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Genetic and physiological relationships in N, P and K mobilisation in some sorghum mutants and parents *

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Summary. The mutation breeding program of alteration in plant type in two local Sorghum varieties resulted in several productive mutants of which 16 are far superior to the parents CRP, CBA and recommended hybrids. An earlier analysis of leaf area and photosynthetic efficiency revealed a diversity of mechanisms between mutants of the same yield group. Differences in the transfer of nutrients from leaf to the panicle were also indicated. Further analysis of the partition of nutrients in the panicle, flag leaf and rachis for N, P and K revealed that most of the mutants are at least equal to the parent in grain N but are superior in N content of flag leaf and rachis. Similarly, three mutants had a higher P content in grain than CRP and all other mutants were equal to CRP. Two mutants had more P in the flag leaf but this was not reflected in the grain. However, no differences were observed for the K content in the flag leaf, grain and rachis. The interrelations of the nutrients in different plant parts suggest that each mutant has a different pattern of nutrient accumulation and transfer. It could be concluded that selection for flag leaf N and P can improve grain N and P. There was no negative association between N and P accumulation in different plant parts. No adverse association was observed for other combinations. A study on the grain digestability of the mutants confirmed that the quality of the protein was not adversely affected in this material. This study indicated that simultaneous improvement of grain yield and grain N, P and K can be obtained even among the few mutants generated in this breeding program contrary to the belief of some cereal breeders that grain yield and its N content have a major negative association limiting the improvement of yield and protein content simultaneously.

Key words: Sorghum mutants – Flag leaf – Rachis – N.P.K. partition

Introduction

During the mutation breeding program on sorghum in the Faculty of Agronomy, an analysis of elite mutants, parents and hybrids, large differences in leaf area, rate of senescence and yield were observed (Valera and Murty 1984). Even among the mutants of the same yield group, differences for the above characters indicated the possible existence of a diversity of mechanisms in the transfer the nutrients. Studies with P^{32} on root activity in some of the mutants revealed differences for the same (Valencia 1983). Therefore, a study of the pattern of partition of N, P and K in the panicle, flag leaf and their interrelationships with yield and the accumulation of these elements in the same organ were studied to understand the genetic diversity present among the mutants and to plan a selection program for improving the capacity of this sorghum material under moisture stress. Genetic differences in the uptake of N, P and K and their dependence on the active root systems have been demonstrated already in cowpea (Adepatu and Akapa 1977).

Materials and methods

The material consisted of 16 genotypes, including 8 mutants of 'Criollo Rojo Pequeño' (CRP) a local short variety, five mutants of 'Criollo Blanco Alto' (CBA) a local tall variety, CRP parent as control and two recommended hybrids for the re-

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gion. The details have been described in an earlier paper (Valera and Murty 1984). The experiment in a randomized complete block design with three replicates was in 3-row plots of 5 m, each spaced at 50 cm × 10 cm, between rows and within rows. The experiment received 50 kg N, +60 kg P_2O_5, and 60 kg K_2O/hectare, in two equal doses, one before sowing and the other six weeks later.

Plant samples were collected at the time of grain maturity in January 1982. Three plants were randomly taken from each plot. The flag leaf, the grain from the panicle and the rachis (after removal of grain) were taken separately for each plant and analysis was done for N, P and K expressed as percentages on a dry weight basis. Duplicate analyses were done for each sub-sample. The correlations between N, P and K within and between plant parts and yield were based on these individual estimations. N was estimated by micro-kjeldahl method, and expressed as percentage of dry matter of the corresponding plant part. Phosphorous was estimated by a colorimetric method and expressed as µg P/g of dry matter. A sample of 0.1 g was incinerated at 200 °C for 30 min and subsequently at 530 °C 5 additional hours. The ash was dissolved in 20 cc of distilled water and filtered. The filter paper was washed with distilled water 5 times and added to the aliquot to make up 50 cc. A sample of 10 cc of this aliquot was utilized for P estimation using a yellow reagent consisting of ammonium molybdata, ammonium metevanadate and HNO_3. After adding this reagent and waiting 30 min, the color of the liquid was determined using a Perkin-Elmer's spectrophotometer, UV and visible spectra at $\lambda = 400$ NM. The test curve was prepared with the control solution of P (100 ppm) diluted to the range of 30–300 µg P/cc. Potash content was determined by Perkin-Elmer's atomic absorption spectrometer model 372 and expressed in gm of K/100 g of dry matter of the specific plant part.

Statistical analysis, included the estimation of sampling error and pooled residuals for testing differences between treatment means. Intercorrelations of N, P and K between plant parts and yields were based on these individual estimations.

Results

The analysis of variance and table of means for each element (N, P, K) in grain, flag leaf and rachis are presented in Tables 1–3. The means were examined on the basis of the parentage of the mutants (CRP mutants, CRP, CBA mutants and hybrids) and also on the basis of four yield groups-yield significantly higher than CRP (Group I), equal to CRP (Group II), less than CRP (Group III) and very inferior to CRP, the two hybrids used as controls (Group IV).

The differences between the genotypes were significant for N and P in grain, flag leaf an rachis. However, no such differences were significant for K, probably due to the high sampling error for this element.

Nitrogen

Differences between genotypes in grain N, flag leaf and rachis were significant. The CBA mutants and hybrid Barinas had less grain N than the CRP parent. All CRP mutants and hybrid Chaguaramas are equal to the CRP parent statistically. However, mutants of CRP had a better yield than CRP although there was no reduction in grain N. This is reflected in the absence of any correlation between yield and grain N and N in rachis (Tables 4 and 5). However, the presence of a positive correlation (0.45) between grain yield and N in flag leaf can be explained.

The low N in the flag leaf is reflected in the low N content in grain in all CBA mutants and the Barinas

Table 1. Means of N, P and K content at harvest in different plant parts in some mutants and hybrids of sorghum (means of 18 samples) in 1981–1982

Variety/mutant	Nitrogen (% of dry matter)			Phosphorous (µg P/g % dry matter)			Potash (% of dry matter)		
	A	B	C	A	B	C	A	B	C
CRP/parent	1.29	1.09	0.43	3,004	3,591	1,653	0.21	0.34	0.45
1028	1.38	1.10	0.46	3,437	3,960	1,933	0.30	0.55	0.57
1151	1.28	0.99	0.44	3,797	3,986	2,727	0.25	0.48	0.58
1243	1.41	1.18	0.56	3,070	3,646	1,843	0.27	0.48	0.50
1261	1.43	1.17	0.45	3,380	4,583	857	0.26	0.48	0.40
1265	1.28	1.15	0.42	3,020	4,387	866	0.30	0.51	0.51
1273	1.36	0.93	0.44	3,425	3,943	2,166	0.31	0.60	0.60
1279	1.40	1.25	0.49	3,077	4,116	1,793	0.13	0.38	0.30
2085	1.42	1.03	0.41	3,231	3,436	1,682	0.27	0.56	0.52
CBA-82	1.20	0.84	0.43	2,809	3,498	1,629	0.30	0.48	0.65
CBA-100	1.22	0.77	0.48	3,299	2,665	1,889	0.27	0.49	0.60
CBA-111	1.24	0.94	0.40	2,914	3,421	1,560	0.28	0.51	0.88
CBA-467	1.22	0.89	0.54	2,601	2,689	1,265	0.30	0.48	0.73
CBA-469	1.13	0.99	0.44	3,388	3,366	2,002	0.33	0.47	0.81
Hybrid barinas	1.10	0.84	0.40	2,714	2,808	1,483	0.23	0.39	0.59
Hybrid chaguarama V	1.52	0.95	0.54	3,732	2,728	2,090	0.31	0.47	0.40

A = grain; B = flag leaf; C = rachis

Table 2. Analysis of variance for N, P and K content in mutants and hybrids of sorghum (1981–82)

Mean squares												
Nitrogen				Phosphorous				Potash				
	DF	A	B	C	DF	A	B	C	DF	A	B	C
1. Treatments (genotypes)	15 (df)	0.2600**	0.3030**	0.0700**	15	1,400,333.0**	4,341,111.0**	2,640,655.5**	15	0.0300 NS	0.0530 NS	0.2800 NS
2. Residual	271 (df)	0.0429	0.0470	0.0130	175	358,862.4	482,843.0	285,676.9	176	0.0900	0.2700	0.4100
Total	287	–	–	–	191	–	–	–	191	–	–	–
SE_d		0.0690	0.0720	0.0370	–	244.7	286.7	193.9	–	0.1200	0.2100	0.2600

A = grain; B = flag leaf; C = rachis; DF = degrees of freedom

Table 3. N, P and K content in different plant parts of mutants and hybrids of sorghum (1981–82)

	Nitrogen (% of dry matter)			Phosphorous (µg P/g of dry matter)			Potash (% of dry matter)		
Varieties	A	B	C	A	B	C	A	B	C
1. CRP Parent	1.02 (0.69–1.24)	0.43 (0.41–0.44)	1.39 (1.33–1.40)	3,591 (2,941–4,109)	1,653 (1,006–2,755)	3,004 (2,536–3,480)	0.34 (0.36–1.11)	0.45 (0.40–1.45)	0.21 (0.14–0.63)
2. CRP Mutants	1.10 (0.93–1.25)	0.46 (0.41–0.56)	1.37 (1.28–1.43)	3,578 (3,436–4,583)	1,733 (857–2,727)	3,304 (3,020–3,796)	0.51 (0.38–0.60)	0.50 (0.30–0.60)	0.26 (0.13–0.31)
3. CBA Mutants	0.89 (0.77–0.79)	0.46 (0.43–0.54)	1.20 (1.13–1.24)	3,128 (2,665–3,498–3,498)	1,692 (1,265–2,002)	3,002 (2,601–3,388)	0.49 (0.47–0.51)	0.73 (0.60–0.88)	0.30 (0.27–0.33)
4. Hybrids	0.89 (0.84–0.95)	0.47 (0.40–0.54)	1.31 (1.10–1.52)	2,768 (2,728–2,808)	1,787 (1,483–2,090)	3,223 (2 714–3,732)	0.43 (0.39–0.47)	0.50 (0.44–0.59)	0.27 (0.23–0.31)
SE_d	0.0690	0.0270	0.0370	286.7	193.9	244.7	0.1200	0.2100	0.2600

( ) = range
A = flag leaf; B = rachis; C = grain

Table 4. Distribution of mutants with higher N.P.K. content than CRP, in grain flag leaf and rachis in four yield groups

Yield group	Grain			Flag leaf			Rachis		
	N	P	K	N	P	K	N	P	K
>CRP	Nil	1,151 1,273 1,028 Chaguaramas	2,085 CBA-469	1,261 1,279	1,261 1,265	2,085 CBA-469	1,243 1,279 CBA-467 Chaguaramas	1,151 1,273 Chaguaramas	2,085 CBA-469
≃CRP	Equal	Other CRP mutants CBA-mutants	All others	2,085 and others CRP mutants	All other CRP mutants CBA-82 CBA-111 CBA-469	All others	Others	All others	All others
≪CRP	All CBA mutants and hybrids	CBA-467	Nil	All CBA mutants and hybrids	Rest CBA mutants and hybrids		Nil	1,261 1,265	Nil

hybrid. But there is no direct relationship between flag leaf N and grain N in CRP and its mutants and the Changuaramas hybrid. Thus, the transfer of N from flag leaf to grain is variable in different mutants. For example, 2085 has the best transfer of N, but 1243 and 1261 both have more N in the flag leaf and in the grain. One thousand two hundred and sixty five, however, has poor transfer while Chaguramas has good transfer. The high residual N in the rachis in CBA 467, Chaguaramas 1243 and 1279 are examples of faulty distribution of nutrients in rachis as compared to CRP.

Phosphorous

There are significant differences between genotypes in P content in grain, flag leaf and rachis. Mutants 1151, 1273 and 1028 and Chaguramas have more P in the grain than CRP. All other CRP mutants are equal to the parent. CBA mutants are also equal to CRP. The mutants 1261 and 1265 have significantly more P in the flag leaf but this is not reflected in grain P. The rest of the CBA mutants and hybrids are inferior to CRP in P flag leaf. Mutants 1151, 1274 and the Chaguarama hybrid have more P left in the rachis than CRP. However, they have more grain P than CRP. Therefore, only mutant 1028 has more grain P and less rachis P with better transfer of P to the grain than the others.

Potash

There are no genotypic differences in grain, flag leaf or rachis for potash. However, 2085 and CBA 469 have consistantly more K in grain, flag leaf and rachis than CRP, with minimal sampling variation.

N, P and K content in realtionship to CRP

A comparison of the distribution of the genotypes with different levels of N, P and K is presented in a two-way table with the N, P, K content in grain, flag leaf and rachis in relationship to the control CRP. The 3 groups are (a) those having a higher nutrient content than CRP, (b) equal to CRP and (c) less than CRP. These results show that none of the mutants are consistently superior to CRP in N, P and K in all of the three plant parts. It is also clear that not a single genotype is superior to CRP for all the three elements in the same plant part. Some mutants appear to have higher nutrient status in more than two combinations of nutrients and plant parts. On this basis, the mutants 1261, 1279, 1265, 2085 and CBA 469 can be considered to be superior to CRP in nutrient accumulation in grain or flag leaf and rachis. All CBA mutants and the hybrids were inferior to CRP in grain N and most of them equal to CRP in grain P and K and N, P, K of flag leaf. The K levels are in general similar in all the mutants. It is necessary to find out why CBA mutants are deficient in this aspect in spite of their larger grain size, hard endosperm and higher seed weight compared to CRP. CBA is also known for rapid grain filling.

Inter-relationships between nutrient accumulation

The correlations between the content of N, P and K in grain, flag leaf and rachis, the relationship between the content of the same nutrient in the three plant parts studied and the relation between grain yield and N, P or K in the above mentioned plant parts are summarised in Table 5. The positive relation between N and P in grain and flag leaf and the absence of any large positive association between N, P and K for grain and flag leaf shows that these two nutrients can be easily incorporated into grain in high levels. The association between N, P and K in the flag leaf will permit selection for higher grain nutrients by initial selection of the content in flag leaf. The absence of any large negative association between N, P and K in the rachis indicates that the transfer of nutrients to the grain is quite good in the present material with little residuals left in the rachis.

From the second part of the above Table 5, an interrelation between the same nutrients between the three plant parts again confirm the high correlation of N, P and K content between grain and flag leaf and also grain and rachis. The limited association between flag leaf and rachis for all three nutrients suggests that, in general, the nutrients from flag leaf are mostly transferred to the grain with some variation between genotypes. The absence of any relation between grain yield and N, P, K levels in the grain shows that it is possible to improve yield with high levels of these nutrients in grain. The significant positive relation between N and P in the flag leaf with yield is encouraging, so that early selection of N and P content in flag leaf can help increase yield levels indirectly. The nutrient content in rachis was low and had no relationship with grain yield. However, the low yield groups appear to retain more P in the rachis (Table 6).

Table 5. Correlations between yield and N, P and K content in some mutants and hybrids of sorghum (1981–82)

	Grain A	Flag leaf B	Rachis C
1. Correlation of yield with			
Nitrogen	0.082	0.450**	0.071$^{\mathrm{n.s}}$
Phosphorous	–0.099$^{\mathrm{n.s}}$	0.440**	–0.240**
Potash	0.002$^{\mathrm{n.s}}$	0.027$^{\mathrm{n.s}}$	0.044$^{\mathrm{n.s}}$
2. Interrelations between plant parts			
	A vs B	A vs C	B vs C
Nitrogen	0.585**	0.397**	0.173*
Phosphorous	0.247**	0.612**	–0.180*
Potash	0.684**	0.568**	0.324**
	A	B	C
N vs P	0.476**	0.755**	0.143*
N vs K	–0.176*	–0.083$^{\mathrm{n.s}}$	–0.285**
P vs K	0.181	–0.157*	0.074$^{\mathrm{n.s}}$

Discussion

The results of this paper show that yield increases in mutants generated from the same variety have no adverse effect on N, P and K content in grain. It is also clear that there are genetic differences among the mutants in the mobilization of these nutrients from the flag leaf to the panicle and the partition of N and P within the panicle, and root activity.

The possibilities of yield improvement by effective selection for such leaf characters as leaf weight, soluble protein content, chlorophyll content and photosynthetic activity, and the time of physiological maturity, is demonstrated in soybean (Secor et al. 1982). Similarly, some characters such as earliness and rapid accumulation of dry matter and an active root system are also important under conditions of moisture stress. Early maturing, high yielding genotypes with a high rate of grain dry matter accumulation have been obtained in maize, wheat and sorghum (Gebeyehou et al. 1982). The importance of leaf area duration and the grain filling period for increasing the genetic potential for yield in wheat was demonstrated by Borojovic and Williams (1982). However, yield and grain quality are dependent on genetic differences in the uptake of N, P and K in soils deficient, as in our study, for these nutrients. The role of active root systems have been indicated in cowpea (Adepetu and Akapa 1977). The importance of total root surface for efficient absorption of the nutrients is emphasized by them. Moreover, the interactions between uptake of major nutrients like K and N during grain filling period is to be considered similar to that found in spring wheat (Koch and Mengel 1977). These researchers observed that higher K improved the translocation of N from the vegetative plant parts to the grain. It will be useful to know which specific enzymes are involved in these interactions. The transfer of nutrients to grain during seed development is emphasized by several people and the possible role of environment on this phenomenon is described by some (Housley Kirlejs et al. 1982; Gebeyehou et al. 1982; Heinrich et al. 1983; Sorrells and Myers 1982). Available information on the relevance of the above results from crops grown under better environments with those on Sorghum, mostly grown under moisture stress and poor management in semi- arid regions, is not adequate.

The stability of sorghum yield in different environments in the USA is due to the maintenance of seed size, seed panicle and number of panicles, particularly in the poor environments (Heinrich et al. 1983). Therefore, selection for seed number and seed size is recommended by them for yield stability as there is no evidence of compensation among the yield components. In grain sorghum early and medium maturing genotypes are more stable than late maturing genotypes (Saeed and Francis 1983). The importance of non-senescence for higher yield in providing more carbohydrates at all mature stages of kernel development as

Table 6. Yield groups and means for N, P and K contents in some mutants and hybrids of sorghum (1981–82)

Yield group	Nitrogen (% of dry matter)			Phosphorous (µg P/g of dry matter)			Potash (% of dry matter)		
	A	B	C	A	B	C	A	B	C
Group I									
(>CRP)	1.34	1.08	0.46	3,073	3,718	1.508	0.26	0.50	0.53
CRP-2085, 1279, 1028, 1265, CBA-467	(1.22–1.42)	(0.89–1.25)	(0.41–0.54)	(2,601–3,437)	(2,689–4,387)	(866–1,933)	(0.13–0.30)	(0.38–0.56)	(0.50–0.73)
Control	1.39	1.09	0.43	3,004	3,591	1,653	0.21	0.34	0.45
Group II									
(≃) CRP)	1.21	0.94	0.43	3,227	3,568	1,980	0.29	0.49	0.74
CRP-1151, CBA-111, 469, 82	(1.13–1.28)	(0.84–0.99)	(0.40–0.44)	(2,809–3,797)	(3,366–3,986)	(1,560–2,727)	(0.25–0.33)	(0.47–0.51)	(0.58–0.88)
Group III									
(<CRP)	1.36	1.01	0.48	3,294	3,709	1,689	0.28	0.51	0.53
CRP-1273, 1261, 1243, CBA-100	(1.22–1.43)	(0.77–1.18)	(0.44–0.56)	(3,070–3 425)	(2,665–4,583)	(857–2,166)	(0.26–0.31)	(0.48–0.60)	(0.40–0.60)
Group IV									
(≪ CRP)	1.31	0.90	0.47	3,223	2,768	1,787	0.27	0.43	0.50
Hyb. barinas, chaguaramas	(1.10–1.52)	(0.84–0.95)	(0.40–0.54)	(2,714–3,732)	(2,728–2,808)	(1,483–2,090)	(0.23–0.31)	(0.39–0.47)	(0.40–0.59)

( ) = range; A = grain; B = flag leaf; C = rachis

compared to rapid senescence is to be recognized (McBee et al. 1983). The positive effect of close spacing on increased carbohydrate level in the culm (McBee and Miller 1982) must also be related to the dwarf mutants in our study. A comparison of mutants from the same variety rather than a comparison of different varieties for the above physiological attributes can help reduce the complexity of the genetic background and enable and understanding of the relationships between yield, and nutrient uptake and partition, as attempted in our present investigation.

Concentration in plant parts and yield

The uptake of N and its relation to yield is important in fertilizer recomendation. Plant analysis even 3 weeks after emergence in barley is found to be a good indicator of N uptake (O'Neill et al. 1983). P concentration in the early growth stage is related both to the rate of application and to final grain yield in corn (Rehm et al. 1983). It was also felt in the ear leaf (similar to flag leaf) at silking. There was an increase in P with a higher rate of P and K application in the early stages but not at the time of silking. At silking, the rate of applied K has no longer any influence on P concentration in the ear leaf. Therefore, the uptake of N, P and K is not mutually contradictory. Hence, it is possible to select, even in the seedling stage, for efficient uptake of N, P and K simultaneously which has also good positive effect on final grain yield. Thus, seedling evaluation for superior N, P, K utilization can be effective for the rapid screening of large number of progenies for final yield. This is very important in soils with low moisture. The efficiency of the root system at the seedling stage is important. The rate of grain filling in the early stages and the rapid transfer of nutrients from leaf to grain in the early stages is important for quality of protein in grain, stability yield and better utilization of applied N as seen in maize by Tsai et al. (1983), and may be applicable to other crops. This was evident in CBA, one of the parents of the mutants in our study.

Root activity and distribution in early growth stage is important in the uptake of N, P and K. While the rooting pattern down the soil profile can be measured by using models (Greenwood et al. 1982), the use of P^{32} in measuring root activity is rapid both in the field and in the laboratory. This latter technique revealed large differences between mutants in our study. In Venezuelan sorghums used for forages and grain, the amount of reserves of nutrients in roots, particularly carbohydrates and N, may be important for regeneration while the amount and the time of fertilizer application may also influence the nutrient reserves in the roots (Tromp 1983). The relative content of soluble and insoluble forms of N and carbohydrates reserves in root systems need further study in the sorghums of Venezuela where cattle are allowed to graze the ratoon crop.

It may be concluded that an alteration in a plant type in CRP and CBA by mutation breeding has opened new possibilities of yield improving with simultaneous increases in the nutrient status of grain, particularly for N and P. This study has also provided the possibility for early selection for yield and nutritional quality by analyzing the flag leaf and selecting for genotypes with better accumulation in the flag leaf. However, as reported earlier, (Valera and Murty 1984) two or more leaves immediately below the flag leaf are equally important in the transfer of the photosynthesic crop to the grain. The composite sample of these three or four leaves may provide another parameter for selection providing sufficient personnel are available for sampling and analysis.

It is interesting that the most productive mutants of CRP have an equal or more leaves than CRP, while in CBA, the leaf number is reduced by nearly 50% in the mutants. The harvest index in the group of mutants is aproximately similar. However, the yield in CRP mutants is accompanied by an increase in biomass production while in CBA mutants it was reduced although partition is better. These results are in contrast to the results found in semidwarf cereals in wheat and rice where there was no increase in biomass production for the past century. Thus, tropical adaptation in Sorghum under semi-arid conditions appears to be more complex than that of other cereals and requires more study with diverse sterile cytoplasms.

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