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A systematic study on bio-inspired frameworks for fertilizer optimization

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Abstract Fertilizers supply nutrients to the soil to intensify soil fertility and improve plant growth. Fertilizer application to the crops was optimized by identifying the optimal fertilizer requirement as per the soil type and encouraging the usage of manure. Complex fertilizers contain multiple nutrients in each individual granule. They are cost-effective as well as highly available, when compared to manure, but they always lead to imbalance of nutrients, either in excess or in shortage. Excessive usage of chemical nutrients affects the soil quality and also affects the ecology. To avoid the imbalance in nutrients, manure application is suggested in this work along with fertilizers. The research finding in fertilizer optimization is performed by using two well-known optimization algorithms, Fruit Fly Optimization (FFO) algorithm and Social Spider Algorithm (SSA) inspired from the biological species, fruit fly and spider. Agricultural region in Coimbatore district, situated in the state of Tamil Nadu, India Results found that excess application of fertilizer brought down with systematic optimization plans, through the harmful influences of fertilizers can be avoided to a greater extent.

Keywords: Bio-inspired algorithms, Fertilizer optimization, Chemical fertilizers, Social Spider Algorithm (SSA), Fruit Fly Optimization algorithm (FFO)

Introduction

Development of optimal strategies for fertilizer usage is one of the significant real-time optimization problems. It is most important to reduce the application of chemical fertilizers to crops, which leads to harmful effects on soil, human health and ecology. Naturally, soil contains a considerable quantity of the essential macronutrients and micronutrients. Fertilizers serve as supplementary sources to enrich the soil nutrients. Fertilizers should be applied to the soil according to the nutrient requirement of the crop and the nutrient shortage in the soil. Soil test is compulsory to reduce the fertilizer application rate (Environmental studies, 2013). One of the most common practices for improving the efficiency of fertilizer is sufficient and balanced application of fertilizers and manure, which is effective in both emerging and developed countries.

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Fertilizer use efficiency is optimized by fertilizer management practices, which apply exact nutrients at the right place and right time. The maximum fertilizer use efficiency always happens at the lower parts of the yield response curve. Fertilizer application rate should be optimized for increase in crop yield and for improvement in the farmer's profitability (Soil and plant nutrient testing lab, 2017).

Bio-inspired computing is a problem solving method that uses artificial intelligence techniques. It imitates the behaviour of swarms like ant, bee, wasp, termites, birds, fruit fly, spider and firefly etc. The different kinds of behaviour in social insects are hunting, foraging, mating, nest building, flocking, co-operative operation, waggle dance, etc. Bio-inspired computing algorithms are able solve the problems of almost all domains including biomedical engineering, cloud and adhoc networks, robotic process automation, cyber-physical systems, data analytics, scheduling in manufacturing, parallel processing, image analysis, power systems and many others (Panigrahi *et al.*, 2011; Brownlee, 2005; Darwish, 2018; Liang *et al.*, 2010, Tsui, 2009, Feng *et al.*, 2013).

Manures are the organic materials collected from the animal wastes, plant and human residues, where they release their nutrients after decomposition of wastes. Organic manures supply the nutrients to crops and also improve soil fertility and ecology. Farmyard manure, green manure, composted coir pith, azolla and neem cake are the widely used varieties of organic manure. Proper recycling of organic wastes and animal wastes in the soil will be helpful to maintain the required quantity of organic matter and hence, recycling of organic wastes has turned into a regular practice in modern agriculture (Thilagavathi *et al.*, 2017).

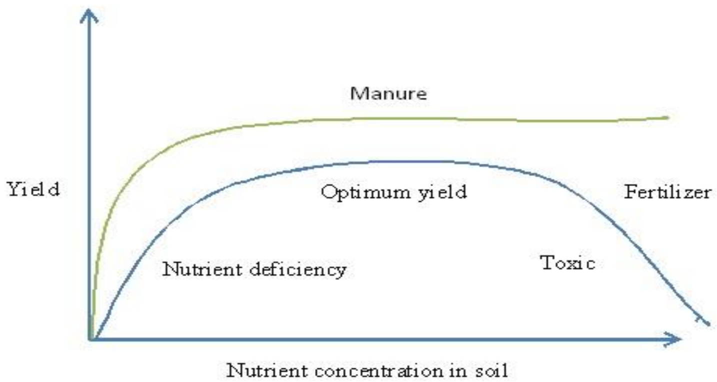

Figure 1. Yield response to fertilizer and manure application (Singh and Sharma, 2014)

The yield response to nutrient concentration in soil is shown in Figure 1. The green curve represents the manure response to soil, which shows the gradual increase in the yield rate (Figure 1). The blue curve indicates the fertilizer application rate, whereas the starting point indicates the nutrient deficiency of soil. The yield level is optimum at certain point and if the fertilizer application rate is further increased or continued for a long time, it affects the yield and also the quality of the soil. Overuse of fertilizers will lead to a down trend in the profit potential.

The objectives of the research are

- To optimize the application of fertilizer to croplands for ecology conservation. Fertilizer optimization refers to allocation of optimal quantity of fertilizers to the crop for yield maximization, based on the crop requirement and availability of soil nutrients.
- To assess the effectiveness of bio-inspired algorithms in solving fertilizer optimization problems.

Materials and methods

In this research work, the agricultural region in Coimbatore district of Tamil Nadu state in India was taken for study, in which a variety of soil types are available with different cropping practices. Crop suitability and growth level differs with respect to various types of soil as well as the soil nutrient availability, irrigation sources and climatic conditions. Sorghum, corn, plantain and peanut are the crops majorly cultivated in Coimbatore region, the details of which are tabulated in Table 1.

Table 1. Nutrient requirement of crops taken for study (Coimbatore district SHB004, Coimbatore district SHB003)

S. No.	Name of the Crop	Required Macronutrients		
		Nitrogen (N) Kg/Ha	Phosphorous (P) Kg/Ha	Potash (K) Kg/Ha
1	Sorghum	90	45	45
2	Sugarcane	300	100	200
3	Cotton	80	40	40
4	Bajra	70	35	35
5	Peanut	25	50	75
6	Corn	135	62.5	50
7	Greengram	25	50	25
8	Blackgram	25	50	25
9	Plantain	210	35	450
10	Onion	30	60	30
11	Turmeric	150	60	108

The types of soil with NPK ratio of soil nutrients are presented in Tables 1 and 2. Manures are categorized into three types, Farm Yard Manure (FYM), Green manure and Green plants.

Table 2. Types of soil

S. No.	Soil Category	N (kg/ha)	P (kg/ha)	K (kg/ha)
1	Soil – A	70	40	40
2	Soil – B	150	50	100
3	Soil – C	80	20	40
4	Soil – D	100	30	50

The frequently used complex fertilizers in the study area, categorized into six types based on NPK ratios (Table 3) and the manures are commonly available shown in Table 4.

Table 3. Complex fertilizer types (TNAU Agritech portal)

S. No.	Fertilizer Type	N (kg/50 kg of Fertilizer)	P (kg/50 kg of Fertilizer)	K (kg/50 kg of Fertilizer)
1	Complex Fertilizer -1 (CF-1)	16	16	16
2	Complex Fertilizer -2 (CF-2)	12	32	16
3	Complex Fertilizer -3 (CF-3)	10	26	26
4	Complex Fertilizer -4 (CF-4)	15	15	15
5	Complex Fertilizer -5 (CF-5)	14	35	14
6	Complex Fertilizer -6 (CF-6)	17	17	17

Table 4. Types of Manure (Bio-organic manure, n.d.)

S. No	Manure	N (%)	P (%)	K (%)
	Farm Yard Manure			
1	Animal waste	1.22	0.62	1.20
2	Goat waste	2.40	0.90	2.00
3	Sheep waste	1.93	1.30	2.30
4	Chicken manure	0.92	1.88	0.60
5	Horse manure	0.70	0.69	0.83
	Green Manure			
6	Gliricidia	2.7	0.5	2.2
7	Sunnhemp	2.6	0.6	2.0
8	Garlic cork	2.3	0.7	1.3
9	Pillippayaru	2.1	0.5	-
10	Kolinchi	1.8	0.4	0.3
11	Avuri	2.4	0.3	0.8
	Green Plants			
12	Awara	2.2	0.4	1.3
13	Atatotai	2.8	0.7	3.2
14	Portia	2.5	0.6	2.0
15	Pungam	3.0	0.4	2.2

Minimization of fertilizer application was a much needed optimization procedure which had heavily influenced on healthy crops and sustainable agricultural practices. Fertilizer optimization is done in this work by considering the types of soil, as well as the common crops grown and common fertilizers used in Coimbatore. Equation (1) denotes the fertilizer optimization objective function. Equation (2) denotes the macronutrient requirement constraint, which is presumed to balance the crop yield (Sivakumar *et al.,* 2019).

$$\text{Minimize } Q=\sum_{re}\sum_{cr}\left[\sum_{f} A_{frecr}\right]L_{recr} \qquad (1)$$

subject to

$$\sum_{f} M_{fp}\, A_{frecr} \geq RE_{crp} - SS_{crp}, \qquad (2)$$

where Q denotes the fertilizer quantity, A_{frecr} denotes the application rate of fertilizer *f* in region *re* for crop *cr*. L_{recr} is the allocated area for crop *cr* in region *re*, M_{fp} is the macronutrient content present in fertilizer *f* where *p* denotes the composite nutrient value of *N, P and K*, RE_{crp} denotes the requirement of nutrient *p* of crop *cr* and SS_{crp} denotes the nutrient availability in soil (Harrison Rware, 2014, Keplinger and Hauck, 2006).

Fertilizer optimization using fruit fly optimization (FFO) algorithm

FFO Algorithm was devised from the foraging behaviour of fruit flies by Pan in 2011. FFO algorithm is one of the intelligent optimization algorithms. Fruit flies have a special sensory perception than other insects in terms of smell and vision. With the help of its olfactory organ, fruit flies can smell food sources almost ahead of 40 kms distance (Shan *et al.,* 2013, Choubey, 2014) and can easily reach the food source by using its vision and smell. The parameters of FFO algorithm are initialized through trial and error method, aiming to achieve the best solution to the problem considered (Pan, 2012 and Yang, 2009).

The fruit flies assume their own initial position at random. Every fruit fly denotes to an arbitrary fertilizer quantity, whereas the optimal fertilizer quantity and minimum cost are obtained from the best position of the fruit fly. The optimal values are found by random initialization of the three-dimensional position, where the x axis, y axis and z axis refer to the primary macronutrients N, P and K respectively. The new positions of the fruit flies are generated from their initial positions, and their fitness functions are evaluated to identify the optimal solution. The fitness function serves as the objective function to identify the optimal fertilizer quantity. The pseudocode of fruit fly algorithm is given in Figure 2. The specifies the parameters applied in the FFO framework is shown in Table 5.

1. Random position of each fruit fly swarm is initialized by using the Equation (3).

Init X; Init Y (3)

2. The direction and distance of food search using the sensory perception of a fruit fly individual are randomly calculated by using Equations (4) and (5).

$$X_i = X + Random \quad (4)$$

$$Y_i = Y + Random \quad (5)$$

3. The distance (Dist) to the origin and the decision value of smell concentration (S) are calculated by using Equation (6) and (7). The smell value is the reciprocal of distance.

$$Dist_i = \sqrt{X_i^2 + Y_i^2} \quad (6)$$

$$S_i = 1/Dist_i \quad (7)$$

4. The smell concentration function with respect to the position of the fruit fly is used as the fitness function, which is calculated by using the smell concentration value (S) as given in Equation (8).

$$Smell_i = Function(S_i) \quad (8)$$

5. The fruit fly with the best smell concentration among the fruit fly swarm will seek the best value, which is calculated as per Equation (9).

[bestSmellbestIndex]=max(Smell) (9)

6. Idenify the best smell concentration value and x, y coordination among the fruit fly swarm.

X =X(bestIndex) (10)

Y =Y(bestIndex) (11)

7. Iterate the optimization through steps 2-5 and check whether the smell concentration is improved, and if any, then execute step 6.

Figure 2. Pseudocode of FFO algorithm

Table 5. Variables used in the optimization framework

Input Variables	Output Variables
1. Availability of macro nutrient contents (N, P, K) **2. Available land area for farming** **3. Chosen crops** **4. Macronutrient requirement of crops** **5. Fertilizer requirements** **6. Fertilizer cost**	1.Optimized fertilizer quantity 2. Overall fertilizer cost

Fertilizer optimization using social spider algorithm (SSA)

Social spider algorithm is a population based algorithmic technique, proposed by Cuevas *et al.* (2013). This algorithm is inspired by the mating, reproduction and cooperative behaviour of social spiders, and is being applied in solving various optimization problems. The social spider colony members are divided into two fundamental groups; member spiders and communal web (spider web). The spider web constitutes the search space (S) where every spider is allotted a position based on its weight and fitness (Cuevas *et al.*, 2013). The flowchart of social spider algorithm for fertilizer optimization is shown in Figure 3.

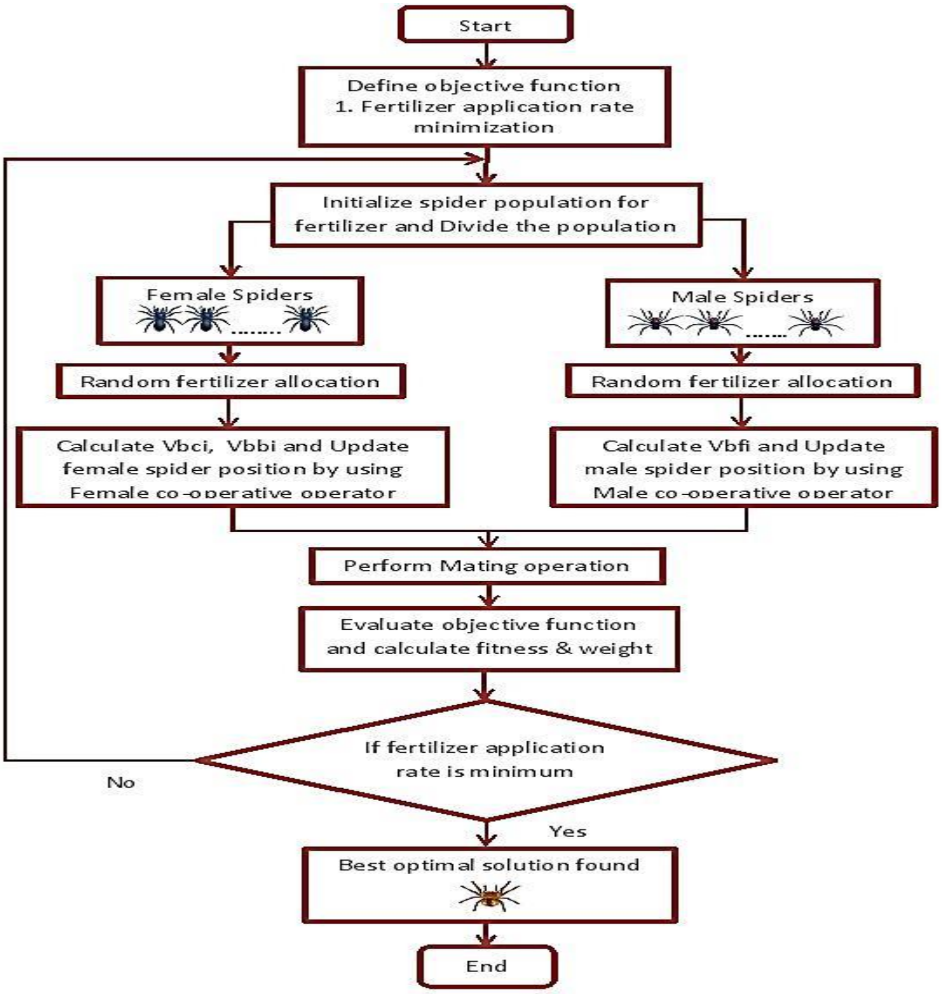

Figure 3. Flowchart of SSA for fertilizer optimization

The algorithm is divided the member spiders into male and female spiders, whereas 30% of spiders are considered as male spiders and 70% of spiders are considered as female spiders. Further, the male spiders are divided into dominant males and non-dominant males with respect to their fitness. The mating operation permitted to exchange of information among the dominant male spiders and female spiders.

Depending upon the other spider's weight and distance between them, the social spiders produced vibrations to perform mating operation. Multiple female spiders are chosen to perform mating operation with a single dominant male spider to generate new spiders. The fitness of the solution is calculated the weight of the spider. From the total population, 65%-90% of the spiders are randomly chosen to be female and the numbers of male spiders are calculated as per Equations (6) and (7).

$$N_{FeS} = Ceil[(0.9 - rand(0,1)*0.25)*TP] \quad (6)$$

$$N_{MaS} = TP - N_{FeS} \quad (7)$$

Where N_{FeS} denotes the female spider count, N_{MaS} denotes the male spider count, TP denotes the total spider population and ceil denotes the real number to an integer number.

Every spider's weight (wt_i) is calculated as per Equation (8). The fitness value of each spider is obtained by its position s_i, maximum fitness b_s and minimum fitness w_s, as given in Equations (9) and (10).

$$Wt_i = \frac{J(s_i)-w_s}{b_s-w_s} \qquad (8)$$

$$b_s = \max_{k\in\{1,2,\ldots,N\}} J(s_k)) \qquad (9)$$

$$w_s=\min_{k\in\{1,2,\ldots,N\}} J(s_k)) \qquad (10)$$

Every spider's vibration is calculated from its weight (wt_i) and its distance ($d_{i,j}$) from another member j as per Equation (11).

$$V_i b_{i,j}=w_j.e^{-d_{i,j}^2} \qquad (11)$$

Euclidian distance among spiders i and j is calculated based on the Equation (12), which is denoted as $d_{i,j.}$

$$d_{i,j}=\sqrt{(x_i-y_i)^2+\left(x_j-y_j\right)^2} \qquad (12)$$

Based on the relationship among the spider pairs, vibrations are classified into three types. Three types of vibrations are used to perform the cooperative performances of male and female spiders.

- *Vibrations Vic_i* – occurs during the transmission of information between the spider i and another nearest spider $c(s_c)$, and is computed using Equation (13).

$$Vic_i=wt_c.e^{-d_{i,c}^2} \qquad (13)$$

- *Vibrations Vib_i* – occurs during the transmission of information between the spider i and the best spider $b(s_b)$ in the group, which is computed using Equation (14).

$$Vib_i=wt_b.e^{-d_{i,b}^2} \qquad (14)$$

- *Vibrations Vif_i* – occurs during the transmission of information between the spider i and the closest female spider $s(s_f)$, and is computed using Equation (15).

$$Vif_i=wt_f.e^{-d_{i,f}^2} \qquad (15)$$

Cooperative behaviour of female spiders is assessed through the vibrations vib_i and vic_i, as given in Equation 16. Cooperative behaviour of male spiders is assessed using vif_i as given in Equation 17. Spiders that are big in size as well as closer in distance often produce strong vibrations.

$$f_i^{k+1} = \begin{cases} \{f_i^k + \alpha.vic_i.\left(s_c - f_i^k\right) + \beta.vib_i.\left(s_b - f_i^k\right) + \delta.\left(rand - \frac{1}{2}\right) \\ \quad with\, probability\, PF \\ \{f_i^k - \alpha.vic_i.\left(s_c - f_i^k\right) - \beta.vib_i.\left(s_b - f_i^k\right) + \delta.\left(rand - \frac{1}{2}\right) \\ \quad with\, probability\, 1-PF \end{cases}$$

(16)

$$m_i^{k+1} = \begin{cases} m_i^k + \alpha . vif_i . (s_f - m_i^k) + \delta . \left(rand - \frac{1}{2}\right) & if\ wt_{N_f+i} > wt_{N_f+m} \\ m_i^k + \alpha . \left(\frac{\sum_{h=1}^{Nm} m_h^k \cdot wt_{N_f+h}}{\sum_{h=1}^{Nm} wt_{N_f+h}} - m_i^k\right) & if\ wt_{N_f+i} \leq wt_{N_f+m} \end{cases} \quad (17)$$

In the above equations, α, β, δ are assigned random values in the range of {0,1}, k denotes the iteration count, s_c denotes the nearest spider with highest weight and s_b denotes the best spider in the population.

The spider attracts or repels other spiders at random, and this random behaviour is denoted by variable r_m, which ranges between 0 and 1. If the random value taken up by r_m is greater than a paricular predetermined threshold value, attraction operation will be performed, or otherwise repulsion will occur between spiders. Equation (18) is used to select the mating range of spiders.

$$r = \frac{\sum_{j=1}^{n}(P_j^{high} - P_j^{low})}{2.n} \quad (18)$$

The set m_g consists of male spiders that are dominant in nature and the set E^g consists of the selective female spiders. The union of sets m_g and E^g (m_gU E^g) leads to reproduction. Equation (19) gives the influence probability, denoted as Psi.

$$Ps_i = \frac{wt_i}{\sum_{j \in T^k} wt_j} \quad (19)$$

Once the influence probability is found, the new spider s_{new} is selected through the roulette wheel method. If the weight of the new spider s_{new} is higher than the weight of any other member in the population, that lower weight member will be replaced by the new spider s_{new}. (Thilagavathi and Amudha, 2019). In this research work SSA is applied to optimize the fertilizer application rate. The fertilizers are considered as social spiders and eleven crops are selected from the Coimbatore region (Thilagavathi *et al.*, 2021).

Results

SSA algorithm and FFO algorithm are used in this research work to minimize the fertilizer quantity applied to crops. The common fertilizers are used by farmers in Coimbatore, soil nutrients availability, and the macronutrient requirement of crops are analysed and the results are presented. In the current practice of fertilizer application to the soil, the fertilizer requirement could not be exactly met, due to various factors. Farmers were not aware of the market availability of complex fertilizers with varying NPK ratios and all the farmers are not done the soil tests in order to know about the soil strength. There was also lack of awareness about the macronutrient requirements of various crops. However, this research work had made an attempt to match the nearest possible fertilizer requirement using algorithmic techniques. The primary factors was taken into consideration of the NPK requirement of the crops and the NPK available in the corresponding soil type where the crop is grown. The optimal fertilizer suggestions given by SSA algorithm and FFO algorithm is shown in Table 6.

Table 6. Optimal fertilizer suggestion by SSA and FFO for the crops taken for study

S. No	Crops with NPK requirement	NPK availability in Soil	Fertilizer suggestion	
			SSA	FFO
1	Sorghum (90:45:45)	Soil -A (70:40:40)	CF-4	CF-6
		Soil -B (150:50:100)	No fertilizer needed	No fertilizer needed
		Soil -C (80:20:40)	CF-3	CF-2
		Soil -D (100:30:50)	CF-3	CF-4
2	Sugarcane (300:100:200)	Soil -A (70:40:40)	CF-4	CF-6
		Soil -B (150:50:100)	CF-1	CF-6
		Soil -C (80:20:40)	CF-1	CF-3
		Soil -D (100:30:50)	CF-5	CF-6
3	Cotton (80:40:40)	Soil -A (70:40:40)	CF-3	CF-2
		Soil -B (150:50:100)	No fertilizer needed	No fertilizer needed
		Soil -C (80:20:40)	CF-6	CF-4
		Soil -D (100:30:50)	CF-4	CF-1
4	Bajra (70:35:35)	Soil -A (70:40:40)	No fertilizer needed	No fertilizer needed
		Soil -B (150:50:100)	No fertilizer needed	No fertilizer needed
		Soil -C (80:20:40)	CF-4	CF-1
		Soil -D (100:30:50)	CF-4	CF-1
5	Peanut (25:50:75)	Soil -A (70:40:40)	CF-6	CF-4
		Soil -B (150:50:100)	No fertilizer needed	No fertilizer needed
		Soil -C (80:20:40)	CF-3	CF-2
		Soil -D (100:30:50)	CF-3	CF-6
6	Corn (135:62:50)	Soil -A (70:40:40)	CF-6	CF-1
		Soil -B (150:50:100)	CF-4	CF-1
		Soil -C (80:20:40)	CF-5	CF-2
		Soil -D (100:30:50)	CF-2	CF-5
7	Greengram (25:50:25)	Soil -A (70:40:40)	CF-4	CF-1
		Soil -B (150:50:100)	No fertilizer needed	No fertilizer needed
		Soil -C (80:20:40)	CF-2	CF-3
		Soil -D (100:30:50)	CF-6	CF-1

Table 6. (Con.)

S. No	Crops with NPK requirement	NPK availability in Soil	Fertilizer suggestion SSA	FFO
8	Blackgram (25:50:25)	Soil -A (70:40:40)	CF-4	CF-1
		Soil -B (150:50:100)	No fertilizer needed	No fertilizer needed
		Soil -C (80:20:40)	CF-2	CF-3
		Soil -D (100:30:50)	CF-6	CF-1
9	Plantain (210:35:450)	Soil -A (70:40:40)	CF-6	CF-1
		Soil -B (150:50:100)	CF-6	CF-1
		Soil -C (80:20:40)	CF-4	CF-6
		Soil -D (100:30:50)	CF-4	CF-6
10	Onion (30:60:30)	Soil -A (70:40:40)	CF-6	CF-1
		Soil -B (150:50:100)	CF-4	CF-1
		Soil -C (80:20:40)	CF-5	CF-2
		Soil -D (100:30:50)	CF-2	CF-3
11	Turmeric (150:60:108)	Soil -A (70:40:40)	CF-6	CF-4
		Soil -B(150:50:100)	CF-4	CF-1
		Soil -C (80:20:40)	CF-6	CF-1
		Soil -D (100:30:50)	CF-4	CF-6

The NPK requirement of eleven crops, four different soil types with varying soil strength and six different types of complex fertilizers with varying NPK ratios are taken into consideration.

Further analysis is shown that the fertilizer combination suggested by SSA is capable of satisfying the nutrient requirement of the crops to the maximum extent with a minimum deviation of 2% to 4% shortage or excess in the NPK required by the crop. Whereas, there is a greater deviation of 7% to 10% shortage or excess in the NPK requirement with respect to the fertilizer combination recommended by FFO. The no fertilizer needed category is stated that the soil had sufficient macronutrient content that is needed by the particular crop and hence, adding excess fertilizer can be avoided. Both SSA and FFO algorithms are implemented and made to identify the best suitable complex fertilizer for each crop as per the soil type. It is identified from the results that SSA was capable of finding near optimal solutions than FFO algorithm.

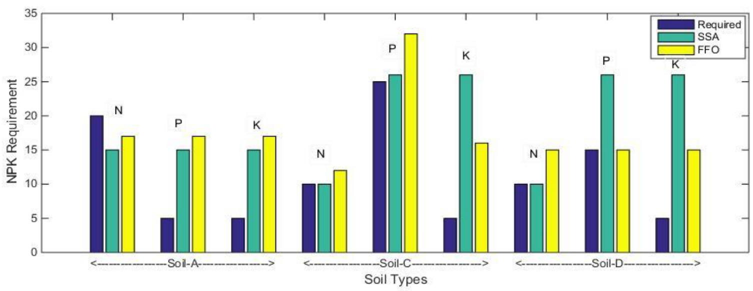

Figure 4. Comparison of NPK requirement of Sorghum crop with SSA and FFO suggestions for various soil types

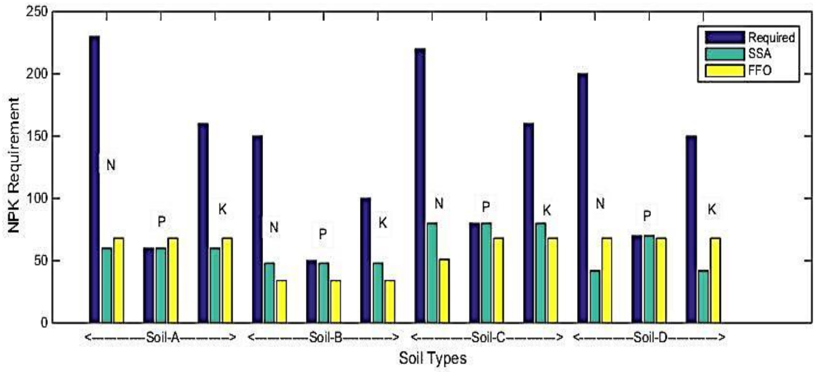

Figure 5. Comparison of NPK requirement of Sugarcane crop with SSA and FFO suggestions for various soil types

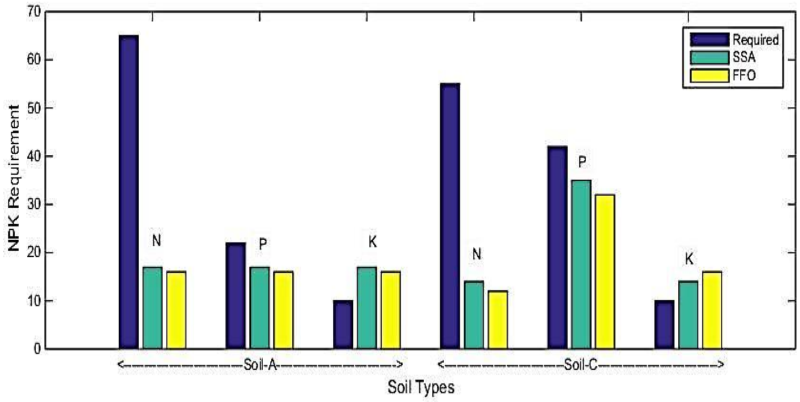

Figure 6. Comparison of NPK requirement of Corn crop with SSA and FFO suggestions for various soil types

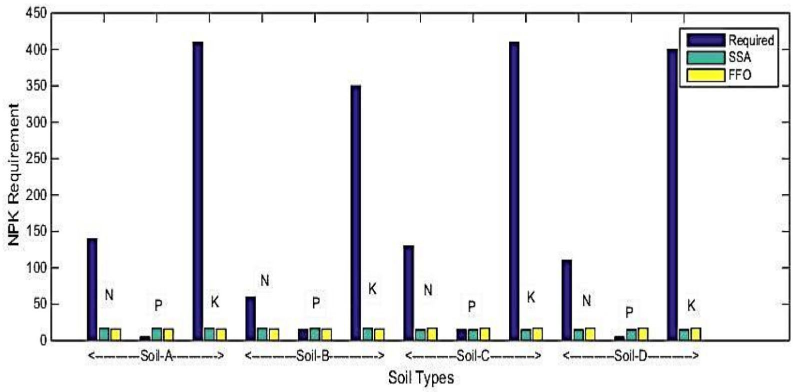

Figure 7. Comparison of NPK requirement of Plantain crop with SSA and FFO suggestions for various soil types

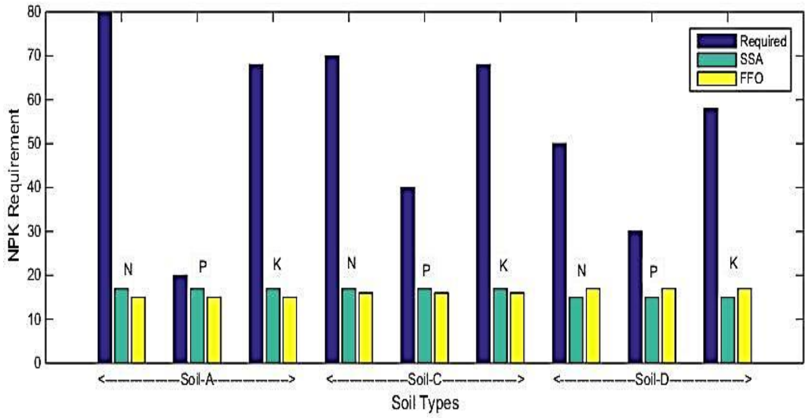

Figure 8. Comparison of NPK requirement of Turmeric crop with SSA and FFO suggestions for various soil types

The graphical assessment of the actual NPK requirement of various crop with SSA suggested NPK and FFO recommended NPK ratios for different types of soil (Figure 4-8). The certain soil types did not require any additional fertilizers, as the soil naturally possess the required nutrients in adequate. It is evidently noticed that the SSA suggested near-optimal NPK ratio as per the requirement in case of P, whereas N and K are deficited in most of the cases. In order to compensate the deficient nutrients, this study is suggested the application of suitable manures, as given in Table 7.

Table 7. Manures suggested to compensate NPK deficiency

S. No	Crop	Soil	Recommended manure & its NPK availability
1	Sugarcane	Soil –A	Pungam (3.0:0.4:2.2)
		Soil –B	Gliricidia (2.7:0.5:2.2)
		Soil –C	Pungam (3.0:0.4:2.2)
		Soil –D	Sunnhemp (2.6:0.6:2.0)
2	Corn	Soil –A	Kolinchi (1.8:0.4:0.3)
		Soil –C	Pillippayaru (2.1:0.5 :-)
3	Plantain	Soil –A	Atatotai (2.8:0.7:3.2)
		Soil –B	Atatotai (2.8:0.7:3.2)
		Soil –C	Atatotai (2.8:0.7:3.2)
		Soil –D	Atatotai (2.8:0.7:3.2)
4	Turmeric	Soil –A	Goat waste (2.4:0.9:2.0)
		Soil –C	Animal waste (1.22:0.62:1.20)
		Soil –D	Horse manure (0.70:0.69:0.83)

Discussion

Every soil type has a unique composition of macronutrient content and hence the addition of fertilizers should definitely vary from soil to soil for every type of crop grown in the particular soil type. Depending upon the nutrient strength of the soil, fertilizer recommendations are given by the algorithms. These suggestions are much helpful in supplying the right quantity of fertilizer to the soil and in avoiding the excess supply of fertilizer as well. The complex fertilizer types are considered in this work in such a way that the NPK ratios are entirely differed and enabled the algorithms to identify the required type of fertilizer for a specific crop grown in a specific soil. On analysing the fertilizer recommendations by the SSA algorithm and the FFO algorithm, it is quite evident that these algorithms have chosen different fertilizer types for most of the test cases except the no fertilizer needed category.

Masrie *et al.* (2017) stated that an Arduino based optical transducer to measure the NPK availability in soil and to categorise the soil strength as Low, Medium and High. This procedure has simplified the process of testing soil nutrients in a cost effective manner. The focus of this work is very much aligning with the objective of the current study towards minimizing the fertilizer usage which is done by analysing the existing macronutrient contents in the soil. Itelima *et al.* (2018) discussed the significance of using bio-fertilizers for sustainable agricultural practices. This research finding recorded that the various types of bio-fertilizers classification based on the type of microorganisms. It is pointed out the unavailability of sufficient quantity of bio-fertilizers as against the demand for fertilizers. Lack of awareness about the harmful effects of chemical fertilizers is also highlighted as one of the key limitations in bio-fertilizer usage.

In this work, the manures are recommended on the nutrient availability in various types of soil, crop requirements and the deficit. For example, in the case of sugarcane, it is identified from the optimal fertilizer that there was a lack of N and K in all the soil types A, B, C and D, the natural manures; Pungam, Gliricidia and sunhemp are recommended to be rich in N and K nutrients. In the case of corn, nutrient shortage is observed only in soil types A and C and Kolinchi and Pillipayaru are suggested. The manure Atatotai is recommended for all the soil types for Plantain crop whereas, goat waste, animal waste and horse manure are suggested for turmeric. Though manures play a major role in ecology conservation and soil strength preservation as well as regeneration, their availability is highly limited. In the present agricultural setup, manures are not able to meet the rising demand and hence, this research is suggested manures as a potential alternative in reducing the usage of chemical fertilizers.

According to the study by Chun-Li *et al.* (2014) who stated that the, continuous usage of chemical fertilizers contaminates ground water and the atmosphere along with the soil in due course of time. In addition, plants will become highly vulnerable to diseases and pest attacks due to degraded atmospheric and soil conditions. Bio-fertilizers are the only promising and healthy alternatives to retain soil fertility and to improve the productivity in agriculture. Knobeloch *et al.* (2009) explained the impacts of excessive fertilizer application in agricultural lands. Long-term usage of chemical fertilizers leads to permanent deposit of unwanted chemicals in the soil thereby reducing the pure nature and fertility of the soil. Unsuitable fertilizers will result only in negative effects on the soil and plants rather than positive outcomes. It is always mandatory to test the soil and apply limited quantity of fertilizers strictly as per the requirement, which will always play a vital role in preserving the ecology. The current study stated that application of manures aided in compensating the lack of nutrients as well as reduced the over usage of chemical fertilizers, which preserved the soil quality. Also, in course of time, manure usage is naturally improved the macronutrient content in the soil, thereby leading to fertile agricultural lands suitable for cultivating all types of crops.

According to Guo *et al.* (2020) reported that the, excessive application of fertilizers increased the nitrogen (N) level in soil more than the required quantity, which in turn to pollute the groundwater and increased the unnecessary weed growth. The authors emphasized the requirement for optimization of fertilizers as per the soil strength and crop requirement. In their paper, Macabiog *et al.* (2020) characterized the NPK nutrient levels of a variety of soil samples. The soil dataset was further modelled and analysed using Artificial Neural Network (ANN) in order to assist farmers adapt precision agriculture.

This research work is minimized the fertilizer application in agriculture, thus preventing the harmful effects of chemical fertilizer on the crops, farm land and the environment. Generally, fertilizers are selected and used by the farmers based on long time practices. The lack of knowledge in optimal fertilizer usage leaded to over usage of fertilizer, which in turn affected the ecology. This work is put in productive efforts to bridge the gap and to provide fertilizer recommendations to the farmers. Social spider algorithm and Fruit fly optimization algorithm are used to identify the optimal fertilizer quantity for different crops considering the naturally available soil nutrients. The common crops grown, the different types of soil available and the common types of fertilizers used in the study area are used to generate various test cases. Optimal fertilizer quantity along with manure recommendations are given in order to compensate the nutrient deficit in soil and to improve the ecology. Farmers have already started realizing the fact that a gradual transformation from the chemical fertilizers to natural manure is needed. This awareness and transition would definitely improve the agricultural scenario of the country in long run.

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