A Novel Bio-Inspired Optimization Model For Intercropping Pattern Recommendation

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Abstract. Intercropping is one of the best cropping pattern methods in crop planning optimization. The intercropping method improves crop yield and profit and reduces weed, pesticides, and irrigation water. The intercropping pattern is the best way to properly utilize the available resources and improve crop yield and profit with available land and water. Social Spider Optimization Algorithm (SSOA) is a relatively new biologically inspired algorithm that is applied to give different intercropping pattern suggestions. Four different land categories and three different cropping patterns are used in this research work. The best intercropping patterns are suggested to each cropping pattern with different landholdings based on their profit, production, and crop water requirement by SSA. The cropping patterns for this research work are collected and formed based on the farmer's practices in Coimbatore district, Tamil Nadu, India. The results showed that the large landholding farmers are suggested to use a single crop pattern or triple crop pattern based on the water availability in the area.

1 Introduction

Intercropping is an important process in crop planning optimization. The implementation of cultivating more than two crops in an equal space at an equal time is called intercropping in agriculture. The main functions of the intercropping method are to reduce the weed, pesticides and increase crop production when compared with sole cropping or mono cropping pattern. Intercropping system is used in effective utilization of available resources like land, water, nutrients and solar energy. Mostly legumes and cereal crops are planted with other crops which improve soil fertility through nitrogen fixation in soil. The main advantage of the intercropping system is to reduce the pest, weed and disease damage but increase the biodiversity like natural ecosystems. It can be used as a model to increase legume grain production. Throughout the world, many intercropping systems have been evaluated successfully with high production from the small landholdings category. Mono-cropping or solo cropping method is not a cost-effective methodology to meet the agriculturalists' requirements [1]. Intercropping method is also called mixed cropping.

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The root structure of intercropping is different from the mono-cropping pattern. The variety of connections between the plants –soil organization is evident through plant interspecific competition, nutrient cycling, soil community composition and structure, pest and disease attenuation. The intercropping variety and competition efficiently increase the nature and extent of crop root networks, efficient resource use in time and space [2].The practice of intercropping is done by small-scale farmers as the growth of more than two crops together, within the same farm throughout the growing period to promote the interaction among constituent crops [3]. The legumes plants are also very important in improving the production and N and P nutrition of cereals. In intercropping system, the reserve of nutrients, total yield and yield between intra and interspecific can be influenced by competition or the presence of ecosystem resources [4, 5]. Legumes-cereals are a suitable intercropping pattern in small-scale farmers because of the capacity of cereals to reduce soil erosion and increasing of soil fertility by legumes. Flexibility, profit maximization, risk minimization are also the causes of intercropping preference by small-scale farmers in addition to increase in soil fertility, ecosystem conservation, weeds control and stable nutrition [6].Cereals intercropped with legumes are a very good method for decreasing soil erosion and for supporting crop productivity. If there is extreme rainfall, then the soil erosion will run off all the nutrients and minerals, resulting in infertile soil with poor crop production. The shallow root crops are very supportive to ventilate the soil to improve water holding. Intercropping patterns tend to increase the soil firmness, diminish erosion of soil and controls surface runoff. [7, 8].The intercropping farming technique allows for the combination of a profitable crop with cover crops to attain reciprocal profits, and also gets distribution benefits across different farming structures. Intercropping schemes provide better crop yields, reduce the use of chemicals and fertilizers, and improve water-use efficiency, especially in the challenging environments of arid and semi-arid countries. [9]

1.1 Benefits of Intercropping

The common advantages of the intercropping system are high yield and production with the available land by optimal utilization of resources, and a variety of crops with different rooting abilities, canopy structure, and nutrient needs. [10]. Mixed cropping is different from the intercropping pattern. Table 1 shows the major difference between intercropping and mixed cropping patterns. Intercropping is a better cropping method than the mixed cropping method. The Tamilnadu agricultural university also suggested some intercropping crops and trees are avocado, pepper, litchi and mangosteen, which can be cultivated in hill stations. Due to the cultivation difficulties of coffee and tea plants, the farmers are suffering to get sufficient income. So, TNAU suggested some crops as intercropping to get additional income from those intercropping crops to balance the economic issues of farmers [11].

Table 1. Difference between Intercropping and mixed cropping.

Mixed Cropping	Intercropping
Aims to minimize the risk of crop failure	Aims to increase productivity per unit area
All crops are cared for equally	Give importance to the main crop
Sowing time is the same for all the crops	Sowing time may be different or the same
There is competition between all the crops	There is no competition between crops

All crops duration almost same	Intercrops are harvested earlier than main crops
Spraying pest control to individual crops is difficult	Pest control can be easily applied to individual crop
Fertilizer application to individual crops is also difficult	Fertilizer can be applied to individual crops as per the need of the crop
Seeds are mixed up before sowing	Seeds are not mixed.

1.2 Drawbacks of Intercropping

The correct crop combination chosen is the most important step in intercropping system. Intercropping management having different cultural practices seems to be a very difficult task. The harvesting of other crops is also challenging in this type of farming. The yield will be reduced if the crops vary in their competitive abilities [12].

1.3 Study Area

Coimbatore district located in Tamil Nadu, India, is the study area taken in this work where various types of crops are grown in different soil types. Crop suitability and growth level differ with respect to every soil type due to the variations in the soil nutrient availability. Coconut, plantain, groundnut, maize, jowar, onion and many types of vegetables and fruits are grown in this region [13-15].

Table 2 Area and Production of Principal crops in Coimbatore

S. No.	Crops	Area in ha.	Annual Production in tonnes
1	Paddy (Rice)	2034	1139
2	Cholam	27441	23105
3	Maize	4166	35797
4	Other cereals	131	194
5	Pulses	10189	5794
6	Sugarcane	927	121181
7	Groundnut	4877	12389
8	Gingelly	444	114
9	Cotton	469	797

2. Mathematical Formulation

Intercropping is a multi-objective optimization problem and the primary aim is to maximize the production to get maximum profit. In this research work, crops are categorized into single crop, double crop and triple crop based on the farmers' real-time usage.

Objective 1: Profit Maximization

The objective function of this work is profit maximization which is given in equation (5.1).

$$Maximize\ \mathrm{F} = \sum_{j}^{m} \sum_{i \in M_j} \left(P_i * U_{i,j,k} - V_{i,j,k} - F_{i,j,k}\right) * X_{i,j,k} \qquad (1)$$

Where,

P_i is the price of the crop,

$V_{i,j,k}$ represents the variable cost for crop i of crop combination j in land type k,
$U_{i,j,k}$ represents the number of farming units of crop i of crop combination j in land type k,
$F_{i,j,k}$ is the fixed cost required per unit area for crop i of crop combination j in land type k,
$X_{i,j,k}$ is the area in hectares of land to be cultivated for crop i of crop combination j in land type k.

Objective 2: Production Maximization

$$Maximize\ P = \sum_{j}^{m} \sum_{i \in M_j} G_{i,j,k} * X_{i,j,k} \quad (2)$$

Where $G_{i,j,k}$ represents the yield rate of production in metric tons per hectare of crop i of crop combination j in land type k.

2.1 Social Spider Algorithm for Intercropping

In this work, Social Spider Optimization Algorithm (SSOA) is applied to suggest the optimal intercropping pattern. Social spider algorithm gives better solutions to all other objective functions compared with other Bio-inspired algorithms. It can solve continuous optimization problems by imitating the foraging behavior of social spiders. Intercropping crops are categorized into different types based on the cultivation style. Fig. 1 shows the behaviour of social spider algorithm [16,17].

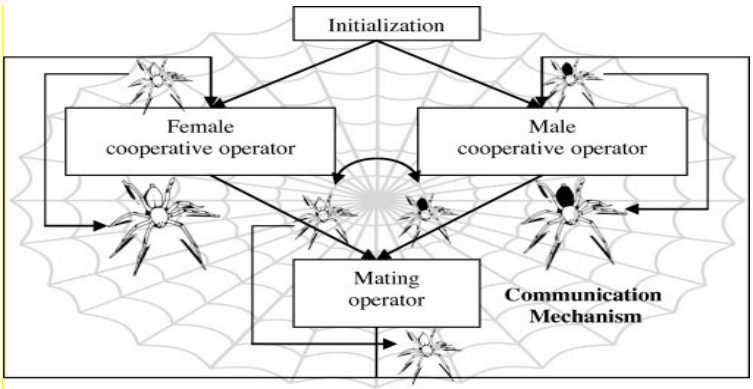

Fig. 1 Behaviour of social spider algorithm

2.2 Merits of SSOA over other Optimization Algorithms

The individual classification technique in SSOA reduces the critical faults present in several Swarm Intelligence (SI) approaches such as inappropriate exploration-exploitation balance and premature convergence. SSOA also avoids the concentration of particles in the best positions, preventing premature convergence to suboptimal solutions and also maintains a limited balance between exploration and exploitation. These characteristics have motivated the use of the SSOA algorithm to solve a wide variety of engineering and real time optimization problems. [18]

3. Results and Discussion

Crops are selected for the experiment, based on the criteria such as crop water requirements, production of the crop, and farmers land availability to cultivate the crop. The selected crops are categorized into three types based on the cultivation practice in

Coimbatore District by the farmers using in real time, which are tabulated in Table 3, Table 4 and Table 5 respectively.

Table 3 Single crop pattern

S. No.	Crop
1	Paddy
2	Sugarcane
3	Coconut
4	Arecanut
5	Banana
6	Cotton
7	Cholam
8	Turmeric

Table 4 Double crop pattern

S. No.	Crops
1	Sugarcane, Onion
2	Paddy, Blackgram
3	Cholam, Redgram
4	Cholam, Blackgram
5	Cholam, Greengram
6	Coconut, Cholam
7	Coconut, Banana
8	Coconut, Turmeric

Table 5 Triple crop pattern

S. No.	Crops
1	Cholam, Redgram, Blackgram
2	Coconut, Banana, Onion
3	Coconut, Banana, Tomato
4	Banana, Tomato, Onion
5	Coconut, Onion, Turmeric
6	Redgram, Blackgram, Cotton
7	Cholam, Cotton, Blackgram

1. Set the initial value of total number of solutions T, population size P, threshold TF, and maximum number of iterations $Itr_{max.}$
2. Set the number of female spiders and F_s and number of male spiders M_s
3. Set k=0
4. For (i=1;i<F_s +1;i++) do
5. For (j=1;j<n+1;j++) do
6. $f_{i,j}^{K} = p_j^{low} + rand(0,1).\left(p_j^{high} - p_j^{low}\right)$
7. End for
8. End for
9. For (k=1;k<M_s+1;k++) do
10. For (j=1;j<n+;j++) do
11. $m_{i,j}^{k} = p_j^{low} + rand(0,1).\left(p_j^{high} - p_j^{low}\right)$
12. End for
13. End for
14. Repeat
15. For (i=1;i<T+1;i++) do
16. $w_i = \frac{J(s_1) - worst_s}{best_s - worst_s}$
17. End for

18. For (i=1;i<F_s+1;i++) do
19. $Vc_i = w_c.e^{-d_{i,c}^2}$ {Calculate the vibrations of the best local}
20. $Vb_i = w_b.e^{-d_{i,b}^2}$ {Calculate the vibrations of the best global}
21. If (r_m< TF) then
22. $f_i^{k+1} = f_i^k + \propto .Vci.\left(s_c - f_i^k\right) + \beta .Vbi.\left(s_b - f_i^k\right) + \delta .(rand - 0.5)$
23. Else
24. $f_i^{k+1} = f_i^k + \propto .Vci.\left(s_c - f_i^k\right) - \beta .Vbi.\left(s_b - f_i^k\right) + \delta .(rand - 0.5)$
25. End if
26. End for
27. Find the median male individual (wF_{s+} m) from M.
28. For (i=1;i<M_s+1;i++)do
29. $Vf_i = w_f.e^{-d_{i,f}^2}$
30. If (wF_s>wF_{+m}) then
31. $m_i^{k+1} = m_i^k + \propto .Vfi.\left(s_f - m_i^k\right) + \delta .(rand - 0.5)$
32. Else
33. $m_i^k + \alpha .\left(\frac{\sum_{h=1}^{N_m} m_h^k \cdot w_{N_f+h}}{\sum_{h=1}^{N_m} w_{N_f+h}} - m_i^k\right)$
34. End if
35. End for
36. $r = \frac{\sum_{j=1}^{n}(P_j^{high} - P_j^{low})}{2.n}$ {Perform the mating operation}
37. For (i=1;i<M_s+1;i++) do
38. If (m ∈ D) then Find E^i
39. If E^i is not empty then Form s_{new} using the roulette wheel method
40. If w_{new}>w_{w0} then
41. Set s_{w0}=s_{new}.
42. End if
43. End if
44. End if
45. End for
46. k=k+1 {iteration counter increasing} until (k<Itr_{max}) {Termination criteria satisfied}
47. Produce the best solution.

Social spider algorithm is used to optimize the intercropping patterns. Single crop pattern is applied to two different constraints such as with no resource constraints and with water resource constraints. In a single crop or solo-crop pattern, only one crop is cultivated to fill the landholding. Table 6 and 7 shows the results of a single crop pattern with no resource constraints and with water resource constraints. The obtained results show that the crop sugarcane gives more profit as well as more production than other crops for both constraints.

Table 6 Single crop pattern suggested by SSOA with no resource constraints

Crop	Profit in Rs.	Production in Kg	TWR in mm^3
Paddy	1320426	9970	1250000
Sugarcane	5747606	261448	19553
Coconut	1458982	9970	800000
Arecanut	2251634	8660	350000

Banana	1266168	11000	50000
Cotton	1164132	3398	258333
Cholam	233690	1684	143518
Turmeric	2063748	6420	30000

Table 7 Single crop pattern suggested by SSOA with water resource constraints

Crop	Profit in Rs.	Production in Kg	TWR in mm^3
Sugarcane	5747606	261448	19553
Turmeric	2063748	6420	30000
Banana	1266168	11000	50000
Cholam	233690	1684	143518
Cotton	1164132	3398	258333
Arecanut	2251634	8660	350000
Coconut	1458982	9970	800000
Paddy	1320426	9970	1250000

Double crop pattern can cultivate more than one crop at a time in the available landholding. Only selected crops can be used in the double crop pattern, which are listed in table 4. Table 8 and 9 shows the double crop pattern results with no resource constraints and with water resource constraints. The obtained results show that the sugarcane, onion crop combination gives maximum profit and production with minimum water requirement. Among all the possible crop combinations the sugarcane, onion crop combination gives better results with both constraints.

Table 8 Double crop pattern suggested by SSOA with no resource constraints

Crop	Profit in Rs.	Production in Kg	TWR in mm^3
Sugarcane, Onion	18262226	281268	99554
Paddy,Blackgram	7084594	12352	1430834
Sugarcane, Soyabean	11531070	268608	109554
Cholam, Redgram	2473576	4288	217046
Cholam,Blackgram	2370657	4066	324352
Cholam, Greengram	1812586	3002	337269
Coconut,Cholam	3511804	11654	943519
Coconut, Banana	5571550	20970	850000
Coconut, Turmeric	7765860	16390	830000

Table 9 Double crop pattern suggested by SSOA with water resource constraints

Crop	Profit in Rs.	Production in Kg	TWR in mm^3
Sugarcane, Onion	36524452	562536	199107
Sugarcane, Soyabean	23062140	537216	219107
Cholam, Redgram	4947152	8576	434092
Cholam, Blackgram	4741314	8132	648704
Cholam, Greengram	3625172	6004	674538
Coconut, Turmeric	15531720	32780	1660000

Coconut, Banana	11143100	41940	1700000
Coconut,Cholam	7023608	23308	1887037
Paddy, Blackgram	14169188	24704	2861667

Triple crop pattern is cultivating more than two crops in the same available landholding. The crop combinations for the triple crop pattern are collected and tabulated in table 5. The combinations are collected from the farmer's real-time usage. Table 10 and 11 shows the results of triple cropland with no resource constraints and with water resource constraints. The obtained results show that the (coconut, banana, tomato) crop combination gives a better solution than the other crop combinations.

Table 10 Triple crop pattern suggested by SSOA with no resource constraints

Crop	Profit in Rs.	Production in Kg	TWR in mm^3
Cholam,Redgram,Blackgram	6834929	6670	397879
Coconut,Banana,Onion	6202082	40790	930000
Coconut,Banana,Tomato	12377310	31970	900000
Banana,Tomato,Onion	5280368	41820	180000
Coconut,Onion,Turmeric	12207772	36210	910000
Redgram,Blackgram,Cotton	10381356	8384	512694
Cholam,Cotton,Blackgram	7157486	7464	582685

Table 11 Triple crop pattern suggested by SSOA with water resource constraints

Crop	Profit in Rs.	Production in Kg	TWR in mm^3
Banana,Tomato,Onion	10560736	83640	360000
Cholam,Redgram,Blackgram	13669858	13340	795759
Redgram,Blackgram,Cotton	20762712	16768	1025389
Cholam,Cotton,Blackgram	14314972	14928	1165372
Coconut,Banana,Tomato	24754620	63940	1800000
Coconut,Onion,Turmeric	24415544	72420	1820000
Coconut,Banana,Onion	12404164	81580	1860000

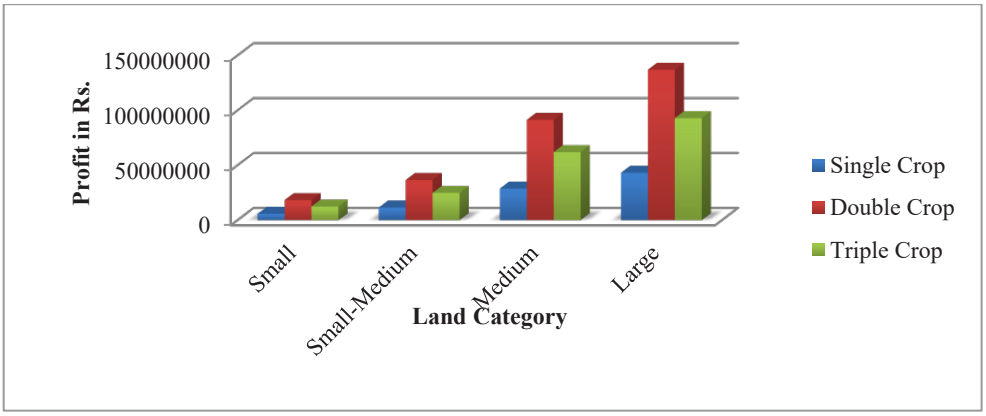

Fig. 2 Profit comparison of different intercropping patterns with land category

The profit of single crop, double crop and triple crop are compared with small, small-medium, medium and large land categories, which is shown in fig. 2. In small land category, the double crop pattern gives better profit than the other two cropping types. In the small-medium land category, the double crop pattern profit is a little bit higher than triple crop and single crop. In medium and large landholding the double crop pattern gives a better profit than the other two types. The obtained results show that the double crop pattern is suitable for all types of land categories.

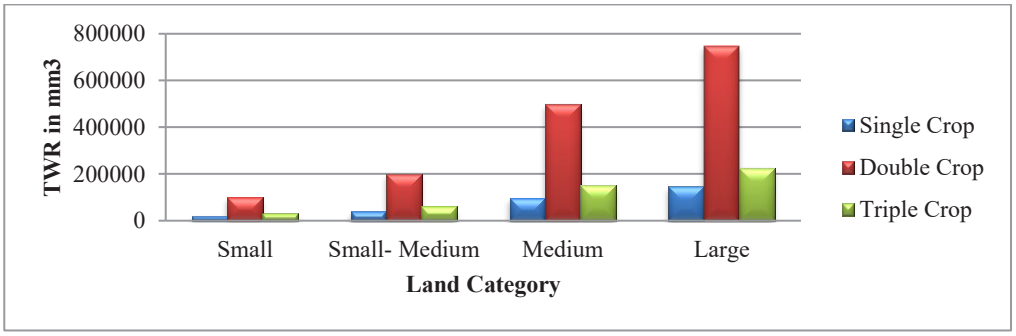

Fig. 3 Water requirement comparison of different intercropping patterns

Fig. 3 depicts the water requirement for a single crop, double crop and triple pattern with small, small-medium, medium and large land categories. In the small land category, the water usage is minimum compared with other cropping patterns. The results show that the intercropping pattern is more suitable for small and small-medium landholding farmers than medium and large landholding farmers.

3.1 Challenges of SSOA

The challenges of SSOA are, it is critical to use the vibration to discrete combinatorial optimization problems and the vibrations caused by web-touching prey are not defined [4].

4 Conclusion

Social spider algorithm was applied to the intercropping system. Most of the farmers are applying only mono cropping patterns in India due to lack of adequate knowledge in the intercropping pattern. In this research work, three cropping patterns and four land categories are considered. The best cropping pattern is suggested based on the land availability and the water resource constraints of farmers. The large landholding farmers are suggested to use a single crop pattern or triple crop pattern based on the water availability.

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