EFFECTS OF PANICLE REMOVAL AND NITROGEN ON YIELD OF GRAIN SORGHUM

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(ABSTRACT)

Grain sorghum is the principal food crop in Botswana. It is often grown in low fertility, coarse-textured soils. It is a common practice within some ethnic groups in Botswana to remove the primary panicle with the expectation that this will increase the grain yield by promoting tillers.

A factorial experiment was conducted in the greenhouse to investigate the effect of panicle removal at anthesis and N on growth and yield of grain sorghum. Two N rates (25 or 100 kg/ha), three cultivars (Segaolane, Northrup King 2660, and Korwane), two main panicle treatments (present or removed), and five replications were used. Panicle removal increased the number of tillers and kernel weight but decreased yield (by reducing kernel number) in Segaolane and NK 2660. The kernel weight in Korwane did not respond to panicle treatments, but grain yield was reduced by panicle removal. In all cultivars, photosynthesis was reduced when the main panicle was removed. Korwane invested more assimilates in

vegetative material (harvest index = 0.15), while Segaolane and NK 2660 partitioned more photosynthates into grain yield (harvest index = 0.5). Nitrogen application increased total dry matter, tillers, grain yield, and number of kernels in each variety except that Korwane was not responsive in kernel number. Nitrogen fertilization decreased kernel weight in two of the varieties but not Korwane. Kernel weight of Korwane was not affected by any of the treatments in this test.

In summary, panicle removal appeared not to be a positive management practice for increasing grain yield of any of the varieties studied. On the other hand, N fertilization was beneficial to yield.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EFFECTS OF PANICLE REMOVAL AND NITROGEN ON YIELD OF GRAIN SORGHUM

1.0 Introduction and Literature Review

1.1 Introduction

Most farmers in Botswana and in other countries in semi-arid regions of Africa grow grain sorghum (*Sorghum bicolor* (L.) Moench). Sorghum is grown in these areas primarily as a staple food crop. The indigenous Botswana cultivars are typically characterized by medium to tall growth, profuse tillering under good growing conditions, and medium to late maturity. These varieties are generally high-yielding in years with adequate rainfall and on fertile soils.

Recently, in Botswana, the traditional varieties have fallen in productivity. The main reason apparently has been inadequate rainfall during their longer growing season. The frequent occurrence of drought has led to many crop failures. Another reason for less than satisfactory yields is that the traditional farmers do not apply chemical fertilizers. This omission is in part because of lack of knowledge about fertilizers. Chemical fertilizers are also expensive to acquire and can be difficult to apply properly. Consequently, sorghum growers may need to adopt other management practices. One approach could be to manage the crop's yield potential under erratic rainfall conditions by manipulating the number and size of fertile tillers.

Among the farmers in some ethnic groups in Botswana, there is a belief that removing the main panicle will increase the grain yield of sorghum. The increased yield due to panicle removal is reputed to be realized from varieties such as 'Korwane' and 'Sekgothane'. A similar practice in Botswana relates to selectively detasselling maize (Zea mays L.), which is thereby believed to produce more and bigger ears. Hypothetically, yield increases might result from the removal of non-grain sinks and the subsequent allocation of more assimilates to the grain heads of sorghum or the ears of maize. How panicle removal might result in higher grain yields is unclear, unless it might result in increased tillering and ultimately greater sink size.

This is an investigation of two grain sorghum varieties that are commonly grown in Botswana. The cultivars 'Segaolane' and Korwane have proved to be relatively reliable in both good and bad years. They are indigenous varieties that have developed through natural and human selection. They are freely tillering or branching and well-adapted to Botswana conditions, where their main panicle is often removed. The primary thrust of this research project is to examine physiological and agronomic consequences of main panicle removal in varieties grown and selected under such management.

1.2 Literature Review

1.2.1 Tillers and Yield

Sorghum, like many cereal crops and other grasses, has the capacity to tiller or branch. Tillers are branches that develop from axillary buds at the base of the plant, where internodes are short and buds are numerous. Tillers forming from the main culm are known as the primary tillers. Those that develop as basal branches from the primary tillers are called secondary tillers and may or may not give rise to tertiary tillers (Langer, 1963). Branches may also develop from axillary buds that occur higher on the culm. This tillering greatly influences the potential grain yield, because new tillers or branches may produce new grain heads (Saleem, 1988). Where there is poor initial crop stand due to poor environmental conditions or for any other reason, tillering becomes more important; because it can compensate for missing plants as the growing conditions improve.

Grain sorghum varies widely in the number of tillers produced. Management and environment can cause differences in tiller number. The ability to tiller is also controlled genetically (Downes, 1968), and the degree of expression of the tillering trait within a variety can be modified by management and environmental factors (Escalanda and Plucknett, 1975b).

Among sorghum varieties, tillers (versus main culms) contribute differentially to total grain yield. Grain produced by tillers may represent from 3% to 67% of the plant's total grain yield (Stickler and Pauli, 1961; Fukai et al., 1986). The variable contribution of tillers to grain yield has also been reported in rice (Oryza sativa L.) and other small grains (Alaoui et al., 1988; Miller et al., 1991).

Tiller removal has been investigated in sorghum. Detillering has been found to increase the number and weight of kernels on the primary culm, if tillers are removed during the early stages of growth (Bruns and Horrocks, 1984). The response to detillering obviously includes a reduction in transpiration from the removed tillers' foliage. Another response to detillering is enhanced root development and better drought tolerance (Bruns and Horrocks, 1984). When tillers are removed late during the growing period, there is loss of grain yield from the main panicle (Fukai et al., 1986; Gerik and Neely, 1987). The evidence of intraplant competition from tillers is more pronounced when tillers are removed after the emergence of the flagleaf (Bruns and Horrocks, 1984). Hulc and Baker (1990) saw similar intraplant competition in wheat.

Translocation between the main culm and tillers can be important in the partitioning of assimilates. In maize, assimilates can move from earless tillers to the ears on the main culm after silking and during grainfill (Carter, 1986).

Before the reproductive stage, very little assimilate moves between the main culm and the tillers. Translocation of the photosynthates to maize tillers from the main culm occurs only when ears are on the tillers. In grain sorghum, it is not clear whether the same phenomenon would occur; but the rationale for removing the main panicle immediately after its emergence may be to foster more grain fill in the tillers.

1.2.2 Nitrogen, Tillers, and Yield

The level of certain nutrients in the soil can greatly influence tillering in grasses. An increase in the supply of N, P, or K generally enhances the expression of tillers in cereal crops (Aspinal, 1961; Escalanda and Plucknett, 1975b). Among the different plant nutrients, N has been found to be of particular importance in tiller development (Saleem, 1988). In rice, tissue N concentrations above 3.5% are required for tiller development (Murata and Matsushima, 1975). As concentrations fall to 2.5%, tillering stops; and a fall in N level to less than 1.5% leads to the death of previously formed tillers.

Charles-Edwards (1984) hypothesized that each growing point in plants requires a minimum rate of assimilate supply for growth to continue. The amount of flux varies for various types of growing points. Charles-Edwards and Beech (1984) observed that frequently branching meristems required onequarter as much assimilate flux as compared with meristems of non-branching plants. Vanderlip et al. (1984) also pointed out that the number of tillers produced in grain sorghum is related to the daily rates of dry matter accumulation. Saleem (1988) showed that a minimum assimilate flux in sorghum is required to maintain the growth of each tiller.

In soils low in N, hybrid Pennisetum tiller number increased with increasing N up to 1000 kg N/ha (Muldoon and Pearson, 1977). In the second year of the same study, the number of tillers decreased beyond 250 kg N/ha. Escalanda and Plucknett (1977) observed more tillers, larger stalks, larger leaf area, and increased grain and stover yields in sorghum when fertilized with up to 250 kg N/ha. Both grain and stover yields declined at higher rates of N. In barley (Hordeum vulgare L.) and wheat (Triticum aestivum L.), tillering increases with increased rate of N supply (Cannell, 1969; Camberato and Bock, 1990). Duration of tillers and reduction in tiller mortality in wheat are enhanced by an increase in supply of N (Mahmoud and Osman, 1981). The number of surviving tillers increases with application of N. Split application of N is more effective in achieving a high number of fertile florets per head (Mahmoud and Osman, 1981). The result is a significant increase in the number of grains per spike.

Gautam and Kaushik (1982) found that N causes hybrid pearl millet (Pennisetum glaucum L.) to increase in height, stem thickness, tiller number, and grain yield. Nitrogen deficiency in sudangrass (Sorghum sudanense L.) reduces the number of tillers (Shen and Harrison, 1965). In grain sorghum, enhanced N supply promotes leaf canopy and higher grain yield (Wright et al., 1985). The amount of light energy intercepted by the denser leaf canopies leads to larger grains and more grains per head. In a similar study, Camberato and Bock (1989) observed that overall grain sorghum yield increased by 15% to 18%.

Improved N supply may increase floret number, proportion of fertile florets, and kernel weight. Better vegetative growth resulting from N fertilization can contribute indirectly to the rate and duration of grainfill. This is due to higher number and size of the leaves. It is therefore important to note that N supply generally plays a major role in the improvement of the grain and stover yields in the Poaceae. The yield effect is only partially via increased tillering.

1.2.3 Photosynthesis and Nitrogen

Photosynthesis is perhaps the most important aspect of a plant's metabolism relative to growth and yield. Photosynthesis is governed by various factors including moisture, temperature, and mineral nutrients. One of the key nutrients that affects photosynthesis is N, which is a component of the photosynthetic enzymes. Nitrogen supply can affect growth and development of the photosynthetic apparatus of the leaf. The 'well-being' of the leaves and their structural development are in part responsible for the accumulation of the dry matter.

The N supply that a plant receives affects its rate of photosynthetic activity. Generally, plants that are supplied with higher levels of N normally produce higher levels of photosynthates than plants that are N deficient (Nevins and Loomis, 1970). Sorghum supplied with adequate levels of N produces photosynthetic assimilates at a higher rate (Maranville et al., 1980) than deficient plants. This increase in assimilates leads to higher dry matter and grain yields.

Some plants or plant parts are able to adjust to different N regimes. Thomas and Thorne (1975) reported that there was no change in the rate of photosynthesis of wheat flagleaves with increased amounts of N. Wheat supplied with increasing levels of N had a longer leaf duration and a lengthened photosynthetic period. Nitrogen-deficient wheat plants senesced earlier than those grown with high N. It was only at senescence that the differences in flagleaf photosynthesis between N treatments became apparent. Sunflower demonstrates similar responses when subjected to similar N fertilization regimes (Fredeen et al., 1991). The photosynthetic rates of young leaves in sunflower and potatoes are markedly different at the end of the growing season than at the beginning (Fredeen et al., 1991; Olesinski et al., 1989).

Leaf age and its interaction with N mobilized are also of importance when measuring photosynthesis. Flagleaves are the youngest leaves in cereal crops. Greater amounts of the leaf N are maintained by the younger leaves. Young fully expanded flagleaves of wheat are not affected by rate of N and never contain less than 80 mmol N m^{-2} (Evans, 1983). Nitrogen is re-mobilized from the older leaves to maintain the leaf N of young leaves (Evans, 1983). Leaves of the same age, with approximately the same photosynthetic rate, may have large differences in their tissue N content (Girardin et al., 1985). Plants that receive lower rates of N have been shown to have the same or higher photosynthetic rates than those that receive higher N. It appears that the maximum rates of photosynthesis of the leaves is more dependent on physiological age than on the nutritional status of leaves (Girardin et al., 1985). The rate of photosynthesis of wheat plants grown with abundant N supply is substantially lower per unit of protein levels than at low N levels (Lawlor et al., 1989).

1.2.4 Plant Spacing, Tillers, and Yield

Plant spacing is a management parameter that can dramatically influence yield. Generally, farmers try to modify the environment to provide the plant with optimum conditions for growth. It is therefore appropriate to consider effects of inter- and intra-plant competition in the field on plant growth.

As plant density increases, interplant competition for the environmental resources increases. Competition between sorghum plants for light, water, and essential nutrients has been reported to limit plant height, leaf area, tillers, and size of the panicles (Langer, 1963; Gifford et al., 1973; Vanderlip et al., 1984; Jones, 1985). The total number of tillers, and more importantly, the number of grain-producing tillers is strongly influenced by management in relation to the resources that maintain plant growth (Escalanda and Plucknett, 1975a; Gerik and Neely, 1987). An investigation of grain, forage, and sweet sorghums revealed different responses. Grain sorghum showed a reduction in the number of tillers and total grain yield with increased plant density, but forage and sweet sorghum yields increased with increased plant population (Kalmbacher and Martin, 1986). This result would be expected where vegetative matter is harvested (versus just grain). Similar grain-yield results to those of grain sorghum have been reported for rice, barley, and wheat (Hulc and Baker, 1990; Miller et al., 1991).

1.3 Objectives

The overall objective of this study is to investigate key responses of grain sorghum to N fertilization and panicle removal. Specifically, the research will examine the following relationships,

a) effects of panicle removal on yield and yield components, with a hypothesis that more yield will be realized from plants when the main culm panicle is removed.

b) effects of N on yield and yield components and on the response to panicle removal. I hypothesize that N will increase tiller or branch number and grain yield.

c) differences between varieties in branching/tillering patterns and photosynthesis in response to N and main panicle removal. I hypothesize that yield, photosynthesis, and tillering responses will be the same in all the varieties.

2.0 Materials and Methods

This experiment was conducted in the greenhouse from 26 January to 10 September 1993. Ross loam (fine-loamy, mixed, mesic Cumulic Hapludolls) was mixed with river sand in equal proportions using a concrete mixer. The resulting soil mix was a sandy loam with a pH of 5.9. Twenty-liter plastic pots, which had openings for drainage were filled with approximately 25 kg of the soil mix. The fertility of the soil was enhanced with N, P, and K. All the pots were supplied with superphosphate at 3159 mg per pot (equivalent to 10.8 kg P/ha) and potassium chloride at 1894 mg per pot (25 kg K/ha). Ammonium nitrate fertilizer was applied to half of the pots at 797 mg per pot (25 kg N/ha), and the other half of the pots received 3188 mg per pot (100 kg N/ha). One-third of these N rates was applied pretransplant together with all P and K, and two-thirds of the N was applied 8 weeks after transplanting. The preplant fertilizer was incorporated thoroughly by hand.

Two Botswana grain sorghum varieties with good branching and tillering habits, 'Segaolane' and 'Korwane', were planted. The seeds were obtained from the Seed Multiplication Unit-Botswana. A third, U.S. variety, 'Northrup King 2660' (NK 2660), was selected from other U.S. cultivars on the basis of its greater tillering when grown under local conditions. The seeds were planted in flats filled with half perlite and half river sand mixture, and seedlings were transplanted to the pots 8 days after emergence. Four more seeds were planted on the sides of each transplanted seedling. Twenty days and 25 days after transplanting, the seedlings were thinned to two and one per pot, respectively. In all cases, the single remaining plant was the transplant.

After the plant heights reached 30 cm, all pots were watered every 3 days and rotated every 5 days. Air temperature was monitored daily. The average daily maximum temperature and monthly range of maximum temperatures within the greenhouse section are shown in Table 1.

At about one and one-half months of growth, reddish spots appeared on leaves of almost all the plants. Leaf samples were taken to the Plant Clinic for investigation. The clinic did not detect any pathogens and indicated that the spots might have been due to imbalances of nutrients in the soil. Two-spotted spider mites (Tetraychus urticae (Kock)) appeared on Segaolane at the beginning of May and slightly later on Korwane. Insecticidal soap was applied at 18 g of soap per liter of water to all the plants. The mite sprays continued at 4-day intervals until six applications were made. Although the mites were controlled, their sucking damage appeared to accelerate senescence of the older leaves.

Table 1. The average daily maximum temperatures and monthly range of maximum temperatures within greenhouse section during the experiment.

		Range	
Month	Average	High	Low
	---------------- °C ----------------		
February	32	42	23
March	33	42	18
April	32	43	24
May	36	38	28
June	36	38	28
July	36	40	30

The number of green leaves per plant was recorded every 2 weeks during the growing period until the 20th week of growth. The height of the plants was measured from soil level to the tip of the last fully expanded leaf when held vertically. This height measurement was done every 2 weeks for 24 weeks.

In half of the pots, the main culm's panicle was removed just above the flagleaf immediately after full emergence. The panicle removal treatment was performed first in Segaolane, i.e. the earliest-maturing variety. The panicles were removed from one-half of the Segaolane plants on the 122th day of growth, after all the panicles had fully emerged. One-half of the NK 2660 panicles were removed on day 132. In each of the first two varieties, all panicles had fully emerged within a week. Korwane was a very heterogeneous and inconsistent variety to work with. The panicles did not emerge uniformly. Emergence extended to a period of over two weeks. A decision was made to remove some panicles while still in the boot. Panicle removal in Korwane was performed on one-half of the plants on day 163.

Photosynthesis of the flagleaf was measured in all the plants 12 days after panicle removal for the Segaolane and NK 2660 varieties. For the Korwane variety, photosynthesis was measured 17 days after panicle removal. The 5-day delay in the measurement was due to cloudy weather. The photosynthesis measurements were taken non-destructively with a Licor Li-6200 portable photosynthesis system.

Harvesting was done 65 days after anthesis (panicle removal) in all varieties. Segaolane was harvested after a 187-day growing period. NK 2660 was next after 197 days, and Korwane was last after 228 days of growth. The harvested plants were separated into vegetative portions (stems plus leaves) and panicles. The panicles were oven-dried at 33°C for 48 hours. Stems and leaves were oven-dried at 65°C for 48 hours. The panicles were threshed and the seeds cleaned by hand. Vegetative dry matter (stems and leaves), grain yields, kernels, kernel weight, and tillers were determined for each plant. In this study, all "tillers" actually were branches, as they developed on the stems and not at the base of the plants.

The experimental design was a randomized complete block, two (N rates) x three (cultivars) x two (main panicle removal treatments) factorial with five replications. Treatments (pots) were re-randomized within replications at 5-day intervals to minimize border and shading effects. General Linear Model Procedure analysis was performed on the data with SAS (Freud and Littell, 1981), and P-values $\leq$ 0.05 were used to establish significant differences. Mean separation was usually accomplished by least significant difference (LSD). Duncan's Multiple Range Test was also used in some cases where main effects interacted to complement the LSD procedure in doing mean separations.

3.0 **Results and Discussion**

The anova table (Table 2) summarizes the statistical analyses for the eight different parameters under study. There were differences within main effects for almost all parameters tested. There were also interactions between the main effects for some parameters. The two-way interactions dictated data presentation either by pooling or not pooling means across main effects. The presentation of data and interpretation of results will be dealt with by individual parameters.

3.1 Height and leaf number

Measurements of height and green leaf counts were taken at maturity. Plant height was not affected by panicle removal. Korwane was the tallest of the three varieties at both N rates (Table 3). The second tallest variety was Segaolane, and the shortest was NK 2660. Nitrogen increased the height of Korwane and NK 2660 varieties but not Segaolane. The averages across the N rates show the Botswana varieties to be taller than NK 2660. Although the height of the plant is genetically determined, the growing period was somewhat associated with height. Segaolane and NK 2660 are shorter season varieties than Korwane.

Table 2. F-values and significance levels according to SAS analyses of variance for several parameters of grain sorghum.

Source	df	Final Height	Green Leaves	Vegetative Mass	Grain Yield	Total Biomass	Harvest Index	Kernels/ Plant	Kernel Weight	Tillers/ Plant	Photosyn. Efficiency
Cultivar	2	279***	9*	102***	194***	5*	343***	13***	78***	19***	15***
N-rate	1	36**	30**	151***	82***	278***	0.6	93***	56***	15***	0.01
Panicle	1	-	-	2	27***	4*	28***	47***	48***	33***	13***
Cultivar x N-rate	2	6*	2	12***	2	7*	2	6*	17***	2	3*
Cultivar x panicle	2	-	-	0.07	2	2	1	3*	17***	2	0.7
Panicle x N-rate	1	-	-	0.7	0.7	1	0.2	2	11***	0.9	3*

*,**,*** = significant at ≤ 0.05, ≤ 0.01, ≤ 0.001 level of probability, respectively.

Table 3. Effect of N fertilization on final height of three grain sorghum cultivars.

Cultivar	N Rate (kg/ha) 25	100	Average
	----------cm----------		
Segaolane	151 c*	154 c	153 M
Northrup King	122 d	144 c	133 N
Korwane	244 b	268 a	256 L
Average	173 B	189 A	

*Means followed by the same lower case letter are not significantly different at 0.05 level according to the Duncan's Multiple Range Test. Means followed by the same upper case letter are not significantly different at 0.05 level according to the LSD procedure.

At the time of maturity, Korwane and NK 2660 had more green leaves than Segaolane when all were averaged across N rates (Table 4). This was also true within the 100 kg N rate. The higher N rate increased the number of green leaves at harvest for the Korwane and NK 2660 cultivars but not Segaolane. Nitrogen likely increased leaf duration, not leaf number per se. The N rate affected the number of green leaves at the end of the experiment. At lower N, leaves senesced earlier.

3.2 Vegetative Dry Matter - Stems and Leaves

Vegetative dry matter accumulation was influenced by cultivar and N rate but not panicle removal (Table 5). At the lower rate of N, Segaolane and NK 2660 were not different in dry matter production but Korwane had 60% more than the other two. At the higher rate of N, Segaolane produced the least vegetative dry matter and Korwane the most, while NK 2660 was intermediate.

All three cultivars produced more dry matter with increased N. Leyshon et al. (1980) reported increased total dry matter was proportionate to N rate in wheat and barley. Their study combined vegetative material and grain dry matter. The results herein are similar when considered as overall biological yield. In this study, lower rates of N

Table 4. Effect of N fertilization on number of green leaves of three grain sorghum cultivars at time of maturity.

Cultivar	N Rate (kg/ha) 25	100	Average
	---------------leaves/plant---------------		
Segaolane	8.0 b*	9.4 b	8.7 M
Northrup King	9.2 b	12.6 a	10.9 L
Korwane	9.0 b	11.2 a	10.1 L
Average	8.7 B	11.1 A	

*Means followed by the same lower case letter are not significantly different at 0.05 level according to the Duncan's Multiple Range Test. Means followed by the same upper case letter are not significantly different at 0.05 level according to the LSD procedure.

Table 5. Effect of N fertilization and panicle removal on vegetative mass (stems plus leaves) and total biomass of three sorghum cultivars.

	N rate[1] (kg/ha)			Panicle[2]	
Parameter/ Cultivar	25	100	Average	Present	Removed
	---------------g/plant---------------				
Vegetative Mass					
Segaolane	39 d*	55 c	47 N	45 b	49 b
NK 2660	40 d	67 b	54 M	52 b	54 b
Korwane	64 bc	109 a	86 L	84 a	88 a
Average	48 B	77 A		61 X	64 X
Total Biomass					
Segaolane	79 c	111 b	95 N	95 a	95 a
NK 2660	83 c	129 a	106 M	111 a	100 a
Korwane	75 c	130 a	103 M	105 a	99 a
Average	79 B	124 A		104 X	98 Y

[1]Pooled across panicle treatments
[2]Pooled across N rates
*Means within a parameter followed by the same lower case letter are not significantly different at 0.05 level according to the Duncan's Multiple Range Test. Means within a parameter followed by the same upper case letter are not significantly different at 0.05 level according to the LSD procedure.

consistently yielded lower dry matter across the varieties. This relationship is an indication that N can limit dry matter in these cultivars.

Among these varieties, Segaolane appeared to have responded least (41% increase) in vegetative dry matter accumulation when comparing the N rates. Korwane had the highest increase (70%) in vegetative dry matter production. NK 2660 fell in between the other two varieties in increased dry matter investment. It is perhaps significant that the longer growing Korwane (228 days) accumulated more vegetative dry matter. The earliest maturing Segaolane (187 days) produced the least vegetative and total dry matter. Panicle removal did not affect vegetative dry matter accumulation for any cultivar under the conditions of this experiment. All varieties responded the same regardless of panicle treatment (panicle present or removed). Korwane, however, had more vegetative dry matter in either case. Panicle removal did slightly reduce total biomass when compared across cultivars and N treatments.

It is apparent that sufficient N is required for maximum production of dry matter. This finding was most apparent for Korwane, which could benefit livestock producers, as they are interested among other things in vegetative material. Segaolane would be the last choice for dry matter production when compared with the other two varieties across N

3.3 Grain Yield

Grain yield per plant was determined at the end of the growing season. Segaolane and NK 2660 produced far more grain than Korwane (Table 6), but percentage-wise (91% increase), Korwane responded most to elevated N supply. The lower N supply produced lower grain yields. Nitrogen is among the key nutrients for the best growth of any crop.

Korwane produced the greatest amount of dry matter but the lowest grain yield. It used much of its assimilates in making the vegetative material. This contrasts with Segaolane and NK 2660 which channeled more photosynthates to grain production. The grain yield of these two cultivars was three-fold greater than Korwane, but they were inferior in vegetative dry matter production. Grain yield is enhanced by N in most grain crops; this study shows the same trend. Higher grain yield with the higher N rate in this study is in agreement with data from other sorghum studies (e.g. Wright et al., 1985).

Panicle removal decreased grain yield in all the varieties. Although there was a decrease in yield in all varieties after panicle removal, higher grain yield occurred at the higher rate of N. Apparently, plants with removed panicles could not completely compensate for the removed florets irrespective of rate of N application.

It is evident that the three cultivars partitioned

Table 6. Response of grain yield to N fertilization and panicle removal in three grain sorghum cultivars.

	Cultivar[1]				Panicle[2]	
N rate	Segaolane	NK 2660	Korwane	Avg.	Present	Removed
(kg/ha)	----------------------g/plant--------------------					
25	41	43	11	32 B	35	28
100	57	62	21	47 A	52	42
Avg.	49 a*	53 a	16 b		44 x	35 y

[1]Pooled across panicle treatments
[2]Pooled across cultivars
*Means followed by the same letter are not significantly different at 0.05 level according to the LSD procedure.

assimilates differently. It also appears that there is an advantage in applying N to increase the yield. In this study, Korwane almost doubled grain yield at the higher rate of N application, but it is probably not economical to increase N rate to increase grain yield of Korwane. Korwane showed the greatest percentage increase to higher N level, yet it still had the least total grain yield. Panicle removal reduced the grain yield under the conditions of this study.

3.4 Kernels per plant

The number of kernels per plant differed among cultivars and between N and panicle treatments (Table 7). For the Segaolane and NK 2660 cultivars, the higher rate of N resulted in more kernels per plant than the lower N rate. Similar results have been reported before. Leyshon et al. (1980) reported N promoted increases in grain yield in wheat and further observed that the increase was primarily due to the effect of N on the number of spikes per plant. Segaolane and NK 2660 produced equivalent numbers of kernels within each N rate. Korwane did not show a significant increase in kernel number in response to N. The failure to detect a difference in kernel number was likely a result of considerable variation in this parameter within the cultivar. The range of values at 25 kg N/ha was from 77 to 508 kernels per plant for Korwane.

Table 7. Effect of N fertilization and panicle removal on number of kernels per plant in three grain sorghum cultivars.

Cultivar	N rate[1] (kg/ha)			Panicle[2]	
	25	100	Average	Present	Removed
	kernels/plant				
Segaolane	412 b*	1088 a	750 L	919 a	581 b
Northrup King	428 b	906 a	667 L	909 a	425 b
Korwane	330 b	583 b	456 M	544 b	369 b
Average	390 B	859 A		791 X	458 Y

[1]Pooled across panicle treatments
[2]Pooled across N rates
*Means followed by the same lower case letter are not significantly different at 0.05 level according to the Duncan's Multiple Range Test. Means followed by the same upper case letter are not significantly different at 0.05 level according to the LSD procedure.

It is also worthwhile to note the great variation in kernel numbers (11 to 955 kernels per plant) for plants with the higher rate of N. Korwane otherwise showed a good deal of variation in height and maturity, suggesting it is the least homogeneous cultivar genetically.

The number of kernels per plant was greater with intact panicles in Segaolane and NK 2660 (Table 7). In Korwane, panicle treatment did not make any difference, and the number of kernels was comparable to the two varieties with removed panicles. The lack of response to panicle removal was again likely due to the variation in Korwane's kernel numbers seen of each treatment (ranged from 11 to 955 kernels per plant). Removal of panicle was a detrimental management practice especially in the Segaolane and NK 2660 varieties under these growth conditions of adequate moisture. Nitrogen still proved to be a management tool in determining the number of kernels per plant.

3.5 Kernel weight

Kernel weight varied widely between treatments in Segaolane and NK 2660 cultivars but not in Korwane (Table 8). Camberato and Bock (1989) found that sorghum kernel weight increases with increased N supply. This study shows the contrary (Table 8). At least Segaolane and NK 2660 produced heavier seeds at

Table 8. Response of kernel weight to N fertilization and panicle removal in three grain sorghum cultivars.

Cultivar	Panicle	N rate (kg/ha) 25	100
		----------mg/kernel---------	
Segaolane	Present	86 c*	45 ef
	Removed	123 b	67 cd
NK 2660	Present	81 cd	61 de
	Removed	174 a	89 c
Korwane	Present	34 f	40 ef
	Removed	36 f	36 f

*Means followed by the same letter are not significantly different at 0.05 level according to the Duncan's Multiple Range Test.

the lower N rate. There was no response of Korwane to N. The Segaolane and NK 2660 varieties produced more kernels per plant (Table 7) at the higher N rate. The assimilates had to be distributed among a larger number of kernels (increased sink) in the higher N plants. The source was apparently limiting at the higher N rate where more seeds were present to be filled. Plants with lower N produced fewer seeds, and the seeds consequently were heavier. Fewer seeds meant a narrower distribution of the photosynthates (i.e., there was a limited sink). Blum et al. (1988) reported similar findings with studies on wheat. Ma et al. (1990) observed similar results in partial degraining of wheat. Partial removal of spikes also produces heavier seeds in wheat (Blade and Baker, 1991).

Panicle removal also resulted in heavier kernels except in Korwane (Table 8). The smaller the sink, the greater the ability of the presumably constant source to fill the sink. Panicle removal resulted in a reduced sink size which was then more adequately supported by the source. Both the Segaolane and NK 2660 varieties produced the heaviest seeds at the lower N rate and with panicle removed. Korwane produced the lightest seeds, and it showed no response to panicle removal.

Something other than N was limiting the kernel weight in Korwane. The explanation of this phenomenon is not clear, but there may be leads from several studies. The capacity for storing starch in cereals may be limited by floret cavity (lemma and palea) (Millet, 1986). Millet (1986) correlated heavier kernels in wheat with larger floret cavities. The capacity may be controlled by growth regulators (Radley, 1978). Brocklehurst (1987) associated kernel weight with the number of endosperm cells and indicated that the number of endosperm cells was fixed where there was no change in kernel weight in some wheat varieties. Earlier, Wardlaw (1970) suggested the stem elongation in tall varieties may compete with the ear for assimilates. He noted that peduncle elongation in tall varieties usually continues to grow even after anthesis, resulting in competition between the stem and the ear. However, Winzeler et al. (1989) reported the ability to increase grain growth under high assimilate supply differs between short and tall varieties of wheat. The restriction in grain growth in tall cultivars was not limited by lack of assimilates.

The explanation made by other researchers concerning lack of kernel weight response to ear treatment and N rate may apply to Korwane. The size and number of the florets was not determined in this study. The number of endosperm cells and growth regulators were also not investigated in my study. Korwane, though, continued to grow after anthesis. The notion of the endosperm cell numbers being fixed is more plausible. The thought is reinforced by Winzeler et al. (1989) findings that assimilates were not limiting in tall varieties of wheat. Korwane, a tall variety did not show response at higher N and panicle removal.

Kernel weight increased with panicle removal, but the greater weight did not compensate for the fewer kernels produced. Rather the greater number of seeds produced by Segaolane and NK 2660 under higher N made up for the lighter kernel weight. Overall, these data indicate that Korwane should not be fertilized with N to increase kernel numbers and kernel weight.

3.6 Branching

Korwane produced more tillers or branches than Segaolane which produced more tillers than NK 2660 (Table 9). NK 2660 had the least tillers, probably because U.S. grain sorghum varieties have been bred to produce fewer tillers. The average number of tillers was lower at the lower N rate. Higher N supply increased branching in all three cultivars. Increases in tiller number with increases in N have been reported in wheat and barley (Cannell, 1969). Gautam and Kaushik (1982) reported similar findings in hybrid pearl millet.

Panicle removal increased the number of tillers in all of the varieties. Auxin suppresses tillering in sorghum via

Table 9. Tillering response to N fertilization and panicle removal in three grain sorghum cultivars.

	Cultivar[1]				Panicle[2]	
N rate	Segaolane	NK 2660	Korwane	Average	Present	Removed
(kg/ha)	----------------------	----------------------	branches[3]/plant	----------------------	----------------------	----------------------
25	1.6	1.1	2.1	1.6 B	1.0	2.2
100	2.0	1.6	3.3	2.3 A	1.8	2.7
Average	1.8 b*	1.4 c	2.7 a		1.4 y	2.5 x

[1]Pooled across panicle treatments

[2]Pooled across cultivars

[3]Branches include the primary culm

*Means followed by the same letter are not significantly different at 0.05 level according to the LSD procedure.

apical dominance. Isbell and Morgan (1982) showed that the auxin is usually concentrated at the apex of the plant. When the apical panicle is removed, the balance between the auxin and gibberellic acid which enhances elongation of buds is altered (Rood, 1985). By removing the panicle, the apical dominance (suppression by auxin) is weakened. The concentration of gibberellin is increased, thus triggering the proliferation of dormant buds. Isbell and Morgan (1982) observed increased tillering in sorghum after removal of the panicle. The same relationship was observed in this study.

Panicle removal is counter-productive when sorghum is grown for grain yield under conditions similar to those in this study. Panicle removal may be appropriate in management where total dry matter is a priority or where climatic conditions would more nearly match the water requirements of tillers. From this standpoint, Korwane is superior in dry matter production. Nitrogen applications will promote tillering (Table 9) as observed in the results for all three cultivars.

3.7 Photosynthesis

Photosynthetic responses to N fertilization were surprising. One would have thought that the higher N rate might have produced higher rates of photosynthesis, but there was no difference (Table 10). There were differences between

Table 10. Response of photosynthesis efficiency to N fertilization and panicle removal in three grain sorghum cultivars.

	Cultivar[1]				Panicle[2]	
N rate	Segaolane	NK 2660	Korwane	Average	Present	Removed
(kg/ha)	moles CO_2/mole PAR					
25	0.006 bc*	0.010 a	0.007 bc	0.008 L	0.010 a	0.006 b
100	0.005 c	0.010 a	0.009 ab	0.008 L	0.009 ab	0.008 ab
Average	0.006 C	0.010 A	0.008 B		0.010 X	0.007 Y

[1]Pooled across panicle treatments

[2]Pooled across cultivars

*Means followed by the same lower case letter are not significantly different at 0.05 level according to the Duncan's Multiple Range Test. Means followed by same upper case letter are not significantly different at 0.05 level according to the LSD procedure.

cultivars, however. NK 2660 produced the highest photosynthesis when averaged across both rates of N. Segaolane had the least photosynthesis when averaged across N rates. The Botswana varieties produced less photosynthates than the NK 2660 variety at all N rates. Perhaps the explanation should take into consideration that the Botswana cultivars normally are grown under higher irradiance. There appears to be more cloudy days during the growing period in Blacksburg than in Botswana.

Higher and lower N rates did not produce differences in photosynthesis among the varieties. The results are confirmed in other studies with wheat (Thomas and Thorne, 1975). Giradin et al. (1985) reported low-N maize produced the same or higher photosynthesis than under high N.

Fredeen et al. (1991) and Olesinki et al. (1989) observed sunflower and potatoes fertilized with high or low N differed in photosynthetic rates at the beginning and the end of the growing season. The longer leaf duration and longer photosynthetic period in high-N plants made them superior in the long run. Nitrogen deficient plants senesced earlier than those grown with high N (Fredeen et al. 1991). This study would likely have shown similar findings had whole-plant photosynthesis been measured at different intervals during the growing period. However, this study only considered the flagleaf after anthesis.

flagleaf after anthesis.

Lower photosynthesis was observed when panicles were removed (Table 10). With removed panicles, photosynthesis was reduced as there was less sink demand. Removal of two-thirds of florets from wheat spikes did not affect the total assimilates from the flagleaf, but it caused more movement towards roots (Carr and Wardlaw, 1965). However, the net photosynthesis of the flagleaf was reduced by half within 3 to 15 hours of removing the entire head in wheat. This finding was associated with increased concentrations of photosynthates in the flagleaf (King, 1976). The source reduced its activity in response to the lowered demand. Photosynthesis in plants with intact panicles (and larger sinks) was distinctly higher. The source was consistently being required to supply the assimilates to the larger sink.

4.0 **Summary and Conclusion**

Nitrogen is known to increase total grain yield in many cereal crops including grain sorghum. The total grain yield is also known to be increased in most cereal crops by the contribution of the tillers. Although tiller contribution to yield is variable in most crops, what is unknown is the contribution made by tillers promoted by primary panicle removal. The intent of this study was to find the effect of N fertilization and panicle removal on yield of grain sorghum. A study of three grain sorghum varieties was undertaken in a greenhouse. Statistical analysis was used to help determine the effects of N fertilization and panicle removal in the three grain sorghum varieties.

Nitrogen rates affected the physiology of all three cultivars in similar ways except that Korwane behaved differently in certain parameters. Increased N increase height, number of green leaves, vegetative dry matter, number of kernels, and number of tillers. Kernel weight was lower at the higher N rate, presumably because of somewhat fixed or limited amounts of photosynthates which were distributed to the increased number of kernels. Flagleaf photosynthesis did not respond to the N rate in any of the cultivars, but there were differences in photosynthetic efficiency among the cultivars. The lack of response to N was probably due to the physiology of flagleaf nutrition. The varieties Segaolane and NK 2660 partitioned the photosynthates in a similar pattern. They invested more of their total assimilates into grain yield. This translated into a higher grain yield harvest index (0.5) for Segaolane and NK 2660 (Table 11). Much more of the assimilates in Korwane went into vegetative material (harvest index = 0.15). Korwane appeared not to respond to N in number of kernels or kernel weight.

Nitrogen is a very important component of crop management for yield (dry matter and grain yield) in grain sorghum. Nitrogen fertilization increased vegetative dry matter, tillers, grain yield and number of kernels in all varieties. Kernel weight was reduced by increases in N fertilization in two varieties but not Korwane.

Panicle removal reduced grain yield, number of kernels per plant, and photosynthesis. Kernel weight was increased by panicle removal in Segaolane and NK 2660. The increase in kernel weight likely occurred because removal of the primary sink (panicle) caused assimilates to be redistributed to other parts of the plant and the fewer kernels that were produced by the tillers. Tillers (branches) increased due to the breaking of apical dominance. The grain yield, kernel numbers, and photosynthesis were reduced in all the varieties by panicle removal. However, panicle treatment did not affect vegetative dry matter in all cultivars. Under our conditions, panicle

Table 11. Grain yield harvest indices response to N fertilization and panicle removal in three grain sorghum cultivars.

N rate	Cultivar[1] Segaolane	NK 2660	Korwane	Avg.	Panicle[2] Present	Removed
kg/ha	---------------------------	---Harvest	Index---	---------------------------		
25	0.51	0.52	0.14	0.39 M	0.43	0.36
100	0.51	0.48	0.16	0.39 M	0.42	0.35
Avg.	0.51 A	0.50 A	0.15 B		0.42 X	0.36 X

[1]Pooled across panicle treatments
[2]Pooled across cultivars
*Means followed by the same letter are not significantly different 0.05 level according to the LSD procedure.

removal was not a successful management technique to increase yield. This practice is not recommended as a sorghum management practice based on this study where moisture is not a limiting factor.

5.0 **Literature cited**

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APPENDIX

The following figures present data collected during the experiment but not incorporated into the text of the thesis.

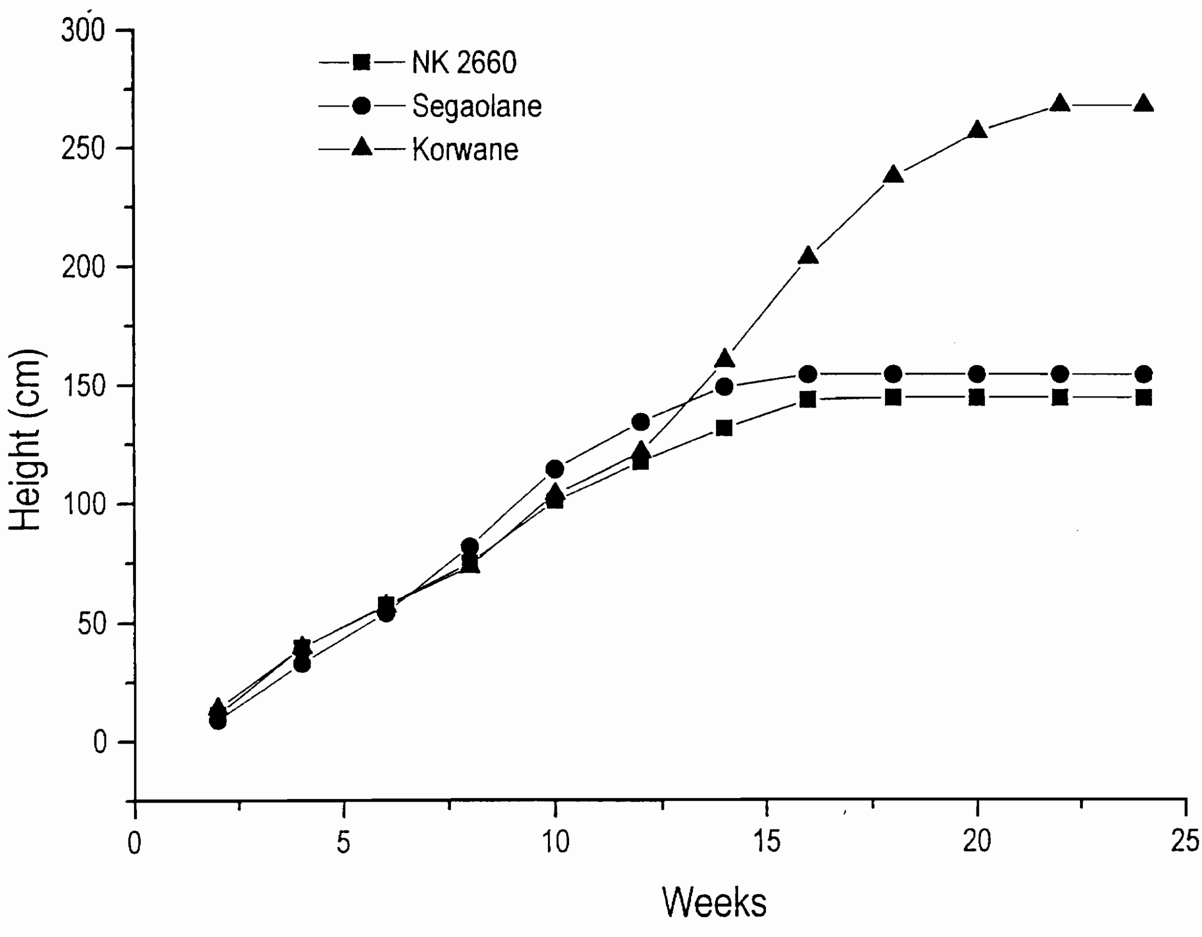

Figure 1. Height growth of three grain sorghum varieties grown at 100 kg N/ha.

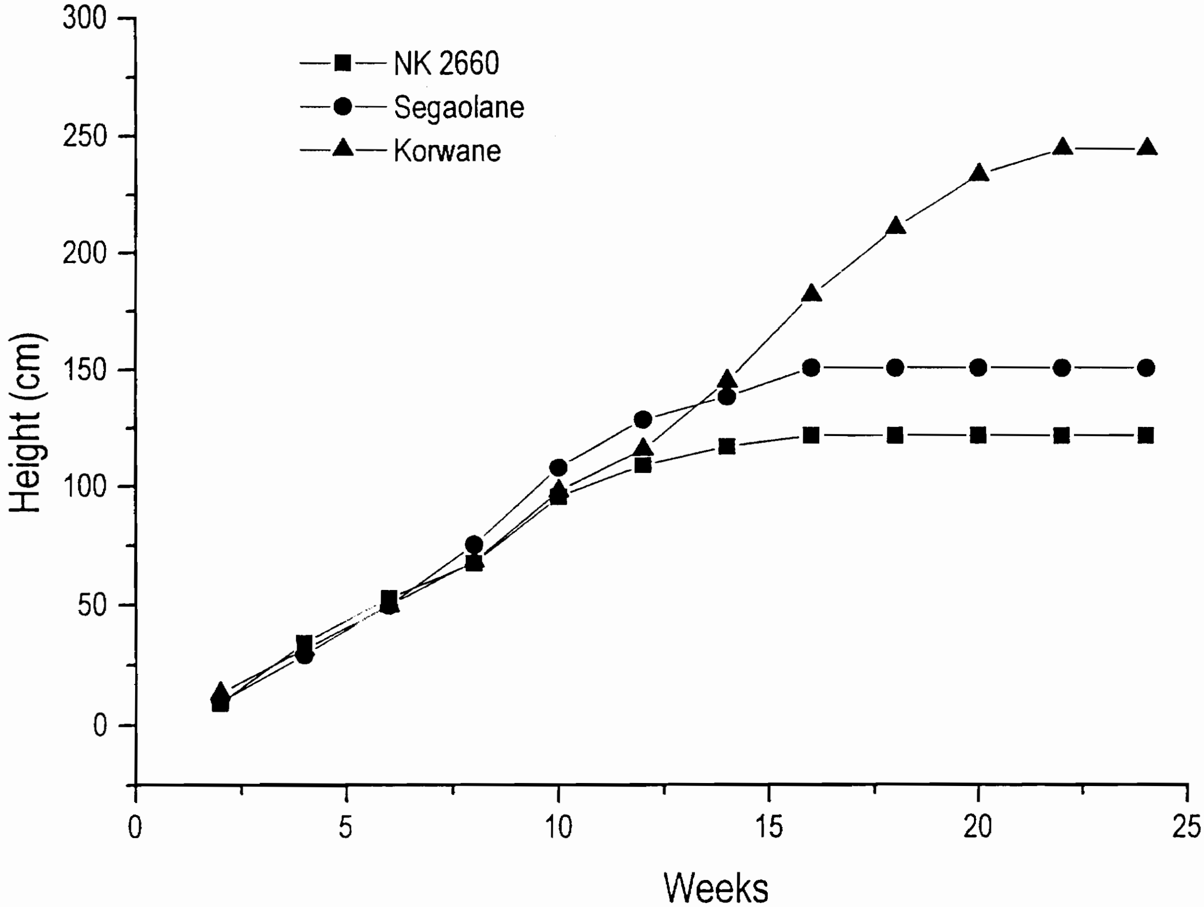

Figure 2. Height growth of three grain sorghum varieties grown at 25 kg N/ha.

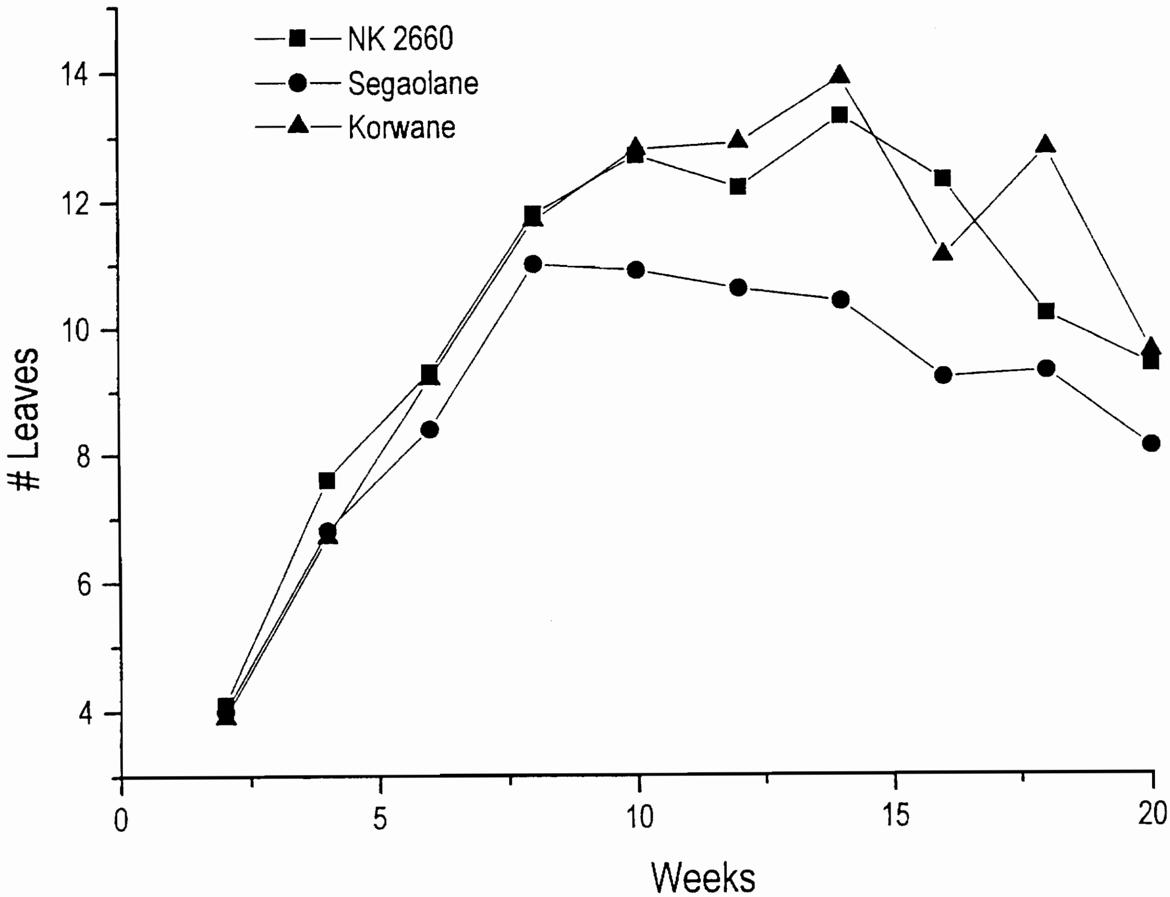

Figure 3. Green-leaf number observed during the growing period of three grain sorghum varieties grown at 100 kg N/ha.

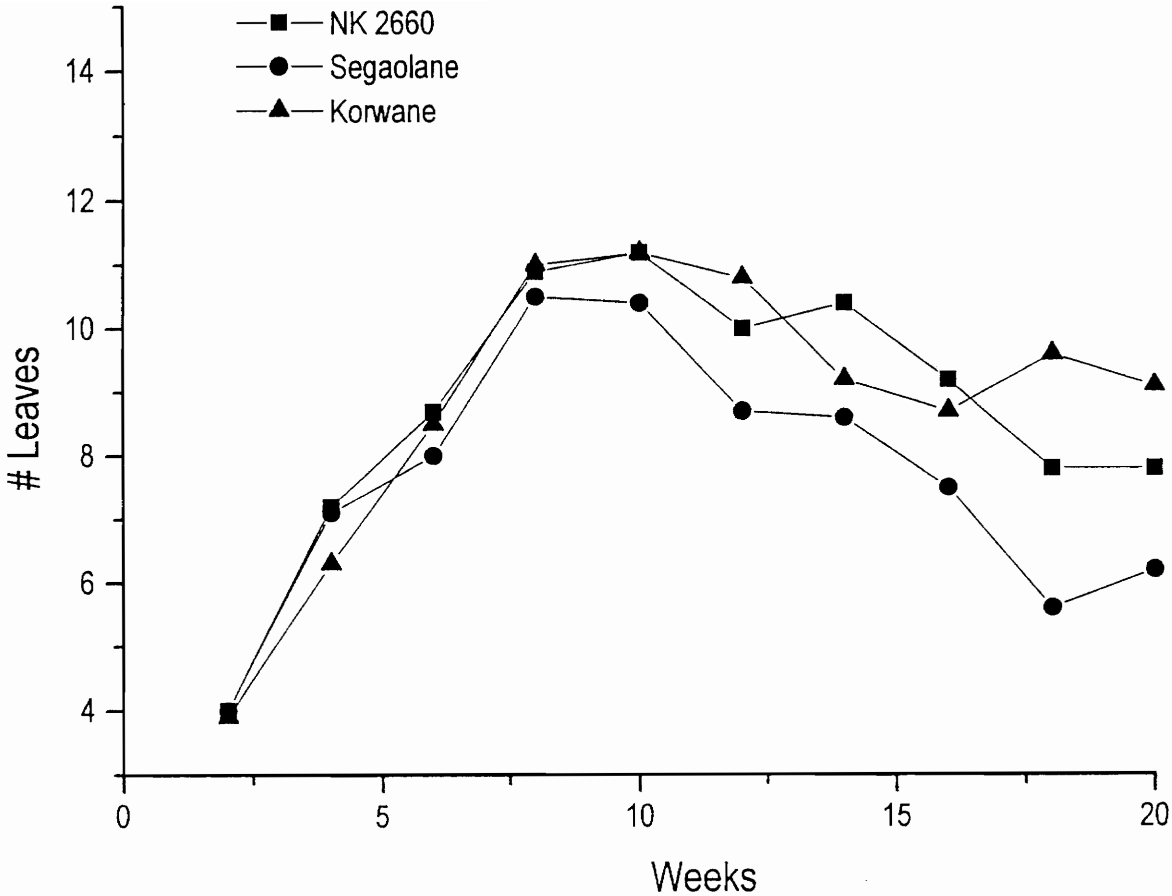

Figure 4. Green-leaf number observed during the growing period of three grain sorghum varieties grown at 25 kg N/ha.

VITA

Gabatshele Mbona Legwaila was born December 5, 1955 in Mathathane, Botswana. He completed his primary and secondary education in Mathathane and Tonota, respectively, during the years 1963 to 1974. He worked for one year before enrolling for a two-year Certificate in Agriculture course at the Botswana Agricultural College. On graduation in 1977, he joined the teaching staff in the College. In 1979, he resumed studies at the University of Botswana and Swaziland in Swaziland for an Associates Degree in Agriculture. Upon completion of work in Swaziland, he went for a BSc in Agriculture at Kansas State University, U.S.A. In 1986, he rejoined Botswana Agricultural College as a Lecturer. He continued teaching at the College and served on various college committees until coming to Virginia Tech in January 1992. He worked with Dr. D.J. Parrish on a Masters of Science degree. Upon graduation in December 1993, he will return to Botswana College of Agriculture.

Gabatshele is married to Agnes with whom they have two sons Oaitse and Oarabile. They live in Sebele where the agriculture college is located. Agnes works for the Ministry of Agriculture, Gaborone.