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Full Length Research Paper

Inheritance studies of aroma and yield attributes in rice (*Oryza sativa* L.) genotypes

Nabieu Kamara[1*], Maxwell Darko Asante[2] and Richard Akromah[3]

[1]Crop Improvement Programme, Rokupr Agricultural Research Centre / Sierra Leone Agricultural Research Institute, Sierra Leone.
[2]Cereals Division, CSIR-Crops Research Institute, Kumasi, Ghana.
[3]Department of Crop and Soil Sciences, Collage of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

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Low yield is one of the main challenges of rice production in Ghana due to poor production practice, environmental stresses and plant genotype. The choice of an efficient breeding procedure depends to a large extent on knowledge of the genetic system controlling the character to be selected. This experiment was done to study the inheritance pattern of aroma attribute of rice and estimate the heritability for some yield attributes in rice (*Oryza sativa* L.). Six generations viz., P1, P2, F1, F2, BCP1 and BCP2 of a cross between IET6279 and IR70445-146-3-3 were used for the study. A randomized complete block design (RCBD) was used with three replications. All the F1 and BCP1 plants of the cross were non-aromatic indicting that the gene controlling aroma in the donor parent was recessive. The segregation ratio of aromatic to non-aromatic plants was 1:3 in F2 and 1:1 in BCP2 plants, confirming the monogenic inheritance of aroma. This shows that there would be a high probability of success in selecting for aroma using pedigree breeding in early generations of F2. High broad sense heritability estimates were observed for all the characters studied except for number of fertile spikelets per plant, suggesting that the influence of the environment was minimal for these characters. Hence, these traits would respond to selection owing to their high genetic variability and transmissibility. Thus, selection based on phenotypic value of these characters would be reliable and effective with low broad sense heritability for number of fertile spikelets per plant, indicating that influence of the environment was high for these characters. Therefore, superior genotypes selection based on phenotypic performance for this trait may not be effective. The analysis of gene effects revealed that additive, dominance and epistatic effects were involved in the inheritance of all the traits studied. However, additive effect, in general was higher in magnitude than dominance gene effect in all the characters. All the traits manifested non-allelic interactions, indicating that epistasis is determined to some extent by the genotypes used for the study. Thus, in the presence of epistasis, grain width showed significant duplicate type of gene interaction which restricted the scope of simple selection for the characters studied. Therefore delaying selections to later generations using recurrent selection will enhance success in improving yield attributes in all genotypes studied.

Key words: Aroma, inheritance, additive, gene action, heritability, monogenic, non-additive, recessive.

INTRODUCTION

Rice belongs to the genus *Oryza,* the family Gramineae*,* and is a widely cultivated crop (Syed and Khaliq*,* 2008). It is the most important staple food crop in the world consumed by more than half of the world population (Kohnaki et al., 2013).

In Ghana, rice has become a major staple in recent decades with a per capita consumption of 25 kg/annum, but most of the consumption is met by imports (MOFA, 2010). In 2009, the country imported over 350,000 tons of milled rice worth 600 million US dollars (Duffuor, 2009). MoFA (2009) revealed that, the estimated national rice consumption stands at 561,400 metric tons per year, while rice produced locally is 107,900 metric tons, leaving a gap of 453,500 metric tons which have to be imported (Directorate of Crop Services, MoFA, 2010). Low yield is one of the main challenges of rice production in Ghana due to poor production practice, environmental stresses and plant genotype.

Aromatic rice, also known as fragrant or perfumed rice, is very popular in Asia and is classified as premium quality rice in markets throughout the world, including Ghana (Diako et al., 2010). There is an increasing demand for aromatic rice being driven by improving living standards of people around the world (Chen et al., 2006). Classical examples of fragrant rice are the Basmati rice cultivars of India and Pakistan, Dulha bhog of Bangladesh, Khao Dawk Mali (Jasmine) of Thailand, Azucena and Milfor of the Philippines and Rojolele of Indonesia (Khush et al., 1979). Aromatic rice varieties are playing a vital role in global rice trading. Major feature of these aromatic rice varieties is aroma which is being appreciated by many people and represents a high value added trait (Dela and Khush, 2000). So, rice needs attention toward improvement in its cooking qualities as well as several biochemical and morphological characteristics (Golam et al., 2004). The demand for aromatic rice is increasing by the day. Unfortunately, this aromatic rice often has undesirable agronomic characters, such as low yield, susceptibility to pests and diseases, and strong shattering (Berner and Hoff, 1986). The agronomic value of a variety depends on many characteristics (Huang et al., 1991) and the most important characteristics are high yielding ability, resistance to diseases and pests, resistance to undesirable environmental factors and high quality of the products. Methods for smelling leaf tissue, grains after heating in water, and reacting with solutions of 1.7% KOH are available (Sood and Siddiq, 1978). Since rice aroma, a polygenic quantitative trait with complex inheritance pattern, is highly influenced by environment, it is difficult to identify genes that determine this trait (Pachauri et al., 2010). Genetic studies on the inheritance of aroma in rice revealed that a recessive nuclear gene controls aroma in rice. Dong et al. (2000) reported that aroma is controlled by a single recessive gene in Jasmine 85 and p1467917 and by two genes in Amber and Dragon Eyeball. Digenic segregation for aroma was also reported by Lin (1991). Sood and Siddiq, (1978) reported that aroma is monogenic recessive to non-aromatic that is, a digenic segregation of 15:1 (Geetha, 1994), 13:3 (Tsuzuki and Shimakawa, 1990) and trigenic ratio of 37 non-aroma: 27 aroma. Further, the recent inheritance studies on aroma indicated 3:1 (non-scented: scented) segregation ratio indicating monogenic, recessive gene control (Lorieux et al., 1996). There is no consensus yet on the nature of inheritance in aromatic characters as described earlier. The lack of agreement among many investigators appears to be related to the differences in the aromatic varieties used and also the differences in the methods used in evaluating aroma.

Rice grain length and width are the two important quantitative traits also closely related to the exterior quality of the rice (Shi et al., 2000). Genetic analyses of length and width of rice kernels have been reported by some of the researchers and most of the studies have shown that rice grain shape is quantitatively inherited (Zhang et al., 2005). It has been shown that rice grain shape is controlled by triploid endosperm genes, cytoplasmic genes, and maternal genes (Shi et al., 2005) and their genotype into environment interaction effects. The length, width and seed thickness is one of the quantitative measures of grain shape. The objective of the present study was to understand the nature of inheritance of aroma, grain length, grain width, number of spikelets per plant and number of fertile spikelets per plant.

MATERIALS AND METHODS

A field experiment was carried out in Fumesua, Kumasi in a forest region of Ghana with soil classification of gleyic Lixisol soil having clay loam texture with moderate soil fertility (N06° 45' 05.3'' latitude and W001° 32' 19.3'' longitude). The experimental material consisted of two lowland varieties (Table 1). Seeds of the two rice varieties were obtained from the Cereals Division, CSIR-Crops Research Institute, Kumasi - Ghana. Crosses were made between

*Corresponding author E-mail: kamara.nabieu@yahoo.com.

Table 1. Salient features of the parents used for the development of F1, F2, BCP1 and BCP2 populations.

Accession	Pedigree	Plant height	Duration	Grain type	Yield (t ha^{-1})	Salient features
IET6279	Indian	Tall	Late	Short, bold	8.5	Non- aromatic
IR70445-146-3-3	IRRI	Medium	Medium early	Long, slender	6.0	Aromatic

the two parents to obtain F1 individuals. The F1 were grown and backcrossed to both parent. The two parents, F1, F2, BCP1 and BCP2 generations were grown in the field at the same time.

Pot culture of F1 plants

The F1 seeds were pre-germinated in a white tissue paper and Petri dish for three days, nursed for 21 days with one seedling transplanted per bucket. The buckets were filled with sterilized top soil to avoid soil contamination. Sowing of the varieties were staggered over a three-week's period in order to synchronize flowering in the varieties. The hybrid plants were provided with 10 g of N P K (15:15:15) at tillering and 10 g of urea at panicle initiation. Standard agronomic operations like irrigation, application of insecticides and hand weeding were employed whenever necessary. Some F1 plants were selfed to produce F2. Some panicles from the same F1 plants were backcrossed to either parent to generate the backcross populations. New crosses between parents were also made to generate fresh F1 seeds.

Field experiment

All seedlings were transplanted to an irrigated lowland field in a randomized complete block design in three replications at CSIR-CRI Fumesua during the minor season of 2015. Each replicate had 60 plants of parents, 25 F1s, 300 F2, 60 BCP1 and BCP2 plants. Spacing of 40 and 20 cm between-row and within-row was followed, respectively at a density of a single plant per hill and data were taken on individual plants for all the populations. The recommended fertilizer rate of 90-60-60- Kg/ha- N-P2O5-K2O was applied: 60-60-60 kg/ha applied two weeks after transplanting top-dressed with 30 kg/ha N at panicle initiation. Weeds were controlled by spraying with a post emergence selective weedicide, Pronil-plus and Propanil. This was followed by hand picking. Field was irrigated whenever necessary using rain water from a fabricated lake through canals with flood method.

Data collection

After 60 days of seeding, determination of presence or absence of aroma was made according to the method described by Sood and Siddiq (1978) and Dong et al. (2001b). Two grams of green leaves were harvested from individual plants cut into small pieces and kept in the test tubes. About 10 ml of 1.7% potassium hydroxide (KOH) solution was added to each test tube. The test tubes were covered immediately after the addition of alkali and left under room temperature for about ten minutes. The test tubes were opened one by one and the content in each was immediately evaluated by smelling. The samples were classified according to the degree of aroma, at a rating scale from zero to three; with zero indicating no aroma, one indicating faint aroma, two indicating aroma and three indicating strong aroma. The evaluation of aroma for individual plants was conducted in three replications by 5 panelists. To prevent overwhelming panel member's senses, no more than 20 samples were evaluated at a time. For each set of data the aromatic and non-aromatic parents were included as controls; where a panel member failed to evaluate the controls, the data was rejected. Samples were divided into three groups based on the average of rating scale values: (i) aromatic (1.5 - 3.0); (ii) questionable (1.2 - 1.4) and (iii) non-aromatic (less than 1.2). Any questionable sample was re-evaluated until it was classified as either aromatic or non-aromatic. Grain length and grain width were measured in millimeter (mm) after harvesting. Number of spikelets per plant was determined by counting total number of spikelets after harvesting. Number of fertile spikelets per plant was also determined by pressing the spikelets with the fingers and noting those that do not have grains after harvesting.

Data analysis

Analysis of variances was done for six population (the two parents, F1, F2, BCP1 and BCP2) within each cross with respect to all the studied traits, and generation means analysis using linear mixed models (REML) was done to estimate genetic effects of the four quantitative traits according to the methodology proposed by Mather and Jinks (1971). Statistical and genetic analyses were performed using Genstat software (15.1). The means and variances obtained were used to estimate genetic parameters such as broad sense and narrow sense heritability.

Gene action controlling four quantitative traits in IET6279 × IR70445-146-3-3 cross

The generation mean analysis model is stated as:

$$Y = m + \alpha a + \beta d + \alpha 2aa + 2\alpha\beta ad + \beta 2dd$$

Where α and β are the coefficients for a and d, respectively, Y = the observed mean, m = mean = mean of the F2, a = pooled additive effects, d = pooled dominance effects, aa = additive × additive gene interaction effects, ad = additive × dominance gene interaction effects, dd = dominance × dominance gene interaction effects. The mode of inheritance of the four yield attribute was estimated by generation mean analysis. Their means and variances were used to perform generation mean analysis.

Heritability in the broad sense

Broad sense heritability (H2b) was estimated using the formula of Allard (1960).

$$H^2b = (VF2 – VE) / VF2$$

Where; H^2_b = Broad sense heritability;
VE = Error variance = (VP1 + VP2 + VF1) / 3;
VF2 = Variance of F2 family;

VP1 = Variance of parent 1;
VP2 = Variance of parent 2;
VF1 = Variance of F1 family.

Narrow sense heritability

Narrow sense heritability (h^2_n) was calculated according to the method of Halloran et al. (1979) as follows:

h^2n = [2VF2 −VBCP1 - VBCP2] / VF2

Where: VF2, VBCP1, and VBCP2 are the variances of the F2, IET6279 × F1 and IR70445-146-3-3 × F1, respectively.

Aroma

Chi-square values of the aroma data obtained from segregating population of the crosses were computed following the procedure described by Gomez and Gomez (1984).

RESULTS

The result of analysis of variance revealed significant differences ($P < 0.01$) among generations for all the characters investigated indicating the presence of sufficient genetic variability and depicting the possibility of selection for desirable yield attributes in rice. The F1 and the backcross to IET6279 (BCP1) from these cross were non-aromatic. The F2 and the backcross to IR70445-146-3-3 (BCP2) from these cross were aromatic (Table 2). The F2 generation was segregated into 203 aromatic and 589 non-aromatic plants fitting into 1:3 ratio ($\chi2 = 0.14$). The backcross to IR70445-146-3-3 (BCP2) cross was segregated into a ratio of 79 aromatic to 92 non-aromatic plants fitting into a 1:1 ratio ($\chi2 = 0.84$). This indicates that aroma in IR70445-146-3-3 is under the control of a single recessive gene (Table 3). The highest mean performance for number of spikelets per plant was recorded for IET6279 (3785) followed by BCP1 (2662); while IR70445-146-3-3 (2194) recorded the lowest mean. The means of F1, F2, BCP1 and BCP2 are all within parental limits. The range of variation in BCP1 was higher than BCP2, F2, F1 and parents. BCP1 recorded the highest CV (4.16%) followed by BCP1 (2.95%); while F1 recorded the lowest (1.28%).

In the case of number of fertile spikelets per plant, the maximum and minimum means were recorded for IET6279 (3181) and IR70445-146-3-3 (2057), respectively. The means of F1, F2, BCP1 and BCP2 were all within parental limits. The range of variation in BCP1 was higher than F1, F2, BCP2 and parents. BCP1 recorded the highest CV (3.47%) followed by IR70445-146-3-3 (1.96%); while IET6279 recorded the lowest (0.53%). For grain length, the highest mean was recorded for IR70445-146-3-3 (10.92) followed by BCP2 (9.73); while IET6279 (8.19) recorded the lowest mean. The means of F1, F2, BCP1 and BCP2 were all within parental limits. The largest range of variation was recorded in BCP1 followed by F2; while IET6279 recorded the smallest range. BCP1 recorded the highest CV (8.34%) followed by BCP1 (7.80%) while IET6279 recorded the lowest (2.89%).

In the case of grain width, IET6279 recorded the highest mean (2.73) followed by F2 (2.71); while IR70445-146-3-3 (2.49) recorded the lowest. The means of F1, F2, BCP1 and BCP2 were all within parental limits. The range of variation in BCP1 was higher than BCP2, F2, F1 and parents. BCP1 had the highest CV (3.17%) followed by BCP2 (1.95%); while F2 recorded the lowest (0.25%) (Table 4).

Heritability was estimated for four agro - morphological characters (Table 5). Broad sense heritability estimates were high for number of spikelets per plant, grain length and grain width but low for number of fertile spikelets per plant. Grain width recorded highest broad sense heritability (86%) with a narrow sense heritability (08%) followed by grain length which recorded 79% and narrow sense of (14%) heritabilities. This was followed by number of spikelets per plant which recorded 65% and narrow sense of (38%) heritabilities, respectively; while heritability estimates of number of fertile spikelets per plant were observed to possess low broad sense heritability. These further indicated that the trait was highly influenced by the environments (Table 5).

The analysis of gene effects in six-parameter model revealed that additive, dominance and epistatic effects were involved in the inheritance of all traits. The additive (a) and dominance (d) genetic effects had a significant contribution in all the characters studied. Additive gene effects were found to be relatively more important, as indicated by the fact that in all cases the additive (a) values were higher than the dominance (d) values. Regarding the non-allelic interactions, the additive × dominance gene effect (ad) was significant for all the characters studied except for grain width, additive × additive gene effect (aa) was significant for grain width and grain width and dominance × dominance (dd) genetic effects was only significant for grain width. The additive × additive and dominance × dominance (dd) interaction were larger in magnitude than their corresponding additive × additive (aa) effects. The dominance (d) and dominance × dominance (dd) effects were in the opposite direction, suggesting that duplicate type of epistasis exists for grain width (Table 6).

DISCUSSION

The inheritance study of quantitative characters in various crosses will help breeders to choose appropriate breeding methods. IR70445-146-3-3 was used as donor in an attempt to incorporate aroma into IET6279. F1 of

Table 2. Number of plants expressing aromatic and non-aromatic grain type according to KOH test in two rice genotypes.

Parents	No. of plants tested	No. of plants	
		Aromatic plants	Non-aromatic plants
IET6279	25	0	25
IR70445-146-3-3	60	60	0
F1	45	0	45
F2	792	203	589
BCP2	171	79	92
BCP1	60	0	60

Table 3. Inheritance pattern of aroma in F2 and BCP2 populations in two rice genotypes.

Cross	No. of plants tested	No. of plants				Ratio	Chi-square	P value
		Non-aromatic plants		Aromatic plants				
		Observed	Expected	Observed	Expected			
F2	792	203	198	589	594	1:3	0.14	3.84
BCP2	171	79	85.5	92	85.5	1:1	0.84	3.84

IET6279/IR70445-146-3-3 was non-aromatic.

A recessive gene, therefore, controls aroma in IR70445-146-3-3. The F2 for IET 6279/IR70445-146-3-3 was segregated into 203 aromatic: 589 non-aromatic plants, indicating a 1: 3 ratio ($\chi 2$ = 0.14). A backcross (test cross), BCP2 (IET6279/IR70445-146-3-3//IR70445-146-3-3) segregated into 79 aromatic: 92 non-aromatic plants were obtained, indicating a 1:1 ratio ($\chi 2$ = 0.84). BCP1 (IET6279/IR70445-146-3-3//IET6279) plants were all non-aromatic. The segregation ratios (F2 and BCP2) indicated that a single recessive gene controls aroma in IR70445-146-3-3. These show that there would be a high probability of success in selecting for aroma using pedigree breeding in early generations of F2 (Table 2). Single gene control of aroma has been widely reported (Pinson, 1994; Dong et al., 2000, 2001a, b). However, multiple gene control of aroma has also been reported (Geetha, 1994; Pinson, 1994; Dong et al., 2000, 2001b). This report has also validated Pinson (1994)'s report that J85 was under the control of a single recessive gene. It must be noted that some researchers have used the same method on different cultivars and have reported both monogenic and digenic inheritance depending on the cultivar used (Pinson, 1994; Dong et al., 2000, 2001b). Tsuzuki and Shimokwa (1990) reported that the lack of agreement among researchers as to whether a single recessive gene, or two or three recessive or dominant genes control aroma in rice, appears to be related to the differences in the aromatic varieties used and also the differences in the methods used in evaluating aroma. It is suggested that some aromatic cultivars contain a single gene whilst others contain two or more aroma genes; and that the difference in opinion on the inheritance of aroma is mainly due to cultivar differences.

The magnitude of heritability is classified as low (below 30%), medium (30 to 60%) and high (above 60%) (Babu et al., 2012). High broad sense heritability was recorded for number of spikelets per plant, grain length and grain width. High heritability values indicate that the characters under study are less influenced by environment in their expression, which suggests that these traits would respond to selection owing to their high genetic variability and transmissibility. Thus, selection based on phenotypic values would be effective for these traits. These findings are in agreement with those of Pallabi et al. (2013) for number of spikelets per plant in rice, Kiani (2013) and Tuhina et al. (2015) for both grain length and grain width. However, these results were contrary to the finding of Rafii et al. (2014) who reported low broad sense heritability for grain length and grain width in rice, respectively. In contrast, number of fertile spikelets per plant had low heritability which indicates greater role of environment on the expression of the traits. Thus, direct selection for these traits will be ineffective. Therefore, methods of selection based on families and progeny testing are more effective and efficient. On the contrary, Pallabi et al. (2013) reported high broad sense heritability for number of fertile spikelets per plant in rice, possibly because the author might have used different genotypes and environmental conditions under which their study was conducted.

Table 4. Mean performance, standard deviation, ranges and coefficient of variation (CV) yield attributes of six generations in two rice genotypes.

Traits	Generation	Mean	StDev	Range	C.V
Number of spikelets per plant	IET6279	3785	59.70	3723-3843	1.58
	IR70445-146-3-3	2194	29.10	2173-2227	1.33
	F1	2219	28.40	2190-2247	1.28
	F2	2652	70.70	2570-2693	2.67
	BCP1	2662	110.60	2593-2789	4.16
	BCP2	2596	76.500	2534-2682	2.95
Number of fertile spikelets per plant	IET6279	3182	16.90	3165-3199	0.53
	IR70445-146-3-3	2057	40.30	2017-2098	1.96
	F1	2182	35.90	2146-2218	1.65
	F2	2333	22.60	2320-2356	0.97
	BCP1	2299	79.70	2238-2389	3.47
	BCP2	2140	14.70	2130-2157	0.69
Grain length (mm)	IET6279	8.19	0.24	7.68-8.63	2.89
	IR70445-146-3-3	10.92	0.36	10.19-11.65	3.31
	F1	9.31	0.33	8.67-9.99	3.54
	F2	9.62	0.68	7.53-11.83	7.11
	BCP1	9.22	0.77	7.72-11.81	8.34
	BCP2	9.73	0.76	7.48-11.9	7.8
Grain width (mm)	IET6279	2.73	0.01	2.72-2.74	0.37
	IR70445-146-3-3	2.49	0.02	2.47-2.52	0.87
	F1	2.55	0.09	2.52-2.59	1.53
	F2	2.71	0.21	2.72-2.74	0.25
	BCP1	2.67	0.18	2.61-2.77	3.17
	BCP2	2.55	0.14	2.48- 2.57	1.95

Table 5. Heritability estimates for yield attributes calculated from estimated variance componentin of rice genotypes.

Characters	Heritability	
	Broad sense (%)	Narrow sense (%)
Number of spikelets per plant	65	38
Number of fertile spikelets per plant	27	10
Grain length (mm)	79	14
Grain width (mm)	86	08

The analysis of gene effects in six-parameter model revealed that additive, dominance and epistatic effects were involved in the inheritance of all traits studied. The additive (a) and dominance (d) genetic effects had a significant contribution in almost all the characters studied. Additive gene effects were found to be relatively more important, as indicated by the fact that in all cases the additive (a) values were higher than the dominance (d) values. These findings are in agreement with Hasib et al. (2002) and Mahalingam and Nadarajan (2010). Snape (1987) pointed out that dominance could be small due to its ambi directional nature. However, previous studies have revealed that epistasis as a basic mechanism cannot be ignored. Thus, formulating breeding policies on the basis of only main gene effects that is, additive and dominance could be misleading (Sand and Lal, 2014).

Table 6. REML estimates of variance components for genetic effects of yield attributes obtained through generation mean analysis in two rice genotypes.

Variables	Characters			
	Number of spikelets per plant	Number of fertile spikelets per plant	Grain length (mm)	Grain width (mm)
m	2656**	2289**	9.569**	2.679**
a	796.7**	546.5**	-1.363**	0.1043**
d	-953.4**	-1592*	-1.192*	-0.9191**
aa	-119.6	-245.4	-0.5698**	-0.4617**
ad	-1499**	-836.2**	1.705*	0.04939
dd	66.14	911.1	0.3792	0.3826**
Type of epistasis	-	-	-	Duplicate

*and **: significant at 5 and 1% probability levels, respectively. (a) additive; (d) dominance; (aa) additive × additive; (ad) additive × dominance; (dd) dominance × dominance gene effects.

The performance of all of the characters studied manifesting non-allelic interactions is an indication that epistasis is determined to some extent by the genotypes used for the study. The additive effects and gene interaction dominance × dominance (dd) or other type digenic complementary gene interaction can be exploited effectively by selection for the improvement of characters. It might be possible to follow the suggestion of Moreno-Gonzalez and Cubero (1993), that where epistasis is more important, recurrent selection and reciprocal recurrent selection can be efficient techniques for selecting desirable cultivars or it might be possible to follow the recommendation of Khattak et al. (2001) to use a bi-parental approach *inter se* crossing and/or recurrent selection for developing high yielding rice lines in advanced generations if we want to exploit all types of gene effects. Presence of non-additive gene for number of spikelets per plant, number of fertile spikelets per plant, grain length and grain width indicate that conventional selection procedure may not be effective enough for improvement of yield. Therefore postponement of selection in later generations or inter-mating among the selected segregants followed by one or two generations of selfing could be suggested to break the undesirable linkage and allow the accumulation of favorable alleles for the improvement of these traits. The results agreed with the findings of Patel et al. (2014) and Jarwar et al. (2014) who reported the influence of both additive and non-additive gene action in control of grain length and grain width in rice while Munhot et al. (2000) and Annadurai and Nadarajan (2001) reported non additive genetic variance for grain yield attribute in rice. Verma et al. (1994) indicated that epistasis plays a vital role in grain components yield except grain number in panicle in rice, Abebe et al. (2017) reported the predominance of non-additive gene action in controlling spikelet traits in rice, and Pallabi et al. (2013) reported the role of additive gene action governed for number of spikelets per plant in rice. Duplicate type of epistasis as evidenced from opposite sign of (d) and (dd) was noticed from the expression of grain width. This type of epistasis tends to cancel or weaken the effect of each other in hybrid combination and hinders the progress made under selection and therefore, selection would have to be deferred till late generations of segregation where dominance effects are dissipated.

Conclusion

Result from this study favored a single recessive gene control of aroma as opposed to multiple gene control. However, a careful review of literature compared to this work suggests that, there are differences in the number of genes controlling aroma in different varieties. An F2 ratio of 1:3 (aromatic: non-aromatic) plants and a backcross (IET6279/ IR70445-146-3-3 // IR70445-146-3-3) ratio of 1:1 indicate that a single recessive gene controls aroma in IR70445-146-3-3. Broad sense heritability estimates were high for number of spikelets per plant, grain length and grain width, while low broad sense heritability estimate was observed for number of fertile spikelets per plant. The analysis of gene effects revealed that additive, dominance and epistatic effects were involved in the inheritance of all the traits. However, additive effect, in general was of higher magnitude than dominance gene effect in all the characters studied. All the traits manifested non-allelic interactions, indicating that epistasis is determined to some extent by the genotypes used for the study. Thus, in the presence of epistasis, grain width showed that significant duplicate type of gene interaction restricted the scope of simple selection for the characters studied. Therefore delaying selections to later generations using recurrent selection will enhance success in improving yield attributes in all the genotypes studied.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Response of summer pulses (mung bean vs. mash bean) to integrated use of organic carbon sources and phosphorus in dry lands

Amanullah[1*], Saifullah[1], Khalid Nawab[2], Asif Iqbal[1], Shah Fahad[3], Muhammad Jamal Khan[4], Habib Akbar[1], Ikramullah[1], Iqbal Hussain[1] and Akhtar Ali[1]

[1]Department of Agronomy, University of Agriculture, Peshawar, Pakistan.
[2]Department of Agriculture Extension and Communication, University of Agriculture, Peshawar, Pakistan.
[3]Department of Agriculture, University of Swabi, Ambar, Pakistan.
[4]Department of Water Management, University of Agriculture, Peshawar, Pakistan.

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Pulses play an important role in addressing hunger, food insecurity, malnutrition, environmental degradation, climate change impacts and human health, thereby supporting the overall achievement of the Sustainable Development Goals. Pulses yield is very low under arid and semiarid climate. Field experiment was conducted to evaluate the impact of phosphorus (0, 30, 60 and 90 kg P ha^{-1}) and organic sources [sole animal manure (10 t ha^{-1}), sole legume residues (10 t ha^{-1}), and integration of animal manures + legume residue (5 t ha^{-1} each)] on the phenological development, growth, yield and yield components of mung bean (*Vigna radiata* L.) in comparison to mash bean (*Vigna mungo* L.) under rainfed/moisture stress condition at the Agronomy Research Farm of The University of Agriculture, Peshawar-Pakistan. The results revealed that increase in P levels resulted in earlier phenological development, improved growth, increased number of nodules plant^{-1}, yield and yield components of both crops. Combined application of animal manures and legume (gram or chickpea) residues (5 t ha^{-1} each) ranked first in terms of better growth and higher yield and yield components of both crops, followed by sole animal manure (cattle manure), while sole legume residues stood at the bottom in the ranking.

Key words: Mung bean, mash bean, phosphorus levels, organic sources, dry land.

INTRODUCTION

Malnutrition is one of the major problems in many parts of the world and is mainly due to protein deficiency in the diet. Pulses (grain legumes) are the major and cheaper source of protein as compared to animal protein. Grain legumes crops cultivated especially for their mature seeds for human consumption are called pulses (Amanullah, 2016). Pulses are important food crops that can play a major role in achieving food security, nutrition, and human health, contributing to the sustainability of agriculture and aiding the mitigation and adaptation to climate change. However, despite the importance given to pulses by the establishment of the International Year of Pulses 2016 (UN, 2013), pulses are not well known to most people (FAO, 2016).

In terms of nutrition and food security, pulses provide a good source of plant based protein as well as fibre, vitamins (e.g., B vitamins) and minerals such as iron, potassium, magnesium and zinc (FAO, 2016). Pulses seeds have high protein content (19 to 33%) (Werner, 2005), which make them an asset in achieving food security worldwide (FAO, 2016). According to Campos-Vega et al. (2010), consumption of pulses may positively impact human health as they can reduce the risk of cardiovascular diseases, prevent diabetes and may protect against obesity, among other things. Mung bean (*Vigna radiata* L., Wilczek), commonly known as green gram, contains 51% carbohydrate, 24 to 26% protein, 4% mineral, and 3% vitamins (Afzal et al., 2008). Mash bean (*Vigna mungo* L., Hepper) known as black gram is one of the most important leguminous crops and its seeds contain about 24% protein, 60% carbohydrates, and 1.3% fats (Ali et al., 2002). Both mung bean and mash bean also contain high amount of vitamins A, B, C and minerals such as potassium, phosphorus and calcium, which are necessary for human body (Rattanawongsa, 1993; Sarwar et al., 2004).

Pulses cultivation loses its importance because of low yield (Amanullah, 2016). However, the low yields and overall production of many pulse crops in many parts of the world is attributed to major constraints which include: (1) strong competition from cereals (wheat, maize and rice), cash and industrial crops (cotton, sugarcane, tobacco, oilseed crops, etc.) which gave better economic returns, (2) lack of modern pulses production technologies designed to maximize resource use and so ineffective crop management practices, (3) shortage of experienced personnel and lack of effective research and extension programmes, and (4) lack of high yielding pulses varieties and the poor state of seed multiplication, certification, distribution systems, etc. (Amanullah, 2016). Due to the high population pressure, the total cultivable land of pulses is also decreasing day by day. That is why pulses cultivation has been shifted to marginal lands because farmers are not interested to use their fertile land for pulse crops cultivation.

Phosphorus unavailability (Amanullah and Khan, 2015; Amanullah and Khalid, 2015) and low organic matter in the soils (Iqbal et al., 2015; Amanullah and Khalid, 2016; Amanullah and Hidaytullah, 2016) decline crop productivity under semiarid climate. Phosphorus fertilization to legumes is more important than that of nitrogen and phosphorus is a major component of compounds whose functions relate to growth, root development, flowering, and ripening and favorably influences the nodulation in legumes crops (Tang et al., 2001; Abel et al., 2002; Raboy, 2003; Shu-Jie et al., 2007). Application of organic manures enhance the fertility of soil and crop production by increasing bioavailability of nutrients, water holding, cation exchange capacity and microbial population and activity (Walker et al., 2004; Clemente and Bernal, 2006; Muhammad and Khattak, 2009). Organic manures remain for longer time in the soil, the nutrients releases slowly and become available to the plants gradually (Malival, 2001; Das, 2005). The ability of the organic materials to supply nutrients differs, as they relate to the rates of decomposition, nutrient release rates and patterns (Kumar and Goh, 2004). The role of pulses in the N and P cycles is ultimately important to adapt to and mitigate climate change, helping to achieve the sustainable development goals (FAO, 2016). When the soil is exploited for crop production without restoring the organic matter and nutrient content, the nutrient cycles are broken, soil fertility declines and the balance in the agro-ecosystem is destroyed (FAO, 2015). Therefore, sustainable agricultural management such as incorporation of different organic sources in soils is urgently needed to enhance crop production under cereal based cropping systems (Amanullah et al., 2015, Amanullah and Khalid, 2016; Amanullah and Hidyatullah, 2016). The objective of this research was to investigate the differences in growth and yield of mung bean and mash bean under various levels of phosphorus and organic sources under semiarid climate.

MATERIALS AND METHODS

Site description

Field experiments were conducted at the Agronomy Research Farm of University of Agriculture, Peshawar, during summer 2015 with the objective to investigate the effects of organic sources (OS) [sole animal manure, sole chickpea residues, and combined animal manure + chickpea residues] and phosphorus (P) levels (30, 60 and 90 kg P ha^{-1}) along with one control (OS and P non applied) on the growth, yield and yield components of mung bean and mash bean under dry land condition. The Agronomy Research Farm is located at 34.01°N, 71.35°E, at an altitude of 350 m above sea level in the Peshawar valley. Peshawar is located at about 1600 km north of the Indian Ocean and has semiarid climate. The research farm is irrigated by the Warsak canal from the Kabul River. Soil texture is clay loam, low in organic matter (0.87%), extractable phosphorus (6.57 mg kg^{-1}), exchangeable potassium (121 mg kg^{-1}), and alkaline (pH 8.2) and is calcareous in nature (Amanullah et al., 2009). The climate of the area is semiarid where the mean annual rainfall is very low (300 to 500 mm), 60 to 70% rainfall occurs in summer, while the remaining 30 to 40% rainfall occurs in winter (Amanullah et al., 2012).

Experimentation

Two separate field experiments were conducted one on mung bean and second on mash bean. The experiment for each crop was laid out in RCB design using three replications. Each replication consisted of 10 treatments (three OS × three P levels plus one control plot). A sub-plot size of 4 m × 4 m, having

*Corresponding author. E-mail: amanullah@aup.edu.pk.

5 rows, 2 m long and 30 cm apart was used. Organic sources used as main plot factor were applied and incorporated in their respective plots one month before sowing. The two sole organic sources (animal manure and chickpea residues) were applied at the rate of 10 t ha^{-1}, while in the case of combined animal manures + chickpea residues treatment, both organic sources were applied at the rate of 5 t ha^{-1} each. The required P levels as single super phosphate (SSP) (18% P_2O_5) were applied at seedbed preparation just before sowing for each crop (each experiment). Mung bean variety "NM-54" and mash bean variety "Mash 48" were used as test crops and each were sown at the rate of 25 to 30 kg ha^{-1} on June 23, 2015. A uniform basal dose of 30 kg N ha^{-1} as urea (46% N) was applied and mixed with the soil during seedbed preparation to all plots for each crop. All other agronomic practices were carried out equally during the growing season. Both crops were harvested in the month of September 2015. Data were recorded on emergence m^{-2}, plant height (cm), number of leaves plant^{-1}, number of branches plant^{-1}, number of nodules plant^{-1}, days to flowering, days to pod formation, number of pods plant^{-1}, number of seeds pod^{-1}, pod length (cm), days to physiological maturity, thousand grains weight (g), biological yield (kg ha^{-1}), grain yield (kg ha^{-1}), and harvest index (%).

(1) Emergence m^{-2}: Emergence rate was recorded when all 50% of the sub-plots seedling appeared.
(2) Plant height (cm): Data on plant height (cm) at physiological maturity was recorded from the base to the tip of the plant with the help of meter rod by selecting five plants randomly from each sub-plot and average was worked out.
(3) Number of leaves plant^{-1}: Number of leaves per plant was found by taking five plants randomly from each sub-plot and mean was worked out.
(4) Number of branches plant^{-1}: Number of branches plant^{-1} was numbered by taking five plants randomly in each sub-plot and mean was worked out.
(5) Number of nodules plant^{-1}: Number of nodules plant^{-1} at the time of pod initiation was counted by uprooting five plants randomly from each subplot.
(6) Days to flowering: Days to flowering date counting until 50% of the plants have flowering in each sub-plot.
(7) Days to pod formation: Days from date of emergence to the pod formation counting until 50% of the plant produced pods in each sub-plot.
(8) Number of pods plant^{-1}: Number of pods plant^{-1} of five randomly selected plants for each sub-plot was counted and the average was calculated.
(9) Number of seeds pod^{-1}: Ten pods selected from five plants from each subplot. The seeds were counted and the average was calculated.
(10) Pod length (cm): The pod lengths of 10 pods were measured by scale which was randomly selected from five plants from each plot and then the average was calculated.
(11) Days to physiological maturity: Days to first physiological maturity were observed when 50% of the pods in each sub-plot change their color to light brown or dark brown.
(12) Thousand grains weight (g): Grains weight was calculated by taking thousand grains from the seed lot of each sub-plot and weighed with the help of electronic balance.
(13) Biological yield (kg ha^{-1}): Data on biological yield was recorded on the three central rows. The three central rows were harvested, the material was dried up to constant weight under sun light weight and then converted into biological yield (kg ha^{-1}) using the following formula:

$$\text{Biological yield (kg ha}-^{1}) = \frac{\text{weight of plant in three rows (kg)}}{\text{no of rows} \times \text{row length} \times R - R \text{ distance}} \times 10{,}000\ m^2$$

(14) Grain yield (kg ha^{-1}): The dried material for biological yield (three central rows) was threshed, seeds were cleaned, weighed and then ground into grain yield (kg ha^{-1}) using the following formula:

$$\text{Grain yield (kg ha}-^{1}) = \frac{\text{Grain weight of three rows (kg)}}{\text{No of rows} \times \text{Row length} \times R - R \text{ distance}} \times 10{,}000\ m^2$$

(15) Harvest index: To find out harvest index, the following formula was used:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield } (kg\ ha^{-1})}{\text{Biological yield } (kg\ ha^{-1})} \times 100$$

Statistical analysis

The collected data on various parameters were subjected to the analysis of variance according to split plot design (Steel et al., 1996) combined over the two crops and means between treatments were compared using least significance difference (LSD) test at 5% level of probability (P≤0.05).

RESULTS

Emergence m^2

Emergence m^2 was significantly by legumes, but phosphorous, organic sources, OS × P, L × P, L × OS, and L × OS × P interactions have no significant effect on days to emergence m^2 (Table 1). Mash bean emergence was 24 plants m^2 and mung bean 30 plants m^2. The control plots have 25 while the rest treated plots have 28 plants m^2.

Plant height

Plant height was significantly affected by legumes, phosphorous levels, organic sources, L × OS and L × P. The interactions of OS × P and L × OS × P have no significant effect on plant height (Table 1). Mash bean plant height (66.7 cm) was smaller than mung bean (77.6 cm). The rest (treated plots) produced significantly taller plants (73 cm) than control (59 cm). Among the P levels, the highest plant height (75.2 cm) was recorded for the highest P level 90 kg P ha^{-1}. Plots treated with the lowest P level 30 kg P ha^{-1} produced the lowest plant height (68.8 cm). Among the organic sources, combined application of AM + CR produced the tallest plants (75.5 cm), followed by sole animal manure (72.4 cm), while the shortest plant height (68.6 cm) was recorded with the application of sole crop residues. In case of OS × L interaction, plant height increased with sole animal manure or combined application of AM + CR than sole crop residues application in both crops (Figure 1). In case of L × P interaction, plant height increased with increase in P levels in both legume crops and the increase was more for mung bean than mash bean (Figure 2).

Table 1. Effect of organic sources [sole animal manure (AM), sole chickpea residues (CR) and combined AM + CR] and phosphorus (P) levels (kg ha^{-1}) on emergence m^2, plant height (cm), number of leaves $plant^{-1}$, number of branches $plant^{-1}$ and nodules $plant^{-1}$ of summer legumes (mungbean and mashbean).

Treatment	Emergence m^2	Plant height (cm)	Number of leaves $plant^{-1}$	Number of branches $plant^{-1}$	Number of nodules $plant^{-1}$
30 kg ha^{-1}	27.6^a	68.8^a	16^c	15.4^a	15.9^b
60 kg ha^{-1}	26.6^a	72.4^b	17^b	16.0^b	18.7^a
90 kg ha^{-1}	27.8^a	75.2^c	19^a	16.9^b	18.7^a
LSD	ns	2.05	0.48	0.8	0.51
Animal manure (AM)	27.3^a	72.4^b	17^b	16.8^a	16.8^b
Crop residue (CR)	26.6^a	68.6^c	16^c	15.1^b	16.9^b
AM + CR	28.1^a	75.5^a	18^a	16.5^a	19.6^a
LSD	ns	2.05	0.48	0.8	0.51
Mungbean	30.0^a	77.6^a	21^a	19.8^a	22.3^a
Mashbean	24.6^b	66.7^b	13^b	12.4^b	13.3^b
LSD	1.5	1.45	0.34	0.59	0.37
Control (no OM/no P)	25^b	59^b	14^b	12^b	10^b
Rest (Treated plots)	28^a	73^a	17^a	16^a	18^a
Interactions					
OS × P	ns	ns	ns	ns	ns
L × OS	ns	*(Figure 1)	**(Figure 3)	ns	**(Figure 5)
L × P	ns	*(Figure 2)	**(Figure 4)	ns	**(Figure 6)
L × OS × P	ns	ns	ns	ns	ns

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$). ns: non-significant data, **,* indicates significant at 1 and 5% level of probability, respectively using LSD test ($P \leq 0.05$). AM: animal manures (10 t ha^{-1}), CR: crop residues (10 t ha^{-1}), and AM+CR: animal manure and crop residues (5 t ha^{-1} each), and OM: organic matter.

Number of leaves $plant^{-1}$

Number of leaves $plant^{-1}$ was significantly affected by legumes, phosphorous, organic sources, L × P and L × OS interactions (Table 1). The interaction of OS × P and L × OS × P have no significant effect on number of leaves $plant^{-1}$ in legumes. Mash bean have less number of leaves $plant^{-1}$ (13) than mung bean (21). The rest (treated plots) produced significantly high number of leaves $plant^{-1}$ (17) than control (14). In case of P, more number of leaves $plant^{-1}$ was observed with 90 kg P ha^{-1} (19). Plots treated with 30 kg P ha^{-1} have minimum (17) leaves $plant^{-1}$ followed by 60 kg P ha^{-1} has 16. Among the organic sources, animal manure treated plots have maximum number of leaves $plant^{-1}$ (17), crop residues have 16, while 18 leaves $plant^{-1}$ were recorded in their combination (AM + CR). In case of L × P interaction, number of leaves $plant^{-1}$ increases with increase in P levels under both legume crops (mash bean and mung bean) (Figure 3). In case of L × OS interaction, number of leaves $plant^{-1}$ increases with increase in sole animal manure and combination of AM + CR residue as compared to sole crop residue (Figure 4).

Number of branches $plant^{-1}$

Number of branches $plant^{-1}$ was significantly affected by legumes, phosphorous levels and organic sources. The interactions of L × OS, L × P, OS × P and L × OS × P have no significant effect on number of branches $plant^{-1}$ (Table 1). Mash bean number of branches $plant^{-1}$ observed 19.8 which is lesser in number than mung bean (12.4). The rest (treated plots) produced significantly high number of branches $plant^{-1}$ (16) than control (12). Among the P levels, high number of branches (16.9) was recorded for the highest P level 90 kg P ha^{-1}. Plots treated with the lowest P level 30 kg P ha^{-1} produced the lowest number of branches $plant^{-1}$ (15.4). Among the organic sources, sole animal manure produced the highest branches $plant^{-1}$ (16.8), followed by combined application of AM + CR (16.5), while the lowest number of branches $plant^{-1}$ (15.1) was recorded with the application of sole crop residues.

Nodules $plant^{-1}$

Nodules $plant^{-1}$ was significantly affected by legumes, phosphorous, organic sources, L × P and L × OS interactions (Table 1). The interactions of OS × P and L × OS × P were found non-significant for nodules $plant^{-1}$. Mung bean as maximum number of nodules $plant^{-1}$ (22.3) than mash bean (13.3 days). The rest (treated plots) produced significantly high number of nodules $plant^{-1}$ (18)

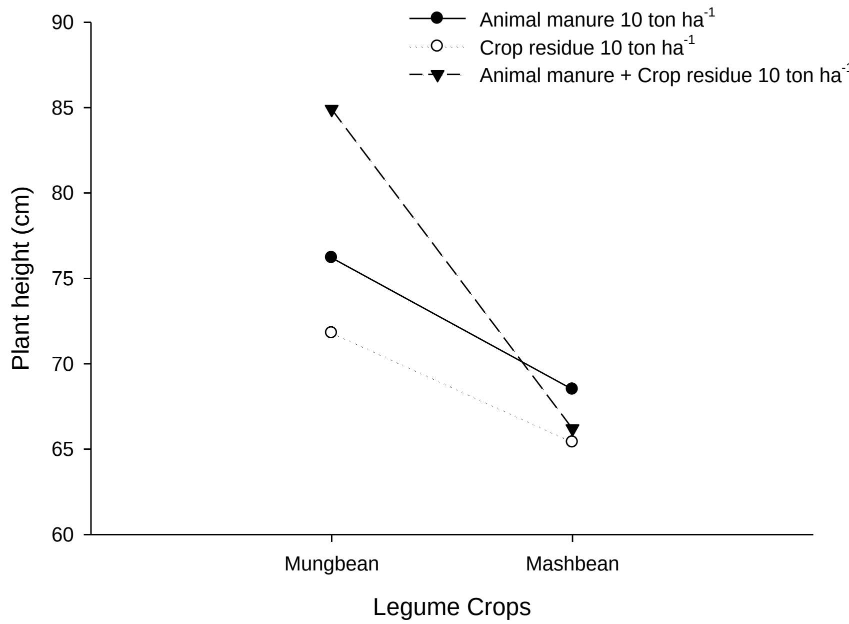

Figure 1. Interactive effect of organic sources and legume crops on plant height (cm).

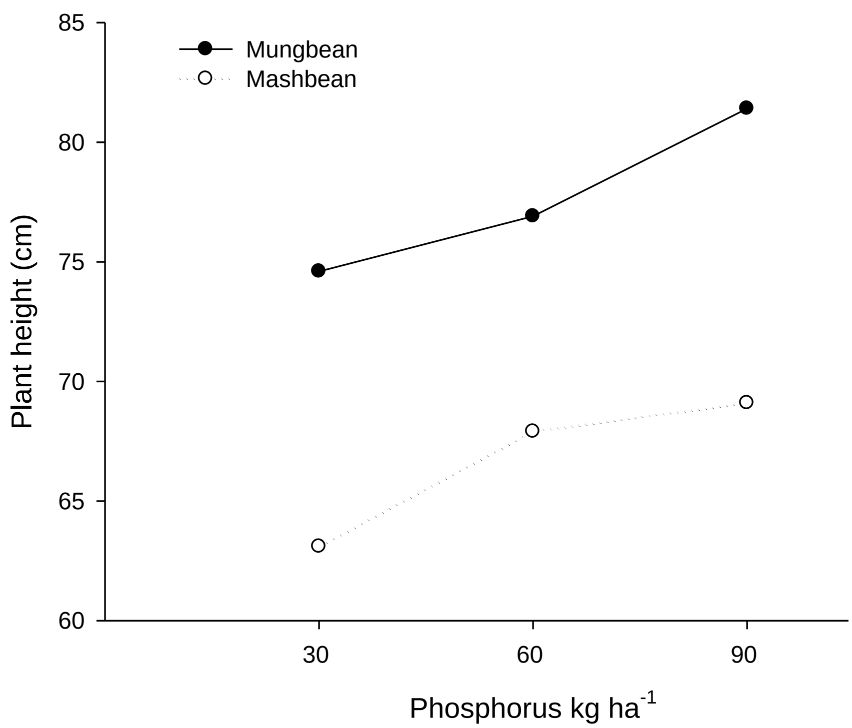

Figure 2. Interactive effect of phosphorus levels and legume crops on plant height (cm).

than control (10). In case of P, more number of nodules plant^{-1} was observed at 90 kg and 60 kg P ha^{-1} (18.7). Plots treated with 30 kg P ha^{-1} have less number of nodules plant^{-1} (15.9). Among the organic sources, animal manure and crop residues have less number (16), while the maximum number of nodules plant^{-1} (19) was

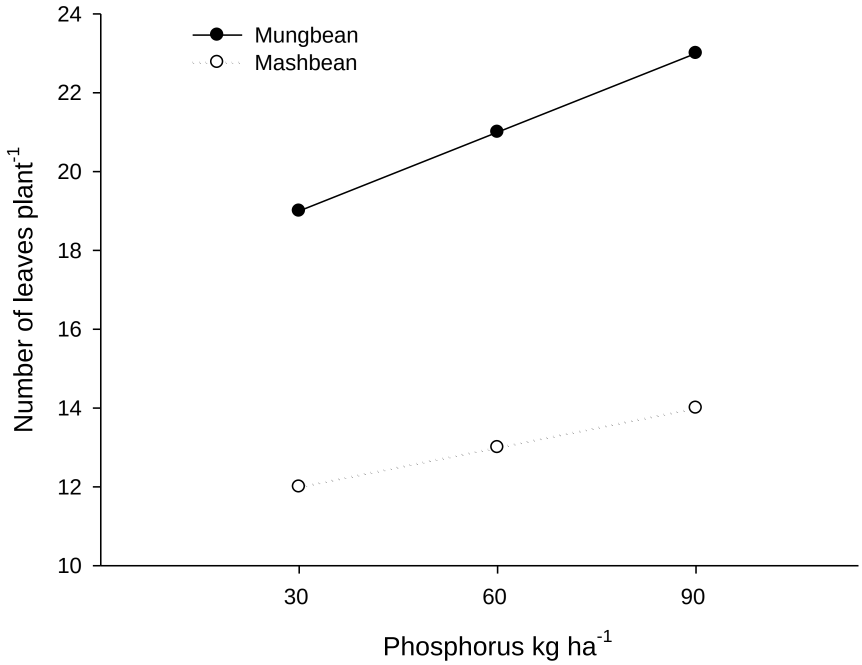

Figure 3. Interactive effect of phosphorus levels and legume crops on number of leaves plant^{-1}.

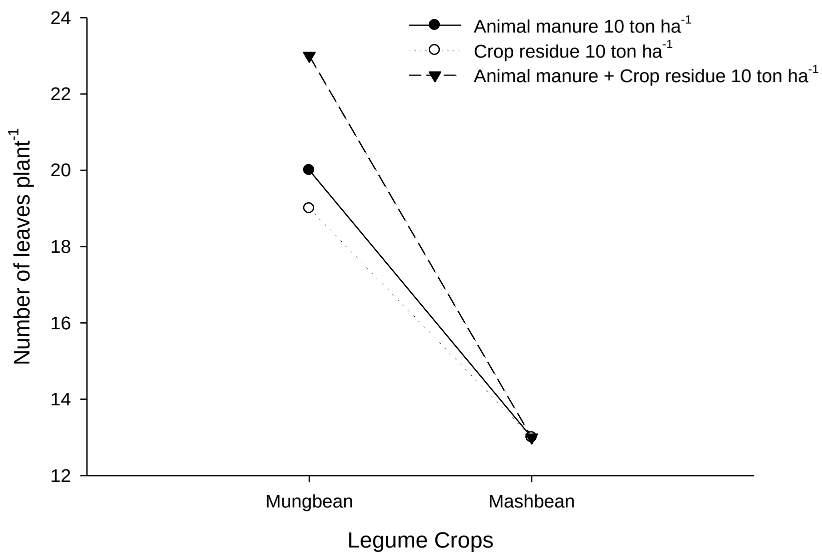

Figure 4. Interactive effect of organic sources and legume crops on number of leaves plant^{-1}.

recorded in their combination (AM + CR). In case of L × P interaction, maximum number of nodules plant^{-1} was noted with the increase in P levels under both legume crops (mash bean and mung bean) Figure 5. In L × OS interaction, maximum number of nodules plant^{-1} resulted in the combine effect of AM + CR followed by sole (AM) with P levels at 90 kg ha^{-1} (Figure 6).

Days to first flowering

Days to first flowering were significantly affected by

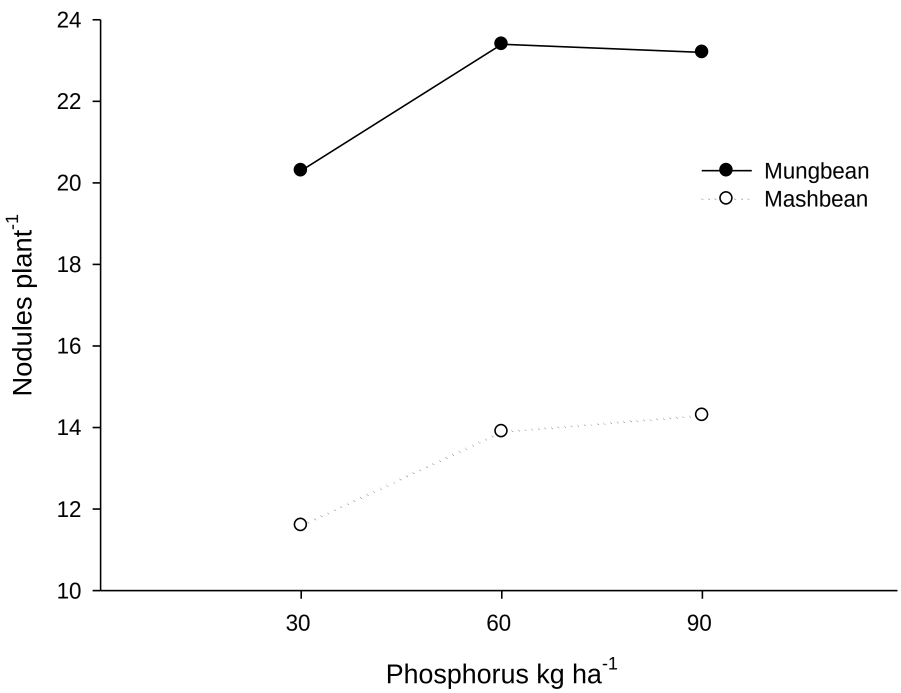

Figure 5. Interactive effect of phosphorus levels and legume crops on nodules plant^{-1}.

legumes but organic sources and phosphorous levels have no significant effect on days to first flowering. All the interactions L × OS, L × P, OS × P and L × OS × P were also found non-significant (Table 2). Mash bean took (42 days) to flowering as compared to mung bean (38 days). The rest (treated plots) cause early flowering (40 days) than control (43 days).

Days to first pod formation

Days to first pod formation was significantly affected by legumes, phosphorous, and organic sources (Table 2). OS × P, L × P, L × OS and L × OS × P interactions were found non-significant for days to first pod formation. Mash bean took maximum days to first pod formation (54) as compared to mung bean (49 days). The rest (treated plots) took maximum days (52) as compared to control (56 days). In case of P, first pod formation was observed with 90 kg and 60 kg P ha^{-1} (51 days). Plots treated with 30 kg P ha^{-1} took more days to pod formation (52 days). Among the organic sources, animal manure and crop residues took maximum days to first pod formation (52), while minimum (51) days were recorded in their combination (AM + CR).

Number of pods plant^{-1}

Number of pods plant^{-1} was significantly affected by legumes (L), phosphorous (P), organic sources and L × OS (Table 2). The interactions of OS × P, L × P and L × OS × P have no significant effect on the number of pods plant^{-1} in legumes. Mash bean have less number of pods plant^{-1} (15.4) as compared to mung bean (24.9). The rest (treated plots) produced significantly high number of pods plant^{-1} (21) than control (12). In case of P, more number of pods was observed with 90 kg P ha^{-1} (21.3). Plots treated with 30 kg P ha^{-1} have less number of pods plant^{-1} (18.7) followed by 60 kg P ha^{-1} (20.5). Among the organic sources, animal manure treated plots have 19.0 pods, crop residues have 19.3, while maximum (22.2 pods plant^{-1}) was recorded in their combination (AM + CR).

Number of seeds pod^{-1}

Number of seeds pod^{-1} was significantly affected by legumes, phosphorous levels, and organic sources. The interactions of OS × P, L × P and L×OS have significantly affected the seeds pod^{-1}, while L × OS × P interaction was found non-significant (Table 2). Mash bean produced 5.8 seeds pod^{-1} as compared to mung bean (10.7). The rest (treated plots) produced higher seeds pod^{-1} (8) than control (7). Among the P levels, the highest seeds (8.7) were recorded for the highest P level 90 kg P ha^{-1}. Plots treated with the lowest P level (30 kg P ha^{-1}) produced the lowest seeds pod^{-1} (7.5). Among the organic sources, application of sole animal manure produced the highest seeds pod^{-1} (8.7), followed by

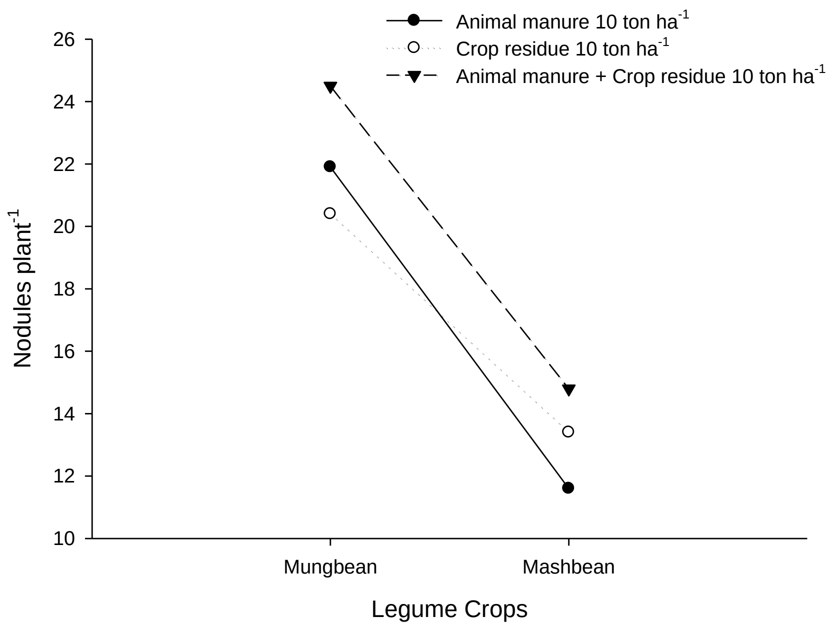

Figure 6. Interactive effect of organic sources and legume crops on nodules plant^{-1}.

Table 2. Effect of organic sources [sole animal manure (AM), sole chickpea residues (CR) and combined AM + CR] and phosphorus (P) levels (kg ha^{-1}) on days to first flowering, days to first pod formation, number of Pods plant^{-1}, seeds pod^{-1} and Pod length (cm) of summer legumes (mungbean and mashbean).

Treatment	Days to first flowering	Days to first pod formation	Number of pods plant^{-1}	Seeds pod^{-1}	Pod length (cm)
30 kg ha^{-1}	40^a	52^a	18.7^c	7.5^b	6.6^c
60 kg ha^{-1}	40^a	51^b	20.5^b	8.6^a	6.8^b
90 kg ha^{-1}	40^a	51^b	21.3^a	8.7^a	7.1^a
LSD	0.62	0.41	0.59	0.39	0.21
Animal manure (AM)	40^a	52^a	19.0^b	8.7^a	7.0^a
Crop residue (CR)	40^a	52^a	19.3^b	7.8^b	6.7^b
AM + CR	40^a	51^b	22.2^a	8.4^a	6.8^c
LSD	0.62	0.41	0.59	0.39	0.21
Mungbean	38^b	49^a	24.9^a	10.7^a	8.5^a
Mashbean	42^a	54^b	15.4^b	5.8^b	5.1^b
LSD	0.46	0.35	0.5	0.29	0.19
Control (no OM/no P)	43^a	56^a	12^b	7^b	5^b
Rest (Treated plots)	40^b	52^b	21^a	8^a	7^a
Interaction					
OS × P	ns	ns	ns	*(Figure 7)	ns
L × OS	ns	ns	ns	**(Figure 8)	ns
L × P	ns	ns	ns	*(Figure 9)	ns
L × OS × P	ns	ns	ns	ns	ns

Means of the same category followed by different letters are significantly different from each other using LSD test ($P \leq 0.05$). ns: non-significant data, **,* indicates significant at 1 and 5% level of probability, respectively using LSD test ($P \leq 0.05$). AM: animal manures (10 t ha^{-1}), CR: crop residues (10 t ha^{-1}), and AM+CR: animal manure and crop residues (5 t ha^{-1} each), and OM: organic matter.

combined application of AM + CR (8.4), while the lowest seeds (7.8) were recorded with the application of sole crop residues. In case of OS × P interaction, increase in seeds pod^{-1} was observed with increase in P level,

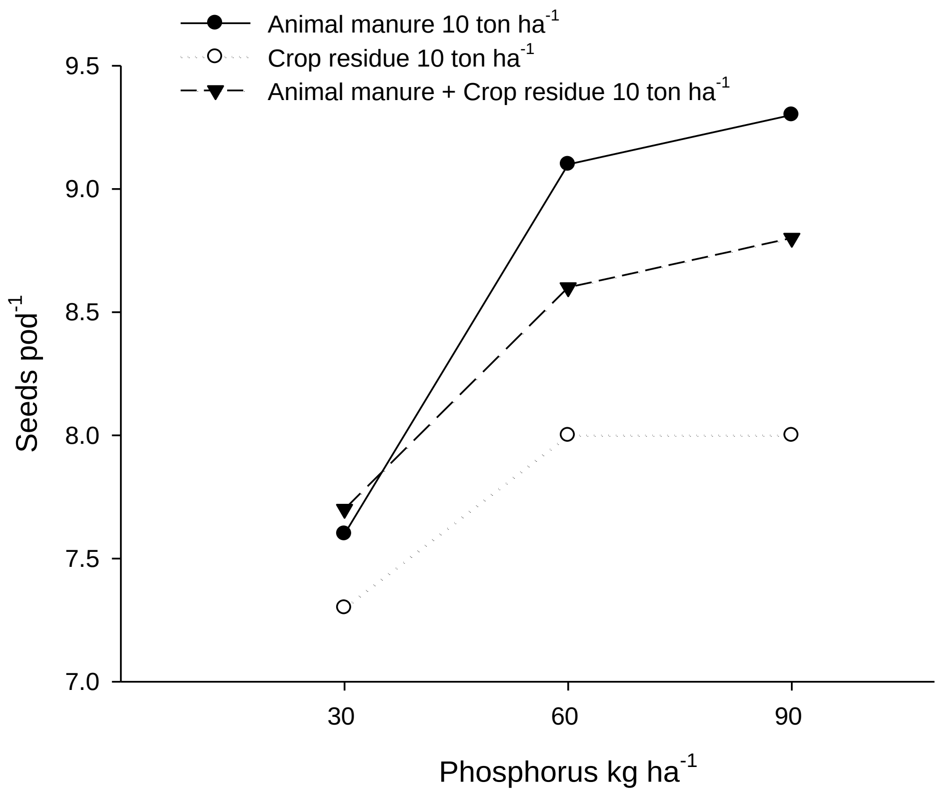

Figure 7. Interactive effect of organic sources and phosphorus levels on number of seeds pod^{-1}.

and the highest increase was obtained under sole animal manure and least increase under sole crop residues (Figure 7). In case of OS × L interaction, seeds increased with sole animal manure, combine application of AM + CR with high level of phosphorus 90 kg ha^{-1} and declined with sole crop residues application for both crops (Figure 8). In case of L × P interaction, seeds pod^{-1} increased at a higher rate with increase in P levels in both legume crops, and the increase was more for mung bean than mash bean (Figure 9).

Pod length

Pod length was significantly affected by legumes (L), phosphorous (P) and organic sources (Table 2). The interactions of OS × P, L × p, L × OS and L × OS × P were found non-significant for pod length. Mash bean have smaller pod length (5.1 cm) than mung bean (8.5 cm). The rest (treated plots) produced significantly longer pods length (7 cm) than control (5). In case of P, the highest pod length was observed with 90 kg P ha^{-1} (7.1 cm). Plots treated with 30 kg P ha^{-1} have smaller pod length of 6.6 cm followed by 60 kg P ha^{-1} with 6.8 cm. Among the organic sources, animal manure treated plots have pod length (7.0 cm), crop residues have 6.7 cm, while pod length of 6.8 cm was recorded in their combination (AM + CR).

Days to physiological maturity

Days to physiological maturity were significantly affected by legumes, phosphorous, organic sources and OS × P interaction (Table 3). The interactions of L × P, L × OS and L × OS × P have no significant effect for days to physiological maturity. Mash bean took maximum days to physiological maturity (69) as compared to mung bean (67 days). In case of P, early physiological maturity was observed with 90 kg P ha^{-1} (71 days). The rest (treated plots) cause early physiological maturity (72 days) than control (74). Plots treated with 30 kg P ha^{-1} and 60 kg P ha^{-1} took more days to physiological maturity (72 days). Among the organic sources, animal manure and crop residues took maximum days to first physiological maturity (72), while minimum days to physiological maturity (71 days) were recorded in their combination (animal manure + crop residues). In case of OS × P interaction, early physiological maturity was observed in combine application of AM + CR and sole (AM) with the increase in P levels under both legume crops

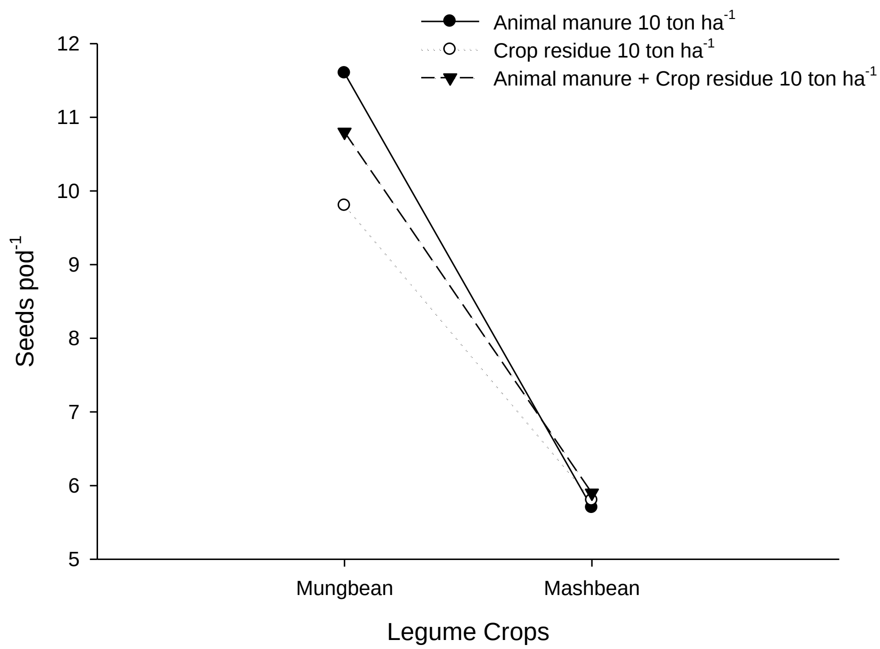

Figure 8. Interactive effect of organic sources and legume crops on number of seeds pod^{-1}.

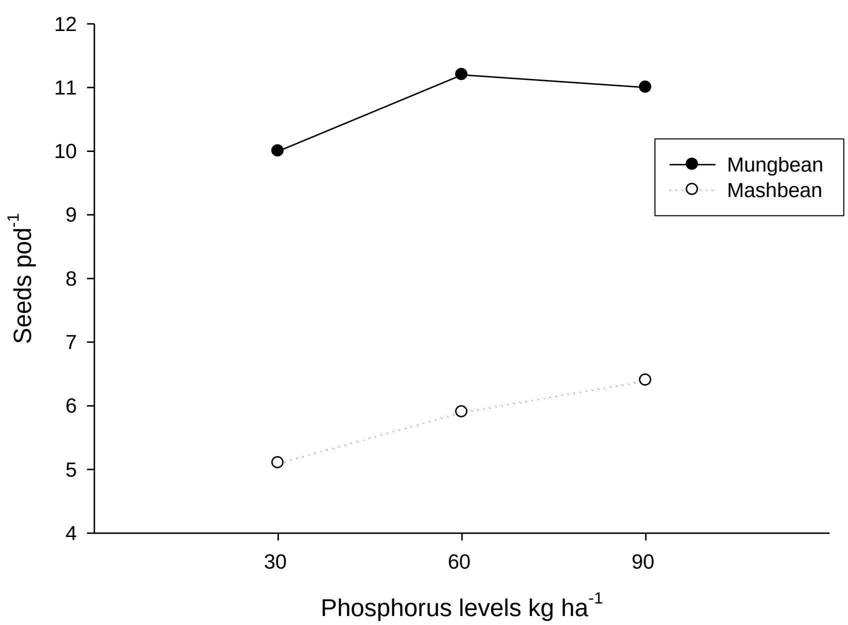

Figure 9. Interactive effect of phosphorus levels and legume crops on seeds pod^{-1}.

(mash bean and mung bean) (Figure 10).

Thousand grains weight

Thousand grain weight was significantly affected by legumes, phosphorous, organic sources, OS × P and L × P and L × OS (Table 3). The interaction of L × OS × P has no significant effect on thousand grain weight in legumes. Mash bean have less thousand grain weight (48.0) than mung bean (53.7). The rest (treated plots) produced significantly high grains weight (53 g) than

Table 3. Effect of organic sources [sole animal manure (AM), sole chickpea residues (CR) and combined AM + CR] and phosphorus (P) levels (kg ha^{-1}) on days to physiological maturity, thousand grains weight (g), grain yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index (%) of summer legumes (mungbean and mashbean).

Treatment	Days to physiological maturity	Thousand grains weight (g)	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
30 kg ha^{-1}	72^{a}	51.3	452^{c}	2607^{c}	17.7^{b}
60 kg ha^{-1}	72^{a}	52.7	500^{b}	2848^{b}	18.0^{b}
90 kg ha^{-1}	71^{b}	53.6	536^{a}	3059^{a}	18.7^{a}
LSD	0.35	1.06	15.26	78.72	0.52
Animal manure (AM)	72^{a}	52.4	541^{a}	2657^{c}	17.9^{b}
Crop residue (CR)	72^{a}	51.7	445^{c}	2724^{b}	17.5^{b}
AM + CR	71^{b}	53.5	502^{b}	3134^{a}	18.9^{a}
LSD	0.35	1.06	15.26	78.72	0.52
Mungbean	68^{b}	54.6^{a}	584^{a}	3695^{a}	17.4^{b}
Mashbean	76^{a}	50.5^{b}	408^{b}	1981^{b}	18.9^{a}
LSD	0.2	0.81	11.3	58.52	0.38
Control (no OM/no P)	74^{a}	42^{b}	269^{b}	1700^{b}	17^{b}
Rest (Treated plots)	72^{b}	53^{a}	496^{a}	2916^{a}	18^{a}
Interaction					
OS × P	**(Figure 10)	*(Figure 11)	*(Figure 14)	**(Figure 17)	ns
L × OS	ns	**(Figure 12)	**(Figure 15)	**(Figure 18)	**(Figure 20)
L × P	ns	**(Figure 13)	**(Figure 16)	*(Figure 19)	ns
L × OS × P	ns	ns	ns	ns	ns

Means of the same category followed by different letters are significantly different from each other using LSD test (P ≤ 0.05). ns: non-significant data, **,* indicates significant at 1 and 5% level of probability, respectively using LSD test (P ≤ 0.05). AM: animal manures (10 t ha^{-1}), CR: crop residues (10 t ha^{-1}), and AM+CR: animal manure and crop residues (5 t ha^{-1} each), and OM: organic matter.

control (42 g). Among the P levels, the highest grain yield (53.6 g) was recorded for the highest P level (90 kg P ha^{-1}). Plots treated with the lowest P level (30 kg P ha^{-1}) produced the lowest grain weight (51.3 g). Among the organic sources, combined application of animal manure + crop residue produced the highest grains weight (53.5 g), followed by application of sole animal manure (52.4 g), while the lowest grain weight (51.7 g) was recorded with the application of sole crop residues. In case of OS × P interaction, increase in grain weight observed with increase in P level and the highest increase was obtained under combined application of AM + CR and least increase under sole crop residues (Figure 11). In case of OS × L interaction, grain weight increased with sole animal manure application, followed by combine application of AM + CR and declined with sole crop residues application for both crops (Figure 12). In case of L × P interaction, grain yield increased at a higher rate with increase in P levels in both legume crops and the increase was more for mung bean than mash bean (Figure 13).

Grain yield

Grain yield was significantly affected by legumes, phosphorous levels, organic sources, OS × P, L × P and L × OS, while L × OS × P interaction has non-significant effect on grain yield (Table 3). Mash bean produced lower grain yield (408 kg ha^{-1}) than mung bean (584 kg ha^{-1}). The rest (treated plots) produced significantly higher grain yield (496 kg ha^{-1}) than control (269 kg ha^{-1}). Among the P levels, the highest grain yield (536 kg ha^{-1}) was recorded for the highest P level (90 kg P ha^{-1}). Plots treated with the lowest P level (30 kg P ha^{-1}) produced the lowest grain yield (452 kg ha^{-1}). Among the organic sources, application of sole animal manure produced the highest grain yield (541 kg ha^{-1}), followed by combined application of AM + CR (502 kg ha^{-1}), while the lowest grain yield (445 kg ha^{-1}) was recorded with the application of sole crop residues. In case of OS × P interaction, increase in grain yield was observed with increase in P level, and the highest increase was obtained under sole animal manure and least increase under sole crop residues (Figure 14). In case of OS × L interaction, grain yield increased with sole animal manure application and declined with sole crop residues application for both crops (Figure 15). In case of L × P interaction, grain yield increased at a higher rate with increase in P levels in both legume crops, and the increase was more for mung bean than mash bean (Figure 16).

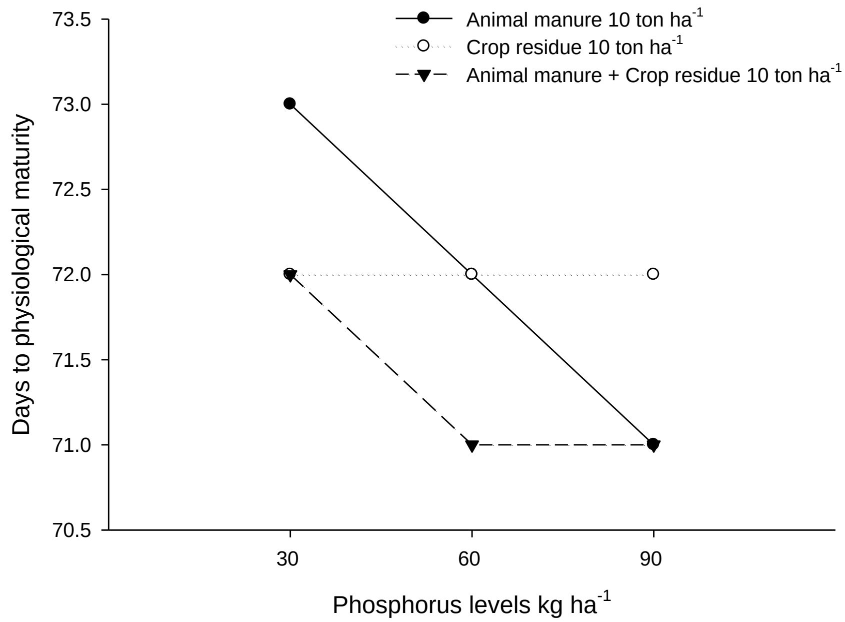

Figure 10. Interactive effect of organic sources and phosphorus levels on days to physiological maturity.

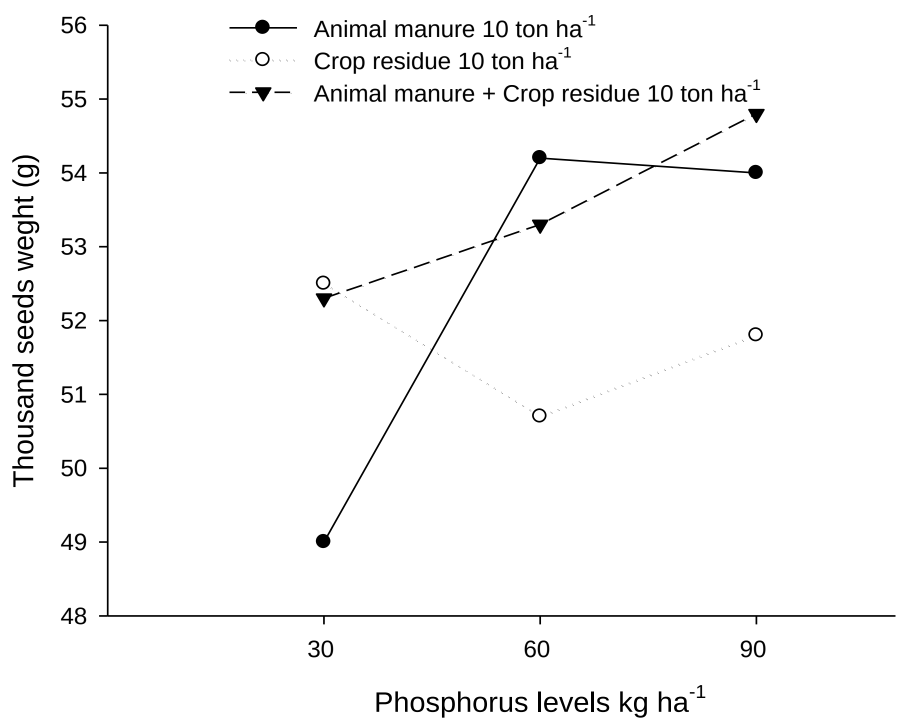

Figure 11. Interactive effect of organic sources and phosphorus levels on thousand seeds weight.

Biological yield

Biological yield was significantly affected by legumes, phosphorous levels and organic sources (Table 3). The interactions OS × P, L × P, and L×OS significantly affected the biological yield, while L × OS × P had no

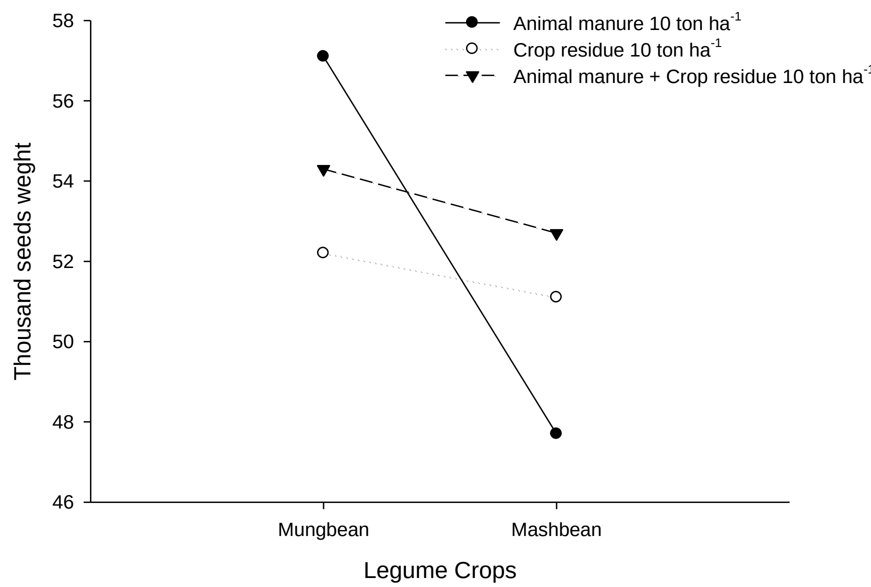

Figure 12. Interactive effect of organic sources and legume crops on thousand seeds weight.

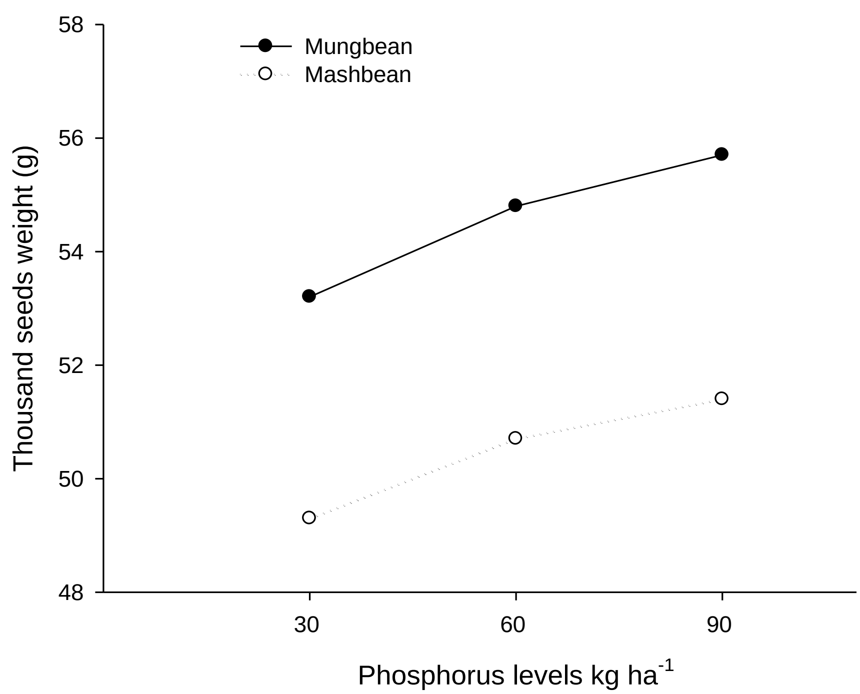

Figure 13. Interactive effect of phosphorus levels and legume crops on thousand seeds weight.

significant effect on biological yield. Mash bean produced lower biological yield (1981 kg ha^{-1}) as compared to mung bean (3695 kg ha^{-1}). The rest (treated plots) produced significantly higher biological yield (2916 kg ha^{-1}) than control (1700 kg ha^{-1}). Among the P levels, the highest biological yield (3059 kg ha^{-1}) was recorded for the highest P level (90 kg P ha^{-1}). Plots treated with the lowest P level (30 kg P ha^{-1}) produced the lowest yield (2607 kg ha^{-1}). Among the organic sources, combined application of AM + CR produced the highest

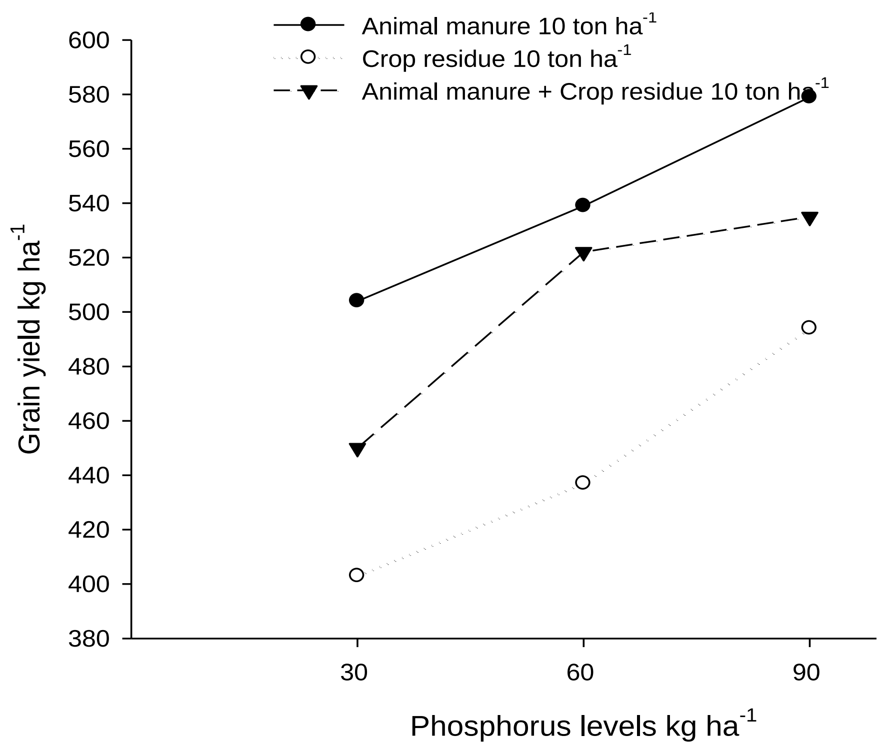

Figure 14. Interactive effect of phosphorus levels and organic sources on grain yield kg ha^{-1}.

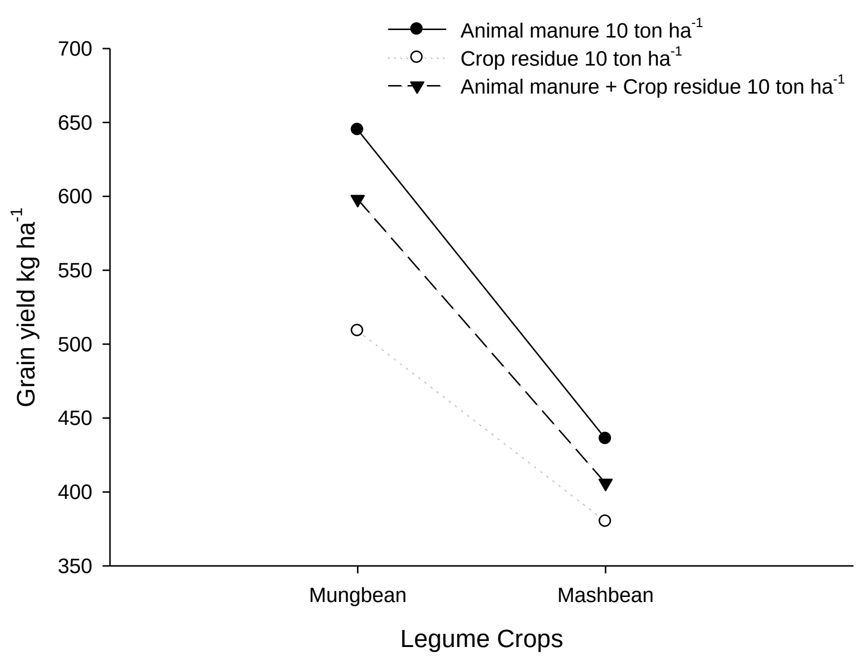

Figure 15. Interactive effect of organic sources and legume crops on grain yield kg ha^{-1}.

biological yield (3134 kg ha^{-1}), followed by application of sole animal manure (2657 kg ha^{-1}), while the lowest biological yield (2724 kg ha^{-1}) was recorded with the application of sole crop residues. In case of OS × P

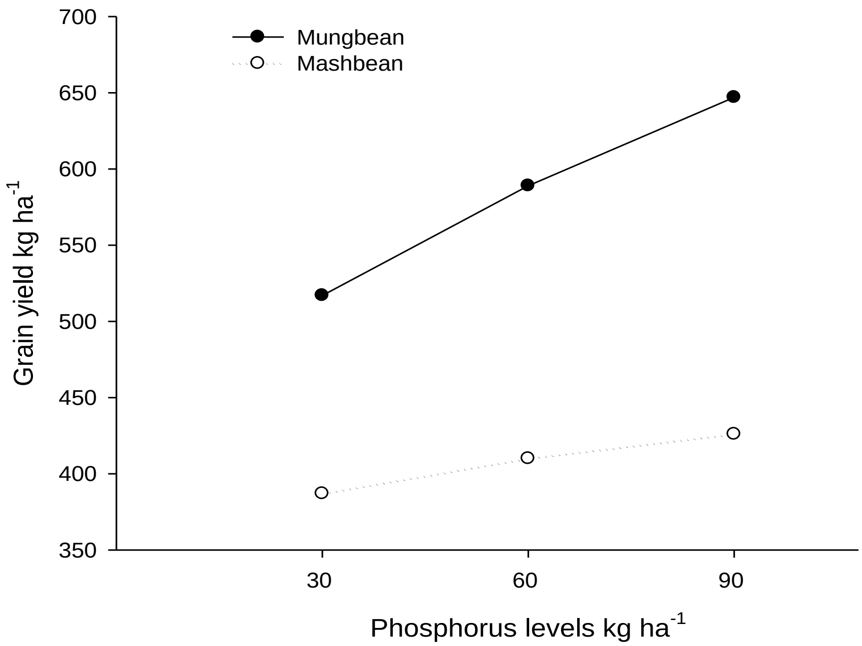

Figure 16. Interactive effect of phosphorus levels and legume crops grain yield kg ha^{-1}.

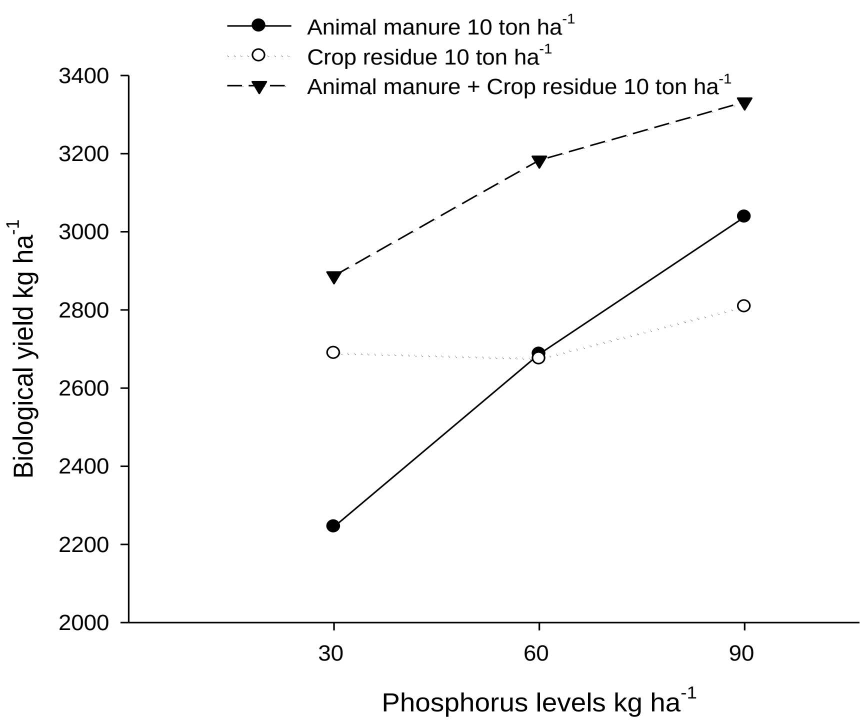

Figure 17. Interactive effect of phosphorus levels and organic sources on biological yield kg ha^{-1}.

interaction, increase in biological yield was observed with increase in P level, and the highest increase was obtained under (AM + CR) and least increase under sole crop residues (Figure 17). In case of OS × L interaction, biological yield increased with sole animal manure application, and declined with sole crop residues application for both crops (Figure 18). In case of L × P interaction, grain yield increased at a

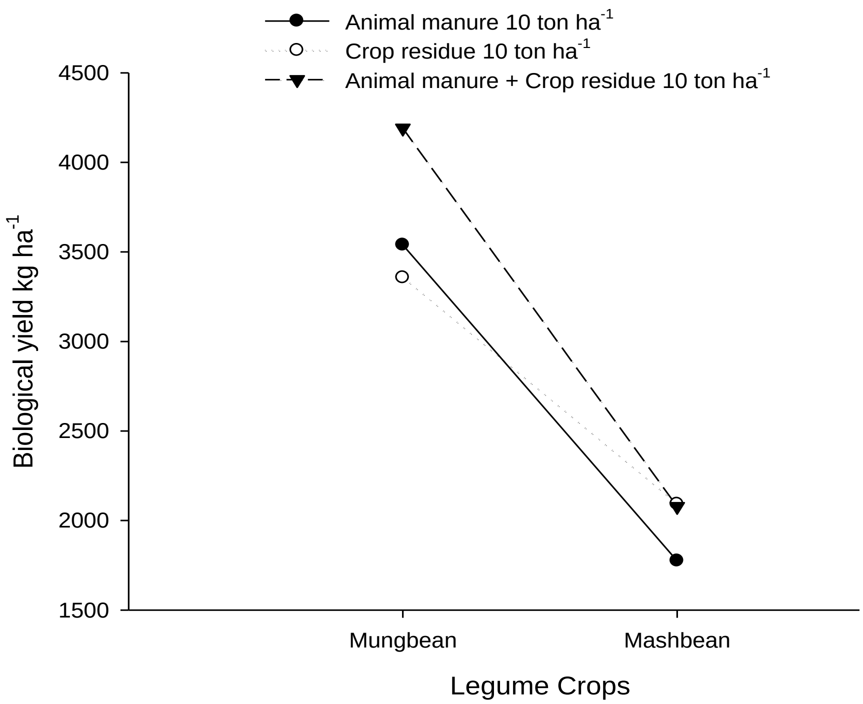

Figure 18. Interactive effect of organic sources and legume crops on biological yield kg ha^{-1}.

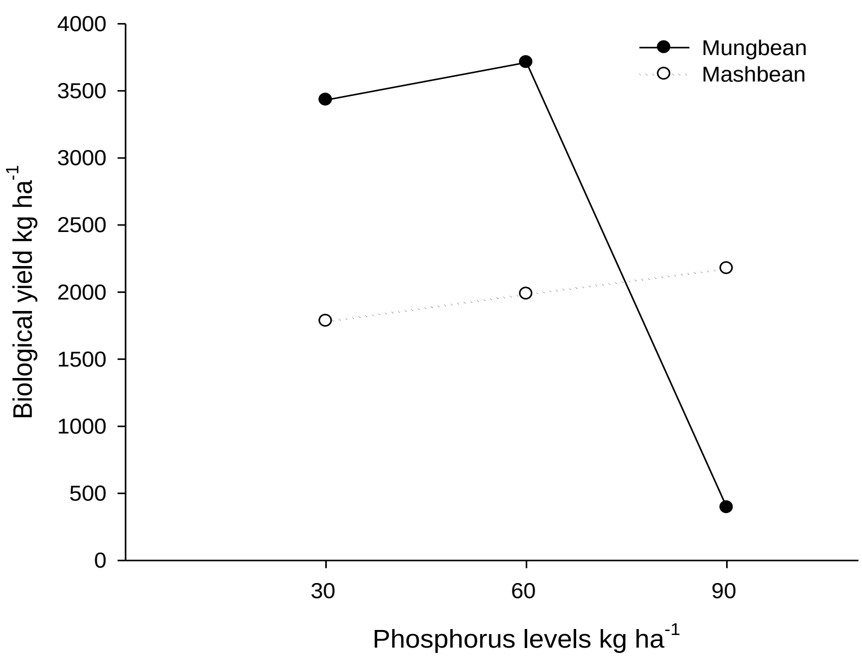

Figure 19. Interactive effect of phosphorus levels and legume crops biological yield kg ha^{-1}.

higher rate with increase in P levels in both legume crops, and the increase was more for mung bean than mash bean (Figure 19).

Harvest index

Harvest index was significantly affected by legumes,

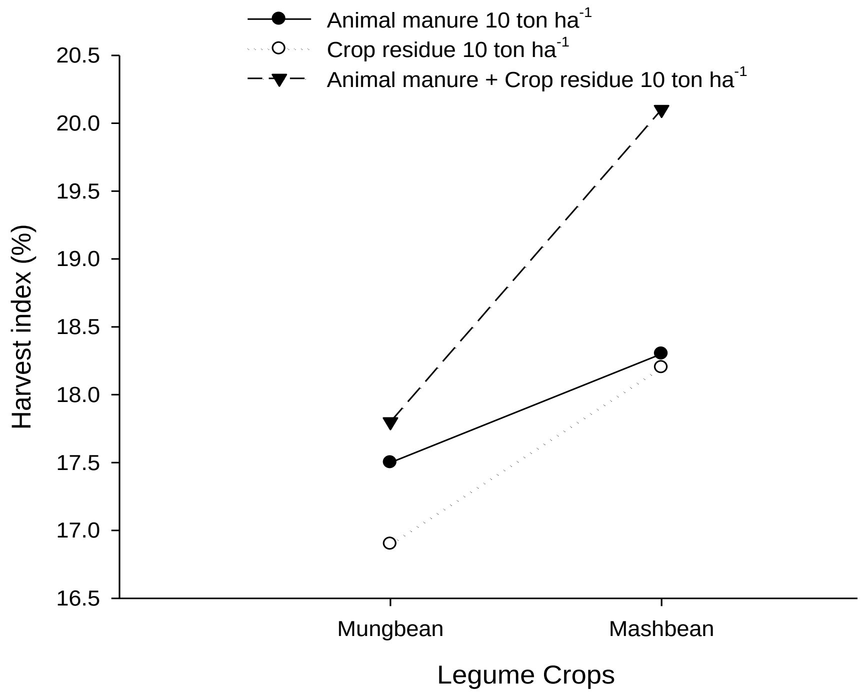

Figure 20. Interactive effect of organic sources and legume crops on harvest index (%).

phosphorous, organic sources and L × OS (Table 3). The interactions of OS × P, L × P and L × OS × P have no significant effect on harvest index in legumes. Mash bean has minimum harvest index (17.4 kg) than mung bean (18.9 kg). The rest (treated plots) produced significantly higher harvest index (18 kg ha^{-1}) than control (17 kg ha^{-1}). In case of P, more yields were observed with 90 kg P ha^{-1} (18.7 kg). Plots treated with 30 kg P ha^{-1} have minimum (17.7 kg) harvest index and 60 kg P ha^{-1} has 18.0 kg. Among the organic sources, animal manure treated plots have 17.9 kg harvest index, chickpea residues have minimum harvest index of 17.5 kg, while maximum (18.9 kg) was recorded in their combination (AM + CR). In case of OS × L interaction, harvest index increased with sole animal manure application and declined with sole crop residues application for both crops (Figure 20).

DISCUSSION

Effect of phosphorus

There was delay in phenological development (days to first flowering, pod formation and physiological maturity) in both summer pulses (mung bean and mash bean) with no P application or the use of lower P rate (30 kg P ha^{-1}). Early phenological development was recorded with higher P rates (60 and 90 kg ha^{-1}). Delayed heading and physiological maturity was observed when P was not applied (P control plots). Early flowering, pods formation and physiological maturity in mung bean were observed with the application of the highest rate of 90 kg P ha^{-1} (Amanullah et al., 2014). Khalil et al. (2010) described that increase in P level results in earlier phonological development. Decrease in P levels caused delay in phenological development of both crops. These results agree with those of Amanullah et al. (2014) who reported that mung bean applied with no P (P-control) had delayed flowering and pods formation. Likewise, delayed maturity in the P-control plots was observed in mung bean (Jan et al., 2012a) and chickpea (Jan et al., 2012b).

Growth parameters in this study, viz. plant height, number of leaves, branches and nodules per plant, increased with increase in P level and the P-control had negative impact on all these parameters as compared to the rest (P treated plots). Ram and Dixit (2001) also found that the application of P at 60 kg ha^{-1} significantly increased the plant height, branches per plant, leaves per plant and dry matter accumulation as compared to control in green gram. Kumar et al. (2000) revealed that application of phosphorus at the rate of 40 kg ha^{-1} significantly increased the growth attributes of urd bean, viz., plant height, number of branches, leaves and leaf area plant^{-1} over preceding levels of phosphorus. Karwasra et al. (2006) reported that application of 50 kg P ha^{-1} enhanced the plant height and branches plant^{-1} over control. Shahid et al. (2009) reported that soybean plant height was significantly increased with increasing P application rate. Moreover, Moniruzzaman et al. (2008) noted that plant height of French bean was significantly increased up to 80 kg P ha^{-1} and then remained constant. The promotion effect of P fertilization on corn plant height was attributed to better development of root system and nutrient absorption (Hussain et al., 2006).

The increase in the number of nodules per plant with application of P over control probably may be due to the increase in the root lengths, number and weight of mung bean with P application. Brady (1984) reported favorable effects of P application on the number and weight of effective nodules on the root system of leguminous crops. Hussain et al. (2014) reported a maximum of 8.67 nodules $plant^{-1}$ in mung bean which received P along with Rhizobium inoculation under semiarid condition. Gowda and Gowda (1978) reported that mung bean requires P to increase N fixation and to improve the yield and quality of grain. Hussain et al. (2014) reported that application of P increased N uptake in mung bean. Chattopadhyay and Dutta (2003) reported that the number of nodules $plant^{-1}$ in cowpea increased with increasing level of phosphorus up to 80 kg P ha^{-1}.

Increase in P level increased pods $plant^{-1}$ and maximum pod $plant^{-1}$ were obtained with 90 kg P ha^{-1}. However, P control plots produced minimum pods $plant^{-1}$. Increase in yield components of both crops probably may be due to the availability of more P from the soil had positive impact on the growth (Malik et al., 2002; Amanullah et al., 2014) and thereby produced more yield components. Maqsood et al. (2001) recorded that lowest number of seeds $plant^{-1}$ was recorded without phosphorus application (0 kg P ha^{-1}) and highest 1000-seed weight was obtained with phosphorus at the rate 75 kg ha^{-l}, while the lowest 1000-seed weight was recorded with no phosphorus application. The findings of Ali (1993) also stated that 1000-seed weight was significantly affected by application of 84 kg P ha^{-l}. The application of phosphate fertilizer at the rate 84 kg ha^{-1} gave the maximum number of pods $plant^{-1}$, number of grains pod^{-1} and 1000-grains weight resulting ultimately in maximum grain yields (Ali et al., 2010). Kumar and Sharma (2005) studied that increase in level of phosphorus up to 40 kg P_2O_5 ha^{-1} significantly increased the number of pods $plant^{-1}$ and number of seeds pod^{-1}. Moniruzzaman et al. (2008) reported that pod length in French bean was significantly increased as P application rate increased from 0 to 80 kg P_2O_5 ha^{-1} and remained relatively constant at higher P rates (120 kg P_2O_5 ha^{-1}). The results also agree with the findings of Turuko and Mohammed (2014), who reported that the highest pod number $plant^{-1}$ in common bean was recorded with P rates of 20 kg ha^{-1}. Similarly, Moniruzzaman et al. (2008) reported that the number of pods $plant^{-1}$ in French bean was increased up to 120 kg P_2O_5 ha^{-1} in 2005 to 2006 and up to 80 kg P_2O_5 ha^{-1} in 2006 to 2007 growing seasons. This may be due to the fact that P increases flower formation and improves fruit setting. Moshtaght (2015) concluded that total pod yield was significantly increased by 32% when P application rate increased from 0 to 100 kg ha^{-1}. Moniruzzaman et al. (2008) and Srinivas and Naik (1990) reported that significantly the highest pod yield was recorded at 80 kg P_2O_5 ha^{-1}. Phosphorus is an essential macronutrient that improves plant growth and yield through the following: (1) P promotes root growth and stimulates lateral root branching that, in turn, increases nutrients absorption from the soil; (2) it plays a vital role in flower formation and fruit setting; (3) it is involved in sugar and starch utilization, photosynthesis, and cell division; (4) it stimulates leaf cell division and elongation, and leaf number, thus increases leaf area index (Assuero et al., 2004; Kavanova et al., 2006), and this improves light interception and photosynthesis and, therefore, increases plant biomass accumulation, and (5) it is a crucial element for nodule formation in legume crop and improves nitrogen fixation (Bhuiyan et al., 2008). Ram and Dixit (2001) reported that phosphorus fertilization at 60 kg P_2O_5 ha^{-1} significantly increased the grain yield and pods $plant^{-1}$ summer green gram in comparison with 20 kg P_2O_5 ha^{-1}. Singh and Agarwal (2001) found that the number of pods $plant^{-1}$, pod length, number of grains pod^{-1}, 1000 grains weight and grain yield in black gram increased significantly with increasing levels of phosphorus up to 60 kg P_2O_5 ha^{-1}. Increase in P level increased seeds pod^{-1} and thousand grains weight. Maximum seeds pod^{-1} and thousand grains weight were recorded with 90 kg ha^{-1}. However, P control plots produced minimum seeds pod^{-1} and thousand grains weight. These results are in line with that of Malik et al. (2002), who reported that the application of phosphorous at the rate of 50 to 75 kg ha^{-1} to mung bean crop significantly increase the number of pods $plant^{-1}$, seeds pod^{-1} and thousand grains weights. The crop fertilized with phosphorus gave significantly higher seed yield than obtained from control treatment. The differences in seed yield among the different phosphorus levels might be due to their variable effects on seed yield components (Maqsood et al., 2001). Rao et al. (1990) and Singh and Tripathi (1992) concluded that application of 40 to 60 kg P ha^{-1} increased the seed yield. Ali et al. (2010) reported that phosphate fertilizer showed significant impact on mung crop compared to that in control plots, but the treatment of phosphate fertilizer at the rate of 84 kg ha^{-1} out yielded rest of the treatments. Emsley (2000) reported that phosphatic fertilization has increasing influence in relation to growth and yield. Higher yields of mung bean have been reported by application of phosphorous at the rate of 90 kg ha^{-1} under field conditions (Lange et al., 2007). Sharma et al. (2003) observed significant improvement in seed yield of mung bean and black gram with the successive increase in the phosphorus level up to 60 kg P_2O_5 ha^{-1}. Kumar and Kushwaha (2006) observed that seed yield and net returns of pigeon pea were increased significantly with phosphorus levels up to 40 kg P_2O_5 ha^{-1} as compared to the control. The increase in grain yield with phosphorus application was due to better plant growth and well development of yield contributing parameters. These results are in line with the findings of Malik et al. (2002), who reported that increase in P level increased grain yield. These results are in line with the findings of Ahmad et al. (1992) who also reported an increase in harvest index of mung bean in response to application of P and N. Maqsood et al. (2001) concluded that harvest index in response to phosphorus differed significantly from one another. The harvest index for 75 kg P ha^{-l} was significantly higher from that of 50 kg P ha^{-1}. These results are in conformity with the findings of Sudhakar et al. (1989) who reported that the application of phosphorus increased the harvest index.

Effect of organic sources

Khadem et al. (2010) reported that manure application affects phenological development. Improvement in branches $plant^{-1}$ of mung bean in farm yard manure amended plots could be attributed to timely and slowly release of nutrient throughout the growing season (Jama et al., 1997). Das (2014) concluded that the number of nodules $plant^{-1}$ was higher in farm yard manure treated plots in comparison with the other treatments without plant growth-promoting rhizobacteria (PGPR). It might be due to higher microbial activity in the soil by the combined application. Das (2014) concluded that number of pods $plant^{-1}$ were higher in farm yard manure treated plots. The input of organic matter increases water holding capacity and permeability of the soil (Hussain et al., 2004). Das (2014) observed that higher pod yield (15 q/ha) was found in farm yard manure treated plot. Ramesh et al. (2006) reported that application of cattle dung manure (4 t ha^{-1}) recorded the highest seed yield on pigeon pea.

Combined effect of organic sources and phosphorus

Maximum seeds pod^{-1} were obtained by the combine effect of phosphorus 90 kg ha^{-1} in combination with animal manure 10 t ha^{-1} followed by 60 kg phosphorus ha^{-1} in mung bean while in mash bean maximum pods $plant^{-1}$, pod $plant^{-1}$, pod length and thousand grain weight was observed on 90 kg phosphorus ha^{-1} along with 10 ton ha^{-1} animal manure followed by 90 $kgha^{-1}$ along with crop residue and animal manure 10 $tonha^{-1}$. In both crops, high grain yield was observed with the combine application of phosphorus and animal manures treated plots; this might be due to timely and slowly release of nutrients from farm yard manure throughout the growing season and might be the possible reason for improving grain yield in farm yard manure amended plots. Biyan (2014) showed that synergistic effect of farm yard manure and chemical fertilizer increased the grain yield. The increase in grain yield was attributed to the increase in pods $plant^{-1}$. Farm yard manure contained high amounts of organic matter which increased the moisture retention of soil and improved dissolution of nutrients, particularly phosphorus (Singh et al., 2010). Application of farm yard manure and chemical fertilizer significantly increased grain yield of mung bean (Choudhary et al., 2011). Increase in phosphorous levels enhanced harvest index and maximum harvest index was obtained with 90 kg P ha^{-1} in mash bean while phosphorus 90 kg ha^{-1} with combination of crop residues and animal manures of 5 ton ha^{-1} each increase the yield in mung bean.

Conclusions

It was concluded from this research work that integrated use of animal manures (cattle manure) and legume (chickpea) residues (5 t ha^{-1} each) improved growth and resulted in higher yield and yield components of both mung bean and mash bean over sole application cattle manure and chickpea residues. The higher P levels resulted in earlier phenological development, improved growth, increased number of nodules $plant^{-1}$, pods $plant^{-1}$, thousand grains weight, grain and biological yield as well as harvest index of both crops (90 = 60 > 30 > 0 kg P ha^{-1}). Changing the cereal-cereal system (wheat-rice and wheat-maize) to cereal-pulses system (wheat-mung bean or wheat-mash bean) could provide a long-term benefit for resource conservation due to their ability to fix N, withstand drought and their lower dependence on external inputs like fertilizer.

CONFLICTS OF INTERESTS

The authors declare that there is no conflict of interest.

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Full Length Research Paper

Reassessing cotton pricing policy in Burkina Faso: How important is price stabilization?

Amadou Gouzaye[1], Jeffrey Vitale[1] and Pilja Park[2*]

[1]Department of Agricultural Economics, Oklahoma State University. 308 Ag Hall, Stillwater, Oklahoma, 74078, United States.
[2]Promised Prairie LLC, 6205 E VFW Road, Glencoe, Oklahoma, 74032, United States.

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This paper focuses on the parastatal marketing of cotton in Burkina Faso. The parastatal companies have bought cotton at a guaranteed price, announced prior to planting, reducing a key element of risk for producers. The cotton sector reforms in the late 1990s and early 2000s have significantly improved the share of international price received by local producers. However, a number of problems must still be solved to improve the living conditions for rural agricultural producers. The purpose of this paper is to reassess parastatal cotton pricing in Burkina Faso by factoring the implicit benefit that producers have obtained from guaranteed prices which reduces the price variability risk. A mean-variance economic risk model was developed to measure the price risk that would have been associated with selling cotton on international markets rather than selling to parastatal companies at a guaranteed price. Results suggest that risk is often a significant factor in producers' decision making, particularly over the past decade, when price volatility would have driven risk averse producers out of international markets. The viability of the parastatal markets, contrary to the prevailing literature which suggests that future policy shifts towards increased privatization, needs to consider price stabilization and the price variability risk associated with the international cotton market.

Key words: Cotton, price risk, mean-variance model, risk premium, certainty equivalent.

INTRODUCTION

Export crops in sub-Saharan Africa (SSA) have traditionally been associated with poor marketing conditions for producers (Diao and Hazell, 2004, Onal, 2012). Export crops have typically been produced within a paternalistic institutional structure, where technology, extension, and marketing are controlled by the parent company, usually a parastatal or multinational. Under this arrangement, the parent company provides producers with modern technology and inputs at subsidized prices to maximize output, but in exchange for these services, producers have received only a fraction of prevailing international prices, with rents accruing to the parent

*Corresponding author. E-mail: pilja@okstate.edu.

company (Rapsomanikis et al., 2003; Delpeuch and Leblois, 2013; Theriault and Tschirley, 2014). This noncompetitive market structure and government ownership creates price distortions that represent an implicit taxation on export crop producers, benefitting urban elites and multinational companies at the expense of the welfare of rural agricultural communities (Kherallah et al., 2000; Baffes, 2007; Delpeuch and Leblois, 2013).

The plight of West African cotton producers has drawn considerable international interest over the past few decades. Equity is a primary concern raised by many in the development literature, who argue that West African cotton producers receive an unequal share of the international cotton price and subsequent profit (Baffes, 2005; Baffes et al., 2009; Baquedano et al., 2010). Empirical studies conducted over both the recent and distant past support this claim, which have found a low share of the international price given to West African cotton producers by the national cotton companies operating in the region (Baffes, 2005; Baffes et al., 2009; Baquedano et al., 2010; Delpeuch and Vandeplas, 2013). West African cotton producers' share of the international cotton price is generally between 39 and 53% (Badiane et al., 2002). As a consequence of the low share of the international price paid to producers, the cotton companies' rent has been relatively high over the last three decades. When the ginning, transportation and marketing cost are subtracted from the international price, the difference between the domestic price and the adjusted international price approximates the cotton companies' rent. That difference was relatively high in the 1970s and 1980s because the price producers received was abnormally low compared to the international price (Baffes, 2007). In some years, the rent of the cotton companies was as high as 67% of the international cotton price. Following the reforms that took place at the end of the 1980s within most cotton sectors in West Africa, the cotton producer's share of the international price has increased significantly over the last two decades relative to the 1970s and the 1980s. However, even with the reforms, the West African cotton producers' share of international price is still low compared to international standards (Tschirley et al., 2009).

The development literature contains alternative explanations for the plight of the West African smallholder cotton farmer along with potential remedies. Bassett (2010) reported that Fairtrade cotton pilot programs in Burkina Faso and Mali, which aimed at providing transfers from developed country retail markets to smallholder farms, failed since it works within the same conventional commodity chain that impoverishes smallholders. In Burkina Faso and Cote d'ivorie, international market share that producers ultimately receive depends on price setting mechanism that is highly influenced by inequalities in their economies that highly favor urban areas and government sector (Bassett, 2014). Cotton producers in Benin, Bukina Faso, and Mali require reducing farmer's financial stress through the establishment of more equitable pricing mechanisms to enable greater on-farm investments in technology and input use, spurring technical efficiency and enhancing profitability (Theriault and Serra, 2014). Other studies have identified alternative reforms such as Nelen (2007), who demonstrates how newly formed farmer's organizations have come to handle complex issues inherent in the cotton sector. This includes the improved bargaining power and partial ownership of the cotton sector in Burkina Faso. Heinisch (2006) showed how developing countries can have advantage in cotton trade when they act as a regional compact. A notable example is how Benin, Burkina Faso, and Mali successfully challenged US cotton subsidies that were blamed on world price declines at the beginning of the 21st century.

Previous cotton market studies have argued that the international market would be more profitable for cotton producers in Burkina Faso (Baffes, 2005; Baffes et al., 2009; Baquedano et al., 2010; Baffes, 2012). Most of these studies support the fact that liberalization in the cotton sectors would improve the producer's share of the international price. However, the pricing mechanism used by West African cotton companies, based on guaranteed prices, insulates producers from uncertainty in the international cotton markets, but transfers the burden to the parastatal. In Burkina Faso, cotton prices are announced by the parastatal cotton companies sometime between March and April, just prior to planting, but cotton is not sold on international markets until the cotton is harvested and ginned, typically eight to twelve months later. International cotton markets are risky since prices can be volatile over the short run, with price collapses occurring frequently between the pre-planting period, when cotton companies announce the guaranteed price, and the post-harvest period, when cotton is sold on international markets (Figure 1). Over the period 1998 to 2009, price collapses had resulted in financial losses for the parastatal cotton companies since the price obtained on international markets had fallen below the price cotton companies were obligated to pay to producers (Estur, 2004). In 2004, there was a 23% fall in the nominal international cotlook 'A' price between May and December, and in 2008 the decline in the international price was 36% over that same seven-month period.

Economic research over the past decades has found that reducing price variability and stabilizing prices has an economic value to producers (Roy, 1952). Risk averse producers prefer, and are willing to pay for, reducing profit variability by choosing alternatives that avoid outcomes considered likely to fall too often below the mean, that is, by reducing variability. Hence, the guaranteed price paid to producers by the parastatal reduces risk and based on current understanding of producer behavior, has an economic value for risk averse producers.

The recent literature on West Africa cotton sector

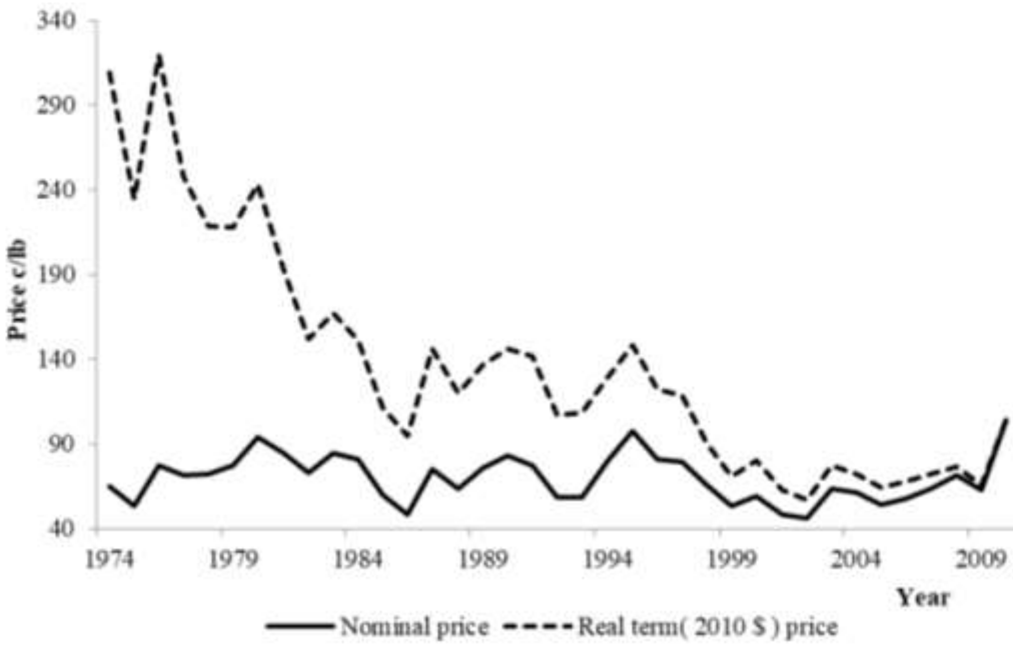

Figure 1. Nominal and real Cotlook 'A' price. The real price is the nominal price adjusted by the GPD deflator for Burkina Faso.
Source: FaoStat.

reform has too often ignored the risk associated with the international market price. Analysis has been based primarily on the post-harvest international cotton price, but for producers the more meaningful cotton price is the expected cotton price, formed prior to planting, when they are making their decisions on how to organize their farm for the upcoming season.

The primary purpose of the present study is to reassess the equity of parastatal cotton pricing in West Africa by including the implicit benefit producers receive from the guaranteed price. A price forecasting procedure is developed to estimated expected cotton prices at planting. A risk model is then utilized to determine how producers would market their cotton between either a guaranteed price provided by parastatal or a hypothetical marketing strategy, in which producers have the autonomy to sell the cotton directly on international markets. The risk model analyzes a 34 year period, from 1976 to 2009, which provides a robust comparison of how parastatal marketing channels have operated vis-a-vis international markets. The main contribution of this paper is to make transparent the benefits of price stability that smallholder producers implicitly capture in terms of their risk preferences that has largely been ignored by previous research.

Cotton parastatal companies in Burkina Faso

Cotton commercial production started in Burkina Faso during the French colonization period in the 1920s (Kaminski, 2007). The production of cotton was imposed on local populations by French colonial power to satisfy the French national and European demand with low cost cotton as input to their textile industry (Basset, 2010). Virtually all of the production was export oriented to Europe. With the 1920s economic recession that affected the industrial production, cotton production stopped in Burkina Faso as a consequence of the food shortage induced by the global economic crisis in the colony (Kaminski, 2007). In 1949, cotton production resumed with the creation of the French Textile Development Company (CFDT). CFDT was a public company that provided inputs and technical assistance to cotton producers during that period. These technical and extension services helped improve cotton production techniques. Cotton quickly became known as "white gold" throughout the West African region. After the independence movement in the early 1960s, cotton production became the main economic activity that attracted foreign investment and generated export earnings for many countries in the region. CFDT continued to own and operate cotton sectors in several West African countries, even after independence.

In Burkina Faso, in the early 1970s the government took a share in the CFDT and a national company (SOFITEX) was created as a subsidiary of CFDT. The public company was a monopoly for inputs supply to producers (seeds, fertilizers and pesticides) and a virtual monopsony for the purchase of the seed cotton (Tschirley et al., 2009). At that time producers were organized under village associations which work with the public company. The extension services and improved varieties that the SOFITEX provided lead to a considerable productivity increase for labor and land inputs. Export earnings from selling cotton on the international market are the primary source of hard currency in these countries and are a vital catalyst to economic development, with cotton's share of GDP being between 2.5 and 6% among the C4 countries (Baghdadli et al., 2007).

In the 1980's when most developing countries experienced economic recession including defaulting on their foreign debt, many countries undertook economic reforms such as privatizing most public companies because of economic recession (Anderson and Masters, 2009). In the late 1980s and early 1990s, with an overvalued currency, cotton companies experienced financial difficulties (Baffes, 2007). In 1994, the CFA Franc was devaluated by 50%. The devaluation helped increase the cotton producers' share of the international price (Baffes, 2007). In late 1990s, many West African countries undertook strong reforms in their respective cotton sectors (Tschirley et al., 2009; Kaminski, 2011; Baffes, 2012). However, even with these reforms, numerous issues related to inefficiencies remain in the cotton sectors (Anderson and Masters, 2009).

Liberalizing cotton sectors would grant more marketing autonomy and higher price to cotton producers (Baffes, 2005). West African cotton producers currently benefit from the guaranteed price provided by the national cotton companies, but much of the price stabilization would likely be removed under more liberalized conditions. So, while a greater share of the international cotton price would be transmitted to the farm gate with a liberalized market, producers would also be exposed to an increased level of price risk (Baffes, 2005). The development literature has for the most part focused primarily on the farm gate price and the share of international price paid to producers, while ignoring the economic value of the guaranteed price under the current parastatal pricing system. Other questions also need to be addressed, such as by whom and how would, market uncertainty be managed in a more liberalized marketing chain.

MATERIALS AND METHODS

Data

Monthly cotton prices were collected over a 34 year period (1976-2009) for the international spot markets. The parastatal price was also gathered over the same period. Of the two alternatives, only the international spot market is subject to price variability; the parastatal price is guaranteed (Figure 3). The parastatal price is the national pan-territorial and pan-seasonal price offered to producers by the parastatal cotton companies. In Burkina Faso, since 2006, the parastatal price has been negotiated each year and announced publicly prior to the planting period, sometime around April. Prior to 2006, the price was determined exclusively by the government, but announced in the same manner prior to the planting period in April. The parastatal price has zero variance because it is a guaranteed price, hence, there is no variation associated with the parastatal price over the time between planting and harvest.

The Northern Europe cotton market, represented by price quotations in Liverpool and Rotterdam, is the market where West African cotton, including cotton from Burkina Faso, has primarily been exported. Increasingly, West Africa cotton exports are marketed in Asia and elsewhere as international markets have expanded (Cotlook, 2011). Prices on the international cotton markets are represented by the Cotlook 'A' Index, an average of the five lowest prices from a selection of nineteen price quotations (Cotlook, 2011). In the present study, the cotlook 'A' index was used because the cotlook 'A' index is considered the most representative of international cotton markets that West African cotton producers would utilize. Monthly data on the spot price are published by the UN Commission on Trade and Development (UNCTAD). In the present study, the December spot price is used because December is the month in which producers usually expect to be able to market their cotton, under the assumption that the ginning industry is able to have the cotton lint available by the end of December each year.

When considering spot markets, a major issue for producers is price uncertainty. Producers form price expectations in the spring time, just prior to planting, to choose the optimal crop portfolio. Since harvest is several months in the future and further time is required to gin the cotton and ready it for international markets, there can be significant price movements between the period just prior to planting when price expectations are formed and the period after harvest when cotton is ready to be marketed. Hence, instead of using the actual price in the post-harvest period, an expected price is forecasted based on the historical observations of cotton prices that have evolved up to the time when price expectations are formed. Hence, each year, the December spot price (the harvest period) is forecasted in May (the planting period). This is considered as a more realistic and meaningful price to producers compared to the post-harvest price used in most of the previous studies.

Overall, the trend of parastatal prices and cotton lint yields during our study periods is presented in Figure 2. Cotton yields were obtained from FAOSTAT for the duration of the study period (FAOSTAT, 2017). The introduction of animal traction, modern seed varieties, insecticides, and the presence of extension services from the national cotton companies enabled cotton producers to increase yields over the past few decades. Compared to other crops in the region, cotton is less dependent on rainfall throughout the growing season and varieties have been developed to adapt cotton plants to the higher heat and water stress conditions in the region.

Theory

Parastatal cotton companies purchase cotton from producers at guaranteed prices, insulating producers from market volatility. Policies to transform parastatal control towards privatization, and increased producer autonomy, will require producers to bear a larger share of the uncertainty and fluctuations in international cotton markets. Price uncertainty has generally a strong influence on agricultural producers' decision-making process (Anderson and Dillon, 1992; Moschini, 2001). Resource allocation, whether it is land, labor or capital, is hampered by uncertainty. Because cotton producers do not know how the cotton price will evolve after the sowing date, their planting decisions are based on price expectations that producers form prior to planting, sometime around March or April. Analytically, price expectations are modeled as stochastic processes that producers, acting rationally, determine based on prior outcomes. In economic theory, producers' decision making processes under uncertainty are generally modeled using

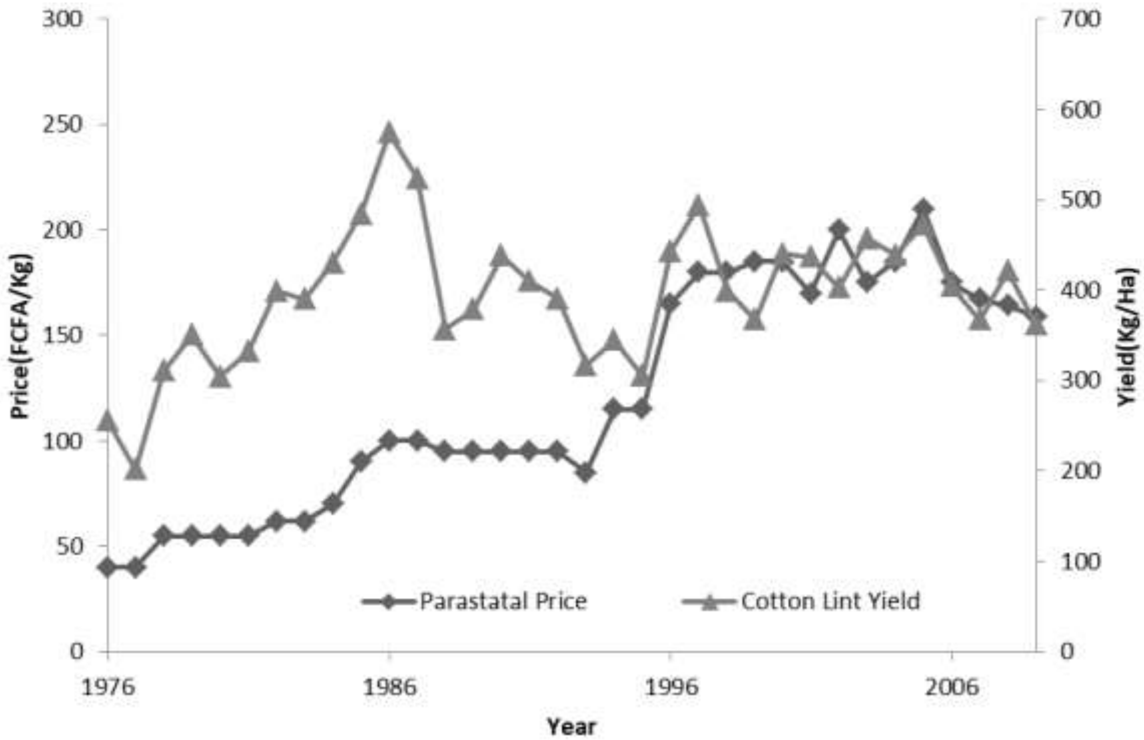

Figure 2. Parastatal price and cotton lint yield, 1978-2009.
Source: FaoStat.

Figure 3. Forecasted international spot and the parastatal prices in Burkina Faso. ***Data sources: parastatal price (International Bank), Spot price (UNCTAD). ****The parastatal price is the national producer's price at the farm gate. The forecasted spot price is the December expected price forecasted with a simple linear time series model. The errors bars represent one standard deviation above the mean and one standard deviation below the mean for the spot price.

the expected utility maximization framework (Markowitz, 1952). Producers are presumed to assess their utility in each of the outcomes (or states) and an expected value is determined based on the probability of the outcomes (or states). For this study, cotton producers expected utility maximization problem, when choosing between the international spot market and the parastatal pricing system, is written as:

$$\underset{\theta}{Max}\, EU(x_1, x_2, \theta) = \theta EU(x_1) + (1-\theta) EU(x_2) \quad (1)$$

where $EU(x_1, x_2, \theta)$ is the overall expected utility from the two marketing channels, x_1 is the stochastic distribution of the international cotton price and x_2 is the parastatal cotton price, θ is the decision variable, the proportion of the production sold on the international market, $EU(x_1)$ and $EU(x_2)$ are expected utility from the international and parastatal marketing channels, respectively.

The expected utility for selling cotton on the international markets is given by:

$$EU(x_1) = \int_{x_1=0}^{\infty} U(x_1) f(x_1) dx \quad (2)$$

where x_1 represents the stochastic choice variable, $f(x_1)$ is the probability density function of the stochastic process that represents how the distribution of international cotton price, x_1, is formed prior to planting around March and April, and

$$EU(x_2) = U(x_2) \quad (3)$$

is the expected utility from the guaranteed parastatal pricing system, x_2, which requires no expectation since the price is guaranteed prior to planting.

Because the marginal utility, $dU(I)/dI$, decreases as profit, I, increases for risk averse individuals, deviations above the mean profit, that is, when prices are higher than expected, generate less expected utility than equal deviations below the mean reduce expected utility, when prices fall short of expectations (Bailey et al., 1980). In an expected utility framework, it thus follows that risk averse producers will prefer a portfolio that reduces stochastic variation about the mean even if it requires accepting a lower expected mean income. Because the expected utility framework requires integrating a utility function, methods have been developed to approximate the formulation given by Equation 1 into more computationally tractable formats. Freund (1956) suggests that the quadratic programming, a Taylor series approximation based on the mean and variance of the support function used in Equation 1, is often the best way to include risk in a decision making process.

Empirical model

In the present study, two marketing channels are considered, the international spot market and the parastatal pricing system of the cotton companies. The international spot market is a hypothetical alternative since all producers have been under contract, through village level farmer cooperatives, to sell all of their cotton to the parastatal cotton company operating in their region. The expected utility given by Equation 1 in the theory section, when expanded using a second order Taylor series, is approximated as a function of the mean and the variance of the stochastic price distribution, that is, the mean variance (or E-V) formulation (Levy and Markowitz, 1979). The quadratic formulation is used in situations where the exact risk preferences of the producers are not available or not required, since the quadratic formulation requires minimal assumptions about producer's risk preferences (Hazell, 1971). The main assumption for the quadratic utility approximation is the stochastic process is normally distributed. When the quadratic formulation is valid, risk is measured by the variance, and higher order moments such as skewness or Kurtosis can be ignored, making the quadratic formulation relatively straightforward to solve (Markowitz, 1952). When the cotton price is normally distributed, the E-V model is an exact representation of the expected utility problem discussed previously (Levy and Markowitz, 1979).

The objective function of the E-V model, Φ, maximizes the expected cotton profit but penalizes deviations around the mean using the variance, that is, the squared distance from the mean. The E-V model maximizes the objective function subject to a land constraint, mandating that all of the cotton is either marketed in the parastatal or international spot market, which operates the same as θ in Equation 1. The E-V model is specified as follows:

$$\max_{A} \Phi = \sum_{j=1}^{2} A_{(t,j)} Y_t P_{(t,j)} - \frac{\gamma}{2} \sum_{j=1}^{2} A^2_{(t,j)} Y_t Var(t,j) \quad (4)$$

Subject to:

$$\sum_{j=1}^{2} A_{(t,j)} \leq 1 \quad (5)$$

$$A_{(t,j)} \geq 0 \quad (6)$$

where Φ is the producer's E-V objective function, that is producer's expected cotton profit, t is the current year (time period), j is the marketing channel (j=1 for parastatal price and j=2 for the Cotllook 'A' market price), A(t, j) is the decision variable or the solution of the E-V model, that is, the fraction of the production for year t sold on market j, Y_t is the cotton yield in year t and $P(t, j)$ is the market price for the jth marketing channel in year t, $Var(t, j)$ is the variance of market price j in year t, and γ is the producer's risk aversion parameter, which is varied using sensitivity analysis.

Risk preferences are generally measured by the risk aversion coefficient (Arrow, 1971). The risk aversion parameter shows producer's willingness to trade-off lower levels of expected profit for reduced variance (Jalota et al., 2007). Agricultural producers are assumed to be rational and they seek to maximize their expected utility of profit (Mapp et al., 1979). Producers that are less risk averse are less willing to trade-off expected profit and variance (or variability). Highly risk averse producers are more willing to trade-off expected profit for reduced variance (or variability). Since risk aversion is an individual preference, sensitivity analysis is used to vary γ to account for risk aversion ranging from risk neutrality (γ = 0) to high risk aversion. The magnitude of the producer's risk aversion parameter was varied using sensitivity analysis and a constant absolute risk aversion preference over income, following the approach of Rolfo (1980), who also investigated agricultural export marketing in the sub-Saharan Africa.

Cotton

A price forecast model was also developed using the SAS Forecast procedure (SAS Institute, 2008) to estimate the predicted cotton price in December, when cotton can be marketed, based on expectations formed several months earlier in May just prior to planting when cropping decisions are made, $P_{Dec}|P_{May}$. The price forecast model used in the procedure combines a time trend and an autoregressive process that are given by the following equations:

$$P_t = a + b_1 t + b_2 t^2 + u_t \tag{7}$$

$$u_t = a_1 u_{t-1} + a_2 u_{t-1} + \cdots + a_p u_{t-p} + \varepsilon_{t.} \tag{8}$$

In Equation 7, P_t is the expected price of cotton in December based on a seven month forecast where *a,* b_1, and b_2, are trend parameters, *t* is the monthly time trend, and u_t is the error component. In Equation 8, a_i's are autoregressive parameters, *t* represents the time period that is the month considered, and ε_t is the random error term. The forecast procedure includes only the parameters for the time lags that are statistically significant in the autoregressive process (SAS Institute, 2008). The forecast procedure generated the mean forecasted December price, the 95% confidence interval, and the standard deviation of the mean, which is used in the E-V model formulation (SAS Institute, 2008).

The SAS forecast model was run consecutively for each of the 34 years using the previous years' monthly prices, prior to May, starting in January 1976, to forecast the December price. The price forecast model is able to use all prior information known up to the current year when expectations are formed in May.

To compare the parastatal price (the price paid for raw cotton at the farm gate) to the international price, the price received on the international market for cotton fiber, the marketing, parastatal transportation, ginning, and the sea freight costs are subtracted from the spot market price. Additional data on these costs as well as the ginning ratio were obtained from the literature (Tschirley et al., 2009; Baffes, 2007). This step was necessary since the parastatal price paid to producers did not factor in any of the costs required to ship, market, or transform the raw cotton purchased at the farm gate into the cotton fiber sold on international markets. The parastatal and international cotton prices series are presented in Figure 3. The price series trend shows that the difference between the two prices and the variability of the international cotton price were not constant over the time period. In the 1970's and early 1980's, the international cotton price was substantially higher than the parastatal price. The variability was relatively low compared to the mean price. Over the 2000 decade, the international price was highly volatile and the levels of two price series were relatively in the same range (Figure 3).

After solving the E-V model that gave us the fraction of which market the cotton to be sold (the value A in Equation 9), the gross profit is calculated as well as its variance for a hypothetical 1 ha farm, using Equations 9 and 10 as follows:

$$\bar{R} = \sum_{j=1}^{3} A_{jt} P_{jt} Y_t \tag{9}$$

$$V_t = Y_t^2 A_t^2 var_t \tag{10}$$

where $\bar{R}$ is the average expected profit, A_{jt}, is the proportion of cotton sold in market *j* for year *t* given by the solution of the E-V model, P_{jt} is the cotton price on market *j* for year *t*, Y_t is the cotton yield for year *t*, V_t is the expected variance of profit, Y_t is the cotton yield for year *t*, A_t is the proportion of cotton to be sold on the international market ratio given by the solution of the E-V model, and var_t is the expected variance of the international market price obtained from the SAS price forecast model.

The cotton companies' rent is calculated as the difference between the profit with the adjusted international spot price and the profit with the parastatal price. The rent is given by the following equation:

$$R_t = Y_t(P_s - P_d) \tag{11}$$

In Equation 11, R_t represents the annual rent earned by the parastatal cotton companies, Y_t is the yield for each year, *t* is the year. P_s is the adjusted international spot price and P_d is the parastatal price.

The risk premium is the amount of money, measured in terms of expected profit, which a risk averse decision maker is willing to pay to reduce profit variability as determined by their level of risk aversion. By definition, the risk premium is zero for risk neutral producers. For a risk averse producer, the risk premium is defined as the difference between the expected profit obtained for their level of risk aversion and the expected profit of the risk neutral producer. Risk premiums grow larger as risk aversion is increased. In the E-V model, as risk aversion is increased, producers will forgo expected profit by selling a larger share of their cotton to the parastatal to reduce variability. In this paper, the risk premium measures the implicit benefit that risk averse producers would have derived from having access to the parastatal marketing channel, even when given the opportunity to sell their cotton on international markets. The risk premium indicates the extent to which risk averse producers would be willing to pay to reduce price variability. The parastatal market provides a price stabilization mechanism, resulting in a mixed marketing strategy in which the international market provides benefits from a higher expected price and the parastatal enables producers to manage risk. The following equation is used for the risk premium calculations:

$$R_p = R_{RNP} - R_{RAP} \tag{12}$$

In Equation 12, R_p is the risk premium, R_{RNP} is the profit of the risk neutral producer and R_{RAP} the profit of risk averse producer.

The certainty equivalent is another measure of risk. For a risk averse producer, the certainty equivalent (CE) is defined as the minimum amount, they would be willing to accept, with certainty, to avoid facing an uncertain (risky) alternative (Hardaker, 2004). The CE is calculated using the following equation:

$$U(CE + R_{PRN}) = U(R_W) \tag{13}$$

where *CE* is the certainty equivalent, R_W the potential profit from international market, R_{PRN} is the profit of a risk averse producer when marketing only through the parastatal market from Equation 4 and *U* is the expected utility function defined in Equation 1.

The international market functions as the uncertain alternative since it contains substantial price variability. So for this study, the CE is the amount that a risk averse producer would pay to avoid having to market exclusively in the international market, and instead markets only with the parastatal company, where profit is certain. Profit from the parastatal market is included with the CE in Equation 13 since it already provides a guaranteed outcome. Hence, the CE as measured by Equation 13, indicates the additional amount, above and beyond the certainty provided by the parastatal pricing, to make producers accept the certain outcome rather than face the uncertainty. Risk neutral producers have a CE equal to the expected profit in the international market since they do not discount variance. Risk averse producers would accept less than the expected profit in the international market. Given the definition used in Equation 13, negative CE values are possible, indicating that the parastatal market exceeded the minimum amount of profit that was needed to pay producers to forgo the risky alternative and accept a certain outcome. Negative CE values are interpreted as a

Table 1. Comparison between the International European spot market and the parastatal pricing system over the period 1976-2009.

γ	Parastatal pricing ratio*	International spot ratio*	Average profit** ($US.ha^{-1})	STDEV of profit ($US.ha^{-1})	Certainty equivalent*** ($US.ha^{-1})	Risk premium# ($US.ha^{-1})
0	0.15	0.85	377.45	70.18	87.41	-
0.001	0.20	0.80	377.43	65.48	87.41	0.02
0.1	0.61	0.39	340.05	23.79	41.93	37.40
1	0.92	0.08	294.21	3.31	-226.78	83.24
5	0.98	0.02	285.15	0.68	-268.38	92.30
50	0.99	0.001	282.09	0.02	-280.62	95.36
100	1.00	0.00	281.97	0	-281.30	95.54

*****The ratios are obtained through the E-V model using the data for the period between 1976 and 1984. **The profit is computed using the ratios, the prices of the two marketing channels and adding them. *** The certainty equivalent is equivalent to the profit that risk averse producer is willing to accept rather than a higher profit that is subject to risk. #The risk premium is the difference between the certainty equivalent and the profit of the risk neutral producer.

benefit since they provide risk averse producers benefits with additional risk management that they would have received from the parastatal.

RESULTS

The international spot market price represented by the cotlook 'A' index was compared to parastatal pricing mechanism using the E-V (mean variance) model to determine the most profitable marketing channel for producers. The international market was not always the optimal marketing strategy selected by the E-V model, even though the international market offers a higher expected price, on average, than the parastatal over the period from 1976 to 2009 (Table 1). Risk neutral producers would have marketed a substantial majority of their production, 85%, in international markets over the 34-year period between 1976 and 2009, with the remaining 15% marketed to the parastatal (Table 1). Since risk neutral producers do not discount variance, in 15% of the years the parastatal market gave producers a higher price than they would have expected to receive on international markets, based on price expectations formed just prior to planting. Previous literature would not have found this result because they were too focused on the actual international spot price at post-harvest, rather than the more appropriate expected price just prior to planting (Baffes, 2005; Baffes et al., 2009; Baquedano et al., 2010). For risk neutral producers, however, the results found from the E-V model are generally consistent with previous studies that indicate producer welfare would be significantly increased if they had greater marketing autonomy.

Risk averse producers (γ>0), because of the uncertainty in forecasting prices between planting and harvest, would have more of an incentive to sell in the parastatal market, where price is guaranteed, than would risk neutral producers. In doing so, however, risk averse producers must trade-off a portion of their expected profit since the expected price of cotton on the international market typically is higher than the parastatal price (Figure 3).

With low risk aversion (γ=0.001) producers would have marketed 20% of their production with the parastatal and 80% on the international market (Table 1). At higher levels of risk aversion, producers would market a greater proportion of their production in the parastatal marketing channel, with its guaranteed price, than in the international market, where price variability can be significant (Table 1). Over the 34-year period, producers with modest risk aversion (γ=1) would have continued to sell an average of 92% of their production with the parastatal marketing system. Producers with a higher risk aversion parameter (γ=50) would continue to sell nearly all of their production, 99%, in the parastatal market (Table 1).

The E-V model thus suggests that international cotton market uncertainty could have been an influential factor on producer's decision making over the past few decades. The marketing decision was very sensitive to risk aversion, as even a slight change in risk aversion resulted in producers shifting a substantial portion of their cotton to the parastatal marketing channel. Hence, when risk is included in the analysis, the results of the E-V model are much less consistent with the literature since the parastatal marketing alternative provides greater economic benefit due to its price certainty.

Risk averse producers, by utilizing the parastatal market to reduce variability, accept lower expected income. The average expected profit of producers with risk aversion parameter of γ=1 was $294.21 ha^{-1} over the period of 1976 to 2009, which represents a 22% reduction compared to the average profit for the risk neutral producer which was $377.45 ha^{-1} over the same period (Table 1). For the more extreme risk averse producer (γ=50), the average expected profit was $282.09 ha^{-1} (Table 1), suggesting a 25% reduction compared to the risk neutral producer's expected profit.

The E-V trade-offs are summarized in the risk premium and certainty equivalent measures (Table 1). Modestly risk averse producers (γ=0.1) would give up only 11% ($37.40/$340.05) of their expected profit as risk premium to reduce variability (Table 1). As more risk averse producers are considered, the risk premium increases. For a highly risk averse producer (γ=50), for example, the risk premium is $95.36 ha^{-1} (Table 1). The highly risk averse producer would be willing to forgo 25% of their expected profit to reduce the standard deviation of profit by nearly 100%, from $70.18 ha^{-1} to $0.02 ha^{-1}(Table 1).

The risk premiums and E-V trade-offs found in this study are consistent with the results from other studies that risk averse producers would be willing to give up 25% of their expected profit to significantly reduce variability, which includes avoiding low and negative incomes (Ouatara et al., 1992; Patillo and Soderbom, 2000). Ouatara et al. (1992) found cocoa producers in Ivory Coast would be willing to accept a 26% loss in expected profit to reduce the profit variance by 11%. Patillo and Soderbom (2000) found a trade-off that was between 80 and 100% for extreme risk aversion in the manufacturing industries in Ghana. The risk premium were higher because by leaving the risky marketing channel in the international market, risk averse producers give up a substantial portion of their expected profit with international price that was high. In the present study, the profit reduction ranges between 5 and 25% and given the presence of guaranteed prices in the parastatal markets the variability of profit is reduced to zero at high levels of risk aversion.

The certainty equivalent measures the amount that a producer would pay to avoid having to face the uncertainty in the international market by marketing their cotton in the parastatal marketing channel, where the guaranteed prices provide certain market outcomes. With low risk aversion (γ=0.001), the certainty equivalent was the same compared to risk neutral producers (γ=0) because there was not a significant change in the proportion of the production that would have been sold on the international market when risk preferences change. For a modestly risk averse producer (γ=0.1), the certainty equivalent averaged $41.93 ha^{-1} over the period from 1976 to 2009 (Table 1). Extremely risk averse producers (γ=100), those who would have sold all their production on parastatal market, had a negative certainty equivalent (Table 1). This is interpreted as a benefit provided by the parastatal pricing to highly risk averse producers, who would have been willing to pay a higher amount to avoid selling on the international markets.

Because the use of parastatal marketing system was found to be much greater over the past decade, a deeper look was taken at different time periods. Four distinct periods are identified based on the study by Baffes (2007). Baffes (2007) identifies four distinct periods in West African cotton sector policy reforms and the difference between the international price and the domestic prices in the West and Central African region. For the periods of 1976 to 1984 and 1994 to 1997, the use of parastatal marketing would have been low except for highly risk averse producers, while for the periods of 1985 to 1993 and 1998 to 2009, the parastatal marketing system would have been utilized to a much higher extent than the previous periods, contrary to what the development literature has been reporting.

1976-1984 Period

The Burkina Faso parastatal cotton price was significantly lower (*P*=0.005) compared to the international spot price over the period of 1976 to 1984 (Figure 3). The parastatal cotton price represented, on average, only 47% of the expected international price of cotton in December, forecasted in May just prior to planting, $P_{Dec}|P_{May}$. The December forecasted international price variability was also modest in the 1976 to 1984 period, with a coefficient of variation of 15% (Figure 3). For all the 9 years, the expected international price in December ($P_{Dec}|P_{May}$) was at least one standard deviation above the parastatal price (Figure 3). Given the significantly higher price and correspondingly low variability, marketing cotton on the international markets was the best marketing channel over the period for both risk neutral (γ=0) and modestly risk averse producers (γ=0.1), which is both evident from the data and also confirmed by the E-V model (Table 2). Over the 9 years from 1976 through 1984, even if producers lose one standard deviation with the spot price, they would have higher price compared to the price offered by the parastatal company.

A risk neutral producer (γ=0) would have sold all of their cotton on the international cotton market in each of the 9 years since the expected international price in December ($P_{Dec}|P_{May}$) was always higher than the parastatal price (Figure 4a). The expected profit would have averaged $354.94 ha^{-1} over the 9 years for risk neutral (γ=0) producers (Table 2). Modestly risk averse producers (γ=0.001) also would have sold their cotton only on the international market, indicating that although there was variability in forecasting international prices, the variability (or STDEV) was not large enough to have any influence on their marketing decisions (Table 2). With identical marketing choices, modestly risk averse producers (γ=0.001) would have earned the same expected profit as risk neutral producers (γ=0), $354.94 ha^{-1} (Table 2). The highly risk averse producers would not have used the international markets even in this period of high international because of their extreme aversion to risk.

Over the 1976 to 1984 period, highly risk averse producers would have used the parastatal marketing in lower proportion compared to the 34-year period between 1976 and 2009 (Table 1). For example, producers with a risk aversion parameter γ = 0.1, would have sold 61% of

Table 2. Comparison between the international European spot market and the parastatal pricing system over the period 1976-1984.

γ	Parastatal pricing ratio*	International spot ratio*	Average profit** ($US.ha^{-1})	STDEV of profit ($US.ha^{-1})	Certainty equivalent*** ($US.ha^{-1})	Risk premium# ($US.ha^{-1})
0	0	1	354.94	56.07	184.93	-
0.001	0	1	354.94	56.07	184.93	0
0.1	0.1	0.9	346.90	49.14	184.93	8.04
1	0.7	0.3	221.34	8.10	-37.50	133.60
5	0.9	0.1	184.62	2.33	-129.68	170.33
50	0.99	0.0	171.02	0.10	-165.98	183.93
100	1.00	0.0	170.02	0	-168.00	184.93

*****The ratios are obtained through the E-V model using the data for the period between 1976 and 1984. **The profit is computed using the ratios, the prices of the two marketing channels and adding them. *** The certainty equivalent is equivalent to the profit that risk averse producer is willing to accept rather than a higher profit that is subject to risk. #The risk premium is the difference between the certainty equivalent and the profit of the risk neutral producer.

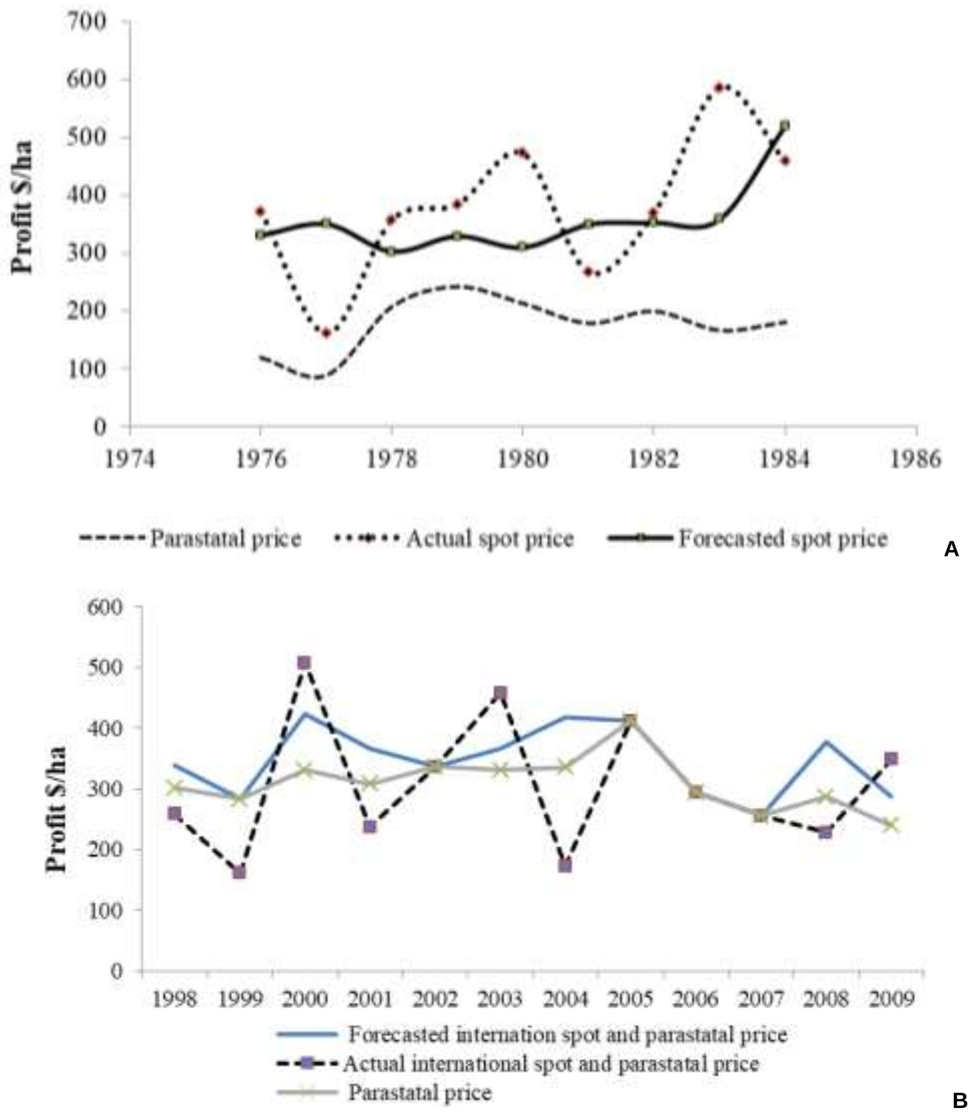

Figure 4. (A) Actual earnings for a risk neutral producer for 1976-1984 period. (B) Actual earnings for a risk neutral producer for 1998-2009 period. *The profit with the parastatal price is the actual profit for producers in Burkina Faso.

Table 3. Comparison between the international European spot market and the parastatal pricing system for the period between 1985 and 1993.

Γ	Parastatal Pricing ratio*	International Spot ratio*	Average profit** ($US.ha^{-1})	STDEV of profit ($US.ha^{-1})	Certainty equivalent*** ($US.ha^{-1})	Risk premium[#] ($US.ha^{-1})
0	0.10	0.90	468.87	103.23	126.44	-
0.001	0.21	0.79	468.83	93.00	126.90	0.04
0.1	0.70	0.30	421.72	39.16	115.97	47.15
1	0.96	0.0	351.22	4.15	-270.01	117.64
5	0.99	0.0	343.89	0.86	-327.54	124.98
50	1.00	0.0	341.93	0.00	-340.49	126.94
100	1.00	0.0	341.93	0.00	-341.21	126.94

*The ratios are obtained through the E-V model using the data for the period between 1976 and 1984. **The profit is computed using the ratios, the prices of the two marketing channels and adding them. *** The certainty equivalent is equivalent to the profit that risk averse producer is willing to accept rather than a higher profit that is subject to risk. [#]The risk premium is the difference between the certainty equivalent and the profit of the risk neutral producer.

their production, on average, for the longer period with the parastatal marketing system, whereas only 10% would have been marketed over the period 1976 to 1984 (Table 2). For the highly risk averse producers (γ=50), 99% of the production would have been sold on the parastatal marketing meaning that they would sell all their production with the parastatal marketing system.

The risk premiums were higher for the period 1976 through 1984 compared to the overall period, 1976-2009 (Tables 1 and 2). The risk premium was high, because by leaving the risky international market, risk averse producers give up a substantial portion of their expected profit with the international market price that was high over the 1976-1984 period. The certainty equivalent was also higher over the period of 1976 to 1984 compared to the period of 1976 to 2009 overall. The risk averse producer's certainty equivalent that was $87.41 ha^{-1} over the longer period was $184.93 ha^{-1} for the 1976 to 1984 period. The certainty equivalent of modestly risk averse producer (γ = 1) was $-37.49 ha^{-1} which is higher compared to $-226.78 ha^{-1} over the period 1976 to 2009. Highly risk averse producers (γ = 50) have a certainty equivalent of $-165.98 ha^{-1} compared to $-280.62 ha^{-1} over the longer period.

The E-V model results reveal that producers had been given greater marketing autonomy, the use of the international market would have had a positive effect on producers' profit between 1976 and 1984. The E-V model findings are consistent with the development literature, which has consistently argued that the international cotton price is poorly transmitted to smallholder producers by rent seeking parastatals. The risk neutral producer's profit would have increased by more than 100% on average over the 9-year period compared to the current marketing practices. The risk neutral producer would sell all their production on the international market over the 9-year period compared to 85% over the longer period from 1976 to 2009. The modestly risk averse producers (γ = 0.1) would have also increased their expected profit by 2.3% ($8.04) on average over this period. These producers would have sold all their production on the international market compared to only 39% over the longer period. However, the highly risk averse producers (γ = 100) would always use the parastatal marketing channel and therefore their expected profit is always the same compared to the actual marketing practices.

1985-1993 and 1993-1997 periods

From 1985 to 1993 the forecasted December international price was low proportionally to the parastatal price given the stable parastatal pricing during this period, resulting in a substantially better transmission of the international cotton price to producers (Figure 3). The parastatal price was 25% lower than the December international price forecasted at May ($P_{Dec}|P_{May}$) during the 1985 to 1993 period, a marked improvement for producers compared to the 1976 to 1984 period, when the parastatal price was 53% lower than the expected international price of December cotton ($P_{Dec}|P_{May}$). Producers profited during the period (1985-1993) with a relatively higher parastatal price offered by the parastatal cotton company. Risk neutral producers (γ=0) would have sold 10% of their production within the parastatal marketing system, with the remaining 90% sold on international markets (Table 3).

The period 1994 through 1997 had a price structure and price trend similar to the period from 1976 through 1984 (Figure 3). In each of the four years, the expected international price ($P_{Dec}|P_{May}$) was at least two standard deviations higher than the parastatal price and on average was 60% higher over the four-year period (Figure 3). The variability associated with the expected international price, as it transitions from planting to post-

Table 4. Comparison between the international European spot market and the parastatal pricing system for the period between 1994 and 1997.

Γ	Parastatal pricing ratio*	International spot ratio*	Average profit** ($US.ha^{-1})	STDEV of profit ($US.ha^{-1})	Certainty equivalent*** ($US.ha^{-1})	Risk premium# ($US.ha^{-1})
0	0	1	390.06	45.40	133.33	-
0.001	0	1	390.06	45.40	133.33	0.00
0.1	0.68	0.33	308.68	13.54	102.80	81.38
1	0.97	0.03	262.07	1.35	-220.77	127.99
5	0.99	0.01	257.92	0.32	-249.53	132.14
50	1	0	256.73	0	-256.01	133.33
100	1	0	256.73	0	-256.37	133.33

*The ratios are obtained through the E-V model using the data for the period between 1976 and 1984. **The profit is computed using the ratios, the prices of the two marketing channels and adding them. *** The certainty equivalent is equivalent to the profit that risk averse producer is willing to accept rather than a higher profit that is subject to risk. #The risk premium is the difference between the certainty equivalent and the profit of the risk neutral producer.

Table 5. Comparison between the International European spot market and the parastatal pricing system from 1998 to 2009.

γ	Parastatal Pricing ratio*	International Spot ratio*	Average profit** ($US.ha^{-1})	STDEV of profit ($US.ha^{-1})	Certainty equivalent ($US.ha^{-1})***	Risk premium# ($US.ha^{-1})
0	0.33	0.67	346.70	33.85	20.4	-
0.001	0.41	0.59	346.70	30.76	37.0	0.00
0.1	0.92	0.08	315.60	4.33	-60.9	31.20
1	0.99	0.01	310.30	0.44	-284.8	36.40
5	1	0	309.70	0	-304.75	37.00
50	1	0	309.70	0	-309.23	37.00
100	1	0	309.70	0	-309.48	37.00

*The ratios are obtained through the E-V model using the data for the period between 1976 and 1984. **The profit is computed using the ratios, the prices of the two marketing channels and adding them. *** The certainty equivalent is equivalent to the profit that risk averse producer is willing to accept rather than a higher profit that is subject to risk. #The risk premium is the difference between the certainty equivalent and the profit of the risk neutral producer.

harvest, was low compared to the other periods, with a coefficient of variation 15% (Figure 3). The risk neutral producers (γ=0) and producers with low risk aversion (γ = 0.001) would have sold all of their production on the international market (Table 4).

1998-2009 period

The period between 1998 and 2009 is another period of low international prices, similar to the period of 1995 and 1993 period. The parastatal price was higher than the forecasted international spot price in four years over the period, that is, in one year out of three the parastatal price was actually higher than the expected international cotton price ($P_{Dec}|P_{May}$). During this most recent period, risk neutral producers (γ=0) would have continued to sell 33% of their production with the parastatal cotton companies compared to 15% over the longer period from 1976 to 2009 (Table 5). The expected profit of risk neutral producers was \$346.70 ha^{-1} with a standard deviation of \$33.85 ha^{-1} (Table 5). For the period from 1976 to 1984 also all the risk neutral producers production would have been sold on the international market. From 1985 to 1993, the fraction was 90% and all production would have been sold on international market for the period from 1994 to 1997. For low risk aversion (γ= 0.001) 41% of the production would have been sold on the parastatal market and 59% on the international markets if producers had the opportunity to market as they wish. The low risk averse producers would have the same expected profit as the risk neutral producers. Modestly risk averse producers (γ=1) would have sold almost all of their production on the parastatal marketing system and would have earned an expected profit of \$310.30 ha^{-1} with a standard deviation of \$0.44 ha^{-1}. Their risk premium is \$36.40 ha^{-1}. The expected profit of highly risk averse producers (γ=50), who would have sold all (100%) of their production with the parastatal, was \$309.70 ha^{-1}, which is 11% lower than the expected profit of risk neutral (γ=0) producer (Table 5). The profit of highly risk averse producers (γ=50) is risk free because its standard

Table 6. Actual and expected profit for risk neutral producer ($US/ha**)**.

Year	Forecasted spot price* combination	Actual spot price** combination	Parastatal price only	Actual international spot only
1998	338.14	258.33	301.73	258.33
1999	283.03	160.63	282.81	160.63
2000	423.71	507.93	331.18	507.93
2001	366.18	237.01	308.47	237.01
2002	336.59	336.59	336.59	466.24
2003	367.17	457.87	330.60	457.88
2004	418.26	173.30	335.81	173.30
2005	412.32	412.32	412.32	273.16
2006	294.63	294.63	294.63	247.17
2007	255.46	255.46	255.46	296.18
2008	378.01	228.07	286.82	228.07
2009	287.30	348.19	240.26	348.19
Average	346.73	305.86	309.72	304.51
STDEV	57.15	109.71	44.86	115.90

*The forecasted spot price is combined with the parastatal market using the proportion suggested by the E-V model. ** The actual spot price is combined with the parastatal market using the proportion suggested by the E-V model.

deviation is zero. The certainly equivalent of highly risk averse producer is $-309.23 ha^{-1} and the risk premium is $37 ha^{-1} (Table 5). Compared to the parastatal pricing system, the increase of the expected profit, with the combination of the international and parastatal market, was only 11% for risk neutral (γ=0) producers (Table 5).

The 1998 to 2009 period was a period of progressive decline in the international cotton price. The parastatal companies often fell into financial distress during this period, particularly as the increased bargaining power of the producers pushed up the price, they were obligated to pay producers even when the international price collapsed. Over the last twelve years, if producers had implemented the E-V model's results, risk neutral producers (γ=0) would have earned lower profit on the international market compared to the profit from the parastatal. For four years, risk neutral producers (γ=0) would have the same profit in both the international and parastatal marketing channels, and they would have had higher profit only in three of the twelve years (Table 5). The risk averse producers (γ>0) who used combinations of the two marketing channels yet would have made approximately the same level of profit as they would if they had remained only in the parastatal channel (Table 5).

The most recent period is perhaps the most illustrative example of how the prevailing view of parastatal pricing should be reconsidered. It was the only period when both the risk neutral and risk averse producers would have benefitted more from the parastatal than the international markets. The expected international price of cotton in December was not significantly different (P>0.05) than the parastatal price, resulting in risk averse producers preferring the parastatal market in most of the years, while in other years when cotton was sold on international markets the profit difference was not significantly different than it would have been through marketing with the parastatal. Risk averse producers have even greater incentives to use the parastatal markets given the high level of variability during this period.

Actual price outcomes

Table 6 presents a comparison between the E_V model's marketing choices for risk neutral producers, based on the forecasted international cotton price ($P_{Dec}|P_{May}$), with the actual international price in December, over the period of 1998 to 2009. The comparison shows that the planting-to-post harvest price forecasts ($P_{Dec}|P_{May}$) would often have been overly optimistic over the last twelve years (Figure 4b). In most of the years, the forecasts were for higher price movements between planting and post-harvest than actually occurred (Figure 4b). For three of the twelve years, 2000, 2003, and 2009, the actual spot price was higher than the forecasted spot price (Figure 4b). On 4 years, the price is exactly equal and in the remaining 5 years, the actual spot price was lower than the forecasted spot price (Figure 4b).

The forecasted profit was equal to the profit with the parastatal price in four out of the twelve years (Figure 4b). The years in which the forecasted profit is the same as the parastatal profit are the years for which the risk neutral producers would sell all the production with the parastatal pricing system, these years are 1999, 2002, 2005, and 2007 (Figure 4b). Over the period of 998 to

2009, the average profit with the actual spot price was \$305.86 ha^{-1} with a standard deviation of \$109.71 ha^{-1}. The average profit with the parastatal price was \$309.72 ha^{-1} with a standard deviation of \$44.86 ha^{-1} (Table 6). The E-V model clearly suggests that there is a positive economic value in the guaranteed parastatal price over the last decade, providing a greater benefit to producers than in any of the other periods. Because the forecast procedure overestimates the spot price, the expected profit with the combination of the forecasted spot price and the parastatal price was higher than the expected profit with the combination of the actual price and the parastatal price (Table 6). With the forecasted international price ($P_{Dec}|P_{May}$), the average annual expected profit over the last 12-year period was \$346.73 ha^{-1} (Table 6) for the risk neutral producers. The standard deviation of the expected profit was around \$57.15. The profit with the combination of actual spot and parastatal price was lower (\$305.86ha^{-1}) for risk neutral producers (γ=0) compared to risk averse producers (γ>0), \$309.72 ha^{-1} (Table 6). The reason why the risk neutral producer had lower actual profit is because the price expectations were too high, resulting in a marketing ratio, from the E-V model, that sold too much cotton on the international market (Table 6).

DISCUSSION

If cotton producers had been granted the opportunity to sell their production with the international spot market as recommended by previous studies; over the past few decades, they would have earned higher expected profit only in certain periods (Baffes et al., 2009; Baquedano et al., 2010). Previous studies in the development literature have not considered the risk associated with the uncertainty from selling cotton on international markets as prices trend between planting and post-harvest. This study provides suggestive evidence that previous claims against parastatal pricing, and concerns over the equity of parastatal pricing, could be overstated when risk is included. Because the international price incurs risk, the parastatal market would often have provided risk averse producers with a marketing alternative to better manage risk. In addition, there were several years in which the parastatal price offered to producers prior to planting was equal or higher than the expected price of cotton on international markets over the last few decades.

Risk neutral producers would have benefitted from market liberalization, particularly during the periods of high international cotton prices, 1976-1984 and 1994-1997. This finding is consistent with the previous literature, which by ignoring risk implicitly limited their scope to risk neutral producers. Risk averse producers have profited the most from the parastatal pricing that has been in place over the past few decades, 1976-2009. Large risk premiums were found by our E-V model, indicating that international cotton markets contain substantial variability, as price trends from planting to post harvest are highly uncertain. Risk averse producers would have been willing to accept a lower price in the parastatal market, with its guaranteed price, rather than sell their cotton in international markets. However, the present study found that in other periods such as the period between 1998 and 2009, the actual profit of risk neutral producers with the expected spot price at planting, is often lower than the profit with the parastatal pricing system.

For the last 12 years in the present study, 1998 to 2009, international cotton prices were low compared to their historic levels, but also contained significant variability. Those trends are expected to continue, as subsidies from developed countries, notably the U.S but the European Union countries, and increased production from Asia and Africa, are likely to impact markets in unpredictable ways (Baffes, 2005). Over the last twelve years, with the low and highly variable prices the parastatal price was, in general, as good as the international spot price, largely due to the price stabilization effect. The parastatal price isolates producers from the international price variability, so policy makers should expect to plan based primarily on the outcomes from the more recent period of 1998 to 2009, rather than the previous periods when there was less need for price stabilization.

The benefits of the parastatal would likely have been higher if the co-benefits of the parastatal marketing system had been included in the E-V model. Throughout the analysis period of 1976 to 2009, parastatal cotton companies provided producers with access to new technology, extension services, credit for input, and invested in rural infrastructure including roads, water, and electricity. While it was beyond the purpose of this paper to quantify those benefits, policies to shift producers away from parastatal control must include careful consideration of how those services would be delivered to producers under more liberalized conditions. It is not clear that parastatal could be justified on their own merits or even as necessary, but evidence from other countries have shown that the private sector has had difficulty in developing the necessary markets for delivering adequate processing, access to new technology, and extension services (Poulton and Wilbald, 2007).

Over the 34 year period from 1976 to 2009, the cotton companies' annual rent averaged around \$21 million representing the producer's surplus. Normally, the surplus should be invested in rural areas. However, the cotton companies do not have transparent plan to redistribute the surplus in rural areas on an on-going basis. Most of the investments have been largely self-serving, e.g. providing roads, electricity and water to facilitate the movement and ginning of cotton that has left non-producing cotton area severely lagging. The lack of equitable rent distribution through investments is the reason why critics have voiced concerns over how the parastatals have managed cotton’s economic surplus.

Conclusion

The present study investigated the potential benefit of two marketing channels for cotton producers in Burkina Faso in face of international price uncertainty. Historical cotton price data over the 34-year period between 1976 and 2009 are used in the present study. An E-V model was specified with a quadratic utility function to approximate producer’s expected utility of income. The single equation and single constraint model was based on a producer decision variable that allocates cotton production in a marketing scenario where producers are given the opportunity to sell cotton to either the existing parastatal company or on international markets. The combination of different marketing channels was used to show the upper limit of the theoretical marketing possibilities.

Our result suggests that, contrary to the conventional wisdom in the development literature, the parastatal pricing system was often a preferred marketing channel compared to international markets. During the periods of high international cotton price, the spot market is the best marketing channel to be used by producers, even though spot market price incurs risk. The periods over which the spot marketing was better than the parastatal pricing system are the period between 1976 and 1984 and the period from 1994 to 1997. For the periods between 1985 and 1993 and 1998 and 2009, the international cotton price was low. Because of the magnitude of the difference between the two prices and due to the fact that spot price was subject to variability, the parastatal pricing system was better than the spot market for risk averse producers.

The results of the present study suggest that policy makers should consider maintaining for producers some type of guaranteed pricing mechanism that could be combined with the opportunity to market cotton on international markets. The guaranteed price could be provided by either parastatal cotton companies or perhaps through producer’s associations. Another alternative would be a guaranteed fund administered through the Ministry of Agriculture, similar to U.S and European farmer support programs. Other price stabilization policies, such as price insurance mechanism or more traditional alternatives such as futures and options may also provide alternative price support system for the cotton sector in Burkina Faso.

While shifting to a policy that encourages cotton producers to operate independently on the international markets may be difficult because of the complexity and competitiveness of international markets, there is evidence that producers in sub-Saharan Africa can be successful in penetrating international markets. West African cotton producers could follow the model of fish and ornamental flowers producers in Kenya, where small holders have been successful in selling their production on the very competitive European markets. One way to do so might be to start by educating producers’ organizations on the requirements of the international market mechanism (Nyangweso and Odhianbo, 2004).

Cotton has often been one of the most important cash crops in developing economies, providing needed export earnings that can be used to generate economic growth in industrial and service sectors. The recent “cotton problem” and depressed world prices has plagued West African cotton producers and left them at a crossroads, deciding whether incentives are adequate to invest in new technology to improve productivity. This is a critical decision since yields are an equally important determinant of profits as price. During 34 years in our study periods, cotton yields have fluctuated without showing any long-run upward trend. The highest yield was 574 kg per hectare in 1986, followed by 494 kg in 1997, after which yields have primarily decreased while cotton prices in real terms have fallen. In Burkina Faso, genetically modified (GM) cotton has already illustrated how introducing modern technology can increase yields by reducing insect damage. Further productivity gains can be achieved by introducing “stacked” GM varieties that are herbicide tolerant. Granting cotton producers higher farm-gate prices will enable producers to invest in new technology such as Bt cotton. With improved pest management, producers would likely make greater investments in fertilizers and other crop amendments, including herbicides, insecticides, and lime.

Another technological advancement that would be beneficial to the West African cotton sector is mechanization, which would significantly increase labor productivity. At the aggregate level, West African cotton sectors made successful investments in the 1970’s and 1980’s when animal traction, along with improved varieties, were introduced and quickly diffused. This enabled farmers to expand acreage and improve land and labor efficiency that fostered a successful cotton-cereal rotation that improved food security. Those gains have plateaued and a new labor paradigm has emerged. Rural labor is continually being pulled into urban areas. Today’s millennial generation, with greater access to urban areas, is less likely to stay on-farm earning agricultural wages of US$2 per day, especially when confronted by labor-intensive activities like cotton picking and hand weeding. Greater use of mechanical power, even based on small 25 HP tractors, is expected to be an alternative that will be increasingly used on Burkinabe cotton farms. Mechanization could also be combined with complementary investments in irrigation infrastructure that would further improve cotton productivity and continue to close the yield gap with more developed countries. The southwest production zone of Burkina Faso in particular contains possibilities for improved water management and irrigation.

Technological advancement of the industry would also benefit from significant investments in human capital and research institutions. These investments would strengthen the sector's productive capacity and meet the challenges it faces over the coming decades by fostering technological breakthroughs to cut production costs and improve labor productivity. To achieve these goals, a well-educated and trained corps of agricultural scientists to prescribe agronomic and entomologic treatments is needed. In this context, particular emphasis should be placed on Burkinabe scientists attaining advanced degrees needed to develop GM crops, which will require developing and monitoring phytosanitary and biosafety protocols and other legal statutes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Growth of moringa (*Moringa oleifera*) seedlings in calcareous, clayey and sandy soils relative to loamy soil

Phatu W. Mashela

Green Biotechnologies Research Centre of Excellence, University of Limpopo, Private Bag X1106, Sovenga 0727, South Africa.

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Calcareous soil, comprising more than 15% $CaCO_3$, which imposes various physical and chemical challenges to plants, is widespread in arid and semi-arid regions. It was against the stated backdrop that an experiment was carried out to compare growth responses of moringa (*Moringa oleifera* Lam.) seedlings in calcareous, clayey and sandy soils relative to those in loamy soil during autumn (January-March) 2015 and validated in 2016. Treatments comprised loamy, calcareous, clayey and sandy soils, arranged in randomised complete block design, with 15 replications. Each soil type was steam-pasteurised, with hardened-off six-week-old seedlings transplanted in 10 L plastic bags containing 9.8 L soil for each. At 90 days after transplanting, treatments had significantly ($p \leq 0.05$) affected growth variables of *M. oleifera* seedlings. Relative to loam soil, calcareous soil reduced dry shoot mass (33%), chlorophyll content (36%) and dry root mass (47%), but increased root length (28%). In contrast, clay increased dry shoot mass (66%), leaf number (25%) and root length (26%), whereas sandy soil increased dry shoot mass (42%) and reduced dry root mass (51%). In conclusion, relative to loam soil, marginal soils such as calcareous, clayey and sandy soils had effects on growth of *M. oleifera* seedlings that included physical and chemical attributes of the soil types.

Key words: Calcareous soil, marginal soil, *Moringa* species, soil pH, soil texture, soil type.

INTRODUCTION

Moringa (*Moringa oleifera* Lam.) tree, dubbed the “miracle tree” (Fuglie, 2001), due to its social, economic, environmental, nutritional and medicinal versatilities, is being adopted at the fastest rate as a cultigen (Mridha, 2015). *M. oleifera* projects in marginal communities are being established on marginal soils such as heavy clay, infertile sandy, sodic and calcareous soils (Foidl et al., 2001). Although soil depth is the most limiting descriptor of marginal soils, physical, chemical and biological features impose serious limitations on crop production

E-mail: phatu.mashela@ul.ac.za. Tel: (015) 268 2190. Fax: (015) 268 2892.

(FAO, 1973). Loam soil is an ideal soil type for *M. oleifera* husbandry (Ramachanran et al., 1980; Bezerra et al., 2004). However, others claimed that the species was well-adapted to a wide range of soil types (Mridha, 2015). The genus *Moringa*, with thirteen species (Leone et al., 2015), had *Moringa drouhardii* as being the only species that originated in Madagascar Province on calcareous soils (Leone et al., 2015), with *M. oleifera* being grown widely in marginal communities.

Clayey soils have good attributes in terms of retention of essential nutrients and moisture, but could affect plant growth through its high resistance to movement and waterlogging (Brady and Weil, 2009). Empirical evidence suggested that *M. olefeira* could excel in clay and sand (Pahla et al., 2013) and sodic (Hegazi, 2015) soils, without limited information for calcareous soil. The latter is defined as soil with $CaCO_3$ greater than 15%, which could exist in various forms (FAO, 1973). Globally, calcareous soil is widely distributed in arid and semi-arid regions (FAO, 1973) and could impose challenges in crop husbandry due to its high $CaCO_3$, which limits and promotes the availability of certain nutrient elements (FAO, 1973; Kabata-Pendias, 2010).

Soil type studies on *M. oleifera* had been limited to sodic soil (Hegazi, 2015), sand and clay soils (Pahla et al., 2013; Hegazi, 2015), with evidence that the crop is tolerant to these marginal conditions. Although calcareous soil is widely distributed in marginal communities where *M. oleifera* is widely adopted for food security, job creation and wealth generation, there is hardly any evidence that the influence of this soil on growth of *M. oleifera* had previously been tested. The objective of this study was to determine the relative effects of calcareous, clay and sandy soils on growth of *M. oleifera* in comparison with effects of loam soil.

MATERIALS AND METHODS

Study location and preparation of materials

The experiment was conducted in the greenhouse at the Green Biotechnologies Research Centre of Excellence, University of Limpopo, South Africa (23°53'10"S, 29°44'15"E) during autumn (January-March) 2015 and validated in 2016. Ambient maximum/minimum temperature averaged 28/22°C, with day temperature controlled using thermostatically-activated fans. Loam, clay and calcareous soils were collected at the Centre, Madisha-Ditoro town (29°42'20"S, 30°56'32"E) and Moletlane (24°20'59"S, 29°19'14"E) town. The soil pH [1:2 soil and water (v/v) ratio] and particle size were quantified using Thomas (1996) and Bouyoucos (1962) methods, respectively. Due to calcareous soil-related challenges in quantifying soil particle size (FAO, 1973), the variable was not quantified.

Seedlings were raised in 160-hole seedling trays using Hygromix-T (Hygrotec, Pretoria) and hardened-off for a week prior to replanting. At three-leaf stage, seedlings were hardened-off outside the greenhouse through intermittent withholding of irrigation water. Four soil types were each steam-pasteurised at 300°C for 2 h, 10 L plastic bags were potted with 9.8 L soil of each soil type and placed on the greenhouse benches at 0.2 m inter-row and 0.2 m intra-row spacing. Uniform six-week-old seedlings of *M. oleifera* were transplanted, with the soil type arranged in a randomised complete block design, with 15 replications.

Cultural practices

At transplanting, the topsoil of each pot was amended once with 5 g 2:1:2 (43) Multifeed fertiliser to provide a total of 0.88 mg N, 0.88 mg K, 0.40 mg P, 2.25 mg Mg, 1.88 mg Fe, 0.19 mg Cu, 0.88 mg Zn, 2.5 mg B, 7.50 mg Mn and 0.18 mg Mo per ml water. Transplants were irrigated to field capacity at transplanting and then with 250 ml tap water every other third day until the sixth week. Thereafter, transplants were irrigated with 350 ml tap water until harvest.

Data collection

At 90 days after initiating the treatments, plant height was measured from the soil surface to the tip of the flag leaf. Chlorophyll content was measured using a digital chlorophyll meter (SPAD) on the third mature leaf below the flag leaf, with leaf number per plant being recorded. Shoots were severed at the soil surface and the stem diameters were measured at 5 cm above the severed ends using a digital Vernier caliper (Model: DC-515). Roots were removed from the plastic containers, washed with running water to remove soil particles and root length was measured. Shoots and roots were dried in air-forced ovens at 70°C for 72 h and weighed.

Data analysis

Data were subjected to analysis of variance (ANOVA) through the SAS software. Leaf number data were transformed [$\log_{10}(x + 1)$] prior to ANOVA to homogenise the variances (Gomez and Gomez, 1984), but untransformed data were discussed. Mean separation for significant treatment effects was achieved through Fisher's least significant difference test at the probability level of 5%. Unless stated otherwise, the discussed treatments were significant at the probability level of 5%.

RESULTS

Seasonal effects on variables were assessed and because there were no seasonal interactions, the data were pooled (n = 120). Soil pH (H_2O) in loam was less than 6 units, whereas in other soils, it was above 8 units, with distinct (except for calcareous soil) particle sizes (Table 1). Soil type had highly significant ($p \leq 0.01$) effects on dry shoot mass, leaf number, chlorophyll content, dry root mass and root length, but had no significant effects on plant height and stem diameter (data not shown). Dry shoot mass of plants grown on clay and sandy soils were not different, but were significantly higher than for those on loam and calcareous soil (Table 2).

Relative to loam, calcareous soil reduced dry shoot mass, chlorophyll content and dry root mass by 33, 36 and 47%, respectively, but increased root length (Table 2). Relative to loam soil, clay soil increased dry shoot mass, leaf number and root length by 66, 25 and 26%, respectively (Table 2). In contrast, sandy soils increased

Table 1. Soil pH and particle size of the four soil types used to assess growth of moringa seedlings.

Soil type	Soil pH		Particle distribution (%)		
	pH (H_2O)	pH (KCl)	Clay	Sand	Silt
Loam	5.69	4.57	48	38	22
Calcareous	8.19	7.98	–	–	–
Clay	8.60	7.43	56	23	23
Sand	8.47	7.64	8.8	86	5.2

Table 2. Relative impact (R.I.) of dry shoot mass, plant height, leaf number, chlorophyll content, dry root mass and root length on *M. oleifera* seedlings raised in clayey, calcareous and sandy soils relative to those in loamy soil (n = 120).

Soil type	Dry shoot mass (g)^{y}		Leaf no. (g)		Chlorophyll content		Dry root mass (g)		Root length (cm)	
	Variable	R.I.^{z}	Variable	R.I.	Variable	R.I.	Variable	R.I.	Variable	R.I.
Loam	$1.09^{b} \pm 0.11$	_	$14.93^{b} \pm 0.57$	_	$44.68^{a} \pm 3.18$	_	$0.76^{a} \pm 0.14^{x}$	_	$87.60^{b} \pm 6.32$	_
Calcareous	$0.73^{b} \pm 0.19$	–33	$14.20^{b} \pm 0.59$	–5	$28.59^{b} \pm 1.93$	–36	$0.40^{b} \pm 0.19$	–47	$111.72^{a} \pm 5.56$	28
Clay	$1.81^{a} \pm 0.26$	66	$18.67^{a} \pm 0.55$	25	$38.45^{a} \pm 1.65$	–14	$0.93^{a} \pm 0.24$	22	$110.65^{a} \pm 5.43$	26
Sand	$1.55^{a} \pm 0.21$	42	$14.33^{b} \pm 1.37$	–1	$44.29^{a} \pm 4.75$	–1	$0.37^{b} \pm 0.17$	–51	$99.33^{ab} \pm 6.24$	13
Cv (%)	20.49		19.14		30.42		10.16		22.57	

^{x}Column means ± SE followed by the same letter were not different ($p \leq 0.05$) according to Fisher's least significant different test. ^{z}Relative impact (%) = [(treatment/control) – 1] × 100.

dry shoot mass by 42% (Table 2) and reduced dry root mass by 51% (Table 2).

DISCUSSION

Effects of calcareous soils

Loam soil, due to its optimal role in soil health (chemical, physical and biological), attributes relative to other soil types (Marschner, 1995) was selected for use as a standard. The reduction of dry shoot mass and dry root mass on *M. oleifera* seedlings in calcareous soils had limited comparative empirically-based studies. In contrast, the significant reduction in chlorophyll content in plants grown in calcareous soil relative to loam soil, suggested that in the long-term, calcareous-grown seedlings would experience photosynthetically active radiation-related challenges as observed in most calcareous soils (Obreza et al., 2015) and salt-affected soils as previously observed on *M. oleifera* seedlings (Hegazi, 2015).

The observed reduction in growth of *M. oleifera* seedlings in calcareous soil was in agreement with the high soil pH, which could result in N, P, Fe, Mn and Cu being in unavailable forms, whereas K, S, Ca, Mg and Mo could occur in luxurious to phytotoxic concentrations (Marschner, 1995; Obreza et al., 2015). The reduction in plant growth variables of *M. oleifera* in calcareous soil could be associated with the imbalances of essential nutrient elements as had been observed on most other plant species in similar soils (Obreza et al., 2015).

Although, it could not be justified to linkup one particular nutrient element to the observed growth responses in this study, it is probable that such ionic imbalances in calcareous soils, along with poor soil aggregates, contributed negatively to plant growth as observed on other crops (FAO, 1973). Magnesium and N for instance, are part of the constituents of chlorophyll molecules and calcareous soils are generally low in the two elements (Obreza et al., 2015).

Increased root length in *M. oleifera* seedlings on calcareous soil in the current study confirmed root growth in other plant species exposed to excessively high Ca ions. Among numerous physiological activities in plants, Ca is associated with mitosis and therefore, cell growth (Hepler, 2005) and by extrapolation, Ca is associated with root elongation. In calcareous soils, despite challenges that reduced most plant growth variables, the observed increase in root length could be associated with the luxurious availability of Ca for cell division in such soils (McMahon et al., 2005).

Effects of clay soil

In contrast to calcareous soil, relative to loam soil in the current study, clay soil increased dry shoot mass, leaf number and root length in *M. oleifera* seedlings. The findings confirmed observations where *M. oleifera* seedlings in clay soil had the highest total plant dry matter (Hegazi, 2015; Pahla et al., 2013). Clay soil is renowned for its excellent cation exchange and water-holding capacities, which under best agricultural practices are known to improve plant growth. In the current study, clay soil improved leaf number, which confirmed observations that dry leaf mass on plants grown in clay soil were significantly higher than of those in sandy soil (Hegazi, 2015). Generally, the decreasing effect on aboveground growth of *M. oleifera* growing on clay was reversed when the soil was amended with cattle manure (Pahla et al., 2013).

Effects of sandy soil

In the current study, sandy soils increased (42%) dry shoot mass, which confirmed other observations where *M. oleifera* seedlings in sandy soil had the highest total plant dry matter (Heiga, 2015; Pahla et al., 2013). The significant reduction of dry root mass on *M. oleifera* seedlings in sandy soil in this study confirmed observations where the variable was the lowest in sandy soils (Pahla et al., 2013; Hegazi, 2015). In *M. oleifera* production, amendment of marginal soils with extreme particle sizes (clay or sand) was managed using organic matter (Pahla et al., 2013) or inorganic fertilisers (Dania et al., 2014). However, challenges imposed by calcareous soil in relation to high $CaCO_3$ had been rather difficult to manage in crop husbandry (Obreza et al., 2015).

Conclusions

Findings in the current study demonstrated that the marginal soils such as calcareous, clayey and sandy soils had both negative and positive attributes on growth of *M. oleifera* seedlings. Relative to loam soil, calcareous soil reduced dry shoot mass, chlorophyll content and dry root mass, but increased root length. In contrast, clay increased dry shoot mass, leaf number and root length; whereas sandy soils increased dry shoot mass, but reduced dry root mass. In conclusion, relative to loam soil, effects of calcareous, clayey and sandy soils on growth of *M. oleifera* seedlings could be driven by the chemical and physical properties of the test soil types.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

In vitro study on the role of the tannins of *Newbouldia laevis and Zanthoxylum zanthoxyloides* on infective larvae of *Trichostrongylus colubriformis*

P. A. Olounladé[1,2,4,6]*, E. V. B. Azando[1,3,4], E. Y. Attakpa[1,3], J. D. Gbenou[5], G. G. Alowanou[1], E. Tchétan[1,4], C. C. Dansou[2,4], M. S. Hounzangbé-Adoté[1], F. Gbaguidi[5], M. Moudachirou[5], H. Hoste[7] and A. Valentin[6]

[1]Laboratoire d'Ethnopharmacologie et de Santé Animale (LESA), Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, 01 BP 526 Cotonou, Bénin.
[2]Laboratoire Pluridisciplinaires, Ecole de Gestion et d'Exploitation des Systèmes d'Elevage, Université Nationale d'Agriculture de Kétou, 01 BP55 Porto-Novo, Bénin.
3Faculté d'Agronomie, Université de Parakou, BP 123 Parakou, Benin.
[4]Laboratoire de Biotechnologie et d'Amélioration Animale (LBAA), Faculté des Sciences Agronomiques, Institut des Sciences Biomédicales Appliquées (ISBA), Université d'Abomey-Calavi, 01 BP 526 Cotonou, Bénin.
[5]Laboratoire de Pharmacognosie et des Huiles essentielles, Faculté des Sciences et Techniques, Université d'Abomey-Calavi, 01 BP 526 Cotonou, Bénin.
[6]Pharma-Dev -UMR 152 / Faculté de Pharmacie, Université de Toulouse III, 35 Chemin des Maraîchers, 31062 Toulouse, Cedex 9 France.
[7]INRA, UMR 1225 Interactions Hôte Agents Pathogènes 23, Chemin des Capelles, F-31076 Toulouse, France.

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Trichostrongylus colubriformis **is an important cause of parasitic gastroenteritis in small ruminants which causes diarrhea, weakness, loss of production and death. The *in vitro* efficacy of tannins of *Newbouldia laevis* and *Zanthoxylum zanthoxyloides* was determined against this parasitic nematode. Larvae of *T. colubriformis* were incubated at 23°C in the leaf extracts of *N. laevis* and *Z. zanthoxyloides* at concentrations of 150, 300, 600 and 1200 µg ml^{-1} for three hours, respectively. Phosphate buffered saline (PBS) was used as negative controls. Inhibition of larval migration was significantly ($P < 0.05$) observed with increasing concentrations of the extracts. In the range of concentration examined, the results were dose-dependent for *N. laevis* but not for *Z. zanthoxyloides.* The addition of Polyvinyl polypyrrolidone (PVPP) inhibited total or part of the anthelmintic effect. These results suggest that the larval migration is at least in part due to the action of tannins and supports the traditional use of *N. laevis* and *Z. zanthoxyloides* against parasites nematodes. Further research is required to isolate and structurally identify the active anthelmintic compounds, and to improve methods of plant extraction of the effective anthelmintic components that will be readily adaptable for use by rural communities against helminthiasis.**

Key words: Larval migration, tannins, *Trichostrongylus colubriformis*, *Newbouldia laevis*, *Zanthoxylum zanthoxyloides,* Benin.

INTRODUCTION

Gastrointestinal nematodes remain a major constraint to economic productivity of livestock throughout the world, being the chief parasitoses responsible for disease-related production losses arising from stock mortality, severe weight loss and poor production, especially in small ruminants (Chiejina, 2001; Bizimenyera et al., 2006). *Trichostrongylus colubriformis*, an intestinal nematode, is one of the most important causes of parasitic enteritis causing protracted diarrhoea, weakness, loss of production and death (Bizimenyera et al., 2006).

In the last 30 years, control of gastrointestinal nematode infections of ruminants has been achieved almost exclusively by use of pharmaceutically derived anthelmintic. Indeed, synthetic and semi-synthetically produced anthelmintics have for long been considered the only effective method of controlling helminthoses (Bizimenyera et al., 2006). However, in the extreme situations of subsistence farming where anthelmintic is either unavailable or unaffordable, massive mortalities of young stock are commonplace in tropical Africa and Asia (Bizimenyera et al., 2006). At the other extreme, misuse and or widespread intensive use of sometimes poor quality synthetic or semi-synthetic anthelmintic has led to the development of a high level multiple anthelmintic resistances that may lead to failure of control of worm parasites in ruminants (Wolstenholme et al., 2004; Bizimenyera et al., 2006). These constraints indicate that total reliance on pharmaceutically derived anthelmintic may present difficulties in the management of gastrointestinal parasitic infections in livestock, necessitating alternative methods of helminth control (Sanyal, 2001; Bizimenyera et al., 2006).

In Benin, the breeding of livestock is an economically important activity and is responsible for sources of jobs and income and contributes to 4 to 6% of the gross domestic product. Besides prestige and savings functions, breeding animals contribute to increasing the income of the breeders through on one hand, the sale of animals and their by-products and on the other hand, through the use of the fertilizer for the fertilization of farms. However, this breeding is confronted with numerous constraints: the high cost of medicines, state of financial fragility of the producers, disturbing appearance of crossed resistances in the modern molecules, the lack of sanitary frame of the breeders and the traditional system of the managements of the herds. Among the constraints, animal health is a limitation to animal production. The levying of these constraints requires the implementation of the efficient practices and the use of available endogenous resources. Among these resources are a number of plants which are believed to have bioactive properties and which are readily available at relatively low cost.

In recent times, there has been an increasing interest in ethnomedical and ethnoveterinary practices across the world, especially as it relates to the use of medicinal plants in treating various ailments (Bizimenyera et al., 2006). Use of indigenous plants preparations as livestock dewormers is gaining ground as one of the alternative and sustainable methods readily adaptable to rural farming communities (Hammond et al., 1997). Important opportunities exist through research on the traditional use of herbal medicine, since 80% of people in developing countries rely on phytomedicine for primary healthcare in both humans and animals (Bizimenyera et al., 2006). As ethnomedicine does not follow western paradigms of scientific proof of efficacy and safety, most medical and veterinary professionals distrust the use of herbs, and know little about them (Thompson, 1997). Numerous plant species and extracts have been evaluated and research efforts have mainly focused on condensed tannins (Hoste et al., 2006; Alonzo-Diaz et al., 2008). Due to the quantity of the different types of secondary compounds that exist in plants that could potentially be used as anthelmintics, rapid and cost-effective in vitro screening is necessary (Whitney et al., 2011).

The plants were chosen on the basis of a recent questionnaire survey in Benin which indicated that they were frequently used by small scale farmers against parasitic infections or to treat associated clinical signs (Hounzangbé-Adoté, 2000). *Newbouldia laevis* and *Zanthoxylum zanthoxyloides* have commonly been used in African folk medicine for the treatment of several diseases such as diarrhea, jaundice, hemorrhoids, dysentery, sore throat, gonorrhea and icterus (Arbonnier, 2004). They are also employed against malaria, sexually transmitted disease, dental caries, arthritis pain, gastroenteritis, dysentery and as vermifuge (Eyong et al., 2005). Leaves are used against infertility (Adjanahoun et al., 1991).

The aim of the present in vitro study was to establish the effects of tannins of leaves of *N. laevis* and *Z. zanthoxyloides* on the larvae L_3 migration of the intestinal parasite of sheep and goats (*T. colubriformis*).

MATERIALS AND METHODS

Collection and preparation of plant material

Samples collected in the south of Benin (Atlantic Department) were identified in National Herbarium of Abomey-Calavi University (Herbier National de l'Université d'Abomey-Calavi). Classification of the species was performed by means of the key according to Cronquist (Cronquist, 1988). Voucher specimens are kept at the Herbarium of Abomey-Calavi University for *Z. zanthoxyloides* under N° AA 6301 / HNB and *N. laevis* under N° AA 6302 / HNB. The plants were dried indoors at room temperature before being ground into powder for extraction.

*Corresponding author. E-mail: abiodouno@yahoo.fr. Tel: +229 97 08 54 68.

Plants extracts preparation

Acetone and ethanol used for each plant are recognized to be both solvents which extract more compounds from plants (Eloff, 1998).

Hydro-ethanolic extract

50 g of each plant powder was refluxed in a water bath under magnetic stirring for one hour in 500 mL of ethanol-water (70:30) mixture. The solution is cooled and then filtered. The operation was repeated twice and before the ethanol was removed under pressure at 40°C. The aqueous solution was partitioned successively with dichloromethane (each 3 × 300 ml), and ethyl acetate (each 3 × 300 ml) respectively to defatted and to remove chlorophyll. Thereafter, the remaining aqueous extract were lyophilized and stored at -70°C, and the yields of extraction (mass/mass) were calculated.

Hydro-acetonic extract

50 g of plant powder was refluxed, filtered and washed as described above for hydro-ethanolic extracts with the exception that ethanol-water was replaced with acetone-water (70:30) mixture. The solution is cooled then filtered. The operation is repeated twice and acetone is removed under pressure at 40°C. The aqueous solution was partitioned successively with dichloromethane (each 3 × 300 ml), and ethyl acetate (each 3 × 300 ml) respectively to defatted and to remove chlorophyll. Thereafter, the remaining aqueous extracts were lyophilized, kept at -70°C and the yields of extraction (mass/mass) were calculated.

Determination of condensed tannins (CT) by the method of Butanol-HCl

The determination of CT was performed by the colorimetric method of Butanol-HCl. developed by Porter et al. (1986), based on the depolymerization reaction of CT in acid medium. This reaction leads to the release of anthocyanidins (colored molecules) corresponding to the cleaved monomer (Makkar, 2000; Schofield et al., 2001). It allows a semi-quantitative determination of CT as the released terminal monomers do not produce the corresponding anthocyanidins and therefore they are not dosed (Schofield et al., 2001). In the plant, the CT is present in different forms: free or bound, that is, attached to proteins or plant fibers (Schofield et al., 2001). The existence of these two forms (free or bound) made the determination of CT more difficult. CT content was analyzed using the Butanol-HCl assay according to Makkar (2000).

Larval preparation

Infective larvae of *T. colubriformis* L_3 were obtained by fecal culture of goats previously artificially infected with pure strains of *T. colubriformis*. After egg hatching, L_3 stage was reached after 10 days. The L_3 were then collected by sedimentation using Baermann's devices. These batches of 1-to-2-month-old larvae were used in the assays.

Bioassays: Larval migration inhibition assay

The larval migration inhibition (LMI) assay was used as described by Rabel et al. (1994) adapted for plant extracts (Jackson and Hoste, 2010), in order to measure inhibiting activity against infective larvae. Larvae were incubated for 3 h at 20°C in PBS plus plant extract solutions, at concentrations of 150, 300, 600 or 1200 µg/mL with three repetitions by concentration. The larvae were then washed three times in phosphate buffer (PBS) (pH 7.2, 0.15 M) and centrifuged. After the last washing, 800 µL of larvae at a concentration of 1000 L_3/mL was pipetted onto a 20-µm mesh. The sieve was inserted into a conical tube, so that it just touched the surface of the PBS contained therein. Three replicates were run at room temperature (23°C) for each plant concentration. In addition, a negative control (larvae incubated in PBS) was run in parallel. After 3 h, the L_3 above the sieve were discarded and those which had actively migrated through the mesh into the PBS below, were counted under an optical microscope (at 40x magnification), based on a 10% aliquot technique.

The percentage of LMI was calculated as $[(T-M)/T\times100)]$ where T is the total number of L_3 deposited in the sieve and M the number of L_3 having migrated through the mesh into the PBS.

Involvement of the tannins in the anthelmintic activity

Polyvinyl polypyrrolidone (PVPP) forms complexes with tannins and polyphenols and thus blocks their potential biological activity (Makkar, 2003). PVPP was added to the plant extracts at a concentration of 1200 µg/mL for 2 h in a 1:50 ratio (Barrau et al., 2005). These solutions were then centrifuged at 4500 RPM, (5 min, 20°C). After centrifugation, the supernatant and the extracts without adding PVPP were used to incubate sheathed infective larvae of *T. colubriformis*. Thereafter, the LMI assay was performed according to the procedure described previously.

Statistical data analysis

Larval migration bioassay: Excel software was used to calculate averages, standard deviations of larval migration and to generate graphical illustration. A GLM (general linear model) statistical test was performed to determine the difference in the mean percentage of LMI rates between the control and the different dose groups (150, 300, 600 and 1200 µg/mL) procedures using Systat 9 software (SPSS Ltd.). The dose-response effect was determined by considering the level of statistical significance at $p < 0.05$. The same test was applied for the comparison of response in the experiment with the extracts at 1200 µg/mL with or without PVPP.

RESULTS

Yield extractions

From the two selected plants, four extracts were obtained. The Table 1 shows the yields obtained for each plant extracts which is an indication that the hydro-ethanolic extracts gave the best yields.

Condensed tannin content of plants

The method of Butanol-HCl showed that the condensed tannins of *Z. zanthoxyloides* were estimated at 2.5% of the dry matter, while condensed tannins of *N. laevis* were estimated at 1.0%.

Inhibition of larval migration

The extracts of *Z. zanthoxyloides* and *N. laevis* inhibit *in vitro* migration of larvae of *T. colubriformis* (Figure 1). This

Table 1. Yield extractions.

Plants used	Plant part	Type of extraction	Yield (%)
Newbouldia laevis	Leaves	Hydro-ethanolic	13 ± 0.7
		Hydro-acétonic	5.3 ± 0.4
Z. zanthoxyloides	Leaves	Hydro-ethanolic	13 ± 0.5
		Hydro-acetonic	9.8 ± 0.4

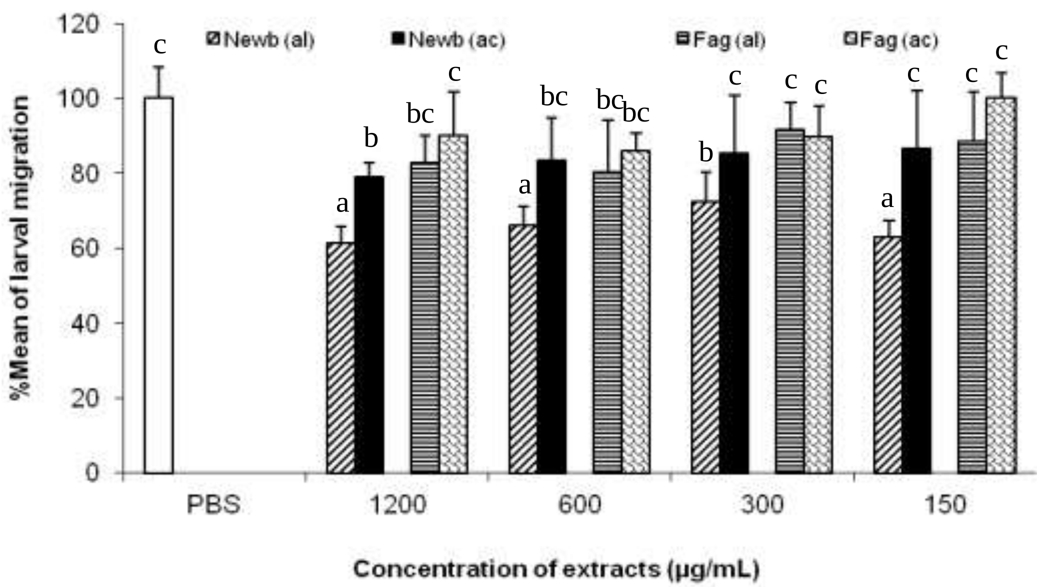

Figure 1. Percent mean of larval migration of *Trichostrongylus colubriformis* incubated with leaf extracts of *Newbouldia laevis* (Newb) and *Z. zanthoxyloïdes* (Fag), ethanolic (al), acetonic (ac).

effect was dependent on plant extracts ($p < 0.001$) but was not concentration dependent ($p > 0.05$) (Figure 1). Ethanol extract of both plants has significantly reduced larval migration ($p < 0.05$). *N. laevis* has showed more effect on larval migration ($p < 0.05$).

Adding polyvinyl polypyrrolidone (PVPP) to the plant extracts completely inhibited the effect of acetone-water extract of *Z. zanthoxyloides* and partially reduced the effect of the ethanol-water extract on parasites (Figure 2). With *N. laevis*, the PVPP only partially reduced the effect of the plant on *T. colubriformis*, regardless of the extraction solvent (acetone-water or ethanol-water).

DISCUSSION

The third stage larvae (L3) are very important on gastrointestinal parasites life cycle such as *T. colubriformis*. It is on this stage that the parasites infest their hosts. Earlier study on West African Dwarf goats showed anthelmintic activity of *Z. zanthoxyloides* and *N. laevis* on the most important gastrointestinal parasites nematodes in small ruminants. The powders of leaves of *Z. zanthoxyloides* and *N. laevis* reduced excretion of strongyles eggs without dose-effect but with a greater efficiency for *N. laevis* (Azando et al., 2011).

The decrease in migration of L_3 larvae of *T. colubriformis* after incubation with plant extracts is due to their immobility or mortality. This inhibition of larval migration depends not on the concentration of plant extracts but on the type of extract.

The aim of the study was to show the involvement of the tannins of *N. laevis* and *Z. zanthoxyloides*, two tropical plants, in the larval migration of *T. colubriformis*, a gastrointestinal hematophagous parasite of small ruminants. Acetone and ethanol were chosen as extraction solvents because they extract polar compounds from plants which are miscible in organic and aqueous solvents and are nontoxic to the organisms used in the tests (Eloff, 1998). The acetone and ethanol extract a number of compounds from plants compared to dichloromethane or hexane (Bizimenyera et al., 2005). Control of gastrointestinal parasites by plants lies among others in the ability of these to affect the viability or fertility of adult

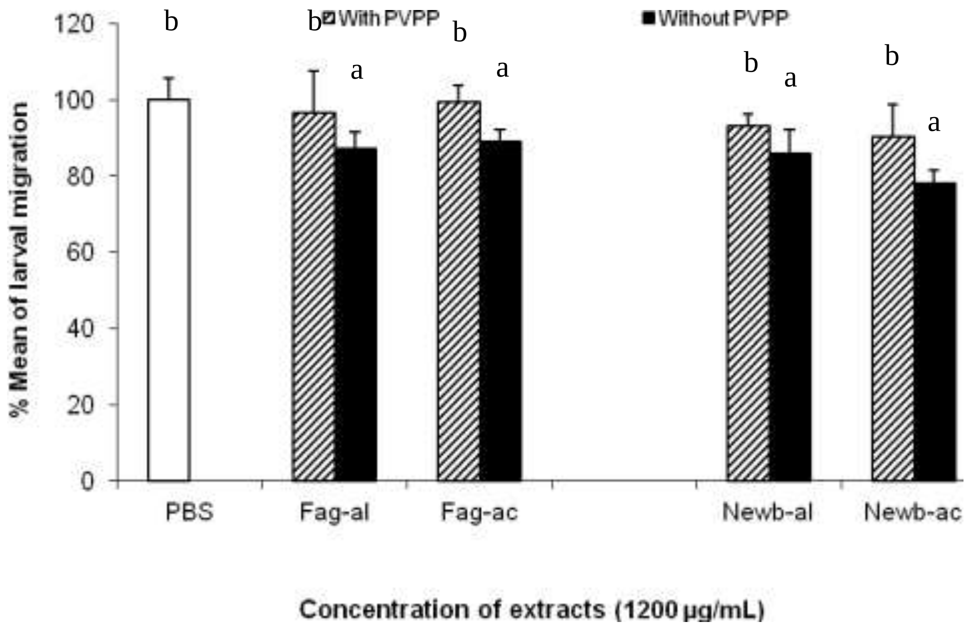

Figure 2. Percent mean of larval migration of *Trichostrongylus colubriformis* incubated with leaf extracts of *Newbouldia laevis* (Newb) and *Z. zanthoxyloïdes* (Fag), ethanolic (al), acetonic (ac) and with or without PVPP.

worms, to reduce egg excretion or to limit the installation of larvae by their immobilization or by inhibition of their exsheathment, thus blocking their life cycle. The reduction in larval migration is due to their immobility or mortality. Aqueous-acetone and aqueous-ethanolic extracts of *N. laevis* and *Z. zanthoxyloides* therefore inhibit *in vitro* migration of infective larvae of *T. colubriformis* and tannins should play an essential role. Brunet et al. (2007) showed that the extract of sainfoin "a plant rich in tannins," affects the kinetics of exsheathing of strongyle L_3 and that this inhibitory effect depends on the extract concentration. Similarly, Bahuaud et al. (2006) showed that some plants more or less rich in tannins can inhibit partially or completely *in vitro* migration of L_3 larvae. But the effectiveness of these tannins depends on their structure and nature of the monomers as shown by the work of Brunet and Hoste (2006). The anthelmintic properties of the plants are related to their phytochemical composition and the results of inhibition tannins suggest the activity of other secondary metabolites. Alkaloids are suspected among others, but according to Bar et al. (2005), flavonoids might also explain the anthelmintic properties of bioactive plants. Some studies have shown that *N. laevis* contains families of compounds such as tannins, flavonoids, alkaloids, anthocyanins, quinone derivatives, saponins, mucilages, steroids, triterpenoids and essential oils (Olounladé, 2005). This plant is also rich in quinones such as newbouldiaquinone (Eyong et al., 2006) or ceramide (Eyong et al., 2005) and alkaloids associated with pigments. Several alkaloids (Dieguez-Hurtado et al., 2003), flavonoids, terpenoids and coumarins (Mara et al., 1992) were isolated from different organs of species of the genus *Zanthoxylum*.

Otherwise, Brunet et al. (2008) found structural damage on L_3 having been in contact with sainfoin extracts. In addition to the inhibition of larval migration, *N. laevis* and *Z. zanthoxyloides* probably induce, on the infective larvae, structural and functional alterations on which it would be interesting to clarify. A dose-dependent inhibition of the migration of L_3 larvae of *T. colubriformis* was highlighted by Hounzangbé-Adoté (2004). The presence of condensed tannins in the two tropical plants, *N. laevis* and *Z. zanthoxyloides* could justify the observed anthelmintic properties. However, the molecules responsible for their anthelmintic effect are still unknown and remain to be identified. Flavonoids and tannins in the polar fraction of *Leuceana leucocephala* (Ademola et al., 2005) and flavonol glycosides in sainfoin (*Onobrychis vicifolia*) (Barrau et al., 2005) showed an effect on the migration of larvae strongle L_3 larvae. The tannins in our plant extracts are partly condensed tannins. Indeed, some condensed tannins (polyphenolic compounds) are known to be active anthelmintic on the different stages of the parasitic cycle of nematodes when tested *in vivo* in sheep and goats (Bahuaud et al., 2006; Hoste et al., 2006; Alonzo-Diaz et al., 2008).

Conclusions

N. laevis and *Z. zanthoxyloides* screened have inhibited larval migration of *H. contortus* with a high rate of reduction related to *N. laevis* extracts. Findings on both plant extracts support the traditional use of both plants in ruminant helminths controlling by small scale farmers. Research work is ongoing for determining better methods of plants extraction, elucidation of the chemical structure of active compounds, and for *in vivo* tests in suitable target livestock. This work may lead, not only to possible isolation of novel anthelmintic from the plants, but also to the development of better methods of plants extraction which are readily adaptable for use by rural communities against helminthiases.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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