Indian Journal of Agronomy **57** (1): 49–54 (March 2012)

Productivity, nitrogen-use efficiency and economics of sweet sorghum (*Sorghum bicolour)* genotypes as influenced by different levels of nitrogen

KHALED MIRI[1], D.S. RANA[2], K.S. RANA[3] AND ASHOK KUMAR[4]

Indian Agricultural Research Institute, New Delhi, 110 012

Received : June 2011; Revised accepted : December 2011

ABSTRACT

A field experiment was conducted at New Delhi, during rainy seasons of 2009 and 2010 to evaluate 3 sweet sorghum {*Sorghum bicolour* (L.) Monech} genotypes ('RSSV 9', 'SSV 84' and hybrid 'CSH 22 SS') under four nitrogen levels (0, 50, 100 and 150 kg N/ha) for productivity of ethanol, grain and fodder, nitrogen-use efficiency and economics of production. Results pooled over two years indicated that stalk yield (75.3 t/ha) and fodder yield (16.0 t/ha) recorded significant increase only up to 100 kg N/ha, while fermentable sugar (4.34 t/ha), estimated ethanol (2.46 KL/ha) and grain yields (2.6 t/ha) responded up to 150 kg N/ha. Hybrid 'CSH 22 SS' recorded 28, 40, 34, 34, 33 and 26% higher stalks (85.6 t/ha), juice (30 KL/ ha), fermentable sugar (4.6 t/ha), estimated ethanol (2.6 KL/ ha), grain (2.4 t/ha and fodder (16.8 t/ha) yields than genotype 'RSSV 9' and 57, 110, 112, 112, 41 and 46% than genotype 'SSV 84'. Sorghum grain equivalent (11.1 t/ha) based on ethanol, grain and fodder yields recorded with 150 kg N/ha was significantly higher over 100 kg N/ha. Hybrid 'CSH 22 SS' recorded significantly higher sorghum grain equivalent yield (11.35 t/ha), when compared to 'SSV 84' (6.15 t/ha) and 'RSSV 9' (8.53 t/ha). Nitrogen-use efficiencies like partial factor productivity, agronomic nitrogen-use efficiency and crop recovery efficiency decreased with increasing dose of nitrogen. 'CSH 22 SS' had the highest agronomic nitrogen-use efficiency (14.5 kg grain/kg N applied) and partial factor productivity (30.7 kg/kg N applied) followed by 'RSSV 9'. Maximum gross returns (₹101,410), net returns (₹55,670) and net B:C ratio (1.17) were recorded with application of 150 kg N/ ha. 'CSH 22 SS' produced the highest net returns (₹55,900), which was (105 and 39% higher over 'SSV 84' and 'RSSV 9', respectively. Application of 150 kg N with 'CSH 22 SS' produced the highest values of juice yield (40KL/ ha), estimated ethanol yield (3.47 KL/ha) and grain yield (3.3 t/ha).

Key words: *Economics, Ethanol yield, Genotypes, Grain yield, Nitrogen-use efficiency, Sweet sorghum.*

Sweet sorghum is an attractive bio-fuel crop because of an easy accessibility of readily fermentable sugars combined with very high yields of green biomass suitable for production of more quantity of ethanol per unit time, per unit cost and per unit of water and nutrients used (Sipos *et al*., 2009; Ratnavathi *et al*., 2010). Besides, bio-fuel, it is good yielder of nutritious food, feed and fodder. India is resorting to the import of ethanol for meeting the requirement of ethanol for blending the petrol as per the programme of Govt. of India. In India, sweet sorghum has been used in the past to produce concentrated syrup with a distinctive flavour due to its characteristic of juicy stalks high in sugar (Lakkana *et al*., 2009). It belongs to the C_4 family with a high photosynthetic activity and drought tolerance; therefore, it can be cultivated in almost all temperate and tropical climatic areas. The ethanol production process is more eco-friendly than that of sugarcane and its molasses (Morris, 2006; Sipos *et al*., 2009). At present, area under sorghum in India is fluctuating around 8 million hectare, a part of which can be easily diverted for sweet sorghum to supplement the requirement of ethanol for blending petrol. Recently a good number of varieties and genotypes of sweet sorghum has been developed under Directorate of Sweet Sorghum, Hyderabad for different locations. There is need to evaluate the suitability of these genotypes for different agro-climatic condition, which is a pre-requisite for exploiting the yield potential of any genotypes.

Nitrogen is the most important among plant nutrients required for crop production and is required in the greatest quantities among fertilizer nutrients. Although N plays a very important role for good growth and development of

Based on a part of Ph.D. thesis of first author submitted to IARI, New Delhi, during 2011

[1&2]**Corresponding authors Email**: kh_miri2003@yahoo.com; dsrana5554@yahoo.com

[2&3]Principal Scientist, Division of Agronomy; [4]Principal Scientist, DMR, New Delhi

sorghum, over-fertilization is often harmful as it results in lodging, more susceptibility to insect-pests and diseases and thus reduction in yield and quality. Fertilizer sources of this nutrient are becoming costly, while inefficient use is partly responsible for air and water pollution and global warming. Nitrogen recommendations will vary with expected yield, soil texture, cultivars and cropping sequence (Amal, 2007). Optimum amounts of N fertilizer combined with other inputs play crucial roles in yield and overall quality of sorghum products. Keeping in view the above facts, the present study was conducted to evaluate sweet sorghum genotypes under different levels of nitrogen for higher productivity, nitrogen-use efficiency and economic returns under agro-climatic conditions of north-west plain zones of India.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* 2009 and 2010 at research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi, to study the effect of nitrogen levels and genotypes on growth and yield attributes and stalk, fermentable sugar, bio-ethanol, grain and fodder yields, nitrogen-use efficiency and economics of production of sweet sorghum genotypes. The experiment was conducted under split plot design with three replications. Four levels of nitrogen (0, 50, 100 and 150 kg N/ha) were assigned to the main-plots and three sweet sorghum genotypes (Two varieties 'RSSV 9' and 'SSV 84'and one hybrid 'CSH 22 SS') to the sub-plots. The soil of experimental site was sandy loam in texture with pH of 7.82 and having 178, 13.6, 218 kg/ha available NPK and 0.36 % organic carbon. Of the total N as per treatment, ½ was applied with recommended dose of phosphorus (60 kg P_2O_5/ha) in the form of single super phosphate and potassium (50 kg K_2O/ha) as muriate of potash as basal. The remaining ½ of the N was applied at 45 days after sowing. Crop sown on 9 July and 30 June in 2009 and 2010, respectively at 60 cm row to row spacing. At 20 days after sowing, plant to plant spacing of 20 cm was maintained after thinning excess plant. Weeds were controlled by pre-emergence application of atrazine (0.50 kg/ha) followed by 2 hand weedings at 20 and 40 days after sowing. Thiodan was sprayed twice to protect crop from stem borer. Rainfall received during the crop season was 411 mm and 564 mm during 2009 and 2010 respectively. Crop received five irrigations during 2009 and three irrigations during 2010 to protect the crop from early, intermittent and terminal drought. For obtaining of total green biomass yield, juice yield, yield of fermentable sugar and bio-ethanol yield from stalks and grain and fodder yields, sweet sorghum plants were harvested at physiological maturity stage. Immediately after harvest from each net plot, tassel removed for grain yield, canes were cleaned for fodder yield and cleaned stalks were crushed using three-roller squeezer to extract juice. Brix percentage in juice was recorded using digital hand refractometer model HI 96801. Yield of fermentable sugars and potential alcohol yield per hectare were obtained using following formula (Spencer and Meade, 1963):

Yield of fermentable sugars (t/ha) = Juice yield (t/ha) × Brix percentage × 0.85

Estimated ethanol yield (KL/ha) = Yield of fermentable sugar (t/ha) / 1.76

For calculation of various nutrient-use efficiency, following formulae were used:-

*Agronomic N efficiency (*kg yield increase per kg N applied) = $(Y_t - Y_0) / N_a$

Physiological N efficiency (kg yield increase per kg increase in N uptake) = $(Y_t - Y_0)/ (U_t - U_0)$

*Partial factor productivity (*kg harvest product per kg N applied*)* = Y_t / N_a

*Crop recovery efficiency (*kg increase in N uptake per kg N applied*)*= $(U_t - U_0) / N_a$

Where, Y_t= Grain yield in the test treatment (kg/ha); Y_0 = Yield in the control plot (kg/ha);

U_t= Total N uptake in the test treatment (kg/ha); U_0= Total N uptake in the control plot (kg/ha); N_a= N applied to the test treatment (kg/ha)

For calculating economics, sale price of ₹ 27/ litre of ethanol as per Government of India and ethanol processing cost of ₹13.25/ litre were used. For grain, minimum support price of ₹ 9000/tonne was used while for fodder sale price of ₹ 600/tonne was used. The data recorded were tabulated and analyzed statistically using Statistical Package for the Social Sciences (SPSS) version 18 software and LSD test at 5 per cent probability level was applied to compare the differences among the treatments, means. Data pooled over two years and pooled data have been presented and discussed in the paper.

RESULTS AND DISCUSSION

Ethanol yield and yield attributes

Nitrogen fertilization up to 150 kg N/ha significantly increased juice yield, fermentable sugar yield and ethanol yield in both the seasons (Table 1). Increase in green stalk yield and brix (%) with application of nitrogen was significant only up to 100 kg N/ ha. An increase to the tune of 42, 76.7, 80.2, 80.5 and 3.85 % in total green stalk yield, juice yield, fermentable sugar yield, ethanol yield and brix (%) respectively was recorded due to application of 150 kg N/ha over control. These variations in ethanol yield and yield attributes due to N application may be traced to the variation in growth attributes. Increase in ethanol yield due to nitrogen in sweet sorghum genotypes was primarily due to increase in fresh stalk yield, juice yield and sugar concentration. The results are in agreement with those obtained by Kumar *et al*. (2008), Poornima *et al*. (2008) and Ratnavathi *et al*. (2010). The difference in total green stalk yield, juice yield, brix (%), fermentable sugar yield and ethanol yield among the three genotypes were significant. Hybrid 'CSH 22 SS' was superior to varieties in all parameters, except brix (%), which was the highest in 'RSSV 9'. In varieties, 'RSSV 9' was significantly superior to 'SSV 84'. Based on two years pooled data, 'CSH 22 SS' recorded 56.7, 110.5, 111 and 112.2% increase in total green stalk yield, juice yield, fermentable sugar yield and ethanol yield, respectively compared to 'SSV 84' and 28.5, 40.0, 33.8 and 33.8% compared to 'RSSV 9', respectively. Increase in brix content 'RSSV 9' over 'SSV 84' and 'CSH 22 SS' was 5.3 and 5.0% respectively. Variations in the growth parameters among the genotypes (Table 1) account for variation in green stalk yield and thereby in juice and ethanol yields. This in turn helped in absorption of large amount of solar radiation and thus production of large quantities of photosynthates, which were eventually accumulated in stalks. Hybrid 'CSH 22 SS' produced greater expected ethanol yield, which was the natural corollary of stripped stalk weight. Similar findings were expressed by Wortmann *et al*. (2010).

Grain and fodder yields and yield attributes

Growth and yield attributes of sweet sorghum showed marked improvement with successive increase in nitrogen level only up to 100 kg N/ha. Effect of N application on grain yield was significant up to 150 kg N/ha, on fodder yield up to 100 kg N/ha and on harvest index up to 50 kg N/ha. This variation in grain and fodder yields corresponds to the variation in growth and yield attributes. Application of 150 kg N /ha caused 116, 68 and 25% increase in grain yield, fodder yield and harvest index, respectively over control. Increased grain yield due to N application could be ascribed to increased biomass production, improved harvest index and increased seed set with N fertilization. Positive effect of nitrogen on grain yield and yield attributes of sweet sorghum was reported by Buah and Nwinkara (2009) and Hugar *et al*, (2010). There were significant variations in growth and yield attributes, grain yield and fodder yield among sweet sorghum genotypes. Hybrid 'CSH 22 SS' produced the highest grain yield and fodder yield, which was 41 and 46 % higher than 'SSV 84 and 33.3 and 26.3% than 'RSSV 9' respectively. Harvest index did not show marked variation among genotypes. Low value of harvest index over the treatment as compared to normal value may be attributed to robust vegetative growth of plant under optimum input

Table 1. Effect of nitrogen levels and genotypes on growth and yield attributes, yields and quality parameters of sweet sorghum (Data pooled over two years)

Treatment	Plant height at harvest (cm)	LAI at 120 DAS	Ear length (cm)	Ear weight (g)	Grain weight/ Ear (g)	1000 grain weight (g)	Stalks yield (t/ha)	Juice yield (KL/ha)	Brix (%)	Fermen-table sugar yield (t/ha)	Estimated ethanol yield (KL/ha)	Fodder yield (t/ha)	Grain yield (t/ha)	Harvest index (%)	Sorghum grain equivalent yield (t/ha)
Nitrogen level (kg/ha)															
Control	233.9	3.86	20.3	51.9	34.3	25.2	56.3	15.8	17.8	2.41	1.37	10	1.2	0.08	5.97
50	249.7	4.16	23.1	60.0	42.4	28.2	65.5	18.7	18.1	2.90	1.65	12.8	1.8	0.10	7.60
100	278.5	4.53	25.4	72.5	51.7	30.1	75.3	25.1	18.6	3.96	2.23	16	2.3	0.10	10.05
150	293.1	4.71	25.6	74.3	53.9	30.6	78.6	27.9	18.2	4.34	2.46	16.8	2.6	0.10	11.1
SEm±	4.5	0.07	0.4	1.5	1.0	0.24	0.79	0.61	0.13	0.10	0.06	0.45	0.04	0.002	0.21
CD (P=0.05)	15.2	0.24	1.45	4.9	3.25	0.82	2.76	2.11	0.45	0.35	0.21	1.5	0.13	.008	0.73
Genotype															
'RSSV 9'	275.9	4.32	18.8	55.9	41.1	29.7	66.6	21.42	18.8	3.43	1.95	13.3	1.8	0.10	8.53
'SSV 84'	227.1	3.87	20.9	49.9	34.7	28.4	54.6	14.28	17.8	2.17	1.23	11.5	1.7	0.10	6.15
'CSH 22 SS.	288.5	4.76	32.35	88.7	58.6	27.9	85.6	29.99	17.9	4.59	2.61	16.8	2.4	0.10	11.35
SEm±	4.1	0.07	0.3	1.4	1.05	0.17	0.69	0.53	0.11	0.09	0.05	0.62	.02	.002	0.17
CD (P=0.05)	12.35	0.22	0.9	4.1	3.15	0.52	2.05	1.59	0.33	0.27	0.15	1.8	.08	NS	0.52

and favourable environmental conditions during the growth period. Variation in yield and yield attributes of sweet sorghum genotypes was also reported by Buah and Nwinkaran (2009).

Interaction effects of genotypes and nitrogen levels

Interaction effect of nitrogen levels and genotypes on juice yield, estimated ethanol yield and grain yield was significant (Table 2). With successive increase in N levels up to 150 kg N /ha, juice yield, estimated ethanol yield and grain yield of hybrid 'CSH 22 SS' was found to increase significantly. In case of 'RSSV 9' significant increase in juice yield was observed only up to 100 kg N/ha, while it was only up to 50 kg N in case of 'SSV 84'. With respect to estimated ethanol yield both ''RSSV9' and 'SSV 84' recorded statistically similar value with 0 and 50 kg N/ha. Subsequent increase up to 100 kg N/ha induced marked increase in estimated ethanol yield only in 'RSSV 9'. Grain yield was found to increase up to 150 kg N/ha in 'RSSV 9' while in 'SSV 84 ' response was significant only up to 100 kg N/ha. This interactive effect of N levels and genotypes is attributed to variation in genetic potential of genotypes. The results are in agreement with that of Rao *et al.*, (2006), who found that hybrids respond to higher levels of nitrogen, (more than 100 kg N/ha) compared to traditional varieties.

Table 2. Interaction effects of nitrogen × genotypes on juice yield, estimated ethanol yield and grain yield of sweet sorghum (pooled analysis)

Genotype	Nitrogen levels (kg/ha)			
	0	50	100	150
	Juice yield (KL/ ha)			
'RSSV9'	17.2	18.6	23.7	26.2
'SSV 84'	10.6	13.2	15.6	17.8
'CSH22 SS'	19.7	24.5	36.0	39.8
	SEm± = 1.06	CD (P=0.05) = 3.18		
	Estimated ethanol yield (KL/ ha)			
'RSSV9'	1.52	1.68	2.21	2.39
'SSV 84'	0.90	1.13	1.36	1.54
'CSH22 SS'	1.67	2.12	3.17	3.47
	SEm± = 0.10		CD (P=0.05) = 0.30	
	Grain yield (t/ha)			
'RSSV9'	1.13	1.70	2.20	2.51
'SSV 84'	1.01	1.51	1.91	2.10
'CSH22 SS'	1.32	2.12	2.92	3.31

Correlation and regression studies

Pooled analysis of data showed a significant correlation between estimated ethanol yield and yield attributes *viz.* Stalk and juice yields and brix percent (Fig. 1), which further justified the beneficial effect of nitrogen fertilization and sweet sorghum genotypes on estimated ethanol yield.

Nitrogen-use efficiency parameters

Nitrogen use efficiency parameters *viz.*, partial factor productivity (PFP), agronomic N-use efficiency (ANUE), physiological N-use efficiency (PNUE) and crop recovery efficiency (CRE) revealed significant variations among nitrogen levels as well as genotypes (Table 3). PFP decreased with increasing dose of nitrogen. The lowest PFP obtained with application of 150 kg N/ha. Application of 100 kg N/ha resulted in 51% decrease in PFP compared to 50 kg N /ha. ANUE and CRE also declined with increasing level of nitrogen and proportionate decrease was more with subsequent increase in N levels. PNUE remained unaffected due to N levels. The behaviour of these characters due to nitrogen treatments may be explained on the basis of their effect on the economic yields. Pandey *et al.* (2001) reported that nitrogen use efficiency parameters decreased as N rate increased. Among the genotypes, 'CSH 22 SS' recorded the highest PFP, ANUE, CRE and

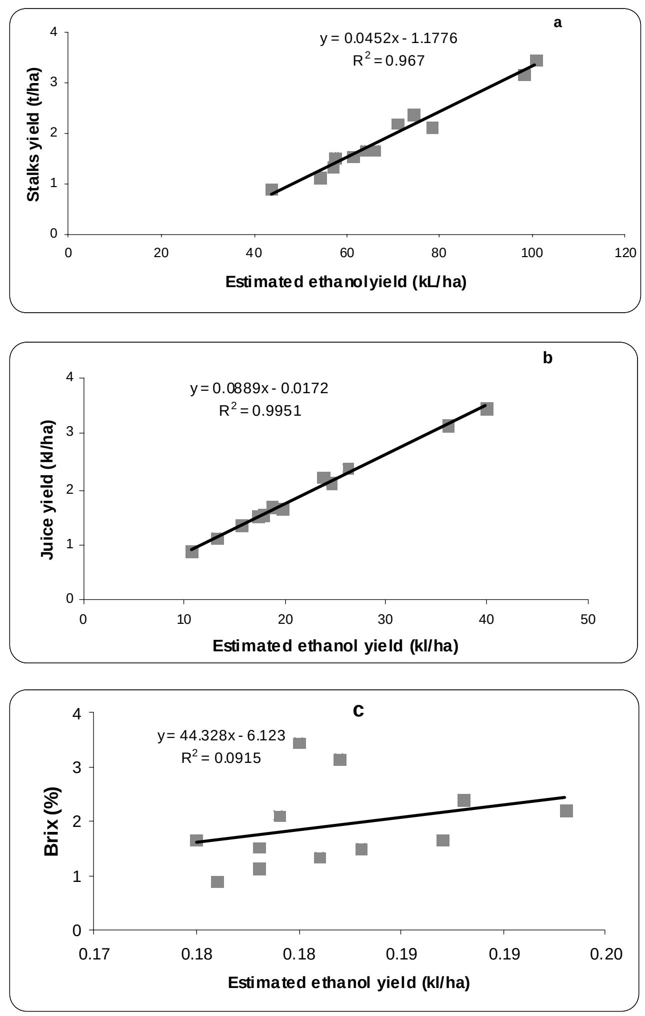

Fig. 1. Regression and correlation between estimated ethanol yield and stalks yield (a), juice yield (b) and brix percentage (c) in pooled analysis

PNUE. ‘CSH 22 SS’ recorded 25.6 and 45.9% increase in PFP over ‘RSSV 9’ and ‘SSV 84’ respectively. With respect to ANUE, ‘CSH 22 SS’ recorded 67.4 and 40% increase compared to ‘SSV 84’ and ‘RSSV 9’, respectively. CRE of ‘CSH 22 SS’ was 53 and 33% higher than ‘SSV 84’ and ‘RSSV 9’, respectively. ‘CSH 22 SS’ recorded the highest PNUE but it was statistically similar to other genotypes. Similar results were obtained by Pandey *et al*. (2001) and Kumar *et al.* (2008) who found higher nitrogen use efficiency parameters in hybrid compared to traditional varieties, which they attributed to the rooting characteristics of sweet sorghum capable of exploiting larger soil volumes.

Sorghum grain equivalent yield (SGEY) and economics

Sorghum grain equivalent yield comprising of grain yield, estimated ethanol yield and fodder yield, indicated significant increase with successive increase in nitrogen level (Table 1). Application of 150kg N/ha recorded 86% higher SGEY (11.1 t/ha) over control. Among the genotypes, ‘CSH 22 SS’ recorded 33 and 84% higher SGEY (11.35 t/ha) than ‘RSSV 9" (8.53 t/ha) and ‘SSV 84’ (6.15t/ha), due to its higher ethanol, grain and fodder yields.

The highest gross returns (₹99,900/ha), net returns (₹ 55,900/ha) and net B: C ratio (1.27) was observed with 150 kg N /ha (Table 3), which were 87, 120 and 46% higher over control. Among genotypes ‘CSH 22 SS’ produced the maximum gross returns (₹102,100/ha) net returns (₹55,900/ha) and B: C ratio (1.21). Gross returns and net returns of ‘CSH 22 SS’ recorded 31 and 37% increase compared to ‘RSSV 9’. The lowest net returns and B: C ratio was recorded in ‘SSV 84’. Gross returns, net returns and B: C ratio of ‘CSH 22 SS’ recorded more increase at high levels of nitrogen compared to varieties. These results are in conformity with earlier observations (Reddy *et al*. 2006).

Based on two years results, cultivation of sweet sorghum hybrid ‘CSH 22 SS’ with 150 kg N/ha is recommended for higher productivity and profitability.

Table 3. Effect of nitrogen levels and genotypes on nitrogen use efficiency and economics of sweet sorghum production (Data pooled over two years)

Treatment	Nitrogen-use efficiencies				Cost of cultivation ($\times 10^3$₹/ha)	Ethanol processing cost ($\times 10^3$₹/ha)	Gross returns ($\times 10^3$₹/ha) from				Net returns ($\times 10^3$₹/ha)	Net B:C
	PFP*	ANUE*	CRE* (%)	PNUE*			Ethanol yield	Fodder yield	Grain yield	Total ratio		
Nitrogen levels (kg/ha)												
Control	-	-	-	-	10.6	18.0	36.9	6.0	10.8	53.8	25.2	0.88
50	35.6	12.5	63.5	20.1	10.8	27.8	44.5	7.7	16.2	68.4	36.2	1.12
100	23.2	11.6	63.5	18.6	11	29.8	60.2	9.6	20.7	90.5	49.7	1.22
150	17.2	9.4	46	20.7	11.3	32.7	66.4	10.1	23.4	99.9	55.9	1.27
SEm±	1.17	0.67	2.2	1.71	-	-	1.6	0.27	0.36	1.89	1.13	-
CD (P=0.05)	3.23	1.86	7.5	NS	-	-	5.6	0.90	1.17	6.6	3.45	-
Genotypes												
‘RSSV9’	24.2	10.4	54.0	19.8	10.8	25.8	52.6	7.9	16.2	76.8	40.2	1.09
‘SSV 84’	21.0	8.7	47..1	19.0	10.8	16.4	33.2	6.9	15.3	55.4	28.2	1.03
‘CSH22 SS’	30.7	14.5	72.0	20.6	11.6	34.6	70.5	10.1	21.6	102.1	55.9	1.21
SEm±	0.5	0.58	2.4	5.6	-	-	1.4	0.37	0.18	1.56	0.8	-
CD (P=0.05)	1.16	1.27	6.3	-	-	-	4.1	1.08	0.72	4.69	2.38	-

PFP = Partial factor productivity (kg harvest product per kg N applied); ANUE = Agronomic N-use efficiency (kg yield increase per kg N applied); CRE (%) = Crop recovery efficiency (kg increase in N uptake per kg N applied x100); PNUE = Physiological N-use efficiency (kg yield increase per kg increase in N uptake)

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