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A decadal analysis of improved sorghum (*Sorghum bicolor*) cultivar response to fertilizer application in rainy season and a hypothetical grain production model

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ABSTRACT

The multi-location testing methodology was based on the principle of an un-biased approach to identify the best performing product, certified by a multi-disciplinary team and popularized through frontline demonstration programme. The data from one of the mandatory trials were summarized over a decade (1998–2007) to understand the results split over 2 periods (1998 to 2002 and 2003 to 2007) and derive physiological basis of yield enhancement. The results during the first half of the decade indicate that the best performing hybrids attained an increase in yield of 0.7 tonnes/ha as compared to the best performing varieties. The translocation of dry matter produced from leaf and stem into the grain was > 25% in hybrids, while it was approaching 25% in the varieties. Proportional increase in grain yield (due to application of external fertilizer input) over the control was linearly related to the N fertilizer use efficiency. Fertilizer N-use efficiency (DY/DN) defined as change in yield for every unit of applied N increased from 10 kg grain to 20 kg grain/kg of N applied. Hence, increase in productivity can be brought about both by genetic improvement as well as associated nutrient management intervention in a rainfed environment. The hypothesized sorghum static model substantiates the physiological basis of sorghum grain yield.

Key words: Fertilizer levels, Nitrogen-use efficiency, model, Sorghum model, Varieties and hybrids

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the staple diets popular among the cereals in the semi-arid tropics of the world. This is highly adaptable to the hot and dry agro-ecological regions compared to other food crops which require more congenial environment. In India, the declining market demand for its use as food, has created a new niche in terms of its use as feed in poultry industry, that has witnessed a growth of 15 to 20% (Borikar *et al*. 2007). Continued efforts to improve sorghum productivity and its quality are being emphasized with changing utilization and declining area under cultivation in recent times.

The All India Coordinated Sorghum Improvement Project (AICSIP) has the national mandate of improving sorghum productivity across different sorghum growing states in India. A multi-disciplinary approach has been the strength of the multi-location testing programme (Kumar and Ramanjaneyulu 2009). Knowledge-based specialized tools available across disciplines were integrated to synergize the crop improvement and management processes. The crop improvement activity (Zone II, core sorghum region includes parts of Maharashtra, Karnataka, Gujarat and Madhya Pradesh) aims at attaining a higher grain proportion which is economically valuable component, while crop management practices improves the productivity by providing an enabling environment. Among the various inputs that improve the efficiency of a cultivar in realizing its potential, fertilizer N plays an important role in both irrigated and rainfed environments.

With the introduction of hybrids and high-yielding varieties, fertilizer use has increased among sorghum cultivating farmers. Hirel *et al*. (2007) in their review emphasized that the regulatory mechanisms of controlling plant nitrogen economy was vital for improving nitrogen-use efficiency and for reducing excessive input of fertilizers, while maintaining acceptable yield. Bertin and Gallais (2000) recommended the use of varieties with better nitrogen-use efficiency (NUE) so as to avoid pollution by nitrates and to maintain a sufficient net income by the farmers. Better nutrient management strategies should aim both to attain higher productivity and sustain them in the long run (Bijay Singh and Yadvinder Singh 2002).

In order to elicit faster improvement in nitrogen-use efficiency (NUE) on farms, breeding and variety testing

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should be conducted at some sites with more than one level of applied N, and that grain N%, N harvest index, and perhaps canopy N ratio (kg N/ha green area) should be measured more widely (Bradley and Daniel 2009). The agronomy trial involving defined nutrient environments and improved genotypes (promoted after 2 years of multi-location testing), was being conducted to understand the cultivar nutrient-use efficiency. The results from these trials were mandatory as well supportive of breeder's claims for a genotypes relatively higher efficiency and resulting in release of the cultivar for wider adoption.

Data pooled over a decade from the multi-location trials have been analyzed and conclusions of the results are presented. Cassman *et al*. (2002) proposed that incremental efficiency or change in yield for each change in applied N from control is a more valid approach than the simpler definition of yield per unit N applied or per unit plant N. Native fertility was the basic reference point that influences the proportional increase due to external inputs (fertilizers) through its utilization by any given cultivar. This paper substantiates by validating a hypothetical sorghum model, the importance of soil fertility gradient and implications of NUE on crop improvement programme and management decisions.

MATERIALS AND METHODS

The decade from 1998 to 2007 has been conveniently divided into 2 halves, based on the experimental design of nutrient by genotype interaction trials. During 1998–2002, a multi-location trial was conducted each year at most AICSIP locations (Table 1) and during 2003–07, the trial was split across 3 different zones/regions (Table 2) based on the criteria of product end use and a combination of locations.

Zone I and III were mainly targeted with an end use of dual purpose sorghums, i e equal importance for grain and fodder, while Zone II encompassing the core sorghum area targeted primarily a higher sorghum grain component. The data was analyzed in a split-plot design. Main plots during

Table 1 Experiment 1K list of locations and test entries for the period 1998–2002

Trial	Region	Year	Location	Test Entries
1(K)	All India	1998	Coimbatore, Palem Akola Indore Surat, Dharwad, Parbhani, Mauranipur, Pantnagar, Udaipur	'SPV 1333', 'SPV 1022', 'SPV 1328', 'SPH 660', 'SPH 792', 'SPH 815', 'SPH 1002', 'SPH 840', 'SPH 960', 'SPH 966', 'SPH 975', 'SPH 976'
		1999	Coimbatore, Palem Akola Indore Surat, Dharwad, Parbhani, Mauranipur, Pantnagar, Udaipur, Bichpuri	'SPV 1430', 'SPH 837', 'SPH 964', 'SPH 981', 'SPH 1037', 'SPH 1065'
		2000	Coimbatore, Palem Akola Indore Surat, Dharwad, Parbhani, Mauranipur, Bichpuri	'SPV 1388', 'SPH 1148'
		2001	Coimbatore, Palem Akola Indore Surat, Dharwad, Mauranipur, Pantnagar, Udaipur	'SPV 1472', 'SPV 1474', 'SPV 1489'
		2002	Akola, Parbhani	'SPH 1182'

Table 2 Zone-wise list of experimental locations and test entries (2003–07)

Trial	Region	Year	Location	Test Entries
1(K)A	Zone I	2003	Palem, Coimbatore	'SPH 1331', 'SPH 1342', 'SPH 1347'
		2004	No trial	
		2005	Palem, Coimbatore	'SPV 1664', 'SPH 1475', 'SPH 1659'
		2006	Palem, Coimbatore	'SPV 1714', 'SPV 1715', 'SPV 1716', 'SPV 1730' 'SPH 1467', 'SPH 1524'
		2007	Palem	'SPV-1733'
1(K)B	Zone II	2003	Akola, Indore, Surat, Dharwad, Parbhani	'SPH 1331', 'SPH 1342', 'SPH 1347'
		2004	Surat, Dharwad, Parbhani	'SPH 1398', 'SPH 1417'
		2005	Akola, Indore, Surat, Dharwad, Parbhani	'SPH 1463', 'SPH 1473'
		2006	No trial	
		2007	Akola, Indore, Surat, Dharwad, Parbhani	'SPV-1746', 'SPH 1567'
1(K)C	Zone III	2003	Udaipur, Mauranipur	'SPH 1331', 'SPH 1347'
		2004	Udaipur, Mauranipur	'SPH 1417'
		2005	Deesa, Udaipur, Mauranipur	'SPV 1664', 'SPH 1467', 'SPH 1476'
		2006	Udaipur	'SPV 1714', 'SPV 1715', 'SPV 1716', 'SPV 1730', 'SPH 1467'
		2007	Deesa, Udaipur, Mauranipur, Pantnagar	'SPV-1730', 'SPV-1733'

the first 5 years were assigned with genotypes, while the fertilizer rates [control, half recommended rate of fertilizer (RDF) and full recommended rate of fertilizer] were assigned to the sub-plots. However, reverse was the case during the next 5 years. The design shift was an attempt to have permanent plots and create a fertility gradient across 3 rates of fertilizers (control, 50% RDF and 100% RDF – 80 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha) with an intention to quantify the response of various sorghum genotypes to different fertilizer rates.

Sorghum grain production can be hypothetically generated using a static model with following sub-components (Kumar 2005).

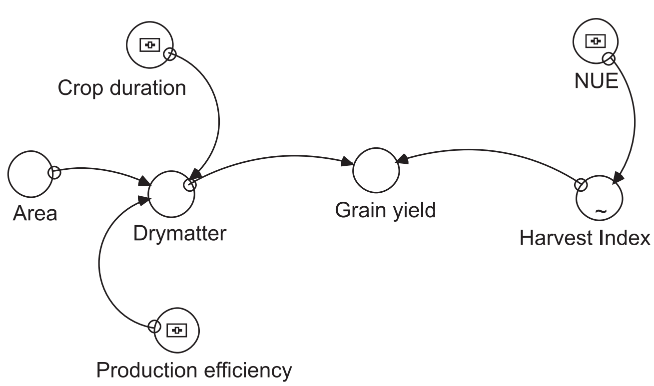
i. Crop duration or the developmental process is a function of photoperiod and temperature. These remain fairly similar for a given location (latitude) or season (weather). But the most important factor is the soil moisture supply which in turn is dependent on the monsoonal pattern.

ii. Sorghum has the ability to remain dormant for long periods under soil moisture stress conditions, and the crop duration gets extended under such conditions.

iii. Total dry matter production by sorghum in a rainfed environment is driven by the efficiency with which the crop is able to use the soil resources like moisture and nutrient. Soil moisture is dependent on the rainfall intensity and distribution, while nutrient release/ availability is linked to soil moisture. These interactions are represented by the production efficiency (PE=g/ sq.m/day).

Dry biomass production = crop duration × PE × unit area

iv. Grain yield is dependent on the ability of the genotype/ cultivar to partition the produced biomass into different parts of the plant. The local cultivars have higher proportion of vegetative matter, while the improved cultivars have a higher reproductive component. Grain yield is a function of total dry matter produced and the harvest index. Harvest index has been found to be linearly related to nitrogen response (kg grain/kg nitrogen) in different growing environments.



The above described model was used to simulate sorghum grain yield using STELLA (1997) software and by varying the inputs in terms of crop duration, production efficiency and NUE.

RESULTS AND DISCUSSION

First half of the decade (*1998–2002*)

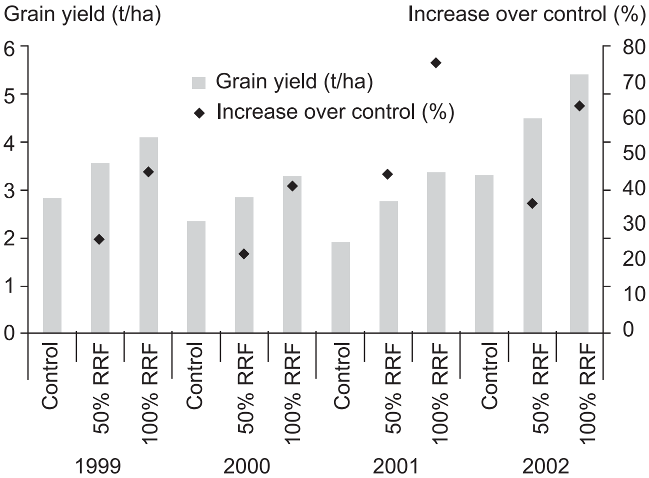
Average grain yield of sorghum varieties tested across different fertility rates varied from 2.5 to 3.3 tonnes/ha, while in case of sorghum hybrids it ranged from 3.2 to 4.0 tonnes/ ha (Table 3). The better performing hybrids were 'SPH 960' (4.1 tonnes/ha) and 'SPH 1182' (4.3 tonnes/ha). The potential of a hybrid compared to a variety yields 0.7 tonnes more at lower and higher levels of the grain yield. Transforming the external inputs into an economically valued product and as well improving the moisture-use efficiency in a rainfed environment has been the strength of the hybrid development programme under the aegis of the All India Coordinated Sorghum Improvement Project (AICSIP).

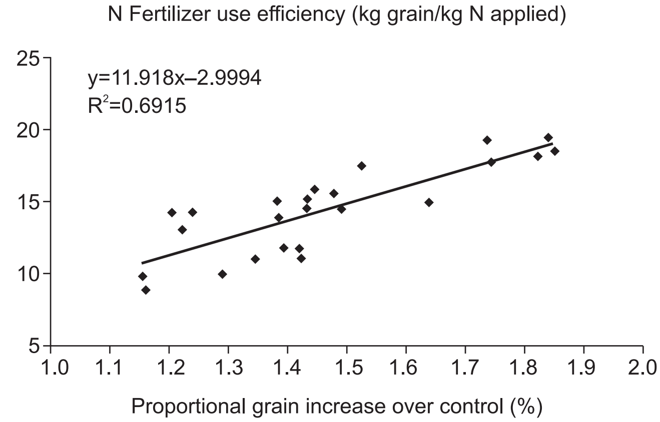
In terms of the sorghum genotype response to external fertilizer inputs the average grain yield increase due to the recommended rate of fertilizer (80 kg N, 40 Kg P_2O_5 and 40 kg K_2O/ha) varied from 3.0 to 5.0 tonnes/ha. The per cent increase due to application of fertilizer over control varied from 35 to 75% (Fig 1).

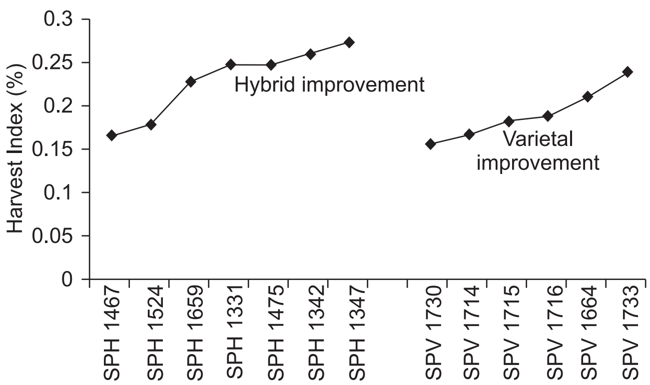
A gradient among the nutrient levels can help identify

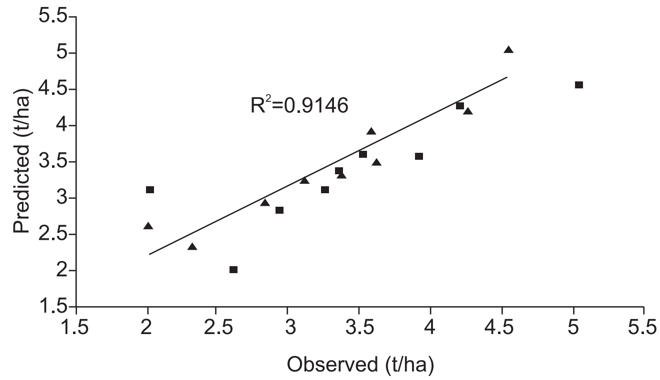
Table 3 Grain yield of sorghum hybrids and varieties tested across multi-locations during *kharif* season from 1998 to 2002

Year	Hybrid	Grain yield (tonnes/ha)	Variety	Grain yield (tonnes/ha)
1998	'SPH 660'	3.67	'SPV 1333'	3.20
	'SPH 792'	3.56	'SPV 1022'	3.22
	'SPH 815'	3.72	'SPV 1328'	3.02
	'SPH 1002'	3.73		
	'SPH 840'	3.84		
	'SPH 960'	4.10		
	'SPH 966'	3.68		
	'SPH 975'	3.90		
	'SPH 976'	3.83		
1999	'SPH 837'	3.41	'SPV 1430'	3.27
	'SPH 964'	3.49		
	'SPH 981'	3.79		
	'SPH 1037'	3.52		
	'SPH 1065'	3.72		
2000	'SPH 837'	3.41	'SPV 1388'	2.88
	'SPH 964'	3.49		
	'SPH 981'	3.79		
	'SPH 1037'	3.52		
	'SPH 1065'	3.72		
	'SPH 1148'	3.15		
2001			'SPV 1472'	2.68
			'SPV 1474'	2.54
			'SPV 1489'	2.52
2002	'SPH 1182'	4.29		









Figs 1–4 **1.** Sorghum grain yield across varying fertility levels and percent increase over control. **2.** Sorghum grain yield across varying fertility levels and percent increase over control. **3.** Hybrid and varietal improvement in terms of the proportion of dry matter transformed in to grain yield during the second half of the decade. **4.** Linear relationship between observed and predicted grain yield of sorghum

genotypes for their efficiency in utilizing the added fertilizer input. The proportional per cent increase in grain yield due to external input of fertilizer varied from 1.3 to 2.0 as compared to that of the control (native fertility). This increase was brought about by utilization of the added fertilizers by the improved genotype as reflected by a positive and linear relation with NUE (Fig 2).

The N utilization efficiency was in the range of 10 to 20 kg grain for every kg of applied fertilizer N. In a rainfed environment the distribution of the rainfall during 2 important phenological stages of the crop plays greater importance, especially with reference to top-dressing of N. The first is the transformation stage from vegetative to reproductive phase when the primordial initiation takes place and the size of the panicle is determined. The second is the flowering stage when the grain number and later grain filling are driven by the second rate of N top-dressed as a schedule of nutrient management.

Second half of the decade (*2003–07*)

Crop improvement programme aims at increasing the proportion of grain in the sorghum plant and harvest index is an indication of the extent of dry matter translocated into grain. Higher values of harvest index (HI) indicated that more dry matter was translocated from leaf and stem to grain in 'SPH 1347' and 'SPH 1733' (Fig 3). Sorghum hybrids attained a mean value of 22% in terms of the proportional transformation into grain, while varieties recorded an average of 19%.

Model validation

The sorghum grain yield was predicted using the static model by varying crop duration and NUE for check cultivars ('CSV 17', 'CSH 14' and 'CSH 16') used in the trial. The crop duration varied between 90 and 120 days and the NUE varied from 10 to 20 kg grain/kg N. The predicted grain yield when plotted against the observed values showed a linear relation with a regression value of 0.91 (Fig 4). The predictive ability helps understand the physiological basis of yield wherein crop phenology, production and NUE drive the sorghum production model. Physiologically production efficiency was important to improve the total dry matter production and NUE to attain a higher grain yield.

Crop improvement gains can be substantiated by the open pollinated variety that attains a grain yield varying from 2.5 to 3.3 tonnes/ha, while in sorghum hybrid the potential yield varied from 3.2 to 4.0 tonnes/ha. Analysis of both halves of the decadal period substantiates that an improved cultivar potential can be attained with appropriate fertilizer use as indicated by higher proportion of grain yield vis-à-vis the control treatment. In terms of the sorghum genotype response to external fertilizer inputs the average grain yield increase due to the recommended dose of fertilizer (80 kg N and 40 kg P_2O_5) varied from 3.0 to 5.0 tonnes/ha. In a rainfed environment where risk due to variability in rainfall amount as well as distribution over the season are pertinent, investments in seed of improved cultivar and fertilizers should be optimized to attain the potential productivity of a sorghum cultivar. A static model hypothesized and validated defined the physiological basis of dry matter production and grain yield in sorghum.

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