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Fuzzy decision support system for improving the crop productivity and efficient use of fertilizers

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ABSTRACT

This work investigates the process of reducing the fertilizer consumption and improving the crop productivity using the fuzzy logic systems. The system comprises two parts; land report based expert knowledge to stimulate the yield potential through appropriate organic lacking minerals in soil. The system structure consists of 8 parallel systems. The integrated knowledge and formation of fuzzy rules were based on multiple domain cores professionals – water, soil and agronomy with expert farmer interviews. This research work is to improve the productivity with minimum consumption of fertilizer. The study has been carried out to access the fertilizer consumption in both the ACZ(Agro Climatic Zone) with an exhaustive daily filed measurements and lab analysis for a duration of three years to determine exact fertilizer need for every individual lands. The above data was analysed in MATLAB to establish feasibility rules for decision support systems for the crops to get the targeted output.

1. Introduction

Farming, for the most part being a mantle passed down from generation to generation, farmers feel obliged to stick to age old patterns of farming right from the seasons of working the ground to ritualistic harvest practices. Only recently in the past decade have farmers started adopting informed crop cycle patterns (Soleri and Cleveland (2004). In general, farmers have an opinion that more fertilizer equals more yields yet it cannot be farther from the truth.

The role of chemical fertilizers is very important and acceptable, because it plays an important role in increasing soil fertility and increasing crop production (Jallah et al., 1991; Simonne et al., 2017). However, long term usage of inappropriate chemical fertilizers will decrease the quality of soil and increase the soil degradation and effects ecological pollution (Ayoub, 1999; Patnaik, 2010). Sometimes the fertility and quality of the soil is heavily affected due to the knowledge void of the farming community. The impact of the chemicals is the most severe among the various others. Savci (2012) and Ning et al. (2016) have mentioned the vulnerabilities of chemical fertilizers and the contamination of various types of environmental pollutions. Aziz et al. (2015) have reported in detail about the need of fertilizers and their impacts on environment. On this basis, we have come to know the effects of chemical agriculture and the adverse effects it has on our agricultural lands. So every attempt at remediating the damage done is being attempted by mindful and discerning farmers/agricultural engineers. But the efforts to shift from modern agricultural practices to primitive yet more effective methods of cultivation presents its own set of complications, as our lands have lost the bounce back ability to cope up with organic and natural cultivation methods to produce a similar quantum of agricultural produce upon termination of chemical inputs. Fertilizer usage and crop production are heavily interlinked processes, especially in horticultural crops (Fageria, 2001). Soil and Water quality, fertilizer quality and quantity, micro nutrients, and climatic factors, are all equally important, and if even one of them is not optimum, then the production is affected (Lal and Moldenhauer, 1987).

Several models have been proposed by many researchers for the issue of fertilizer consumption considered through various points of view. Zhang et al. (2016) using the platform of Network of Science and Technology Backyards (STB), have examined fertilizer consumptions during the span of crop cultivation. As per their findings, the yield of wheat increased by 11% with addition of 1.5% Nitrogen alone. Nájera et al. (2015) evaluated soil fertility from soil samples of 31 maize cultivating farmers by testing micronutrient and macronutrients. They found that the Maize does fairly well in neutral- alkaline soils along with high inputs of NPK and Zn. Delzeit et al. (2017) presented a concept of trade-off between crop production and crop diversity, along

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with crop land expansion for improving food security, in the context of possible food shortage scenario in the decades to come (Natarajan et al., 2016) have analysed sugarcane yields in Coimbatore, Tamil Nadu and have suggested optimum parameters for both soil nutrients as well as environmental factors for cultivating sugarcane. Toyonaga et al. (2005) addressed the problem of crops chosen seasonally in Japan. Apart from their formulated problem, they also introduced the concept of fuzzy based profit coefficients for a more efficient and effective farming model. Fan et al. (2011) concentrates on the use of minimum amount of fertilizer to get efficient outcome with respect to environmental pollution in China. Papadopoulos et al. (2011) analysed the nitrogen fertilization requirement for cotton through a fuzzy based decision support system, which analysed 30 years of rainfall data and 8 years of temperature data. Šeremešić et al. (2013) had conducted a long term experiment of 20 years, analyzing climatic data such as temperature and rainfall for their effects on the yields of maize using fuzzy logic. Ashraf et al. (2014) had designed a decision support system for wheat crops, with fuzzy systems, which deals with fertilization by primary (NPK) nutrients alone. Yengoh and Ardö (2014), using fuzzy logic sets, analysed the food security provided by bolstering the production of two different food crops, by the method of fuzzy linear regression. Habib et al. (2017) implemented fuzzy logic, based on climatic parameters, oriented towards tomato cultivation for the entire South Asian Agro Zone. They developed and introduced three climate control systems for their study which uses the concept of Adaptive neuro-fuzzy inference system (ANFIS). Sivakami and Karthikeyan (2009) has designed and evaluated a Decision Support System for maize using Visual Studio 6 Programming Language.

Ogunkunle and Beckett (1988) and Malley et al. (2004) emphasizes that soil analysis process does not directly improve performance, but it maintains soil fertility and maintains the crop growth rate as it is a walkway platform between soil nutrient and soil fertility. Rajput et al. (2016) and Wani et al. (2017) reported that the crops are grown with long term soil analysis process has resulted in increased soil performance, soil organic carbon, soil nutrient and soil micro organisms which eventually culminates into increased benefit cost ratio by reducing the pollution and indirect cost.

The aim of the proposed system design is to improve the productivity and its quality with less fertilizer utilization which is carried out in several stages. The first step would be identifying the condition of the field and constant monitoring of its fertility using periodical standard soil and water analysis tests. It would be followed by planning the crop cycle for the entire period of the study along with the fertigation planning and finally the growth phase of the crop where in the farmers would be kept informed about the condition of the soil and remedial measures, if necessary in case of impending crop failure. Soil inputs, if they are in excess, deteriorate soil quality (Wallace, 1994). Therefore the soil was examined and the nutrient balance sheets were obtained which is crop specific. Based on the soil analysis test report from the experts, it depends on the nutrient prerequisite for a particular crop. As an illustration for *Allium cepa*, the nutrient balance sheet shows the nutrient available in the soil (Table 2). Nutrient balance sheet is a valuation of nutrient in the soil and provides valuable information such as its losses, pattern of fertilizer used in agricultural practices and the rule of applied nutrition to farming systems (Eulenstein et al., 2014). The method tested in this study warrants against these failures while ensuring the levels of inputs stay at the required minimums, which in turn also reduces production costs, with the consequent increase in Benefit Cost Ratio (BCR). The method also provides a way of returning back to sustainable agriculture in calculated increments by reduction of soil inputs, allowing for recovery period of the soil and by finally sensitizing the soil to organic inputs by cutting out excess chemical fertilizers. The method utilizes the concept of fuzzy logic to evaluate the required inputs for the soil and the crop. Fuzzy logic has become the go to technique which is being applied in many research platforms, including Medical, Wireless Sensor Networks, Artificial Intelligence and Engineering Applications; Electrical Energy Consumption, Fog Forecasting (Azadeh et al., 2013; Miao et al., 2012). Previously, fuzzy system has been utilized in the purview of agriculture for managing fertilizer consumptions and in particular to reduce excess usage of primary nutrients like NPK either individually or as a whole and simultaneously use the minimum amount of fertilizer to improve the productivity. By following this process environmental pollution has been reduced to half and emission of N_2O and CO_2 compounds has also been reduced (Fan et al., 2011).

This is an attempt to employ fuzzy based system to validate an array of soil, nutrients, water and climatic parameters to arrive at conclusions on best inputs for the particular crop and soil. In agriculture, the role played by land, water and fertilizer cannot be defined individually. However each has a sizeable contribution in association with the rest towards better productivity. There had been attempts by researchers, earlier, with primary, secondary and micronutrients of the soil. But the proposed system, the nutrient concentration along with water and climatic conditions are given cognizance for determining the productivity. The soil data is obtained through periodic soil tests done on each farmer's land. It is evaluated at frequent intervals to monitor changes in soil properties immediately after changes in input patterns. The increased consumption of fertilizers has been due to ignorance in effective crop rotations, wherein farmers have been accustomed to a particular crop cycle throughout their lives and are unable change out of it, and uninformed usage of fertilizers, where most of the farmers believe that more fertilizers gives higher yield. The apparent failure of the farmer to think beyond the field, to the market and be cognizant of the climatic predictions has been another big reason for the dire state of agriculture in the country. Our model takes into account all of these parameters and provides comprehensive suggestions for every individual farmer, backed by the validation of experienced agricultural engineers and farmers in their ACZ (Agro Climatic Zone). During the study period from 2013 to 2015 the results obtained were in line with our expectations. Considering the mentioned literatures, it is seen that previous studies do not go beyond the purview of primary nutrients. Therefore in this proposed system a routine soil analysis process has been carried out for all nutrients including secondary and micro nutrients, and across multiple crops. The system pays cognizance on expert opinion regarding the parameters monitored and tracks the outcome of every suggestion implemented.

2. Methods and materials

This section provides the explicit information about the methodology. The study began in 2012–13 and ended in 2015–16 and a study was conducted in two agro climatic zones. For this purpose 80(each 40) farm lands were selected and the study appears in detail in the system implementation section presented as the supplementary material. Crop Cultivation is followed by regular inspection of soil parameters, climatic parameters, water quality and fertilization. The uncertainty involved in the determination of each of the natural factors results in vagueness. Fuzzy system quantifies vagueness into a meaningful parameter for analysis. Therefore, we have created a fuzzy based model. The soil parameters, climate parameters, water quality and fertilization are continuously monitored and thereby increased the productivity using low fertilizer consumption. Crops under study were *Allium cepa*, *Momordica charantia*, *Lagenaria siceraria*, *Musa*, *Trichosanthes cucumerina*, *Citrullus lanatus*, *Cucumis melo*, *Solanum lycopersicum*, *Solanum melongena*, Capsicum frutescens, *Brassica oleracea var. botrytis*, *Oryza sativa* in the two agro climatic zones.

2.1. Fertilizer balance

In order to reduce the fertilizer consumption the availability of nutrient concentration in the soil is calculated using the given equation below

$$E_X = \frac{\left(\int_{Actual\ Value}^{Essential\ Value} PN * \int_{Actual\ Value}^{Essential\ Value} SN * \int_{Actual\ Value}^{Essential\ Value} MN\right)}{(Essential\ Nutrient\ Scale\ of\ PN * Essential\ Nutrient\ Scale\ of\ SN * Essential\ Nutrient\ Scale\ of\ MN)}$$

where

PN – Primary Nutrient
SN – Secondary Nutrient
MN – Micro Nutrient
E_x – Fertilizer Balance

Primarily, lithosphere holds nutrients in soil but sometimes the available nutrient strength is insufficient and even does not support the plant growth. Due to that impact the course of soil analysis procedure is the only option to overcome the lack of nutrient problem, in which to allocate the deficiency of nutrient levels were determined by experts and measured on a 0–5 scale.

Each of the individual nutrients concentration levels are considered as individual gains of a cascaded system. Hence, the individual concentration levels are multiplied to arrive at the composite gain of the cascaded system. The soil samples tested for the individual nutrient concentration are distributed throughout the land. Each shows a slight variation in the concentration of a particular nutrient. To arrive at the overall concentration of the nutrient, integrated gains of the individual samples are considered.

For instance the value of $E_x = 0$, the soil does not need any recommendations, in contrast when the value of $E_x = 1$ the 100% recommendations are needed. If the value of $E_x < 0.5$ and $E_x > 0.5$ then the recommendations are 75% and 25% respectively.

2.2. Decision support system design

Problems in the real world are complex because of uncertain element. The probability theory has been detected and used to handle the complex uncertainties in the world, but it is only used for situations based on random actions. In such circumstances, fuzzy logic revealed the ability to solve such an ambiguous and its uncertainty incontinence. Therefore, Fuzzy logic is logic is to solve the problems between the obvious logical values and classical accuracy. The first concept of the fuzzy was introduced by Professor Lotfi A. Zadeh to the world. The fuzzy logic is an extension of the Boolean logic, which also deals with the value of the truth, where the true value of the truth is absolutely true and completely false.

A Decision Support System or simply called a fuzzy system is designed based on expert suggestions view but followed standardized fuzzy logic decision making system (Ross, 2009) platform. The fuzzy conventional system structure is shown in Fig. 1.

The proposed fuzzy system structure along with integration of expert knowledge is presented in Fig. 2. The fuzzy sets comprising the expert knowledge of soil, water, climate and agronomists. The expert knowledge facilitates the formation of the final decision rule. However the fuzzy system incorporates several state variables, to achieve the target output. The proposed fuzzy system design process has been based on the concepts of crop nutrient based cultivation procedures and minimum usage of fertilizer and fertigation schedules towards high productivity for nominal parameter ranges and is split into three specialized categorized viz., soil and water property variables, climatic variables and agronomy suggestions. The parameters under consideration are numerous and hence to analyse them using traditional methodologies is not possible, and hence the need for a fuzzy logic system. The proposed system is a multi-input and single output system. The inputs range up to 25 in the present case. To ease the system design, the given number of inputs is classified into sub groups. Each subgroup consists of inputs which fall in related domain. MATLAB R2014a tool is used to simulate the system. The fuzzy logic controllers are extensively used in the mechanism of controlling numerous systems. The process of fuzzy logic operation had been followed by three steps. 1. Fuzzification 2. Rule evaluation 3. Defuzzification. For that purpose of aggregation rule combines there are the three types of graphical inference techniques (fuzzy controllers) are available. 1. Mamdani Systems 2. Sugeno Systems 3. Trukamoto Systems. The typical multi input and single output fuzzy rule follow as

If Input1 is A1 AND Input2 is A2, Then Output is Y1
If Input1 is B1 AND Input2 is B2, Then Output is Y2

Where Input1, Input2 Output is variables of the fuzzy system and A1, A2, B1, B2, Y1, Y2 are fuzzy sets. The degree, to which the fuzzy action is taken, depends on the degree of truth in the antecedent proposition.

In this proposed system the first two types of fuzzy controllers has been approached and finally while makes system implementation process. The delay in executing all the rule bases in a single cycle is more. Hence attempts were made to categorize the parameters from a common base into many sub groups. Each sub group is allowed to execute in parallel and the outputs from the sub groups are further reduced until single outputs is arrived. The entire process is attempted with an initiation of a crop i.e., rule base is instantiated for a particular crop variety. The system is modeled by taking into the consideration the expert suggestion and farmer opinion from the two Agro Climatic Zones (ACZ). The North Eastern Zone and Western Zones are the two ACZ taken into consideration. Fig. 3 gives the integration of the Decision Support System, identifying individual input data that focuses on reducing fertilizers and the recommendation chart to be used at the system level. The 25 inputs fed into the system, when considered as a whole, burns down to more than 20,000 rules resulting in complexity. Hence, the 25 inputs are grouped into 8 related categories as given below. The classification is based on The British Association Meeting (1955) notification and our experts. Overall, there are 8 fuzzy systems designed to simulate the productivity with minimal usage of fertilizer consumption. Required to the system evaluation and emergence need of crop cultivation each of the constituents of the sub-groups consists of the following.

1. Primary Nutrient Variables: As per the British Association Meeting and FAO 2012 and common fertilizers of International standard, the nutrients of Nitrogen (N), Phosphorous (P) and Potassium (K) presence in the soil is essential for each and every crop cultivation procedure.
2. Secondary Nutrient Variables: Three number of nutrient comes under this category. They are Calcium (Ca), Magnesium (Mg) and Sulphur (S).
3. Micro Nutrient Variables: This is an important and very essential nutrient which influences the productivity. They are Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B) and Molybdenum (Mo).
4. Climatic Variables: This includes the Rainfall (mm), Temperature

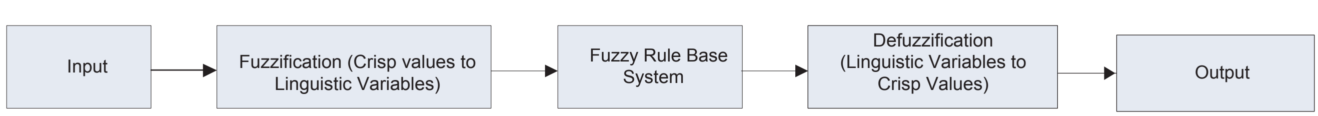

Fig. 1. Basic fuzzy Structure.

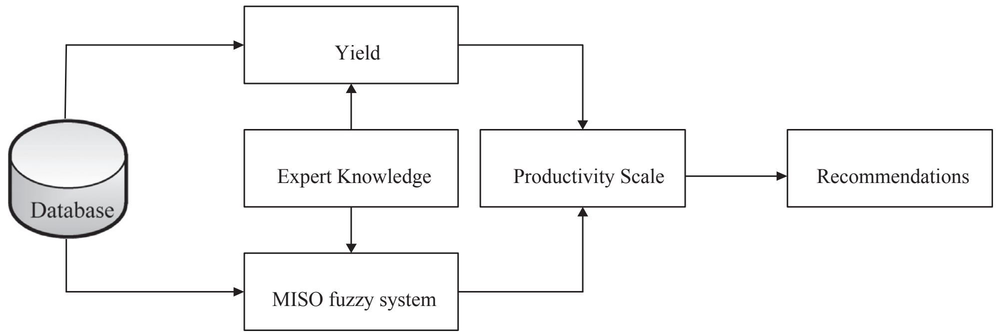

Fig. 2. Proposed decision fuzzy system structure.

(°C) and Humidity (RH).

5. Soil Property Variables: The variable includes soil organic matter (OM) content, soil type, soil pH and soil electrical conductivity.
6. Water Property Variables: Water quality, pH and concentration of minerals for crop cultivation come under water property variables.
7. Seasonal Variables: There are three types of standardized Indian crop cultivation seasons – Kharfi season, Rabi season and summer season.
8. Pesticide Incidence Variables: Apart from the regular external attacks, problem emanate from factors like fungus, weeds affect leaves, roots and other parts of the plant which results in eventual death of the plant in some instances.
9. Productivity Variable: The target is to maximize the productivity.

2.3. Process of fuzzification

The membership functions were used in the fuzzy systems of entire level due to is appropriate of transferring the linguistic variables. Basically, fuzzy logic rule can be defined as an if-then construct. The process begins with individually categorized input variables and a final output response is obtained by processing each variable individually within the purview of some set rules. In Figs. 4 and 5 membership function structures shows the corresponding fuzzy sets towards of Iron and Potassium variables are presented respectively. Fuzzy set of linguistic variables shape for membership functions between the variables designed through domain expert suggestions. A process of fuzzy rule design parameter combined examples will represent in Table 1 which is eventually utilized to fuzzy rule base of the system subsequent the straight suggestion facts from the estimating expert calculating better productivity view. The experts from three specialized categorizes soil, water and climatic change and adaptation from College of Engineering, Guindy, Centre for Water Resources, Anna University with field personals and farmers from two ACZ. Apart from that categorized domain suggestions the designer of the system is entire responsible of every design stage of system operation. The choice of crop during a particular season in each ACZ is taken and the input from the farmer and the same is fed into the proposed DSS to arrive whether the choice made is suitable or not. The function used for the fuzzification of parameters in the variable iron and potassium is the trapezoidal membership function given below. The low or high in the input level seem to have no effect in most of the cases, hence the trapezoidal membership function is justified. The mathematical representation of trapezoidal membership function is

$$trapmf(a;w,x,y,z) = \begin{cases} 0, & a \leqslant w \\ \frac{a-w}{x-w}, & w \leqslant a \leqslant x \\ 1, & x \leqslant a \leqslant \\ \frac{z-a}{z-y}, & y \leqslant a \leqslant z \\ 0, & z \leqslant a \end{cases}$$

As per this earlier concept, fuzzy set is completely characterized by its membership function and the mathematical expression described in this paper is the most commonly used.

2.4. Fuzzy rule base

Seasonal factors are important for all crops, since it make significant effects in production (Iizumi and Ramankutty, 2015). Except for horticulture crops, season is very crucial factor especially very essential for paddy, watermelon and muskmelon cultivation (Pereira et al., 2017; Pivonia et al., 2002; Reddy and Hodges, 2000). For example expert knowledge led to the formation of under Climatic parameters, variables such as Rainfall, Temperature and Humidity, 27 rules are framed and finally only one rule alone is termed as the most feasible rule for implementation. For instance, if the rainfall, temperature and humidity are at optimal levels for the particular crop, then productivity ought to be maximized. Sometimes a pesticide incidence was performing the crucial importance of yield deciding factors, as per this suitable fuzzy rule were analysed by crop wise and it is demonstrated in below. In addition, all the variables of measuring unit is show and ensuring prevailing concentration of all nutrients of a particular land which is planned for any one of the horticultural crops are in Table 2.

Even with the optimal turnout of climatic factors, the absence of some micro nutrients like Iron, Zinc, Manganese, Copper, Boron or Molybdenum is low and then maximum productivity cannot be achieved. The incredibly diverse nature of every farm land, with variations arising out of being in different climate zones creates a decision making situation wherein the cumulative branching of decisions at each parameter amounts to a very large and complex system requiring tremendous computing capacity. To avoid this stalemate, we have chosen the most dominating traits for plant growth consisting of eight major types of inputs and one output variable. In terms of arriving at maximum productivity, the fuzzy rules associated with expert's opinions framework is between the range of [0, 1]. Parameterized value segregation process ultimately deals with combined fuzzy intentions and consequently expert knowledge. As a result knowledge data provided by all respective department scientists and respective crop producers from our study area is taken into consideration. In some of peculiar cases, producer is also the decision knowledge provider and his inputs are incorporated in the system design process.

2.5. Fuzzy inference system

The demonstration of system with better productivity which takes in eight factors such as soil and water property, primary and secondary nutrient, micro nutrient, pesticide incidence, seasonal parameters and climatic parameters. As an example in NEZ, suggestions by the experts enlisted better productivity for the crop Paddy if the climatic conditions of temperature, rainfall and humidity lie in the range of 30–40 °C, 1500 mm and 70–80% respectively during the Rabi season. The beneficiaries followed the suggestions and the table below shows better productivity for the crop paddy as the climatic conditions paralleled the

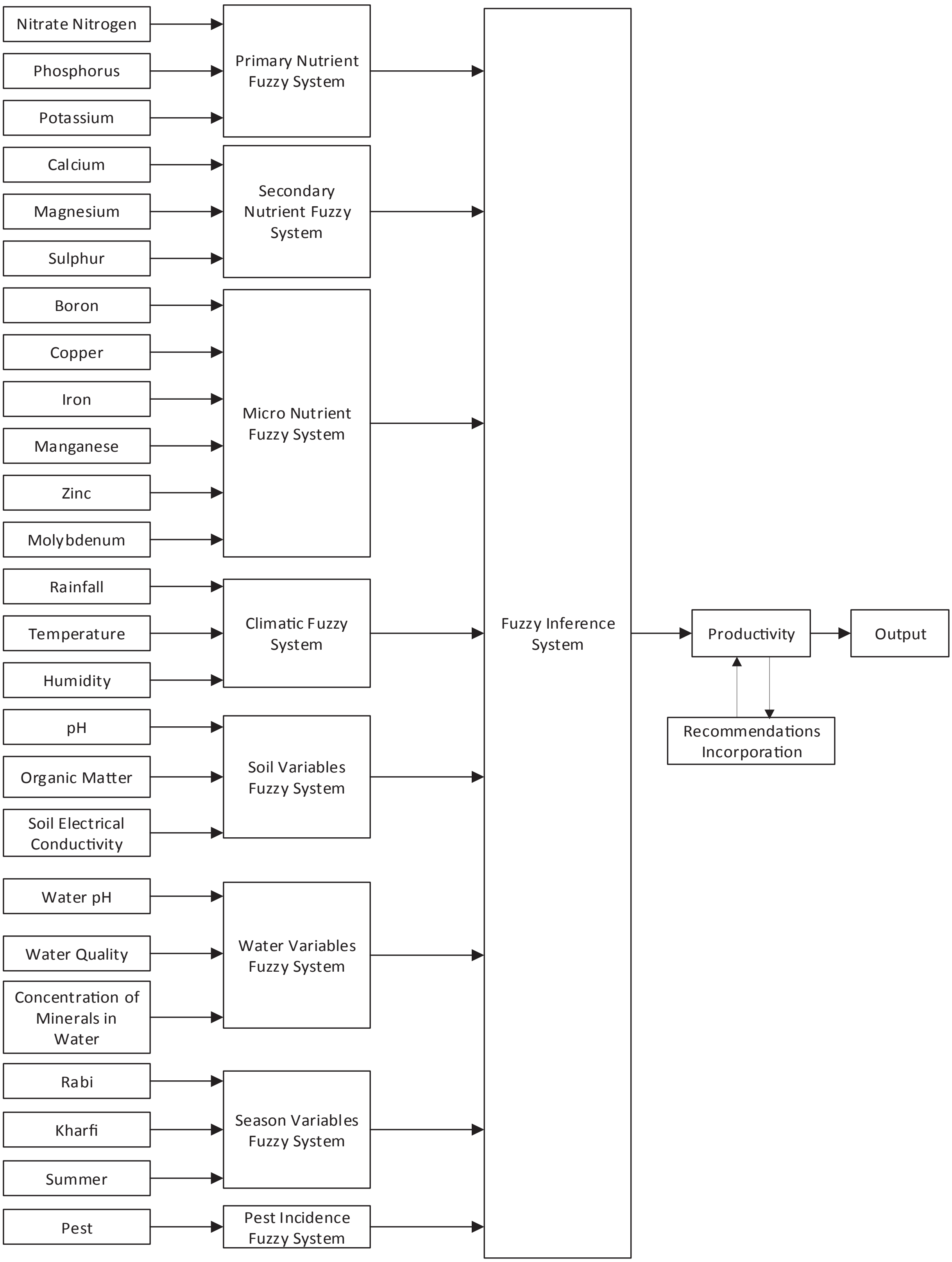

Fig. 3. Block diagram of fuzzy decision support system for agriculture.

suggestions.

Table 3 shows the average climatic conditions for the entire three years for both the ACZ. The data pertaining Temperature, Rainfall and Humidity are partitioned into low, average and above average for better crop cultivation. The same partition is also applicable to all the other climatic parameters and other factors such as primary and secondary nutrients and so on. The climatic parameters play a vital role in the crop cultivation as happened in the NEZ in December 2015 where all the other factors were favourable for better productivity but the overwhelming rainfall badly affected the productivity. Fig. 6 shows the

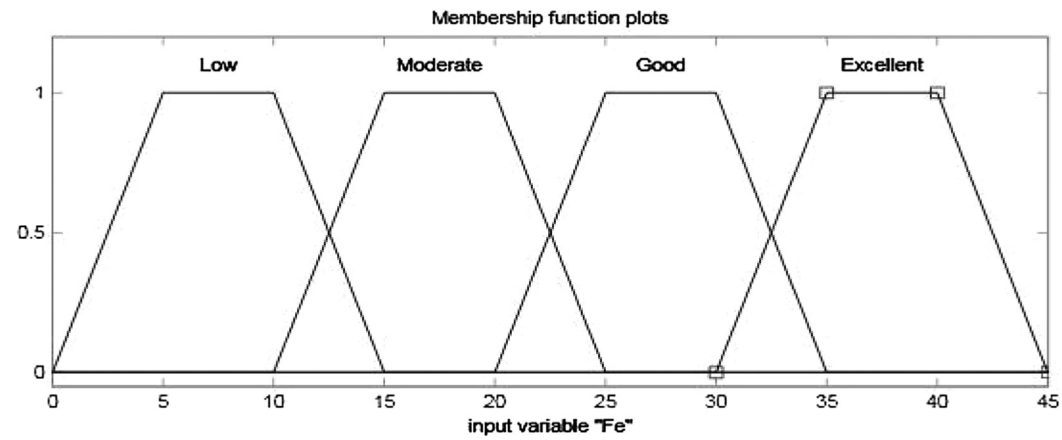

Fig. 4. Fuzzy sets of the linguistic variables of iron.

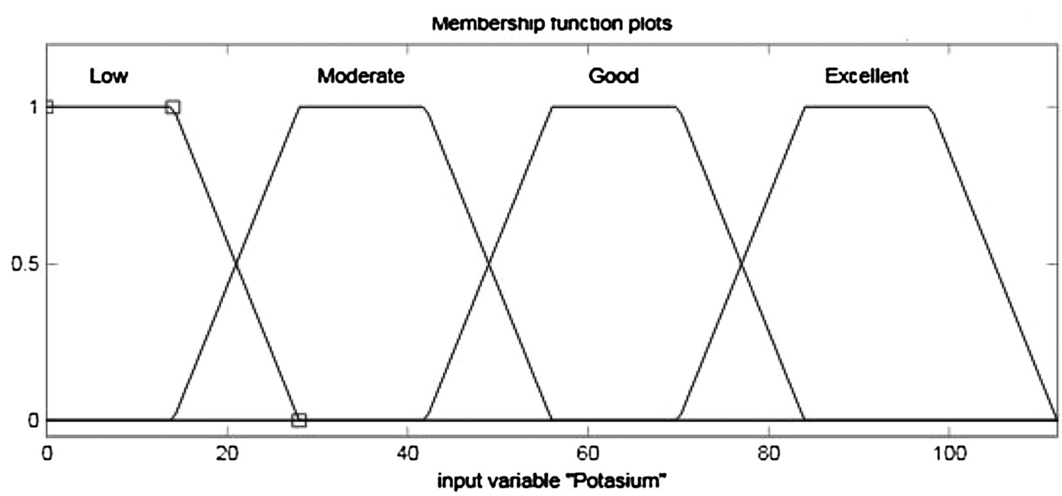

Fig. 5. Fuzzy sets of the linguistic variables of potassium.

Table 1
Rule base of the proposed system.

Rule.No.1	If Primary Nutrient Output is Poor AND Secondary Nutrient Output is Poor AND Micro Nutrient Output is Poor AND Climatic Parameter Output is Poor AND Seasonal factor Output is Poor AND Soil Properties is Satisfied AND Water Properties is Satisfied AND Pesticide Incidence is Very High Level THEN is Poor Productivity
Rule.No.2	If Primary Nutrient Output is Poor AND Secondary Nutrient Output is Moderate AND Micro Nutrient Output is Poor AND Climatic Parameter Output is Poor AND Seasonal factor Output is Poor AND Soil Properties is Satisfied AND Water Properties is Satisfied AND Pesticide Incidence is Very High Level THEN is Poor Productivity
Rule.No.3	If Primary Nutrient Output is Poor AND Secondary Nutrient Output is Good AND Micro Nutrient Output is Poor AND Climatic Parameter Output is Poor AND Seasonal factor Output is Poor AND Soil Properties is Satisfied AND Water Properties is Satisfied AND Pesticide Incidence is Very High Level THEN is Poor Productivity
	”
	”
	”
Rule.No.2500	If Primary Nutrient Output is Poor AND Secondary Nutrient Output is Excellent AND Micro Nutrient Output is Poor AND Climatic Parameter Output is Excellent AND Seasonal factor Output is Moderate AND Soil Properties is Satisfied AND Water Properties is Dissatisfied AND Pesticide Incidence is Very High Level THEN is Poor Productivity
Rule.No.16000	If Primary Nutrient Output is Excellent AND Secondary Nutrient Output is Excellent AND Micro Nutrient Output is Excellent AND Climatic Parameter Output is Moderate AND Seasonal factor is Good AND Soil Properties is Dissatisfied AND Water Properties is Dissatisfied AND Pesticide Incidence is Medium Level THEN is Good Productivity

suitable climatic fuzzy rule for both the ACZ (see Table 4).

The experts' view on the yield lists four categories like Poor, Moderate, Good and Excellent productivity. The productivity is strongly dependant on crop variety. For example, in the case of tomato, 30–40 tonne per hectare is good for traditional variety whereas the hybrid variety is deemed good only when the yield is 80–95 tonne per hectare. Similar data for traditional tomato variety is poor, moderate, good and excellent if the productivity is 0–20 tonne/ha, 20–30 tonne/ha, 40 tonne/ha and above 40 tonne/ha respectively. As mentioned earlier, the productivity is crop specific-Crop Production Techniques of Horticultural Crops (Crop Production Techniques of Horticultural Crops, TamilNadu Agriculture University, 2013).

2.6. Defuzzification

Defuzzification provides the arithmetic value to the fuzzy variable

Table 2
Soil sample report for a particular land: *Allium cepa* (to be planned crop).

S. no	Parameter	Unit	Concentration
1	pH	–	7.50
2	Electrical Conductivity	ms/cm	0.26
3	Organic Matter	%	0.72
4	Nitrate Nitrogen	ppm	26.20
5	Available Phosphorus	ppm	32.63
6	Potassium Exchangeable	ppm	227
7	Calcium Exchangeable	ppm	1001
8	Magnesium Exchangeable	ppm	337
9	Sulphur	ppm	29.80
10	Sodium	ppm	290
11	Zinc	ppm	5.53
12	Manganese	ppm	16.55
13	Iron	ppm	5.47
14	Copper	ppm	1.85
15	Boron	ppm	1.20
16	Molybdenum	ppm	50.12

Table 3
Experts prediction for climatic parameter.

Temperature	
Low	Below 25 °C
Average	26–40 °C
Above Average	Greater than 40 °C
Rainfall	
Low	Below 750 mm
Average	750–1500 mm
Above Average	Above 1500 mm
Humidity	
Low	Below 75%
Average	75–90%
Above Average	Above 90%

resulting from the membership functions. It is important as it generates the crisp value from the fuzzy sets. The centroid defuzzification technique is shown below.

$$E = \frac{\sum_{i=0}^{n} A_i \mu_b(Ai)}{\sum_{i=0}^{n} \mu_b(Ai)}$$

where

μ_b−membership function truth value and x is the domain value of i.

3. Results and discussions

The results field level report from the year 2013 to 2015 shows that the higher productivity is directly related to the soil nutrient based crop cultivation and lesser consumption of fertilizer. The finding shows that horticultural crops recorded a better productivity of 30% to 50% by the 80 beneficiaries over the two ACZ. The horticultural crops cultivated are *Solanum melongena*, *solanum lycopersicum*, *Lagenaria siceraria*, *trichosanthes cucumerina* and *musa* and so on. Apart from the above remaining a fruit variety like as water melon and musk melon has also been cultivated in the NEZ. The better productivity is obtained with lesser usage of fertilizers. The cost of cultivation been reduced to about 30% with productivity increased up to 70%. This is vital citing the fact that the increased productivity comes in with lesser fertilizer consumption as the trend is marching towards sustainable agriculture. But a sudden shift towards sustainable farming might endanger the factors like soil health. Considering this, the suggestions by experts of slowly moving towards fertilizer free cultivation is obtained. However initial attempts in restoring the soil nutrient by addition of particular fertilizer entertained.

Fig. 7 shows the productivity BC ratio for three years consisting of 12 crops. During the three years the Musa crop has enjoyed the highest BC ratio which is close to 7. The crop *Citrullus lanatus* and *Cucumis melo* BC ratio though increased in 2014 remained stagnant in 2015 due to record level high rainfalls during that year. Overall, Musa tops the chart in BC ratio followed by *brassica oleracea var. botrytis* and *Allium cepa*. After switching over from the regular crop cycles and agricultural practices to the new informed crop cycle patterns and soil nutrient based agriculture, the farmers have come to understand much about the soil based fertilizer recommendations. Within the interval of 2013–2015 our fertilizer consumptions have come down considerably as shown in Fig. 8. An open house discussion was conducted in both the ACZs. During the sessions many insights were discussed regarding fertilizer consumption, benefit cost ratio, crop based cultivation methods etc. The farmers welcomed the time space scheduling between crops which was vigorously implemented by our field assistants. The farmers

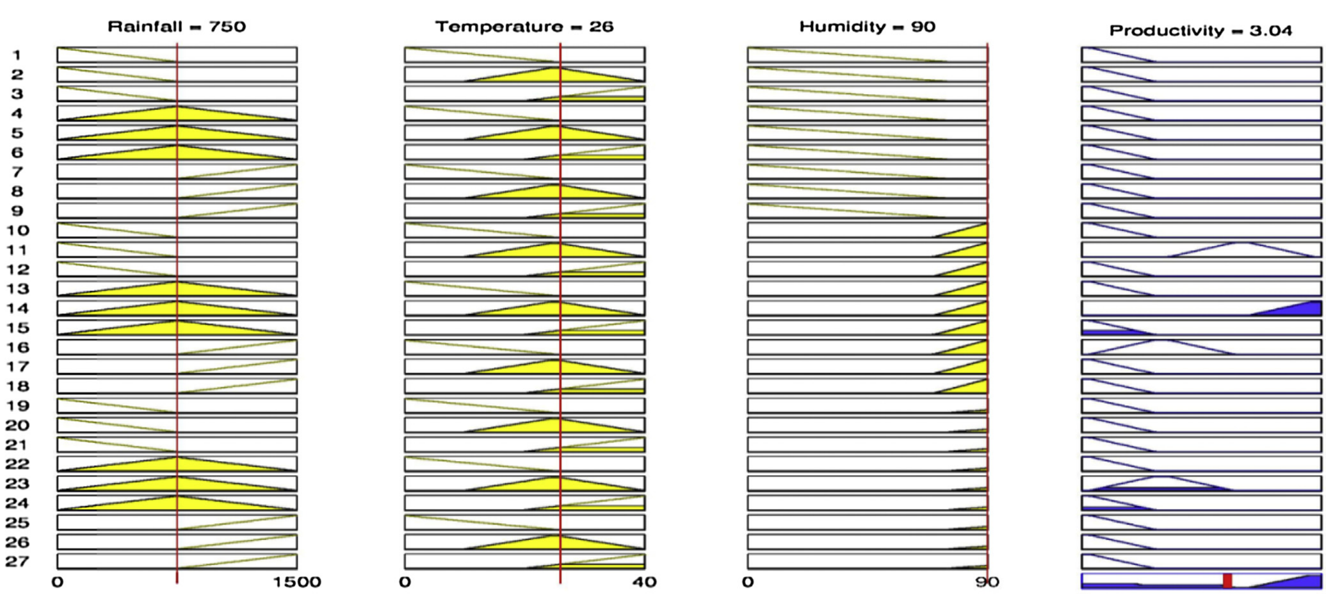

Fig. 6. Rule based system design for climatic parameter.

Table 4
Descriptive numeric statistics data.

S.No	Parameter	Minimum	Maximum	Actual mean	Standard deviation
1	pH	5.94	8.75	7.41	0.89
2	Electrical Conductivity	0.04	1.01	0.22	0.16
3	Organic Matter	0.66	1.55	1.10	0.35
4	Nitrate Nitrogen (ppm)	8.9	52.7	24.10	9.40
5	Available Phosphorus (ppm)	8.57	70.28	30.96	15.52
6	Potassium Exchangeable (ppm)	29	600	164.16	111.03
7	Calcium Exchangeable (ppm)	100	3173	1622.356	824.79
8	Magnesium Exchangeable (ppm)	277	1028	495.46	233.52
9	Sulphur (ppm)	7	68.5	22.38	17.27
10	Sodium (ppm)	83	290	179.38	120.14
11	Zinc (ppm)	1.04	5.4	1.66	1.07
12	Manganese (ppm)	4.29	37.38	508.17	31.02
13	Iron (ppm)	5.78	189.58	33.37	45.51
14	Copper (ppm)	2.18	5.3	2.28	0.92
15	Boron (ppm)	0.6	1.2	0.88	0.14
16	Molybdenum (ppm)	25.06	113.20	13.36	6.10

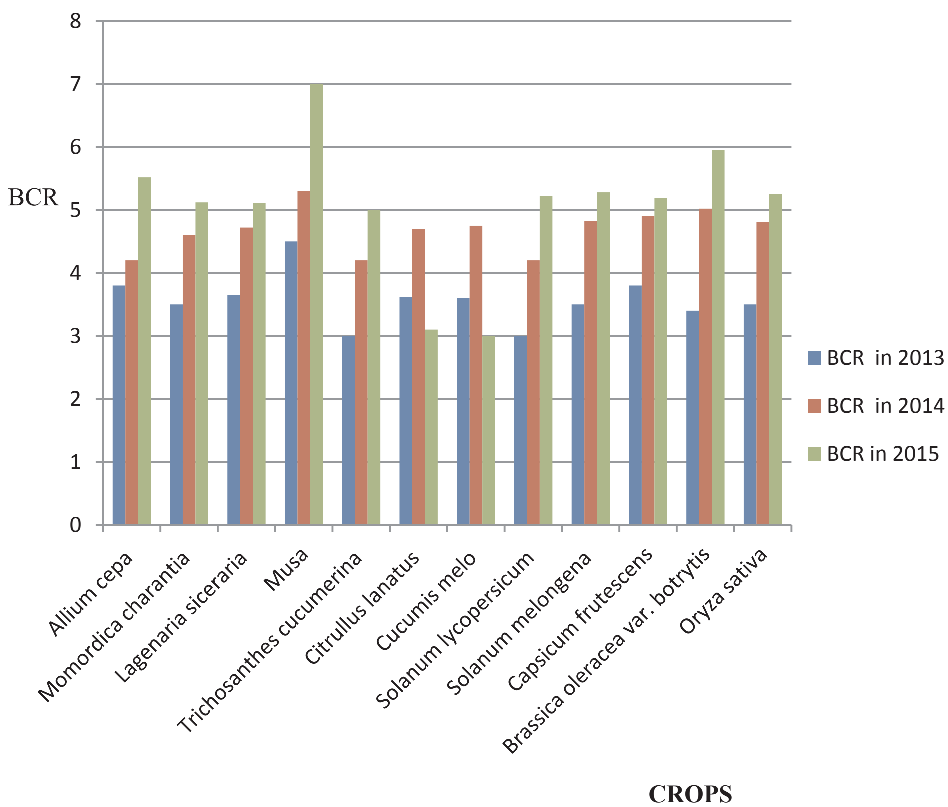

Fig. 7. BCR for different crops.

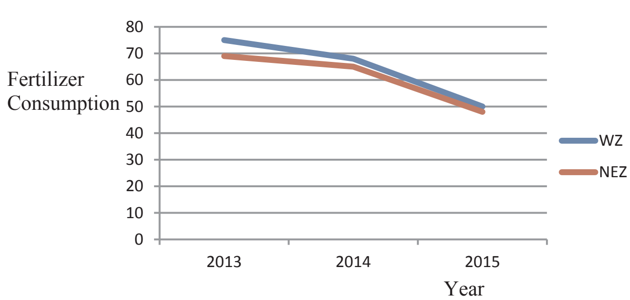

Fig. 8. Consumption of fertilizer.

from western zone (WZ) revealed that their Musa crops' productivity reached the BC ratio of nearly seven during the project period with the fertilizer consumption way below their usual levels. Similarly farmers from North eastern zone (NEZ) appreciated the switch over to horticultural crops wherein they achieved a previously unattained BC ratio with fertilizer consumption at a minimum level. The COC (cost of cultivation) of horticulture crops was reported to be nearly 50% of yield profit, whereas, the COC of *Oryza sativa* was reported to be lower, and the same was quoted as a reason to stick with the *Oryza sativa* cropping by the NEZ farmers attached before the commencement of the project. But on realizing the overall profits to be higher under the scheme proposed through the project, the farmers were finally convinced that soil nutrient based cultivation pays off dividends down the line. Though some farmers have decided to continue their *Oryza sativa* cultivation they are convinced of simultaneously taking up horticulture crops.

Table 5
Comparison between the two methods.

System	Crop	Actual Prediction	Actual Productivity	Recommendations	BCR Increased	Fertilizer Consumption (in terms of percentage)
AgRIS	–	85%	–	Recommendations Provided	2–4	75%
System without Recommendation	*Allium cepa*, *Solanum lycopersicum*, *Musa*, *Solanum melongena*, *Momordica charantia*, *Lagenaria siceraria*, *Trichosanthes cucumerina*, *Brassica oleracea var. botrytis*, *Citrullus lanatus*, *Cucumis melo*, *Oryza sativa*	–	–	Recommendations not provided	1–2	95%
Proposed System	*Allium cepa*, *Solanum lycopersicum*, *Musa*, *Solanum melongena*, *Momordica charantia*, *Lagenaria siceraria*, *Trichosanthes cucumerina*, *Brassica oleracea var. botrytis*, *Citrullus lanatus*, *Cucumis melo*, *Oryza sativa*	90%	95%	Recommendations provided as per the expert advices	5–8	Deliberately reduced In the order of 10 to 15%

The consumption of fertilizers over the period from 2013 to 2015 is shown in Fig. 8. As seen from the figure, the reduction for the first period 2013–2014 was not appreciable and it hovers around 7%. The effect is due to the lack of awareness among the farmers. The second period between 2014 and 2015 shows a major reduction in the fertilizers consumption to the tune of 18%. The reduction in the fertilizers consumption directly affects the BC ratio. The cost of cultivation reduces considerably as the usage of the fertilizers is reduced.

The outcome of the project work has truly ratified our projections. The adoption of a horticultural crop based crop cycle has shown a marked increase in the Benefit Cost Ratio for almost the entirety of our farmer base in the North Eastern Zone. The farmers have realized the potential of horticultural crops over their traditional crop cycles consisting of *Oryza sativa* and few other support crops. Our farmers have heartily shared their success stories through the adoption of a soil nutrient based cultivation procedure.

3.1. Comparative analysis

This proposed system is not only predicting the production and the reasons for its support, but also the pedagogues of experts, including the proposals to produce more than predicted production. Prior to this proposed system (Reddy and Ankaiah, 2005) exactly made such a novelty but they did not use fuzzy logic concepts. The idea to combine fuzzy concepts with decision support system consists of the following three categories. Firstly, systematic soil based analysis components were incorporated with expert recommendations. On the other hand feature in the incorporation of membership function manipulators were being used for system performance level. Moreover, the problem in hand is the ambiguity associated with natural parameters. For instance, the inorganic resources usually vary from place to place, and the impacts of these changes are explained by using fuzzy logic. The proposed system consists of two sets, one with recommendations and the other without recommendations. Experts' suggestion resulted in higher BCR as the fertilizer consumption is reduced. Table 5 provides the details of the same.

4. Conclusion

The fuzzy logic system developed in this research as part of the Decision Support System, concentrates on maximizing crop productivity while minimizing fertilizer usage. This study inspects the fuzzy logic based decision making for designing crop cultivation procedures for cultivating horticulture crops, based on the climatic parameters along with soil properties. The real time effects on ground have been examined in this paper and have been found to reflect the literature. The fuzzy rules were defined with in-situ information and further improvised using suggestions from industry experts. The DSS affirms that systems can be developed to maximize crop productivity based on fuzzy logic by carefully considering soil profile, water quality, primary, secondary and micro nutrient availability, seasonal factors and pest incidence. The actual end user of the project is Director Horticulture officer, District Administration through respective soil specialist and agronomist. The proposed system resulted in four times improvement in the BCR in addition to reduction of fertilizer consumption by 8 times. The system is expected to take shape as a handheld device for the farmers in the future with the help of embedded system and VLSI technology.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.compag.2018.03.030.

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