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MATHEMATICAL MODEL OF HONEY BEE POLLINATION FOR THE ADVANCEMENT OF FOOD SECURITY IN NIGERIA

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Abstract: The sustainability of agriculture requires robust functioning of ecosystem services. Bees and forest beekeeping contribute to the sustainability of forest ecosystems by facilitating pollination, which in turn enhances tree regeneration and preserves the biodiversity of the forest and food productivity. In this study, crisp deterministic mathematical model was applied to determine optimal location of bee colonies for successful pollination of plants in chosen farms. Branch and Bound method an established tool in optimization for determination of the optimal location of honey bee colony was applied, to evaluate and analyze the model while Lingo 17.0 software was used to solve with real data collected from a beekeeper in Ewu – Esan local government area of Edo state, Nigeria. The results of the model were used, for optimal location of apiary sites, for honey bee colonies which is paramount to achieving food sufficiency in Nigeria. Honey bees foraged and pollinated plants successfully in fields, where adequate attention was given to the distribution of beehives.

Keywords: *Crisp deterministic model, Placement of bee colonies, Optimal location, Honey bee pollination, and Increasing harvested product.*

1. INTRODUCTION.

Agriculture is a vital institute that cater for the wellbeing of human existence through provision of its products. In recent days, great danger confronts humans in many parts of the world and in particular Nigeria as a result of food insecurity which is as a result of obvious factors like climate change, population explosion and non-adherence to innovations in modern agricultural processes. According to Food and Agriculture Organization of the United Nations (FAO) [1], food security takes place when there is universal access to enough, secure, and nourishing food that meets individuals' dietary needs and tastes, enabling them to lead active and healthy lives. [2] defined food security as the situation in which a family's members are free from hunger or the threat of starvation. Food insecurity mostly stems from poverty and has enduring consequences on the resilience of families, communities, and nations in their efforts to advance and thrive. In [3], food insecurity is a stressful physiological and psychological state. A number of African nations are suffering from food insecurity. Unquestionably, sub-Saharan Africa has been plagued by food shortages, insecurity, and the prevalence of malnutrition for more than three decades for no discernible reason. Several unsuccessful domestic economic policy measures and international policy recommendations can be identified as the main factors responsible for the widespread food insecurity in Africa [4].

Climate change is classify as one of the major challenges of our time and adds considerable stress to our societies and to the environment [5]. In [6], climate change is recognized as one of the greatest threats to agricultural productivity in several regions of the world. The reality of climate is longer questionable as we can observe daily rising case of sea level, change in the pattern of precipitation, flooding and the like. Climate change is a major contributor to the food insecurity in the world. [5] opined that restoring and maintaining important ecosystems can help communities in their adaptation efforts and support livelihoods that hope on the services of these ecosystems.

Beekeeping is the practice of honey bee rearing that combines the knowledge of the social behavior and biology of the bees with that of the environment and the use of apiary equipment to maximize honey production and output of other bee hives production [7]. Best practices in beekeeping and pollination management help to increase agricultural products [8]. Solitary and social bees are the primary insect pollinators responsible for the majority of pollination in both controlled and natural settings. The process of insect pollination is of great significance in terrestrial habitats, since it plays a crucial role in providing essential ecosystem services for human well-being [9]. According to the work of Zekiro [10], several honey bees play a vital role in providing pollination services that are essential for the sexual reproduction of agricultural crops, hence enhancing both their quality and quantity. The pollination carried out by honey bees is crucial for human nutrition as it ensures food security, household income, and ecological services [11]. Honey bees account for 80% of the pollination service, as stated in reference [10]. Honey bees from different colonies choose a food source that best meets the needs of their respective colonies [12].

The application of mathematical model in enhancing agricultural productivity is possible through effective and efficient distribution of beehives colonies in the apiary or farm sites meant to be pollinated by the bees. A beekeeper is required to take a decision that will boost his production. According to the work of Azagbaekwue et al [13], the aim of a decision maker in his decision making, is to maximize profit in an uncertain market environment. The knowledge of optimal distribution of beehives helps in ensuring food security as adequate number of plants/crops will be properly pollinated, [14] stated that optimal spatial distribution of beehives will maximize the production of honey and minimize the cost of production as well as overcrowding.

However, little or less has been stated about the relationship between honey bee pollination and the food security in Nigeria. This study intend to use crisp deterministic mathematical model to determine optimal location of bee colonies for successful pollination of plants which in turn advance food production in Nigeria.

2. Model Formulation

In this section, a mathematical model of foraging honey bees that pollinate plants/crops in a given site is constructed. A graphical representation of the field that indicates the placement of the beehives in connection to the plants is made. The model has the following assumptions: The distance between a site and a plant cluster should be less than or equal to the maximum flight distance of the honey bee. The beehives are located in apiaries with a different number of colonies, each apiary is considered as one whole, the strength of the apiary depends on the number of bee colonies in it. The carrying capacity of a plant is the amount of bees that can be accommodated by a plant at a given period. Thus, a plant can be visited by a number of bees at same time but within the range of its carrying capacity.

The aim of this paper is to maximize the number of plants pollinated and minimize the effort employed to achieve it such that food security is assured.

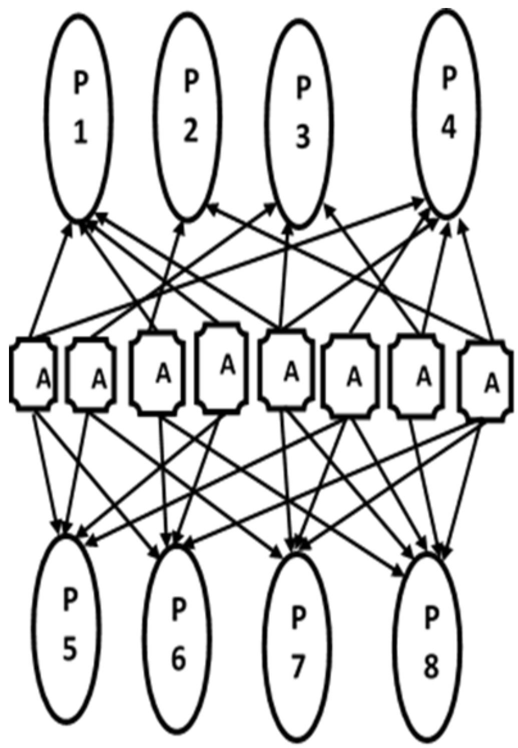

Fig. 1: Graphical Representation of Apiary and Plant Clusters.

In Fig.1, apiary is represented by A1 – A8 and plant cluster by P1 – P8 while the arrow indicates the

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connection between them. The strength of each bee colony does not change for a certain period of time and the carrying capacity remains constant. A bee is expected to perform a maximum flight of 4km to avoid excessive energy consumption during foraging.

Definition of variables, parameters and data:

a – number of apiary sites

p – number of plant clusters

c – number of colonies

X_i – number of colonies to be allocated to apiary site i, $i = 1,2,\ldots,a$ $X_i \in Z^+$

y_j – carrying capacity of plant cluster j, $y_j \in R^+$

w_i – priority weight given to site i, $w_i \in Z^+$

z_{ki} – number of beehives from the k^{th} apiary, that can be allocated at site i, $i = 1, 2,\ldots.,a$, $k = 1,2,\ldots.,c$, $z_{ki} \in Z^+$

b_k – number of hives from the k^{th} apiary $b_k \in Z^+$

R_i – number of beehives allocated at i^{th} sites that will not be able to pollinate j^{th} plants

C_i = { j: plant cluster j is connected to site i}, $i = 1,2,\ldots,a$

F_j = { i: site i is connected to plant cluster j}, $j = 1,2,\ldots,p$

x_{ij} – fraction of colonies of i that can be accommodated by plant cluster j, $i = 1,2,\ldots,a$, $j = 1,2,\ldots,p$, $x_{ij} \in Z^+$.

Using figure 1, the problem can be stated:

Maximize $\sum_{i=1}^{a} w_i X_i - \sum_{i=1}^{a} R_i$ (1)

Subject to:

$$\sum_{j\in C_i} x_{ij} - X_i = 0, \quad i = 1,2,\ldots,a \tag{2}$$

$$\sum_{i\in F_j} x_{ij} - y_i \leq 0, \quad j = 1,2,\ldots,p \tag{3}$$

$$\sum_{k=1}^{c} z_{ki} - R_i - X_i = 0 \tag{4}$$

$$\sum_{i=1}^{a} z_{ki} \leq b_k, \forall k = 1,2,\ldots,c. \tag{5}$$

In the objective function, maximizing the number of colonies that will enhance pollination of the plants is paramount putting into consideration the farmer's priority weight preference as well as minimizing the colonies that cannot pollinate plants. Equation (2) indicates the total number of colonies that are allocated to apiary connected to the plant cluster. Equation (3) indicates the effects of number of colonies in apiary to the carrying capacity of plants connected to it. Equation (4) indicates how the number of colonies will be allocated to the apiaries on the bases that the colony will not be subdivide into parts. Equation (5) indicates, part or all of the beehives that can be allocated in different sites.

3. Model Implementation

In this section, the model formulated will be applied using data obtained from the field. The aim of this study is to enhance food security through the activities of honey bee pollination and crisp deterministic mathematical model was applied to determine optimal location of bee colonies for successful foraging and pollination of plants in chosen farms/sites. 'The designed model was evaluated and analyzed using Branch and Bound' method an established tool in optimization for determination of the optimal location honey bee colony. In the process of searching for solution,, the branch and bound method was used to efficiently explore promising regions of the solution space while pruning branches that were suboptimal. This helps in focusing the search on the most promising areas, leading to faster convergence and better solutions.

Numerical Implication.

The study considers a bee farmer having 8 apiaries at different locations and each having different numbers of colonies, carrying capacities and priority weights as shown in table 1

Table 1: Data from beekeepers

Apiaries	1	2	3	4	5	6	7	8
Number of colonies (c_i)	45	60	52	90	21	32	30	100
Carrying capacities (y_i)	71	31	18	43	61	8	22	54
Priority weights (w_i)	5	9	3	8	7	6	4	2

Equations $(1) - (5)$ was solved using data collected from Ewu – Esan Local Government Area of Edo State, Nigeria (Table 1) with Lingo 17.0 software and the result presented in Table $2 - 4$.

Table2: The number of bee colonies of *i* apiary site, which will be allocated to *j* plant cluster.

i / j	**1**	**2**	**3**	**4**	**5**	**6**	**7**	8
1	-	-	45	-	-	-	-	-
2	-	-	-	-	-	-	-	60
3	-	-	-	-	-	-	52	-
4	-	-	-	-	-	-	-	90
5	-	-	-	-	-	21	-	-
6	-	32	-	-	-	-	-	-
7	-	-	-	-	-	30	-	-
8	-	-	-	-	100	-	-	-

Table 3: Number of bee colonies and quantity of bees rejected at site i, with regards to priority of the beekeeper

	X_i – number of colonies in site i	R_i – number of bees rejected site i	
1	0	0	
2	32	0	
3	45	0	
4	0	0	
5	100	0	
6	51	0	
7	52	0	
8	150	0	

Table 4: Carrying capacity of plant clusters allocated to site i for effective pollination

Site / Capacity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	8	-	-
3	71	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	54
6	-	-	-	-	61	-	22	-
7	-	-	18	-	-	-	-	-
8	-	31	-	43	-	-	-	-

4. Discussion of Results:

Table 2 shows that 45 numbers bee colonies of apiary site 1 should be allocated at plant cluster 3, 60 numbers bee colonies of apiary site 2 and 90 numbers bee colonies of apiary site 4 should be allocated at plant cluster 8, 52 numbers bee colonies of apiary site 3 should be allocated at plant cluster 7, 21 numbers bee colonies of apiary site 5 and 30 numbers bee colonies of apiary site 7 should be allocated at plant cluster 6, 100 numbers bee colonies of apiary site 8 should be allocated at plant cluster 5.

Table 3 shows proper placement of the beehives such that over population does not occur. In other words, no foraging bee is rejected. Hence, the table indicates that 35 number bee colonies can be comprehensively be accommodated and fed by apiary 2, 45 number bee colonies will be fed adequately by apiary 3, 100 number bee colonies will be fed comfortably by apiary 5, 51 number bee colonies can be fed successfully by apiary 6, 52 number bee colonies can be fed by apiary 7, 150 number bee colonies can be fed by apiary 8.

Table 4 shows the proportion of the carrying capacities allotted to different sites in other to maximize the pollination of plants therein. Thus, from the table, it is observed that site 2 has capacity of 8, site 3 has the capacity of 71, site 5 has the capacity of 54, site 6 has the capacity of 83, site 7 has the capacity of 18, site 8 has the capacity of 74, while sites 1 and 4 have no assigned capacity.

From the Tables above, there is nothing assigned to sites 1 and 4. The beekeeper has to avoid these sites because allocating colonies to such sites could cause serious damages to him especially areas with harmful plants that is, plants infected with diseases and virus. Areas not satisfying his priority weight may be

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avoided such as the distance of the apiary to his home. Also areas that lacks carrying capacity for the foraging bees should be avoided.

The results from the tables demonstrate that the model is efficient for optimal location of apiary sites for honey bee colonies which paramount to achieving food sufficiency in Nigeria.

5. Conclusion:

In recent days, it is a known fact that great danger confronts humans in many parts of the world, particularly in Nigeria as a result of food insecurity which is as a result of obvious factors like climate change, population explosion and non-adherence to innovations in modern agricultural processes. The need to address this enormous food insecurity bedeviling our nation is the concern for this paper.

In this paper, crisp deterministic mathematical model was designed to determine optimal location of bee colonies for efficient foraging and pollination of plants in chosen farms/sites. The designed model was evaluated using branch and bound method.

The results of the model can be used for optimal location of apiary sites for honey bee colonies which are paramount to achieving food sufficiency in Nigeria. Honey bees can forage and pollinate plants successfully in a field where adequate attention is given to the distribution of beehives in different sites. This study can be extended to include the cost of relocation of beehives to other sites.

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