} and Mg^{2+} of the soils ranged from 1669.7 to 4525.1 and 221 to 610.5 mg/kg, respectively (Table 2) and increased with increase in soil pH (Van diest, 1978). The cation exchange capacity (CEC) varied from moderate to very high (Landon, 2014) and ranged between 17.4 and 46.4 meq/100g. Base saturation (BS) of the soils ranged from 35 to 83.4 and it was low in Hula district as compared to the other districts (P<0.05) (Table 1) and increased with increase in soil pH. If BS is considered as a criteria for leaching, about 55.56% of Hula, 77.78% of Dale and 66.67% of Awassa-Zuriya districts soils were, moderately leached (30 to 50% BS), weakly leached (50 to 70% BS) and very weakly leached (70 to 100% BS), respectively (Pam and Murphy, 2007). Electrical conductivity (EC) of Awassa-Zuriya, Dale and Hula districts soils ranged from 0.1 to 0.22, 0.11 to 0.18 and 0.09 to 0.18 dSm^{-1}, respectively (Table 1). According to EthioSIS (2014), all

Table 1. Descriptive statistics of some selected soil properties of enset farming system soils in Sidama.

District	Descriptive statistics	pH	EC (Ds/m)	OM (%)	BS (%)	Bulk density (g/cm^3)	CEC (Cmol/kg)	WHC (%)	Soil texture (%)		
									Sand	Clay	Silt
Awassa-Zuriya (N = 27)	Mean	7.0[a]	0.15[a]	2.9[a]	67.3[a]	0.83[a]	28.3[a]	59.6[a]	32[a]	34[a]	33.6[a]
	StdDev	0.4	0.04	0.8	7.1	0.08	8.99	6	12.9	10.4	4.7
	Minimum	6.2	0.10	2.1	59	0.71	17.4	53.3	14	20	30
	Maximum	7.5	0.22	4.8	80.9	0.94	43.4	70	50	48	45
	CV%	5.7	26.7	27.6	10.5	9.64	31.8	10.1	40.3	30.6	14
Dale (N = 27)	Mean	6.9[a]	0.14[a]	4.5[b]	65.9[a]	0.97[b]	30.9[a]	68.8[b]	31.3[a]	39.8[a]	26.7[ab]
	StdDev	0.4	0.02	1.0	7.2	0.10	6.03	5.04	7.9	6.8	6.6
	Minimum	6.3	0.11	3.4	58.3	0.87	27.1	59	19	30	19
	Maximum	7.6	0.18	6.6	71.7	1.22	46.4	76.8	44	50	38
	CV%	5.8	14.3	22.2	10.9	10.3	19.5	7.3	25.2	17.1	24.7
Hula (N = 27)	Mean	5.1[b]	0.14[a]	5.41[b]	51.5[b]	0.95[b]	32[a]	74.6[b]	37.9[a]	36.4[a]	24.8[b]
	StdDev	0.25	0.03	0.97	16.6	0.06	5.3	5.59	11.4	11.3	6.9
	Minimum	4.7	0.09	4.34	35	0.87	26	64.5	26	17	16
	Maximum	5.4	0.18	7.10	83.4	1.08	42.6	81	56	46	40
	CV%	5.01	21.4	17.9	32.2	6.3	16.6	7.5	30.1	31	27.8
Total (81)	Mean	6.6	0.14	4.28	61.7	0.92	30.4	67.7	33.74	36.7	28.3
	StdDev	0.88	0.031	1.4	12.8	0.1	6.9	8.24	10.9	9.6	7
	Minimum	4.7	0.09	2.1	35	0.71	17.4	53.3	14	17	16
	Maximum	7.6	0.22	7.1	83.4	1.22	46.4	81	56	50	45
	CV%	13.34	22.3	32	20.7	11.3	22.6	12.2	32.4	26.24	24.9
	F value	23.1****	0.68[NS]	16.35****	5.2*	8.02**	0.66[NS]	16.56****	0.98[NS]	0.8[NS]	5.1*

N=Number of total samples per district, **** =P<0.0001, *** = P<0.001, ** =P<0. 01, * =p<0.05, NS = non-significant, Means with similar letters are not Statistically significant at P = 0.05, Std Dev = standard deviation, CV% = coefficient of variation, F value = statistical F test.

the soil samples analyzed were salt free.

Available phosphorus, sulfur and total nitrogen (TN)

The TN status of the study area ranged from 0.12 to 0.37 mg/kg and was noticeably variable, CV>30% (Gomes and Garcia, 2002) (Table 2). The results showed that available phosphorus content varied from 2.13 to 403 mg/kg and decreased with decrease in soils pH. Moreover, extremely high variation (CV% =159) in available phosphorus was found among the districts, while maximum within the district variability was recorded for the Hula (high land) soils. The result is in line with the findings of Mamo et al. (1998) who reported the variable P status for Ethiopian highland soils. The available S ranged from 20.65 to 45.78 mg/kg in soils of the study area and significant difference between means was

Table 2. Descriptive statistics of some soil macronutrients and sodium under enset farming system soils of Sidama.

District	Descriptive statistics	Ca	Mg	TN	P	S	Na
		mg/kg					
Awassa-Zuriya (N = 27)	Mean	2997[a]	306.3[a]	0.15[a]	129.6[a]	35.6[a]	98.9[a]
	StdDev	850.2	80.6	0.03	117.3	8.51	53
	Minimum	1892.9	221	0.12	30.2	20.65	51.1
	Maximum	4212.4	486.9	0.19	403.3	45.78	229.6
	CV%	28.4	26.3	0.2	90	23.9	53.6
Dale (N = 27)	Mean	3215.3[a]	349.7[a]	0.21[b]	16[b]	26.4[b]	37.9[b]
	StdDev	626.6	59.8	0.05	8.97	3.41	11.6
	Minimum	2548.5	256.5	0.17	4.51	22.6	22.8
	Maximum	4525.1	436.6	0.3	31	33.8	52.8
	CV%	19.5	17.1	23.8	56.1	12.9	30.6
Hula (N = 27)	Mean	2413.2[a]	388.7[a]	0.30[c]	15.62[b]	32.1[ab]	40.4[b]
	StdDev	603.2	96.9	0.04	14.48	5.96	11.4
	Minimum	1669.7	286.4	0.25	2.13	26.7	24.9
	Maximum	3415.4	610.5	0.37	45.9	44.2	62
	CV%	25	24.9	13.3	92.7	18.6	28.2
Total (81)	Mean	2875.2	348.2	0.22	53.7	31.3	59.1
	StdDev	757.8	84.6	0.07	85.5	7.2	42.1
	Minimum	1669.7	221	0.12	2.13	20.65	22.8
	Maximum	4525.1	610.5	0.37	403.3	45.78	229.6
	CV%	26.4	24.3	33.2	159.1	22.9	71.2
	F value	3.14[NS]	2.36[NS]	35.3****	8.3**	4.9*	10.5***

N=number of total samples per district, **** =P<0.0001, *** = P<0.001, ** =P<0.01, * = p<0.05, NS = non-significant. Means with similar letters are not statistically significant at P = 0.05. V% = coefficient of variance, Std Dev = standard deviation, F value = statistical F test.

indicated for Dale and Awassa-Zuriya districts (P<0.05).

Forms of potassium in the soils and percent potassium saturation (KSP)

Data of various forms of K determined in the soils and percent potassium saturation are presented in Table 3. For all samples, coefficient of variation (CV%) values of water soluble K, exchangeable K, non-exchangeable K and percent potassium saturation were 75.6, 82.13, 48.99 and 68.2%, respectively. This indicated that the distribution of the different K forms and percent K saturation in the soils varied considerably (Gomes and Garcia, 2002). It may be attributed to the differences in the chemical properties of the soils and possibly the extent to which K ions in the different agro-ecologies have leached due to variations in the rain intensity among the districts (Jones, 1982) and variations in the amounts of animal manure applied from district to district.

Total soil K contents give an indication of the relative amounts of K-containing minerals in soils. In the study, total K values ranged from 1358.9 to 3181.5 mg/kg (Table 3). Wild (1971) reported total potassium that varied between 596.7 and 39799.5 mg/kg in 31 soils from the savanna zone of Nigeria. He noticed the dependence of total K content on the nature of parent material from which the soil was formed. The present results are far below this range, indicating narrow range and that the soils are from somewhat related mineralogy. When each district was considered separately, total K ranged from 1601.4 to 3068, 1806 to 2840.8 and 1358.9 to 3181.5 mg/kg in enset farming system soils of Awassa-Zuriya, Dale and Hula districts, respectively (Table 3). The mean values for the soils of Awassa-Zuriya, Dale and Hula districts were found to be 2386, 2300 and 2100 mg/kg, respectively with the highest range observed in Hula which was followed by Awassa-Zuriya. The high ranges in Hula and Awassa-Zuriya shows variations in the soils' mineralogy, while comparatively narrow range in Dale was observed, indicating little mineralogical variation among the Dale soils.

The Hula district, which had higher mean percentage clay content (36.4%) and lowest mean soil pH (5.1), showed the lowest mean (2100 mg/kg) total K content. This is in good agreement with Suddhiprakarn et al.

Table 3. Descriptive statistics of soil potassium forms and percent potassium saturation of soils under *enset* farming system of Sidama zone.

District	Descriptive statistics	Water soluble K (mg/kg)	Exch. K (mg/kg)	Non-exch. K (mg/kg)	Total K (mg/kg)	Potassium saturation (%)
Awassa-Zuriya (N = 27)	Mean	69.4[a]	572.29[a]	973.8[a]	2386[a]	6.5[a]
	StdDev	20.2	324.8	370.3	478.12	1.9
	Minimum	50	208.41	642.6	1601.4	4.4
	Maximum	110.5	1144.8	1714.9	3068	9.2
	CV%	29.1	56.75	38	20	29.2
Dale (N = 27)	Mean	19.5[b]	195.66[b]	743.4[ab]	2300[a]	3.5[b]
	StdDev	2.43	24.9	361.5	367	2.1
	Minimum	14.7	143.74	425.5	1806	1.3
	Maximum	22.6	227.7	1658.5	2840.8	7.8
	CV%	12.5	12.73	48.6	16	60
Hula (N = 27)	Mean	17.8[b]	177.9[b]	501.1[b]	2100[a]	1.53[c]
	StdDev	1.31	13.24	181.8	673.9	0.40
	Minimum	15.3	130.9	241.5	1358.9	1
	Maximum	19.2	355.5	818.5	3181.5	2.35
	CV%	7.4	7.44	36.3	32.1	26.14
Total (81)	Mean	35.57	315.28	739.43	2261.8	3.85
	StdDev	26.9	258.95	362.3	516.1	2.6
	Minimum	14.7	130.9	241.5	1358.9	1
	Maximum	110.5	1144.8	1714.9	3181.5	9.2
	CV%	75.6	82.13	48.99	22.82	68.2
	F value	56.12****	12.6***	5.02*	0.71NS	20.35****

N=Number of total samples per district, **** =P<0.0001, *** = P<0.001, * = p<0.05, NS = non-significant. Means with similar letters are not statistically significant at P = 0.05, StdDev = standard deviation, CV% = coefficient of variation, F value = statistical F test.

(2010) who noted that high soil clay contents with low soil pH are often associated with low total K concentration. It indicates that the Hula soils are highly weathered and leached of basic cations. According to Gomes and Garcia (2002), distribution of total K in Hula district showed very high variations (CV% > 30) probably due to variations in the amounts of manure applied and differences in the chemical properties of the soils. Over all, there were no significant differences in total K means among the studied districts.

Potassium present in soil solution as soluble cation is termed as water soluble K. It is readily absorbed by the plants and relatively unbound by cation exchange forces and invariably subject to leaching losses in relation to soil properties (Lalitha and Dhakshinamoorthy, 2013). In the present study, it ranged from 50 to 110.5, 14.7 to 22.6 and 15.3 to 19.2 mg/kg for Awassa-Zuriya, Dale and Hula districts, respectively. The mean values were 69.4, 19.5 and 17.8 mg/kg for Awassa-Zuriya, Dale and Hula districts, respectively. In proportion, about 55.6 and 100% of Dale and Hula districts were low in soil solution K status, respectively. The values in these areas were lower than the critical value of 19.5 mg/kg which was proposed by International Potash Institute (IPI, 2001) for water extractable potassium. These low values do not retard the release of exchangeable K, but are not enough to support plant growth. However, the release of exchangeable K is not fast enough to meet the requirement for rapidly growing crops (Bhaskarachary, 2011). The soil solution K status of Awassa-Zuriya (district with comparatively high sand and least clay proportion) was above the critical value indicating high probability of its leaching (Jones, 1982) (Table 1). The result is in line with the findings of Moraes and Dynia (1992) who found that sandy soils have greater K concentrations in solution than clayey soils. In sandy soils, a greater proportion of exchangeable K is present on planar (loose) sites which release K more readily than edge or interlayer positions (Sadusky et al., 1987).

The exchangeable K status ranged from 208.41 to 1144.8, 143.74 to 227.7 and 130.9 to 355.5 mg/kg in enset farming system soils of Awassa-Zuriya, Dale and Hula districts, respectively (Table 3). The mean values for the soils of Awassa-Zuriya, Dale and Hula districts were found to be 694.7, 428.1 and 189.8 mg/kg, respectively. According to the critical level adopted by EthioSIS (2014), 33.33 and 88.89% of Dale and Hula districts fall in low (90 to 190 mg/kg) exchangeable K status, respectively. The exchangeable K status of 55.56, 66.67 and 11.1% of Awassa-Zuriya, Dale and Hula, respectively was found to fall within the optimum range (190 to 600 mg/kg). The other 22.22% of Awassa-Zuriya district soils was high (600 to 900 mg/kg) in exchangeable K status with the remaining 22.2% very high (>900 mg/kg) in exchangeable K.

As with the low total K concentrations measured in the Hula district soils, the exchangeable and water soluble K concentrations were also low in almost all the samples. This observation can be attributed to the lowest mean soil pH (5.1) since most of the K^+ ions are displaced into the soil solution where leaching loss is high. The higher available K concentration measured in the higher pH (7.0) in Awassa-Zuriya appears to confirm this conclusion. Here, the higher content of exchangeable K may be due to the predominance of potassium rich minerals such as mica containing minerals (Patil et al., 2011). Over all, the status of available K indicated the need for site specific K management for Dale district, while Hula requires K recommendation for all its areas. When the Awassa-Zuriya district is considered, the high solution K could be lost through leaching in summer seasons (Jones, 1982) and hence K recommendation could also be required as a soil management alternative.

Potassium: magnesium ratio of the Awassa-Zuriya district soils were greater than 0.7. This indicates that there is no interference of Mg in K uptake (Mg induced K deficiency) (Loide, 2004). On the other hand, potassium : magnesium ratio was found to be less than 0.7 for nearly all soils of Hula and Dale districts indicating Mg induced K deficiency. Similarly, Hailu et al. (2015) reported lower ratio of K to Mg (less than 0.7) and added that Mg might induce K deficiency in soils of southern and central highlands of Ethiopia, respectively. This pointed out that both Dale and Hula districts require recommendation for K fertilizers to boost crop productivity.

The non-exchangeable K measured in the soils varied from 241.5 to 1714.9 mg/kg. It ranged from 642.6 to 1714.9, 425.5 to 1658.5 and 241.5 to 818.5 mg/kg for Awassa-Zuriya, Dale and Hula districts, respectively. The mean values were 973.8, 743.4 and 501.1 mg/kg for Awassa-Zuriya, Dale and Hula districts, respectively. According to the critical level adopted by Srinivasarao et al. (2007) for nitric acid extractable potassium, 3.7, 25.9 and 70.4% of the studied soils were low (<300 mg/kg), medium (300 to 600 mg/kg) and high (>600 mg/kg), respectively in non-exchangeable K. From this, it can be said that nearly all soils were good in K supplying power. Moreover, the results indicated that water soluble, exchangeable and non-exchangeable K concentrations measured in the soils accounted for 0.6 to 4.6, 5.3 to 55.8 and 14.1 to 66.8% of total K concentrations; respectively, indicating that the non-exchangeable K concentrations in the soils constituted the highest proportion of the total K, while the water soluble K accounted for the lowest proportion of the total K.

Considering the proportions of all the various forms of K to the total K in the Hula district, the value for the non-exchangeable K pool was the highest (32.9%). This observation might also be explained by the low pH of the soil in the Hula district.

The percentage of CEC saturated with K (KSP) for all the soils ranged between 1 and 9.2%, with a mean of 3.9%. Although, the KSP mean value of all soils is higher than the critical value (2.3) proposed by FAO-UNESCO (1997), 44.4% of Dale and 88.9% of Hula district soils were found to be below the critical level. This indicated the saturation of CEC with other cations while the proportion of potassium ions is very minimal particularly in Hula district. On the other hand, all soils in Awassa-Zuriya district contained KSP above the critical value.

Correlations among forms of soil K and some selected soils properties

Results of simple correlation analysis between different forms of K and some soil chemical properties are given in Table 4. All the K forms negatively correlated with organic matter while significant correlation existed between SOM, water soluble K (r= 0.5141, P<0.01) and exchangeable K (r= 0.4370, P<0.05). This indicated that the experimental soils are not characterized by variable charge systems (pH dependent charges) (Van Ranst, 2006). Thus, the charge generated could be negative and does not depend on the pH of the soil and created due to isomorphous substitution of cations in clay minerals.

Positive and significant correlations occurred between pH and water soluble K (r= 0.5496, P<0.01), exchangeable K (r= 0.7034, P<0.0001), non-exchangeable K (r= 0.5833, P<0.01), but insignificantly correlated with total K (Table 4). The correlation observed between soil pH and K forms (water soluble and exchangeable K) is in agreement with Kozak et al. (2005) who reported positive correlation of available K forms with pH. The study demonstrated that K forms correlated positively with PBS where non-exchangeable (r= 3892, P<0.05) and total K (r= 0.5429, P<0.01) indicated significant correlation. Furthermore, water soluble K significantly (P < 0.05) and negatively (r = -0.5593) correlated with WHC, while exchangeable, non-exchangeable and total K correlated negatively and insignificantly. The present finding agreed with the finding of Barber (1978) who observed that high moisture content adversely affected the mobility of K into the soil solution.

The study showed that the Hula district with mean clay of 36.4%, which had the highest percentage gravimetric soil moisture content (74.6%), recorded the lowest levels of all the K forms determined. This was in line with Greg

Table 4. Pearson cross - correlation matrix between the forms of potassium and some selected soil properties.

	pH	OM	CEC	Clay	Silt	WHC	P	%BS	Soln. K	Exch. K	Non-exch. K	Total K
pH	1	-0.4847*	0.0555	-0.0195	0.4041*	-0.5392**	0.5647**	0.4310*	0.5496**	0.7034****	0.5833**	0.2815
SOM		1	0.4925**	0.0816	-0.4311*	0.6854****	-0.4606*	-0.4536*	-0.5622**	-0.3668*	-0.3790	-0.3702
CEC			1	0.1861	-0.1385	0.4424*	-0.3085	-0.4478*	0.0184	0.0808	0.1793	-0.0450
Clay				1	-0.2496	0.1238	0.0239	-0.1201	-0.1973	-0.0278	0.0208	0.1127
Silt					1	-0.4075*	0.3622	0.2538	0.5003**	0.4275*	0.3290	0.1226
WHC						1	-0.4578*	-0.3795*	-0.5593**	-0.3409	-0.2661	-0.3157
P							1	0.3282	0.4510*	0.3238	0.1437	-0.1089
%BS								1	0.3080	0.3193	0.3892*	0.5429**
Soln. K									1	0.6198***	0.5811*	0.2813
Exch. K										1	0.2721	0.4671*
Non-exch. K											1	0.5279**
Total K												1

*Significant at P<0.05, **significant at P<0.01, *** significant at P<0.001, **** significant at P<0.0001. WHC = water holding capacity, P = available phosphorus.

et al. (2011) who noticed less mobility of potassium from the exchangeable site into the soil solution in fine textured soil with high proportion of water held. All the K forms positively correlated with silt proportion while only significant correlation existed between water soluble K (r= 0.5003, P<0.01) and exchangeable K (r= 0.4275, P<0.05). This suggested that K status of the soils is largely governed by finer fraction of soil. Lastly, there occurred significant (P<0.05) and positive (r= 0.4510) correlation between water soluble K and available phosphorus.

The study showed the existence of significant (P < 0.001) positive correlation (r = 0.6198) between water soluble and exchangeable K, and between water soluble K and non-exchangeable K (r = 0.5811, P < 0.05). This observation is in agreement with Ghiri et al. (2011) who reported positive and significant associations among available and fixed K. It was not unexpected because exchangeable potassium is usually released into the soil solution from the exchange complex when plants and/or leaching deplete the soluble potassium since they are in equilibrium. Exchangeable K pool is also in equilibrium with fixed or non-exchangeable K and as K is depleted from exchange site due to the equilibrium position shift tosoil solution, non-exchangeable K pool starts to replenish the exchangeable K pool. Further, there occurred significant (P<0.05) and positive correlation (r= 0.4671) between exchangeable and total K, and between non-exchangeable and total K (r= 0.5279, P<0.01), while positive but insignificant correlation existed with water soluble K. Similar results were reported by Venkatesh and Sathyanrayan (1994) in some black soils of North Karnataka, India. Generally, all the forms of soil potassium in this study were inter-correlated, indicating the existence of dynamic equilibrium among them and release of K from non-exchangeable pool to available pool for crop uptake (Venkatesh and Sathyanarayana, 1994).

CONCLUSION AND RECOMMENDATIONS

Wide variability among the districts was observed in water soluble K, exchangeable K, non-exchangeable K and percent potassium saturation, indicating potassium fertility gaps. The high clay soils percent (55.6%) in Dale and Hula districts indicated the need for site specific K fertilizer application since exchangeable K could be fixed by clay and its availability may be reduced. The high proportion of acidic reaction in Hula with medium at Dale district, and low at Awassa-Zuriya reveals variations in leaching of exchangeable bases where increased leaching loss is expected in soils of low pH. This agreed with the lowest mean total K content (2100 mg/kg) in Hula. The total K content in Hula might also be affected by its high mean clay percentage (36.4%).

The study also showed the moderate leaching of base cations in Hula if PBS is considered as criteria for leaching.

Over all, the water soluble and exchangeable K pools at Hula were low and high at Awassa-Zuriya. At Dale, nearly half of the soils studied had low water soluble and exchangeable K pools. The low status of both K pools particularly in Hula may be due to the lowest mean soil pH (5.1). Soils of Hula and Dale districts were not only low in the available K status. They were also low in available P while most of the Awassa-Zuriya district soils had low TN. On the other hand, nearly all soils of Hula and Dale districts had less than 0.7 potassium : magnesium (K:Mg) ratio, indicating Mg induced K deficiency, while the potassium saturation percent (KSP) of almost all the Hula soils and some of the Dale soils was below the critical level (2.3). It can therefore be concluded that site specific potash fertilization and all areas of potash fertilization would be required for Dale and Hula, respectively for sustainable crop production. Moreover, potash fertilizer recommendation may also be required as a soil management alternative in Awassa-Zuriya since water soluble K is high and could be lost through leaching in summer season. This study also indicated that the non-exchangeable K measured in the soils was sufficient. This indicated good capacity of soils in K supplying power. It also found that the proportion of non-exchangeable K was highest in the total K. Lastly, correlations study indicated positive effects of pH, PBS and silt% on K forms while SOM and WHC negatively affected them. The later indicates that the soils are not characterized by variable charge systems. Finally, positive relationships existed among soil K forms, indicating dynamic equilibrium between them.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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