Journal of the Nigerian Association of Mathematical Physics
***Volume34,(March, 2016*), pp 227 – 232**
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A Fuzzy Logic Model for Effective Distribution of Fertilizer in Nigeria

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Abstract

The purpose of applying fertilizer to a soil is to improve the fertility of the soil so as to obtain a better yield. Excessive application of fertilizer could result in poor yields. A study of some soil samples shows that some have certain nutrients in short supply while others have enough. Further study reveals that farmers lack knowledge of the nutrients needs of the soil, so they apply fertilizer ignorant of what type of fertilizer to apply. In doing this misapplication, more nutrients could be added to a soil that is already saturated with a particular mineral and sometimes further depriving the same soil with some minerals that are in short supply. Such misapplications do not only constitute a waste but also help in depleting the soil fertility resulting in poor yields. In this study, the soil nutrients of Ugep in Cross River state in Nigeria are anlaysed, from the analysis it was discovered that some brands of fertilizer used in that part of the world are not suitable for such soils. Based on these findings, a fuzzy logic model for fertilizer distribution is developed. The results show that if the model is implemented in Ugep, a better yield of crops would be derived.

Key words: Agriculture, Fertilizer, Fuzzy logic, Nitrogen, Phosphorous, Potassium, Soil.

1.0 Introduction

The soil being the top part of the earth surface contains minerals, gases, organic substances and living organisms. The life of a mankind is sustained by soil. Both humans and animals have explored and exploited the soil sometimes to their detriment. One of the ways the soil is explored and exploited is in agriculture. Man has cultivated the soil in order to sustain life. The soil naturally was created with all the fertility to sustain mankind but its exploitation has resulted in a depletion of some of its constituents.

In an attempt to replenish these depleted nutrients, man has devised a means. One of such means is in the application of fertilizer to the soil to increase productivity. Fertilizers come in 2 folds; the organic and inorganic fertilizers. Organic fertilizers are obtained from plants and animals such as farm wastes, faeces and residues from plants processing while inorganic fertilizer is manufactured using minerals such as Nitrogen, Phosphorous and Potassium.

The natural fertilizer cycle shows that as plants grow they mine nutrients they need from the soil [1]. When crops are harvested, those nutrients also go to the market leaving a shortage of nutrients in the soil. Fertilizing does nothing more than complete the plant cycle to ensure that crops get what they need to grow. Fertilizer use is indispensable in Nigerian agriculture as fertilizers help to increase crop production as well as improve the quality of crops and fodder for animals [2]. Continuous cropping with adequate nutrients supplement to replenish the soil and crop requirements often results in nutrient mining and sub-optimal yields. With adequate fertilizer use, food could be produced in quantity and diversity than our soil and land resources would otherwise support.

Fertilizers use is directly connected to the forces of driving crop supply through the increase in productivity and this also has direct and indirect consequences for the environment [3]. Presently, Nigerian farmers are more interested in the quantity of fertilizer applied without paying attention to the quality. Misapplication of fertilizers could have a dire consequence on the quality of soil, so also is the over application which could reduce crops' yield and further add toxic waste to the soil. To this end, Ibia [4] suggested that testing soil before fertilizer recommendation and use is the most efficient strategy to manage soil quality in addition to using organic materials with chemical fertilizers.

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Fuzzy logic is an information processing technique that employs linguistics variables that are not necessarily precise but may be vague and ambiguous to process data [5]. It is indeed a superset of the conventional Boolean logic. Currently, fertilizer blending, distribution and usage are operated using the classical logic where it is either applied or not applied. This is done irrespective of the exact contents of the principal nutrients in the soil.
This study seeks to develop a fuzzy logic model that would emphasis on the particular brand of fertilizer recommended based on the nutrient deficiency of the soil that such a fertilizer would be used on. In Section 2, the consumption of fertilizers and distribution is discussed. The design of the fuzzy logic model is presented in Section 3 while the practical implementation using MATLAB 7.5 is presented in Section 4. Discussion of the results obtained using a soil sample from Ugep is discussed in Section 5 where some recommendations are made and a conclusion is also drawn.

2.0 Fertilizer Consumption and Distribution in Nigeria

Consumption of fertilizer in Nigeria is at a very low rate basically due to the fact that the farming populace is mainly illiterate who do not understand how to apply fertilizer and are not ready to learn. They still believe in the ancient tradition of farming with the attendant crude tools and techniques which results in poor yields. Some farmers believe that application of fertilizers brings bumper yields to crop in terms of quantity but that the quality of such products is relatively low especially in taste. It is also the belief of others that fertilizer adds toxic to the soil and that after the first harvest subsequent harvests may not be as good as the first, that is, fertility is lost after continuous application of fertilizer to the soil. Table 1 shows the 2003 average cereal yields, land area cultivated and the corresponding agricultural inputs in selected countries.

Table1: The 2003 average cereal yields, land area cultivated and the corresponding agricultural inputs in selected countries.

Country	Yield(Kg/Ha)	AreaCultivated (000ha)	Fertilizer (Kg/ha)
Nigeria	1058	21096	6.6
Ghana	1406	1477	6.0
South Africa	2676	4465	55.8
Brazil	3129	18614	120.1
Argentina	3212	10474	24.4
Indonesia	4229	14755	132
Malaysia	3275	696	654.8
Netherlands	7974	226	428.6
UK	7082	3106	314.7
Canada	2638	17071	55.0
USA	6138	55604	109.3

Source: FGN[6]

Nigeria with 6.6 Kg/ha is a far cry from the Food and Agricultural Organisation's (FAO) recommendation of 23 Kg/ha.
The more than 22 fertilizer marketing and blending plants engage in the blending and marketing of fertilizers in the country. Until 2014, distribution of fertilizers was marred by political favours and nepotism other than agricultural needs. The deficiency of a particular nutrient in the soil of a certain agricultural zone is not usually considered in the blending and distribution of fertilizers. This tends to lead to excessive application of a particular nutrient at the detriment of the soil while some soils are denied what are needed to increase their fertility. Excessive application of a nutrient like nitrogen leads to increase amine content which raises the nitrate content to a detrimental level. IFA [7] lists the adverse effects of fertilizers and their use on the environment to include the following:

(a) Accumulation of dangerous or even toxic substances such as Cadmium from mineral phosphate fertilizer or from industrial waste products in soil.
(b) Eutrophication of surface water with its negative effect on oxygen supply (damaging effects to fish and other animals); nitrate accumulation in ground water, thus diminishing the quality of drinking water.
(c) Unwanted enrichment of the atmosphere with ammonia from organic fertilizer and inorganic fertilizer.

Griffith [8] suggests the undertaking of soil and plant analysis as part of the basis for nutrient and fertilizer recommendation and use. The timing of fertilizer application to correspond to the best period of need and optimum soil and environment conditions is also recommended to curb the adverse effect of fertilizer and its use on the soil and environment.

3.0 Fuzzy Logic Model

The fuzzy logic model for this study consists of the fuzzification, rule base, composition and the output modules the defuzzification module is not captured since what are needed are the values of the individual input variables namely, Nitrogen, Phosphorous and Potassium and their evaluated values of membership function. The crisp values are not necessary for the study so the defuzzification module is ignored. The model is depicted in Figure 1.

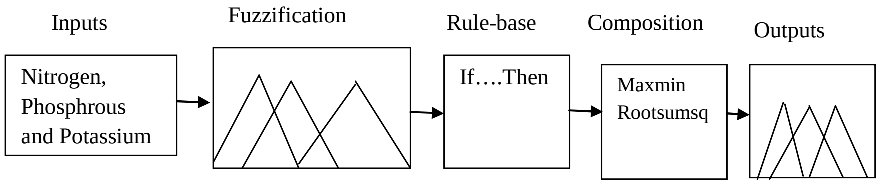

Figure 1: The Fuzzy Logic Model

The model accepts numeric inputs in the form of the values of the principal nutrients in a particular agricultural zone, these are fuzzified accordingly. From the fuzzified inputs, fuzzy rules are generated and composed using the maxmin operator to obtain the minimum value of every fired rule from where the maximum value of allthe minimums is obtained. Finally, the root sum square method of inference is used to evaluate the value of degree of certainty of the amount of each nutrient needed to fertilize such agricultural zone.

According to [4], the critical limit of soil fertility in the South East of Nigeria ecological zone is summarized in Table 2

Table 2: Critical Limit of Soil Fertility in South Eastern Nigeria Ecological Zone.

Nutrient	Extractable nutrient form	Fertility Rating		
		Low	Medium	High
Nitrogen	Total(%)	<0.15	0.15-0.20	>0.20
Phosphorous	Bray P1(mgkg^{1-})	<8.0	8-0-20.0	>20.0
Potassium	Exch K(cmol kg^{1-})	<0.20	0.20-0.40	>0.40

This could be used to deduce some fuzzification functions as shown in Equations (1)-(3)

$$\text{Nitrogen} = \begin{cases} 0.0 < f \le 0.14 & \text{low} \\ 0.15 < f \le 0.20 & \text{medium}.................................(1) \\ 0.20 < f \le 1.0 & \text{high} \end{cases}$$

$$\text{Phosphorous} = \begin{cases} 0.0 < f \le 0.07 & \text{low} \\ 0.15 < \text{f} \le 0.20 & \text{medium} ....(2) \\ 0.20 < \text{f} \le 1.0 & \text{high} \end{cases}$$

$$\text{Potassium} = \begin{cases} 0.0 < f \le 0.19 & \text{low} \\ 0.20 < \text{f} \le 0.40 & \text{medium} ....(3) \\ 0.41 < \text{f} \le 1.0 & \text{high} \end{cases}$$

These functions form the fuzzification component of the fuzzy logic model. The fuzzification module is further expanded to include some fuzzy rules represented as production rules and presented in Figure 4 are extracted to depict the premise and consequent part. The premise part shows the membership function of Nitrogen, phosphorus and potassium combining to form the consequent part which depicts the composition of fertilizer for a particular nutrient. For example, the first rule: if nitrogen is low, phosphorus is medium and potassium is high then nitrogen is high means if the nutrient contents of nitrogen is low, phosphorus is medium and potassium is high then let the contents of nitrogen in the fertilizer produced be high.

Each rule is evaluated and tested to see if it fires in respect to the given set of values of the membership function using the AND operator. The maxmin method of fuzzification is employed to obtain values of each of the nutrients. Since values are needed for each of the nutrients to form the composition of fertilizer, then defuzzification of the values obtained is ignored.

A typical case of Ugep soil was used to demonstrate the functionality of the study. Analysis of Ugep soil reveals the following parameters.

Total N = 0.08(%)
Phosphorous = 24.50 (mg/kg)
Potassium =0.14 (Cmol/kg)
Particle size
Sand = 81.80%
Silt = 6.00%

Clay = 12.70%

Textural class = Loamy sand

Equations (1) – (3) show that Ugep soil has low concentration of nitrogen, high concentration of phosphorous and low concentration of potassium. Applying these parameters in the rule base shows that only 13 out of the 20 rules fire for Ugep soil. This consists of 5 rules for Nitrogen, 4 each for phosphorus and potassium. These are evaluated into their minimum values of membership function which are further subjected into the root mean square inference which is the square root of the sum of squares of the fired rules represented as

$$F = \sqrt{\sum_{i=1}^{n} r_i^2} \quad \text{……………………………………………………..} \qquad (4)$$

where F is the fertility value and r is the fired rule.

These are evaluated thus for Nitrogen, phosphorus and potassium respectively

Nitrogen: The square root of the summation of rules 1,2,5,7 and 12;

$$F= \sqrt{\sum r_1^2, r_2^2, r_5^2, r_7^2, r_{12}^2} = 0.27 \text{ ……………………….} \qquad (5)$$

Phosphorous: The square root of the summation of rules 13,16,18 and 20;

$$F = \sqrt{\sum r_{13}^2}, r_{16}^2, r_{18}^2, r_{20}^2 = 0.39 \text{ ……………………….} \qquad (6)$$

Potassium: The square root of the summation of rules 4,9,10, and 11;

$$F = \sqrt{\sum r_4^2}, r_9^2, r_{10}^2, r_{11}^2 = 0.26 \text{ …………………………..} \qquad (7)$$

From the computations, Ugep needs a fertilizer of high Nitrogen 0.27%, High phosphorous of 39 (mg/kg) and medium potassium of 0.26 (cm0l/kg) composition.

4.0 Practical Demonstration using MATLAB

MATLAB 7.5 was used to demonstrate the practical functionality of the study with the following screen shots shown in Figures 2-5.

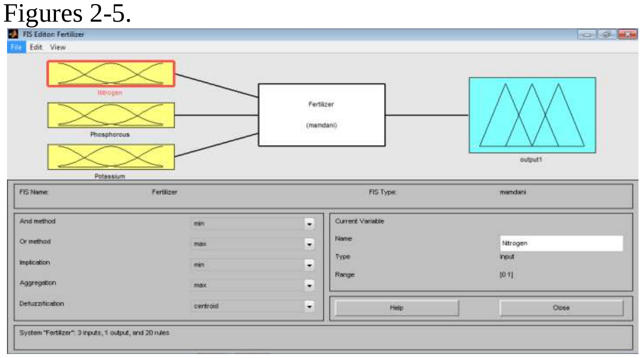

Figure 2: The Fuzzy System Editor

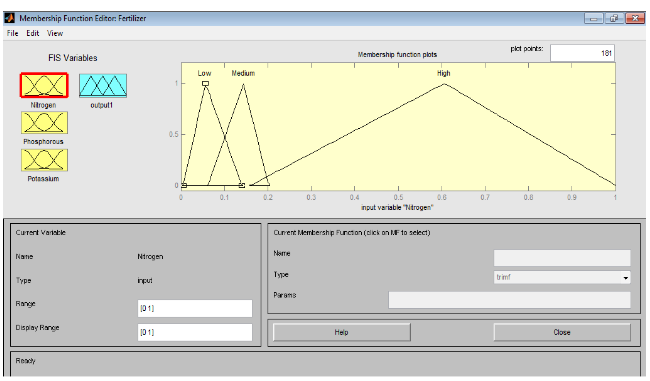

Figure 3: The Editor for Nitrogen Membership Function

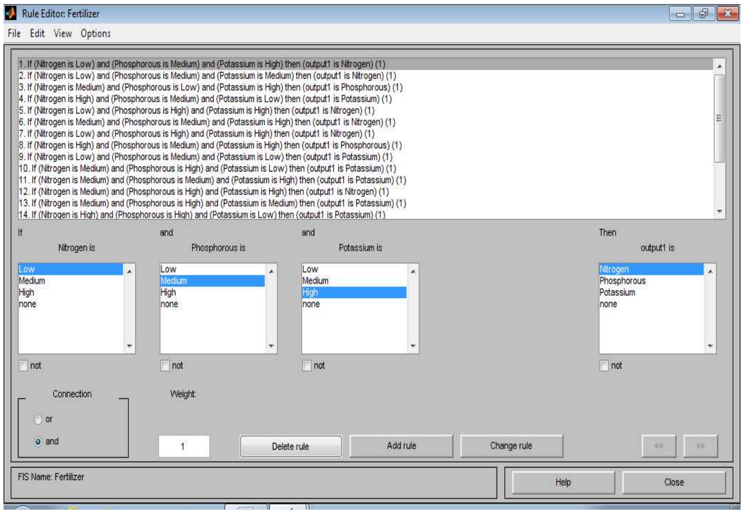

Figure 4: The Fuzzy Rules Editor

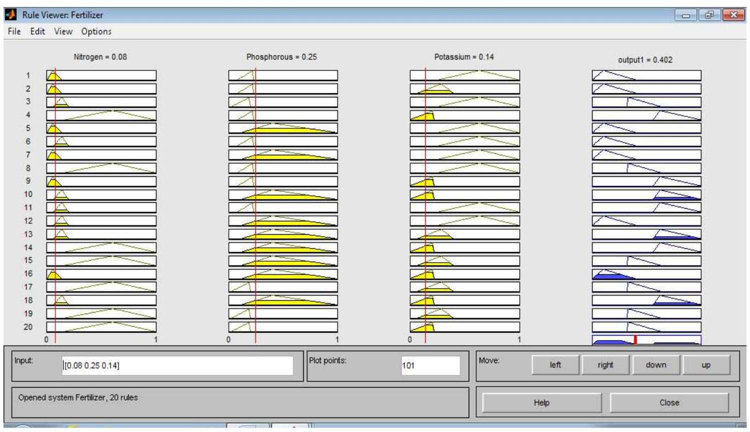

Figure 5: The Rule Viewer

5.0 Discussion and Conclusion

Presently, the common brand of fertilizer available in the market is the NPK(15:15:15) representing equal composition of nutrients(Nitrogen, Phosphorous and potassium). The purpose of applying fertilizer to the soil is to replenish the depleted nutrients so as to increase crop yields. Different zones are blessed with different degrees of mineral composition. Some are rich in potassium but lack nitrogen or phosphorous. Again, some crops need certain minerals more than they need others. Misapplication of fertilizer could result in poor yield tending to complicate the problems intended to be solved. In some cases, toxic substances are accumulated in the soil as a result thereby posing a great danger to crops.
A study of the Ugep soil (South eastern Nigeria Agricultural zone) reveals that it is very rich in phosphorous but deficient in nitrogen and potassium. Unfortunately, Ugep soil is manured with fertilizer of the same composition with that used in the Western zone which has different mineral compositions. This constitutes a waste of both human and material resources. This is because the blending and distribution of fertilizer is undertaken using the traditional Boolean logic. A fuzzy logic model resolves conflicts by collaboration and aggregation of the datasets. Instead of specifying the exactness or otherwise of the results, it outputs the degree of certainty. Here the degrees of certainties of Nitrogen, Phosphorous and Potassium measures that could be applied in a soil having parameters such as in Ugep to obtain an optimal yield are specified.
The study is at an experimental stage with the hope of expanding to other zones after obtaining data from such zones. MATLAB 7.5 was used to demonstrate the practical functionality of the study. The rules derived from the fuzzified data were generated based on static knowledge of blending fertilizer. Efforts to reach out to some experts were abortive so the study depends on static knowledge to derive the fuzzy rules. Expert experiential knowledge is needed to test what is obtained from the structured knowledge if the study is to be implemented at a commercial level. With more rules and datasets, the results obtained in this study would be improved upon.

Fertilizer blending companies it must be stated need to collaborate with Agricultural Extension officers and soil scientists in testing soil nutrients in different Agricultural zones to ascertain the degree of nutrients composition. It is based on the deficiency of such nutrients that fertilizers could be blended to supplement. Distribution of fertilizer should also be done based on these needs.

6.0 References

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