1321

Technology Blending and Agrarian Prosperity (1990) *Eds J P Verma A Varma*
© Malhotra Publishing House New Delhi-110 064 India

EVALUATING FERTILIZER USE STRATEGIES FOR SORGHUM - A SYSTEMS APPROACH

G Alagarswamy[1], S M Virmani[1] D C Godwin[2] and U Singh[2]
[1]Cereals and Resource Management Program International Crops Research Institute for the Semi Arid Tropics (ICRISAT) Patancheru Andhra Pradesh 502 324 India [2]International Fertilizer Development Center (IFDS) P O Box 2040 Muscle Shoals AL 35662 USA

Sorghum is major cereal crop grown in the semi arid tropics (SAT) for food feed and forage In the Indian SAT sorghum is grown on 15 6 million ha and total production is 11 85 million tonnes Sorghum growing areas are characterized by erratic rainfall and impoverished soils Because of such uncertainties fertilizers usage in sorghum based cropping system in the SAT is not common (Krantz *et al* 1978) Only 15 percent of the area cropped to sorghum in the SAT received some amount of fertilizer (Tandon 1977) A study by Spratt and Chowdhury (1978) indicates that even in dry years economic responses could be obtained with nitrogen (N) application upto 40 kg ha ^{1} In a recent review of fertilizer research in India s SAT Katyal (1989) indicated positive and significant responses to N fertilizer Earlier conclusions of low fertilizer usage in the SAT are probably conservative but underscore the need for more research on the variability of fertilizer response

In the SAT the variation in the efficiency of applied N is primarily due to erratic climate A survey of N uptake by sorghum in the SAT (Craswell and Godwin 1984) showed that the response to applied N ranged from 2 to 24 kg of extra grain for every kg of N applied They also analyzed low efficiency events and showed that these were not due to periodic droughts as is generally assumed but primarily due to the nature of rainfall events leading to periodic inundation of soil Short time water logging is conducive to N losses through both leaching and denitrification Hence efficient fertilizer management practices in dry land depend on (a) the amount and time of application of fertilizer and (b) the environmental conditions as defined by the crop growth stages climate and management inputs (Virmani *et al* 1989) Such vital information is needed and can only be obtained for well-managed long-term fertilizer response studies.

A ^{15}N field experiment conducted in a Vertisol and an Alfisol at ICRISAT Centre, Patancheru (17°N) for two years showed that utilization of added N by rainy season sorghum was greater in relatively dry year compared to a wet year (Moraghan *et al.*, 1984, a, b). Because of weather impacts on fertilizer use efficiency, it is very difficult to identify an optimum fertilizer strategy unless long-term fertilizer response studies are conducted. Such studies are not only rare but also éxpensive and time consuming.

In recent years, climatically-driven crop simulation models have become a valuable analytical tool for decision-making. Several crop simulation models are operational and in use (Whisler *et al.*, 1986). Further, several well-tested weather generator models are also available (Richardson, 1981; Stern *et al.*, 1982) that generate stochastically long-term weather scenarios. Coupling of crop simulation models to long-term historical and generated climatic data provides a powerful way to quantify the variablity caused by climate in evaluating the response of fertilizers In doing so, fertilizer scheduling can be optimized by accounting for uncertainties of weather-related fertilizer response variations. Risk analysis (RA) procedure that assists in selecting strategies under conditions of uncertainty could then be adapted to evaluate different strategies (Godwin and Vlek, 1984).

This study was undertaken to simulate the response of sorghum to different levels of applied N in different agro-climates using a crop simulation model, to test the methodology and demonstrate the potential use of crop simulation models for decision making. Case studies simulated were:

- Four fertilizer strategies in a shallow Alfisol
- A fertilizer strategy in 2 locations with variable risks associated
- Two fertilizer strategies in 3 locations with same soil type
- Fertilizer application methods in 2 soil types

DECISION SUPPORT SYSTEM

Before results are presented, it may be useful to discuss the software available for decision support systems, and its use. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) has developed a decision support software for agrotechnology transfer (DSSAT) which includes crop simulation models, a weather generator and RA. The RA procedure can be used to construct a cumulative probability density function (CPDF) using simulated results. The simulated yields are ranked in an ascending order and for each year a probability percent (depending on the number of years simulated) is assigned Then a linear segmented estimation of CPDF is used to evaluate the strategy of interest

MODEL EVALUATION

In the crop estimation through Resource and Environment Synthesis (CERES) family of models sorghum is the most recent and detailed description of model is given elsewhere (Virmani *et al* 1989) It is essential to evaluate any simulation model before it is used operationally Testing sorghum model on independent data sets is rather limited The data used for validation included experiments conducted at ICRISAT (Huda 1988) N fertilizer efficiency experiments in SAT soils (ICRISAT/IFDC) data sets from northern Australia (Myers 1980 Wright 1985 a b) and from the USA (Steiner 1986) The observed grain yield in these experiments varied from 1 8 t ha ^{1}

The performance of CERES sorghum model in predicting grain yield and nitrogen uptake is presented in Figrs 1 and 2 respectively The preliminary

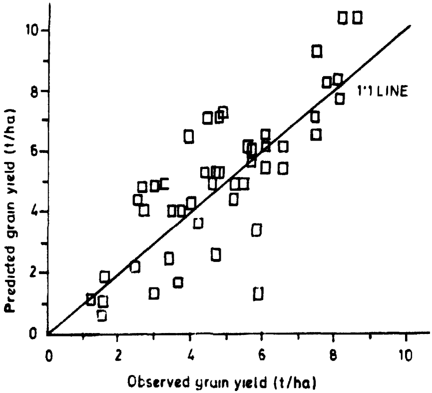

Fig. 1 Comparison of predictions of CERES sorghum model with observed grain yield

testing of the model against a range of data sets originating from latitudes 30° North to 30° South indicated that the model is generally robust in simulating yield and total N uptake

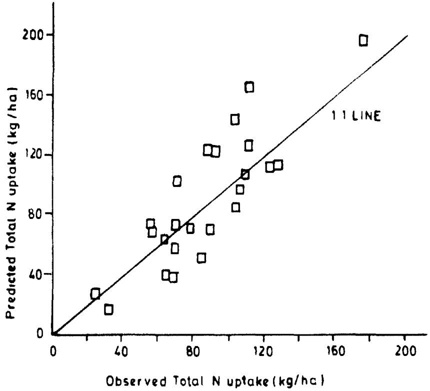

Fig 2 Comparison of predictions of CERES sorghum model with observed total N uptake at maturity

EVALUATING FERTILIZER STRATEGIES

Initial conditions

The weather generator program in DSSAT was used to stochastically generate daily weather in each location In all simulations urea is used as N source In all cases except when evaluating the time of application of fertilizer all the fertilizer N was applied at one time and incorporated to a depth of 5 cm in the soil at the time of planting The genetic coefficients established for sorghum hybrid CSH 1 (Alagarswamy *et al* 1988) were used Normal planting date was set to June 18 every year but the seedling emergence date depended on simulated water availability in the soil surface The soil profile characteristics for each site were derived form the Benchmark soils project report (Murthy *et al* 1982) Plant population was maintained at 120 000 plants per hectare

Simulations were run for 25 years Initial conditions such as extractable soil water and initial mineralizable N in the soil profile were same for each year and for each soil group This approach allowed estimation weather induced variability where all other conditions were maintained as constant The yield simulations of 25 crop years were used for formulating the CPOFs These were independent of each other and had no serial dependence

Comparison of different fertilizer use strategies in one location

Four fertilizer strategies simulated for shallow Alfisol at Hyderabad were no fertilizer and 30 60 and 150 kg N ha [1] The range of responses obtained is shown in Fig 3 When no fertilizer was applied the crops failed to mature in 5 percent of the years (probably due to severe N stress) The CPDFs in

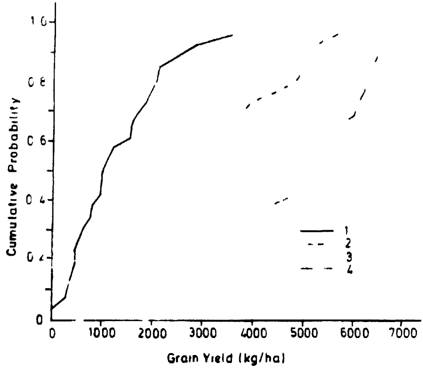

Fig. 3 Cumulative probability density function for simulated grain yield response to four fertilizer strategies at Hyderabad on the shallow Alfison (1 = no applied fertilizer 2 3 and 4 are 30 60 and 150 kg N/ha respectively)

low yielding years (grain yield less that 2000 kg ha ^{1}) for strategies 2 3 and 4 lie close to one another in 25 percent of the years indicating little or no response to added fertilizer beyond 30 kg ha ^{1} The CPDFs are widely separated in the relatively high yielding (above 2000 kg ha ^{1}) years indicating high response to fertilizer application Among the fertilizer rates strategy 4 seems best suited because it has a higher frequency of better outcomes than the others In six out of 25 years grain yields in strategy 4 ranged form 5500 to 700 kg ha ^{1}

Comparison of different fertilizer use strategies in two locations

When various strategies in two locations with two different soil types were evaluated a variable response pattern was obtained The CPDF for Hisar (Latitude 29°N annual rainfall 447 mm) is typical of what would likely happen to sorghum production in a very risky location There is a clear response to 30 kg ha ^{1} fertilizer rate Noticeably in one third of the years higher rates of N are detrimental for grain yield Response to N rates above 30 kg ha ^{1} is evident only in 40 percent of the years In years with higher yields (above 2500 kg ha ^{1}) a clear response to added fertilizers is seen The response to added fertilizer flattens after 60 kg ha ^{1} as seen from the CPDF curves The grain yield for 60 kg N ha ^{1} strategy ranges from 400 to 3900 kg ha ^{1} Similar differences are also evident for higher N rates The CPDF curves indicate that Hisar is a high risk location for applying fertilizer N to sorghum

In contrast to Hisar the response to the same fertilizer strategies is clearly evident in Ranchi (Latitude 23°N annual rainfall 1462 mm) In 90 percent the years grain yields very very little in each of the different strategies Even with a small dose of fertilizer (30 kg N ha ^{1}) grain yields range from 1800 to 2500 kg ha ^{1} This simulation indicates that Ranchi constitutes a fertilizer responsive environment with least risk

Comparison of strategies in locations with same soil type

In the Benchmark soils transfer of technology approach it is generally assumed that a technology developed in a given soil series can be easily transferred to another location with the same soil series in the humid tropics In this simulation exercise a comparison of N response in three locations having Barsi series of Vertisols (Central Peninsular India) in a semi- arid tropical environment were evaluated

Several N rates were simulated but for the sake of brevity, results from 30 and 90 kg N ha ^{1} rates are given in Fig 4 A response to N fertilizer is evident as CPDFs are clearly separated for fertilizer rates Even with low rate of N, only in 10 percent of the years, grain yields are less than 3000 kg ha ^{1} in Parbhani (Latitude 19°N annual rainfall 903 mm) Similar responses are noted in 20 and 30 percent of the years in Pune (Latitude

18°N, annual rainfall 715 mm) and Sholapur (Latitude 17°N, annual rainfall 743 mm) respectively. In high yield years (3500 kg ha^{-1}), the CPDFs are somewhat similar but a higher response is evident in Pune.

At 90 kg N ha^{-1}, risk associated with fertilizer application is clearly evident from Fig 4. For example, both at Pune and Sholapur, in 35 percent of the years simulated grain yield will be markedly lower than 5000 kg ha^{-1}. This order of risk is noted in only 10 percent of the years in Parbhani. Even though the mean simulated yield in Parbhani is less as compared to Pune, Parbhani shows more stable yields and, therefore, presents less risk to fertilizer application Although all the three selected locations have Barsi series of Vertisols, Pune and Sholapur are riskier locations for fertilizer application compared to Parbhani. In the SAT, a consideration to both the soil series and moisture environment will be needed for deciding technology transfer related issues

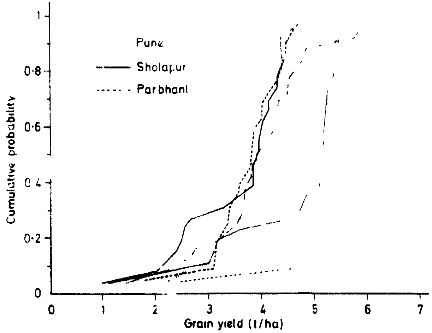

Fig. 4 : Cumulative probability density function for grain yield at three locations with same soil series (thick lines 30 kg N/ha and thin lines 90 kg N/ha)

Evaluation of fertilizer application strategy

The timing of N fertilizer application has a direct implication for its efficient use. By following an appropriate fertilizer schedule, N losses can be minimized. We simulated strategies involving all fertilizer N applied at planting, and compared it to that of split application, that is, half at planting and half three weeks later. Simulations for Vertisols and Alfisols of Hyderabad were carried out and a comparison of two strategies is shown in Fig. 5. Comparisons are reported as yield advantage (positive or negative) over the basal application.

Results of this simulation indicate that it is generally advantageous to split fertilizer applications in the Alfisols. In the Vertisols, there is no advantage of splitting the fertilizer application. The simulation indicates that yield advantage due to splitting was due to higher percentage of improvement

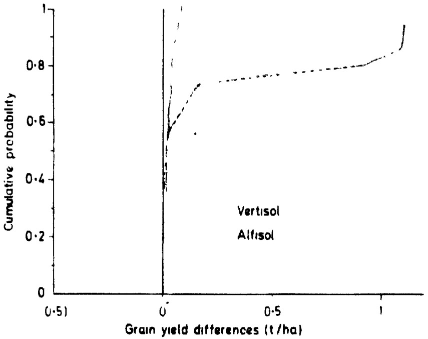

Fig. 5 : Cumulative probability density function for simulated yield advantage due to split application strategy compared to basal application at Hyderabad

in apparent recovery of fertilizer N combined with lower losses of N in the soil profile Results for 15 N experiments are in line with these observations Moraghan *et al* (1984a b) reported that split application of urea increased N uptake and higher fertilizer recovery by the sorghum crop In addition split application strategy gives the farmer some control over the timing of second application of N fertilizer If the growing season turns out to be unfavorable the second application may be reduced or withheld This then can considerably improve both fertilizer use efficiency and the economics of fertilizer application

CONCLUSIONS

The post green revolution yield increases have generally taken place in irrigated agriculture Such dramatic yield increases are not yet seen in crops of SAT However research efforts are underway to increase grain yield in these crops The conservatism about fertilizer usage in SAT agriculture is changing In this changing scenario better fertilizer management strategies are vital for SAT agriculture in view of the erratic climate In the past for a variety of reasons fertilizer management strategies were developed from conventional fertilizer rate experiments using a reductionist approach In future developing fertilizer management strategies especially for the SAT will demand systems approach Recent developments in crop simulation and stochastic weather generator models offer a valuable systems management tool Use of this analytical tool will help optimize fertilizer scheduling by accounting for uncertainties due to weather related fertilizer response variations

References

Alagarwamy G Ritchie J T Godwin D C and Singh U 1988 A user s guide to CERES sorghum Version 2 00 IFDC (International Fertilizer Development Center Alabama USA) Technical Bulletin

Craswell E T and Godwin D C 1984 The efficiency of nitrogen fertilizers applied to creals in different climates *Adv Plant Nutr* 1 1 55

Godwin D C and Vlek P L G 1985 Simulation of nitrogen dynamics in wheat croping systems In *Wheat Growth and Modelling* (W Day and R K Atkin Eds) pp 293 306 NATO ASI series Plenum Publishing Corp ration New York

Huda A K S 1988 Simulating yields of sorghum and pearl millet in the SAT *Field Crops Res* **15** 309 325

Katyal J C 1989 Nitrogen fertilizers-their use and management in the Indian SAT Proc Symp on Colloquium on Soil Fertility and Fertilizer Management in Semi-Arid Tropics 10 11 October 1988 ICRISAT Centre Patancheru India

Krantz B A Kampen J and Virmani S M 1978 Soils and water conservation and utilization for increased food production in the semiarid tropics Paper presented at the 11th International Society of Soil Science Edmonton Canada

Moraghan J T Rego T J Buresh R J Vlek P L G Burford J R Singh S and Sahrawat K L 1984a Laballed nitrogen fertilizer research with urea in the semi arid tropics II Field studies on a Vertisol *Plant and Soil* **80** 21 23

Moraghan J T Rego T J Buresh R J 1984b Labelled nitrogen fertilizer research with urea in the semi arid tropics III Field studies on Alfisol *Plant and Soil* **82** 193 203

Murthy R S Hirekerur L R Deshpande S B and Venkat Rao B V 1982 Benchmark soils of India Morphology Characteristics and Classification for Resource Managment National Bureau of Soil Survey and Land Use Planning (ICAR) 374 pp

Myers R J K 1980 The root system of again sorghum crop *Field Crops Res* **3** 53 64

Richardson C W 1981 Stochastic simulation of daily percipitation temperature and solar radiation *Water Resources Res* **17** 182 190

Spratt E D and Chowdhury S L 1978 Improved cropping system for rainfed agriculture in India *Field Crops Res* **2** 103 126

Steinr J C 1986 Dryland grain sorghum water use Light interception and growth responses to planting geometry

Stern R D Dennett M D and Dale I C 1982 Analyzing daily rainfall measurements to give agronomically useful results II A modeling approach *Expt Agric* **19** 237 253

Tandon H L S 1977 The status of and some factors affecting fertilizer use in Indian Agreculture Invitational Lecture to the Justus liebig University Gressen (Tropical Institute) Lahn West Germany

Virmani S M Huda A K S Singh R P Rego T J and Subba Rao K V 1988 Elements of climate-their relevance to tropics Proc Sysp on Colloquium on Soil Fertility and Fertilizer Managment in Semi Arid Tropics 10 11 October 1988 ICRISAT Centre Patancheru India

Virmani S M Tandon H L S and Alagarswamy G 1989 Modeling the Growth and Development of Sorghum and Pearl Millet Research Bulletin No 12, Patancheru 502 324 India International Crops Research Institute for the Semi-Arid Tropics 42 pp

Whisler, F D , Acock, B , Baker, D N , Fye, R E , Hodges, H F , Lambert, J R , Lemmon, H E , Mekinion, J M and Reddy, V R 1986 Crop simulation models in agronomic systems *Adv Agron* **40**, 141-208

Wright, G C 1985a Furrow irrigation of grain sorghum in a tropical environment-I Influence of period of inundation and nitrogen fertilizer on dry matter production, grain yield, and soil aeration *Aust J Agric Res* **36**, 73-82

Wright, G C 1985b Furrow irrigation of grain sorghum in a tropical environment II Influence of period of inundation on the soil and fertilizer nitrogen by the crop *Aust J Agric Res* **36**, 83-89