Genotypic variation in biomass production and nitrogen use efficiency in pearl millet [*Pennisetum americanum* (L.) Leeke]*

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Summary Twenty diverse pearl millet genotypes ranging from landraces to high yielding hybrids were studied for genotypic variation in nitrogen (N) use efficiency in high (100 kg N/ha) and low fertility (20 kg N/ha) over two years in the field.

The combined data over years and fertility levels indicated that despite taking up similar amounts of N, genotypes differed significantly in biomass production and thus in N use efficiency. A West African genotype, Souna B, had N use efficiency values 32% higher than the less efficient Indian genotype BJ 104 even though both genotypes had similar N uptake. An increase in N fertility decreased N use efficiency since the percentage increase in biomass was smaller than the percentage increase in N uptake.

Introduction

Nitrogen (N) fertilizers are required to maximize cereal crop food production in some environments and global production and consumption of fertilizer N are expanding. In spite of an increase in the use of N fertilizers, the poor efficiency with which many crop plants recover fertilizer N from the soil has been generally recognized[2]. Low recovery of fertilizer N from the soil and growing concern over the nitrate pollution of ground waters, have increased the need to improve the plant's efficiency to recover and use the fertilizer N.

Breeding plants for less favourable environments emphasizes developing plants to fit their environment rather than modifying the soil through fertilizer input. For plant breeding practices to be successful in alleviating soil stress problems in crop production, genetic variability must exist within the plant species. Many aspects of mineral nutrition are under genetic control[8]; the efficiency of N utilization in tomatoes has particularly been reported to be controlled by a few major dominant genes[15]. Genotypic differences in N uptake and/or utilization have been recognized in maize[3,6,12], sorghum[10], pearl millet[1] and wheat[7]. However, detailed information on genetic differences in N utilization has not been reported for pearl millet. Such information may be important since this crop is generally grown in infertile soils with little or no fertilizer input.

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Identification of intraspecific variation in N use efficiency is also necessary to investigate mechanisms controlling such variations in pearl millet. The specific objectives of this field investigation were to:

(i) identify and document within-species variation for the ability of pearl millet (*Pennisetum americanum* (L.) Leeke] genotypes to absorb and utilize N, and

(ii) study the effect of levels of N applied on N utilization.

Materials and methods

From a large diverse genotype set that was evaluated for performance under 20 and 100 kg N/ha, the top and bottom ten genotypes were selected for detailed investigation reported here. These 20 genotypes representing a range of materials including improved landraces, inbred lines, varieties and high yielding F_1 hybrids (Table 1) were grown on Alfisol at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India during 1978 and 1980 rainy season at high (100 kg N + 25 kg P/ha) and low (20 kg N + 9 kg P/ha) fertility, using di-ammonium phosphate and Urea. Available soil N was measured only during 1980. Nearly 50 kg N/ha of nitrate N accumulated in the profile (120 cm depth) at the beginning of the season. The experimental site has been designated as high and low fertility environments based on pearl millet productivity and N uptake by the plants (the maximum values: for biomass 1030 and 675 g/m^2; for N uptake 12.4 and 5.8 g/m^2 for HF and LF respectively). The rainfall during the cropping season (June-September) was 1007 in 1978 and 727 mm in 1980. The experiment was conducted as a split plot design with fertility as main plots and genotypes as subplots. Plots were 4 m (1978) or 9 m (1980) long and consisted of four rows at 75 cm spacing. Excess seeds were planted and thinned to a final stand of 13.3 plants/m^2.

Table 1. List of genotypes, genetic constitution, their origin and days to flowering

Genotype	Genetic constitution	Country of origin	Days to flowering	
			HF	LF
Souna B	Open pollinated variety	Mali	60	62
P3 Kolo	Open pollinated variety	Niger	57	57
3/4 Hainei Khirei	Open pollinated variety	Niger	54	56
IP 2757*	Germplasm accession	Niger	48	49
Serere 17	Breeding line	Uganda	52	52
Serere Comp. 1(M)	Breeding composite	Uganda	49	50
Serere Comp. 2(M)	Breeding composite	Uganda	46	47
Super Serere Comp.	Breeding composite	Uganda	49	49
ICI 266	Inbred line	India	48	49
700112	Breeding line	Nigeria	52	53
700651	Breeding line	Nigeria	52	54
700440	Breeding line	Nigeria	53	56
700331	Breeding line	Nigeria	56	57
700772	Breeding line	Nigeria	50	50
700250	Breeding line	Nigeria	57	56
700441	Breeding line	Nigeria	51	51
700471	Breeding line	Nigeria	53	53
ICMS 7703	Open pollinated variety	India	47	49
BK 560	F_1 Hybrid	India	44	45
BJ 104	F_1 Hybrid	India	42	43

* IP = International *Pennisetum*

Table 2. Intraspecific variation in biomass, N uptake and N use efficiency in 20 pearl millet genotypes[a]

Genotypes	Biomass (g/m^2)	N uptake (g/m^2)	N use efficiency (g/g)
Souna B	813 ab*	7.5 a–c	123 a
P3 Kolo	740 a–e	7.8 a–c	106 b–d
3/4 Hainei Khirei	731 a–f	7.1 a–c	112 bc
IP 2757	717 b–g	7.4 a–c	109 bc
Serere 17	751 a–d	7.1 a–c	105 b–d
Serere Comp. 1(M)	769 a–c	8.2 ab	105 b–d
Serere Comp. 2(M)	717 b–g	7.9 a–c	101 c–e
Super Serere Comp.	714 b–g	7.1 a–c	113 bc
ICI 266	612 h	6.8 a–c	102 c–e
700112	727 a–f	7.0 a–c	114 ab
700651	711 c–g	7.6 a–c	105 b–e
700440	696 c–h	7.2 a–c	109 bc
700331	761 a–d	7.9 a–c	111 bc
700772	673 c–h	7.7 a–c	102 c–e
700250	663 d–h	7.1 a–c	101 c–e
700441	632 f–h	7.1 a–c	102 c–e
700471	598 h	6.5 c	103 b–e
ICMS 7703	818 a	8.4 a	108 bc
BK 560	645 e–h	7.7 a–c	95 de
BJ 104	620 gh	7.7 a–c	93 e

[a] Data represent means over two years and two fertility levels.

* Any means within a column followed by the same letter are not significantly different at $P = 0.05$, according to Duncan's Multiple Range Test.

At physiological maturity (black layer at the hylar region of the seed) an 80 cm length of the two internal rows of the plot was cut 1 cm above the soil (16 plants). These samples were oven dried at 80 °C for 72 h, weighed and ground to pass through a 0.5 mm screen. Organic nitrogen was determined from 0.5 g acid (2 ml sulphuric acid + hydrogen peroxide) digested plant material using a colorimetric method in a Technicon Auto Analyser. From the above ground biomass and N concentration values N uptake and N use efficiency (above ground biomass production per unit of N in the plant) values were calculated. The term N use efficiency used here is equivalent to the inverse of N concentration.

Results and discussion

Genotypic variation in N use efficiency

Differences in N uptake between two fertility levels were substantial (genotypic mean N uptake: 10.5 and 4.5 g/m^2 for HF and LF respectively). The fertility X genotype and the year X fertility X genotype interactions were not significant. Hence for the sake of simplicity, the combined data for two fertility rates over two years were used to document genotypic variations for N uptake and N use efficiency. The genotype means were ranked for biomass, N uptake and N use efficiency and compared (Table 2). Genotypes differed widely in N use efficiency.

Table 3. Effects of high fertility (HF) and low fertility (LF) on N use efficiency of 20 pearl millet genotypes

Genotypes	Nitrogen use efficiency (g/g)*	
	HF	LF
Souna B	105.5	140.4
P3 Kolo	91.8	120.1
3/4 Hainei Khirei	97.2	126.9
IP 2757	86.6	131.6
Serere 17	91.5	118.6
Serere Comp. 1(M)	92.0	118.7
Serere Comp. 2(M)	85.0	116.2
Super Serere Comp.	93.3	131.6
ICI 266	81.2	122.1
700112	97.4	131.4
700651	93.2	116.5
700440	91.3	126.3
700331	94.0	128.1
700772	79.3	124.3
700250	89.5	113.3
700441	85.2	119.6
700471	87.1	118.5
ICMS 7703	90.1	125.7
BK 560	97.2	113.4
BJ 104	75.3	111.4
Mean	89.2	122.7

* Data represent mean over two years.

Except for genotype 700471, genotypes did not differ in N uptake. However, consistent and significant ($P < 0.001$) differences in N use efficiency between genotypes were measured. The N use efficiency values were highest in West African improved landrace Souna B and lowest in Indian hybrid BJ 104. Differences in the ability of genotypes to utilize N were not related to N uptake. Souna B had 30% higher N use efficiency than BJ 104, even though both genotypes had a similar N uptake values. The differences in N use efficiency between these genotypes were confirmed in nutrient culture solution experiments (Alagarswamy *et al.* unpublished data).

Genotypic differences for N use efficiency at similar N uptake levels are important for better utilization of fertilizer N. The improvement in plant N use efficiency combined with better root distribution and improved fertilizer management practices are likely to improve crop productivity and economy of fertilizer application. Such economic benefits have been anticipated[13]. In addition benefits could be achieved by reducing environmental pollution by nitrate in the ground water.

Significant correlations existed between N use efficiency and days to flowering among all the genotypes ($r = 0.45$ $P < 0.001$), indicating that

more efficient genotypes tended to be later maturing. However, biomass production was not related to days to flowering.

Effects of N level on N use efficiency

The effect of applied N level on N use efficiency for the 20 genotypes is presented in Table 3. Increase in the amount of applied N decreased N use efficiency in all genotypes. The N use efficiency values decreased by 25% in an efficient genotype Souna B compared to a 32% reduction in an inefficient genotype BJ 104 with an increase in N supply. These results are in contrast to those reported for sorghum, where both efficient and inefficient genotypes showed similar decrease in N use efficiency as N was increased in nutrient solution[17]. The decline in N use efficiency at HF was due to differential effects of N supply on N uptake and biomass production. The overall mean N uptake for the genotypes increased by 130% while the biomass increased by only 60% in response to increased N level. N use efficiency was thus inversely related to N uptake ($r = -0.74$, $P < 0.001$). Increased N supply is generally known to reduce N use efficiency in maize[12,14], wheat, triticale and rye[9,16], and in sorghum[11,17].

Plant species differ in N use efficiency. Plants with C_4 metabolism utilize N more efficiently than C_3 species[5]. C_4 plants have been found to have higher CO_2 exchange rates per unit tissue N and a steeper linear increase in CO exchange rate with increased leaf N than C_3 plants[4]. However, the mechanisms for intraspecific variations in N use efficiency are not yet known. Hence documenting the existence of intraspecific variation in N use efficiency is a necessary preliminary prior to investigate the mechanisms for variation in N use efficiency among pearl millet genotypes.

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