1244

Biomass and harvest index as indicators of nitrogen uptake and translocation to the grain in sorghum genotypes

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Introduction

Nitrogen is usually the most limiting nutrient for crop production and the poor recovery of applied fertilizer nitrogen by crops is of world wide concern. The differential response of sorghum (*Sorghum bicolor* L. Moench) genotypes to applied nitrogen suggests that differences in nitrogen uptake, translocation and accumulation in the grain exist[1]. This paper deals with (i) the extent of variation in sorghum for the above characters, (ii) correlations of these traits with agronomic traits such as days to flower, biomass and grain yield and, (iii) the implications of (i) and (ii) in breeding and crop management.

Materials and methods

Two trials were conducted at the ICRISAT Center on deep Vertisols during the post rainy (winter) season under high fertility (100 kg N, 60 kg P_2O_5/ha) and intensive plant protection with four replications. Trial I contained 40 elite breeding entries and Trial II contained 48 selected germplasm lines. Trial I received a basal application of fertilizer (100 kg N, 60 kg P_2O_5) and no irrigation. Trial II recieved 60 kg N and 60 kg P_2O_5 in the seed bed and 40 kg N 28 days after planting. Irrigation was applied on the 22nd, 42nd, and 63rd day. Each plot consisted of 4 rows of 5 m length; the plant population was 12.1/m^2.

At maturity, 10 plants were randomly harvested for growth analysis. Dry weights of plant parts (culm, leaf, grain and chaff) were determined after drying the samples at 80°C for 24 hours. N concentration was determined on dry samples (ground in a Willey mill) using the standard micro-Kjeldhal method.

Tissue N percentages were multiplied by their dry weights to determine total content per plant part. GPP was computed by multiplying grain N percentage by 6.25. Harvest index (HI: grain wt./total above ground dry wt.) and nitrogen translocaton index (NTI: grain N/total N of the above-ground parts) were expressed as percentages.

Abbreviations GPP, grain protein percentage; HI, harvest index; N, Nitrogen; NTI, nitrogen translocation index; P, probability

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Results and discussion

Variations in agronomic and nitrogen physiology traits (Table 1)

There was significant ($P < 0.05$) genotypic variation for all the traits listed in Table 1. The variability was generally larger in germplasm lines (Trial II) than in elite breeding material adapted to the postrainy season (Trial I).

Plants in Trial II were generally late in flowering. This was partly due to a week's delay in sowing during the cooler winter season and partly due to variations in genotypes. Irrigation further delayed maturity and the biomass was substantially higher in Trial II. In spite of lower HI, the grain yield in Trial II was also higher than in Trial I. Both plant and grain N contents were higher in Trial II, but the efficiency of transfer of dry matter or N to the grain (HI and NTI, repectively) was higher in Trial I.

Correlations between traits (Table 2)

The biomass was positively correlated with days to flower and grain yield in both the trials. Biomass was also found to be significantly and negatively correlated with HI in Trial I; this was probably due to water stress during the grain filling stage.

GPP was negatively correlated with HI, indicating that a proportionally greater transfer of dry matter occurs than N, resulting in its dilution. Kramer[4] has shown that the measured genetic variability for GPP is less after adjusting for HI.

Both total plant N and the N in the grain were strongly correlated with total biomass and grain yield. They were usually correlated with all those traits with

Table 1. Phenotypic variability in agronomic and nitrogen physiology traits in sorghum

	Trial I				Trial II			
	Mean	Standard deviation	Range	Check CSH1	Mean	Standard deviation	Range	Check CSH1
Grain yield (g/plant)	30.2	10.9	54.3–9.0	38.2	43.3	16.30	95.1–21.6	62.3
Biomass (g/plant)	68.0	22.5	132.0–31.2	69.2	119.2	53.7	278.7–50.5	118.7
HI (%)	44.7	9.2	60.7–20.9	55.2	38.5	9.1	53.9–13.7	52.2
Days to flowering	69.0	6.5	95.0–57.0	68.0	75.3	10.1	99.0–61.0	73.0
Protein % in grain	9.86	0.86	11.631–7.988	8.463	10.44	1.63	15.63–6.25	10.56
Total N in plant (g)	0.628	0.203	1.140–0.224	0.639	1.13	0.39	2.3–0.6	1.45
Total N in grain (g)	0.471	0.164	0.826–0.159	0.517	0.71	0.26	1.56–0.36	1.00
NTI (%)	74.6	7.9	85.7–54.8	80.9	63.1	8.4	79.5–34.0	69.4

Table 2. Phenotypic correlation coefficients between agronomic and nitrogen physiology traits in sorghum (The upper row values refer to Trial I; values for Trial II are found in parentheses)

	Grain yield	Biomass	HI	Days to flowering	Grain protein %	Total N plant	Total N grain
Biomass	0.755 ***†						
	(0.701)***‡						
HI	0.520 ***	−0.109					
	(0.202)	(−0.504)***					
Days to flowering	0.048	0.475 **	−0.414 *				
	(0.339)*	(0.743)***	(0.656)***				
Grain protein %	−0.327 *	−0.096	−0.355 *	0.112			
	(−0.237)	(0.147)	(−0.377)**	(−0.026)			
Total N/plant	0.889 ***	0.870 ***	0.229	0.245	0.031		
	(0.812)***	(0.929)***	(−0.269)	(0.596)***	(0.229)		
Total N grain	0.969***	0.781 ***	0.452 **	0.082	−0.104	0.956 ***	
	(0.917)***	(0.761)***	(0.066)	(0.325)*	(0.159)	(0.916)***	
NTI	0.510 **	0.007	0.837 ***	−0.303	−0.425 **	0.155	0.422 **
	(0.340)*	(0.237)	(0.762)***	(−0.597)***	(−0.018)	(−0.023)	(0.159)

† Corresponds to Trial I (n = 40) * $P < 0.05$
‡ Corresponds to Trial II (n = 48) ** $P < 0.01$
*** $P < 0.001$

which biomass and grain yields were correlated. This shows the greater importance of increasing dry weight than of increasing N concentration itself, for harvesting more nitrogen in the grain. Thus, for any further increased grain protein content, after maintaining high HI, one should increase the biomass productivity, which will be influenced by crop growth duration. Maintenance of green-leaf area for a longer duration and the continued uptake of N during grain filling[5] should be given due consideration for increasing GPP at high yields.

Nitrogen uptake and metabolism are energy dependent and hence greater photosynthetic activity is required to support higher uptake[2]. Plants flowering late have larger leaf area[6] and possibly deeper roots. Such plants are usually large in size and have greater capacity for photosynthesis, N uptake and assimilation. Preliminary results show that in general the genotypes capable of promoting nitrogen fixation are late maturing and large in size (S. P. Wani, ICRISAT, personal communication). In such plants the correlation between GPP and grain yield is likely to be insignificant (Trial II). Late maturing plants give more stover (fodder) with same grain yield than early genotypes[6]. Tucker and Bennett[7] have reported that short-season sorghum hybrids have a shorter critical period (6–7th leaf to boot) for N uptake than long season hydrids, and hence demand a higher level of N during this period. They are also likely to lose much N to weeds since their ability to compete with the latter is less (as the canopy is less competitive) than long-season cultivars. However, where irrigation is not available or the season is short, selection for early flowering and high HI is the best strategy for harvesting maximum grain and protein.

Breeding for nitrogen uptake and translocation

In both the trials the total N in the plant and NTI were strongly and positively correlated with total biomass and HI. This suggested that selection for high biomass and HI is sufficient to ensure high N uptake and translocation. Similarly, F_3 progenies selected for high biomass and HI also have high N content and NTI[3].

Exceptions to the general trends do exist however. From re-evaluation of the

Table 3 Variability in biomass, grain yield, nitrogen uptake, and translocation in selected sorghum genotypes

	P-721	IS 858	IS 2223	Diallel 642	IS 6380
Biomass (g/plant)	60.6	79.1	53.6	61.5	70.2
Grain yield (g/plant)	18.3	27.2	21.8	24.1	15.1
HI (%)	39.6	36.6	41.5	33.7	26.7
Total N (g/plant)	0.78	0.77	0.48	0.56	0.67
NTI (%)	49.2	52.1	57.4	40.3	34.6

original study it was possible to identify genotypes with approximately the same biomass and HI which varied considerably in nutrient uptake and transfer to the grain. For example, P-721 and Diallel 642 both have similar dry weights (60.6 and 61.5 g/plant respectively, Table 3), but P-721 takes up 39 per cent more N than Diallel 642 (0.78 and 0.56 g N/plant, respectively) and has nine per cent higher NTI. Such individual differences are usually masked when the data for the whole set of heterogenous genotypes are analysed.

In order to determine whether such differences are significant in a practical breeding program, we made crosses between contrasting parents and selected F_2 plants for a range of dry weights per plant and HIs. In F_3 progenies, estimates of dry weight, grain yield, and N in the grain and whole plant were made[3]. The biomass and total nutrient taken up by F_3 progenies in each family were again strongly correlated [*e.g.*, in progenies of IS 2223 × IS 6380 cross the correlation coefficient (r) between dry weight and total nitrogen was 0.91, $P<0.01$]. We observed similar relationships between HI and NTI ($r=0.88$, $P<0.01$). Therefore, we conclude that selection for biomass and HI also effectively includes selection for traits concerned with nutrient efficiency.

Hence the routine screening for these traits is unnecessary; only the parents used in the crosses or the material in the final stages of breeding program need to be analyzed for N to confirm that they have more than average N uptake and translocation efficiency.

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