GIS based decision support system for precision farming of cassava in India

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ABSTRACT

Precision farming is the new concept of farming where spatial and temporal variability of soil and plant characteristics are taken into account for increasing the productivity of crop plants. In India, precision farming has been recommended for horticultural crops, rice, wheat, cassava, etc. Cultivation of cassava for industrial use needs field specific nutrient management practice and experiments have been conducted in different parts of India to develop site specific nutrient management (SSNM). Geospatial technologies such as remote sensing, GIS and GPS are being used to develop precision farming technologies for different crops. A nutrient decision support system (CASSNUM) software has been developed by CTCRI for site specific nutrient management of cassava in India. Based on field experiments over large number of cassava farms in India, we have developed fertilizer calculation charts which can be used for deciding on the rate of NPK fertilizers for specific yield targets. Application of fertilizers based on actual requirement of nutrients and indigenous supply has resulted in significant increase in yield, nutrient use efficiency and economic returns to farmers. In certain situations, farmers were applying excess amounts of nutrients than is needed and SSNM recommendations could increase yield by decreasing the rate of application of certain nutrients especially potassium. Results of the on farm experiments clearly demonstrated the importance of field specific management of various inputs to break the yield barrier observed in many crops. Studies are being undertaken by the authors to further refine the GIS based nutrient decision support system for precision farming of cassava.

Keywords: precision farming, GIS, cassava, site specific nutrient management, QUEFTS model

INTRODUCTION

Decision Support Systems (DSS) are interactive computer based systems that help decision makers utilize data and models to solve unstructured problems [1]. These powerful tools improve the performance of decision makers while reducing the time and human resources required for analyzing complex decisions. Precision agriculture is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality [2]. Geographic information system (GIS) is the organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information. Precision farming is concerned with spatial and temporal variability and the spatial analysis capability of GIS enables precision agriculture.

Cassava is a staple food crop for more than 600 million inhabitants in the tropics and subtropics. It is cultivated as an annual and biennial crop for its starchy roots (approximately 85 % starch on dry mass basis and less than 3 % protein) that can be harvested at 8 to 18 months after planting. In India, cassava is cultivated in varied agroclimatic and pedogenic environments. In Kerala state,

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where it has been introduced into India more than 300 years ago, it is cultivated mostly in laterite soils (Ultisols) [3,4]. In Tamil Nadu state, where it is cultivated mainly for the industrial uses, cassava is grown in black soils (Vertisols) and red soils (Alfisols). In Andhra Pradesh state, where also it is cultivated mainly for industrial uses, cassava is cultivated in sandy loam and coastal alluvial soils (Inceptisols). Sago and starch are also manufactured from cassava roots by nearly 1200 factories in India especially in the states of Tamil Nadu and Andhra Pradesh. The states of West Bengal, Maharashtra, Gujarat, Rajasthan and Madhya Pradesh are the largest consumers of sago in India.

Fertilizer recommendation for cassava in India started with the establishment and research work initiated in 1960s at Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram, Kerala, India. From earlier studies on different cassava clones grown with different levels of organic manures and inorganic fertilizers, it is recommended to apply 12.5 t/ha of farm yard manure (FYM) and 100:100:100 kg/ha N, P_2O_5 and K_2O [5]. But, later studies showed that the rate of P application can be reduced to 50%, thus changing the NPK recommendation to 100:50:100 kg/ha. Based on these and other related studies, now it is recommended to apply 100:50:100 kg/ha N, P_2O_5 and K_2O for high-yielding cassava varieties [6].

Cassava nutrient management by blanket fertilizer recommendations over wide areas and soil types over the past 40 years or so in India have resulted in significant yield increase. But when we extrapolate the results from experimental stations to farmers' fields, the yield cannot be increased beyond a certain level due to the high temporal and spatial variability of soil and plant properties. Studies in other crops clearly showed that further increase in yield and nutrient use efficiency can be possible only by managing this large spatial and temporal variability existing in soil nutrient supply, nutrient use efficiency and crop response to nutrients among different farms [7.8]. The present study was conducted with the objective of validating the QUEFTS model [9] by conducting on farm experiments in major cassava growing areas of India, developing a nutrient decision support system by computer programming and developing GIS based prescription maps for precision farming of cassava.

MATERIALS AND METHODS

On-farm validation experiments were conducted in Kerala, Tamil Nadu, Andhra Pradesh and Maharashtra during 2007-2010. The experiment was laid out in randomized complete block design (RCBD) with five treatments and four replicates per treatment. Twenty on farm experiments were laid for three consecutive years, i.e., 2007-2008, 2008-2009 and 2009-2010. The treatments were N omission plot (a plot without the application of nitrogen fertilizer), P omission plot (a plot without the application of phosphorus fertilizer), K omission plot (a plot without the application of potassium fertilizer), SSNM (site specific nutrient management) plot (a plot with balanced fertilizer NPK application) and Farmers Fertilizer Practice (FFP) plot.

Analysis of soil and plant samples

Soil samples were collected from different treatment plots before planting to assess the initial fertility status of the soil. The samples were collected again at 3-4 months after planting and also at the time of harvest. All the collected soil samples were analyzed for pH, organic carbon (OC), available nitrogen, available phosphorus and available potassium. pH was determined using a pH meter. The OC was analyzed using Walkley-Black titration method, available nitrogen by microdiffusion method. For acidic soils, available phosphorus was extracted by using Bray and Kurtz No. 1 method (extraction by 0.03 M ammonium fluoride and 0.025 M HCl) and for alkaline soils, it was extracted using Olsen's method (extraction by 0.5 M sodium bicarbonate with pH 8.5).

In both methods, the extracted samples were analyzed in a spectrophotometer using ascorbic acid blue colour method. Available potassium was estimated on flame photometer [10]. Youngest fully expanded leaf (YFEL) blades, which are the index tissue for critical nutrient concentration (CNC), were collected at 3-4 months after planting and samples of leaf, stem and tuber were collected at the time of harvest. All these plant samples were analyzed for N, P and K contents. Based on the nutrient concentration and dry weights, total uptake of N, P and K were also estimated.

Validation of QUEFTS model

Nutrient use efficiency parameters like agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) were calculated using the equations: Agronomic efficiency (AE) = $\Delta Y/Nr$; Recovery efficiency (RE) = $\Delta Np/Nr$; Physiological efficiency (PE) = $\Delta Y/ \Delta Np$, where ΔY is the incremental increase in tuber yield that results from nutrient application, Nr is the rate of nutrient applied, ΔNp is the increase in plant nutrient accumulation that results from nutrient application [11].

Nutrient decision support system and GIS based prescription maps for precision farming of cassava in India

Based on the results of the validation experiments, a nutrient decision support system software for site specific nutrient management of cassava, CASSNUM, was developed with .NET Technologies using ASP.NET and C# as front end and MS Access used for data storage. GIS based prescription maps were also developed using ArcGIS and QGIS softwares for field specific nutrient management of cassava.

RESULTS AND DISCUSSION

Table 1 gives the details of the model validation in Tamil Nadu region. It can be observed that imbalanced NPK fertilizer application resulted in an actual yield of 11.41 t ha^{-1} tuberous root dry matter whereas the model predicted a yield of 10.50 t ha^{-1} tuberous root dry matter. Figure 1 shows the relation between cassava tuberous root yields predicted by the model and measured yields at different cassava production regions, and it showed good agreement, which indicates that the calibrated model can be used to improve NPK fertilizer recommendations for cassava in India. Table 2 gives the influence of SSNM on root yield, plant nutrient uptake and NPK fertilizer use in cassava farms in India. The results of the study very clearly indicated the superiority of SSNM over farmer's fertilizer practice (FFP) in increasing the root yield of cassava. Among N, P and K, there was significant increase in the uptake of N and P in SSNM plot compared to FFP plot. But, in the case of K, the uptake was lower in SSNM which was due to the fact that most farmers apply indiscriminate levels of K fertilizer. This is very evident when we analyze the rates of N, P and K fertilizers used in SSNM and FFP plots. The effects of SSNM on nutrient use efficiency parameters are shown in table 3. There was significant improvement in the nutrient use efficiency parameters such as agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) in SSNM plots compared to FFP plots.

Cassava site specific nutrient decision support system (CASSNUM)

A decision support system software for site specific nutrient management (CASSNUM) has been developed. The CASSNUM contains different modules such as N, P and K management, site

Table 1. Predicted yield of cassava by the QUEFTS model at Salem in Tamil Nadu, India.

Nutrient	Indigenous supply (kg ha^{-1})	NPK fertilizer requirement (kg ha^{-1})	Predicted nutrient uptake (kg ha^{-1})	Predicted yield (t ha^{-1})
N	134.2	120	185	10.50
P	15.7	30	24	
K	123.4	93	164	

The measured yield is 11.41 t ha^{-1}; the yield potential was set to 24.50 t ha^{-1}.

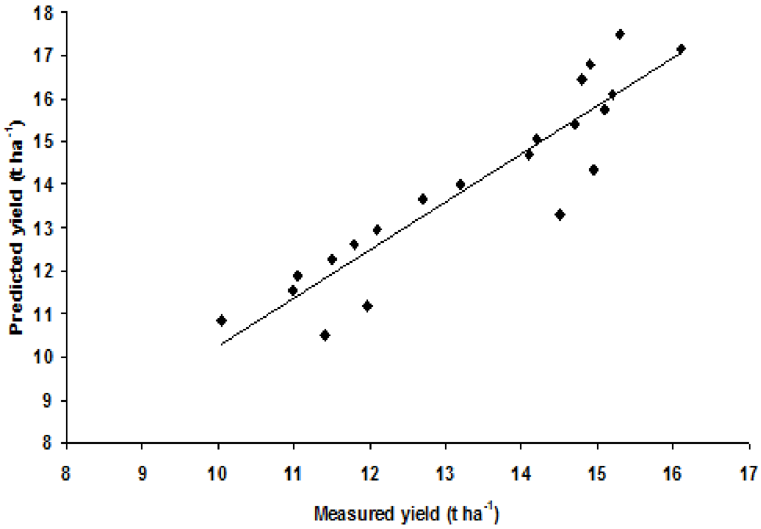

Figure 1. Cassava tuberous root yields predicted by QUEFTS model and measured in major cassava production regions of India.

Table 2. Effect of site specific nutrient management (SSNM) on root yield, plant nutrient uptake and NPK fertilizer use in cassava farms in India.

Parameters	Treatment			P>ITI
	SSNM	FFP	Δ	
Tuberous root yield, t ha^{-1}	37.35	28.63	8.72	0.005
Plant N uptake, kg ha^{-1}	204.53	172.71	31.82	0.004
Plant P uptake, kg ha^{-1}	23.79	18.62	5.17	0.002
Plant K uptake, kg ha^{-1}	201.01	208.89	-7.88	0.011
N fertilizer, kg ha^{-1}	105	59	46	0.004
P fertilizer, kg ha^{-1}	91	51	40	0.004
K fertilizer, kg ha^{-1}	105	123	-18	0.006

Δ: SSNM – FFP; P>ITI: probability of a significant mean difference between SSNM and FFP.

Table 3. Effect on site specific nutrient management (SSNM) on fertilizer NPK use efficiency of cassava farms in India.

Treatment	SSNM	FFP	Δ	P>ITI	P>IFI
$AE_{N,}$ kg tuber kg N^{-1}	80	47	33	0.000	0.002
$AE_{P,}$ kg tuber kg P^{-1}	87	70	17	0.022	0.003
$AE_{K,}$ kg tuber kg K^{-1}	115	74	41	0.000	0.030
$RE_{N,}$ kg N kg N^{-1}	0.52	0.38	0.14	0.000	0.004
$RE_{P,}$ kg P kg P^{-1}	0.11	0.10	0.01	0.003	0.008
$RE_{K,}$ kg K kg K^{-1}	0.37	0.24	0.13	0.002	0.040
PE_N, kg tuber kg N^{-1}	157	90	67	0.000	0.010
PE_P, kg tuber kg P^{-1}	279	187	92	0.003	0.017
PE_K, kg tuber kg K^{-1}	69	47	22	0.040	0.025

specific nutrient disorders, GIS based SSNM approach, etc. The farmers can find out the quantity of NPK fertilizers required for their field for a specific yield target. The input data needed to calculate site specific NPK recommendations are soil test data or yield of nutrient omission plots. A screenshot of the CASSNUM website is shown in figure 2.

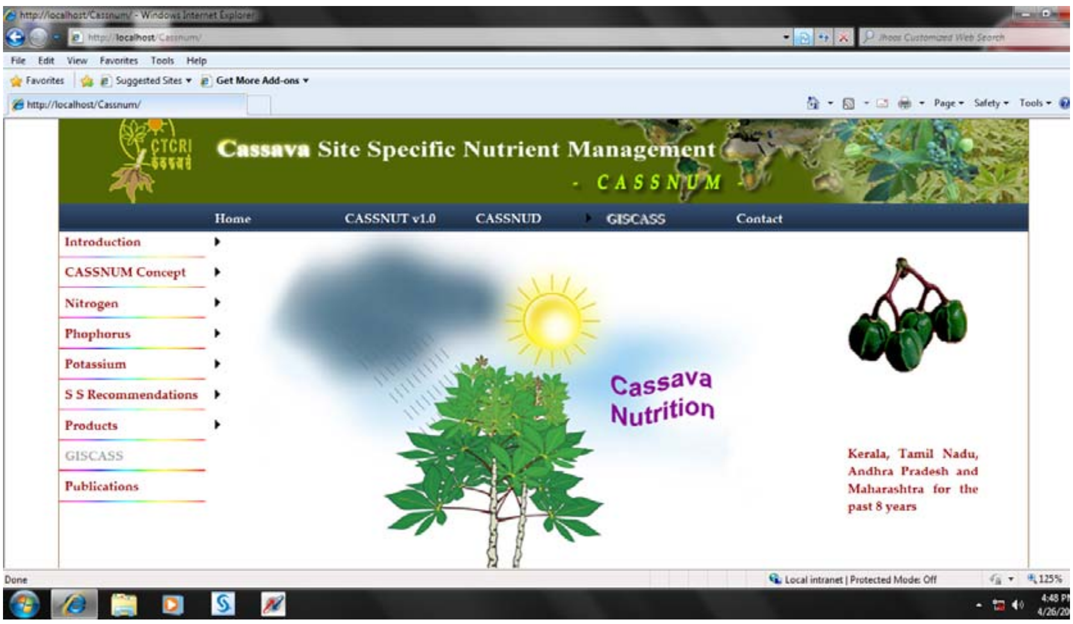

Figure 2. A screen shot of the cassava site specific nutrient management (CASSNUM) website.

GIS based NPK prescription maps for SSNM of cassava

Based on the results of the present study, NPK prescription maps of major cassava production domains of India have also been developed. The layers used for developing the maps included soil map and indigenous N, P and K supply maps. Figure 3 shows an example of the GIS based maps developed for SSNM of cassava in Kerala. The figure shows the N recommendation map for a target yield of 30 t ha^{-1}.

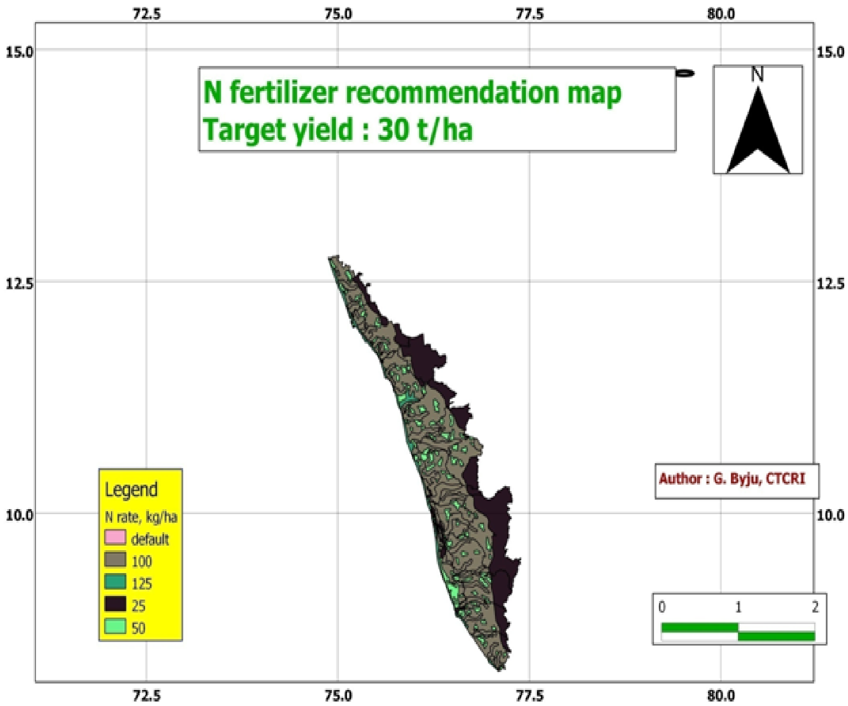

Figure 3. GIS based N fertilizer recommendation map of Kerala for a target yield of 30 t ha^{-1}.

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