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Optimum Plant Mix Selection for Urban Home Gardens: an Attempt on Genetic Algorithm and Integer Linear Programming

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Abstract

Home gardening is a highly deliberated topic in the current world as a consequence of social, economic, and environmental benefits. Due to the lack of mathematical applications in non-profit-based home gardens, this study is mainly focused on the social and environmental aspects of home gardening rather than focusing on the economic perspective. Therefore, this study was scrutinized in an urban city in Sri Lanka where home gardening is disparate from the economic perspective due to various reasons. In the initial stage of the research process, a novel approach to plant ranking was proposed under the concept of home gardening. The Genetic Algorithm (GA) and Integer Linear Programming (ILP) models were proposed in this study under two scenarios and implemented using both primary and secondary data. Implementation of GA was performed using MATLAB software and parameter values were determined by the trial and error method. The second scenario was accomplished through the ILP model along with sensitivity analysis using Excel Solver. Both methods provided optimum plant mix effectively and efficiently for the selected garden considering a horizontal space.

Keywords: Home Gardening; Genetic Algorithm; Integer Linear Programming; Optimum plant mix; Plant diversity; Plantation area.

1. Introduction

Optimizing home gardens has become a colloquy in the real world which attracts the research world from different perspectives due to the social, economic, and environmental benefits. This research is focused on a mathematical and computational approach to optimize home gardening more effectively and efficiently.

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As discussed in the study [1], home gardens are identified as a mixed cropping system that dwells near the home. A similar definition holds the study [2] by stating the home garden as a land area with combined plants near the family home to satisfy the physical, social and economic needs. According to the studies [3,4], the home garden is identified as a dynamic and complex sustainable land use system with a high diversity of plants under different species, and it is also defined as a supplementary production system that is located near residencies and managed by family members. Furthermore, Sri Lankans not only engaged in large-scale cultivation but also small-scale cultivation such as home gardens [1,3,5]. Even though Sri Lanka has rich soil content and a satisfactory level of water for cultivation, the available land area is limited due to the high rate of urbanization, and essential to be properly managed to obtain maximum use. Moreover, as a result of urbanization, plant diversity and food safety are on a threatening level. Home gardening is one of the most effective ways to overcome this problem [6]. Therefore, optimizing the available land area for plantation should be highly considered to increase plant diversity and ensure food safety. To enhance plant diversity and utilize the available limited plantation area effectively, gardeners should have a better understanding of what to plant and how much to plant. To satisfy these requirements, proper plant selection should be carried out systematically due to the available rich plant diversity within Sri Lanka. This research provides a satisfactory solution to this problem with the use of deterministic (Linear Programming (LP), Integer Linear Programming (ILP), etc.) and non-deterministic (Heuristic Algorithm (HA) and Meta-Heuristic Algorithm (MHA)) optimization techniques. The real-world problem is converted into a mathematical context to obtain optimum outcomes when there exist scarce resources to manage carefully. Most of the researchers paid attention to optimizing farm areas based on an economic perspective. The process of crop production encompasses several stages and crop selection is the first step among others [7]. Crop planning has become a major problem due to the inadequate availability of recourse [7], [8]. Therefore researchers tend to find more precise systematic ways of crop planning [7]. Increase productivity while the proper allocation of resources drags high attention in the agricultural sector. Rigorous analysis of the literature, clearly visualized some of these studies have focused on deterministic approaches while others have proposed non-deterministic approaches for crop selection optimization. The main motivation of the study [9] has focused on maximizing the net profit of a farm area in Zimbabwe using the LP model with constrained to the land, labour, fertilizer, and cost of other operations, basically associated with four types of crops: maize, cabbages, potatoes, and tomatoes. The model was solved using Microsoft excel solver 2017 and based on the results it was argued that the LP model can increase the profit margin by 76%. The comparison between the traditional method followed by the farmers based on their experience and the proposed method under the study [9] revealed that following the traditional method leads to suboptimal allocation of available results even though it provides some profit and is unable to meet the optimal profit margin. Therefore, it emphasized the need for a more systematic approach to crop planning in order to obtain the optimum result. Similarly, the study [10] has proposed the LP model to maximize production through optimum land allocation for fourteen major crops, and the study was carried out with respect to various factors such as land utilization, labour, seeds, fertilization, and yields for the crops for one year period. The main motivation of the study focused to enhance production to maximize profit. The results were obtained by LINDO software and according to the results, LP model was proposed as a suitable model for finding the optimal land allocation for crop planning. Furthermore, with the consideration of the economic value of farming, the objective of the study [8] also addressed the problem of identifying the optimum cropping patterns that can highly affect sustainable production. It was argued that the LP model is more productive than the traditional method used by the farmers to determine the optimum crop combination to maximize the profit of farmland while satisfying family consumption. The comparison of the results performed in the study emphasized that traditional methods do not guarantee the optimal solution. Even though a great deal of research has been conducted on optimizing farmland, very few studies have addressed the importance of optimizing home gardens. By considering this problem up to some extent, Ward and Symons in the study [11] explored a two-stage LP model to optimize urban agriculture in dry climates by considering the cost of water requirements. But, the main objective of the study also directed toward maximizing the net value of the garden by considering dietary food groups, available land area, and total water cost. The study [11] fortified that LP model is a suitable method to solve complex problems despite the simplicity and flexibility of the model construction. Nevertheless, while many studies have suggested the LP model for crop selection, some of the studies have paid attention to MHAs. Meta-heuristic algorithms are capable of solving multi-objective optimal crop mix planning problems and MHAs are an effective tool in profit and production maximization [12]. The comparative analysis between generalized differential evolution 3 (GDE3), the Non-dominated Sorting Genetic algorithm (NSGA-II), and the ε-constrained algorithm has revealed that GDE3 is performed comparatively well in optimum crop mix selection for profit maximization despite the simplicity of the mechanism. The performance of the GDE3 was analyzed by the study [12] based on the statistical performance metrics of additive epsilon indicator, generational distance, inverted generational distance, and spacing. According to the studies [13], [14], Adeyemo and Otieno have suggested and argued that the Differential Evolution algorithm is a more effective and efficient method for optimum crop planning. The study [13], discussed that both DE and LP models provide the same result and the convergence speed of DE is effective and efficient. In addition, the study [13] explored that the parameter combination can affect the performance of DE and the best performance was provided when the population size is 160, the crossover constant is 0.95 and the weighting factor is 0.5. In the presence of complex cropping patterns, a multi-objective differential evolution algorithm (MDEA) is suggested as a successful application of crop planning [14]. Furthermore, it was observed that the best results were obtained using a population size is 40, a crossover factor equal to 0.95, and a weighting factor is 0.5 [14]. Consequently, it was revealed that the parameter combination is problem specific and sensitivity analysis should be carried out to identify the best parameter combination in each study. While the study [13] focused on obtaining the maximum income, the study [14] paid attention to three main objectives: maximization of total net profit, maximization of total planting area, and minimization of irrigation water requirement. However, both studies stipulate the economic value of agricultural land. Critique of the prior studies has revealed that all the crop planning and home gardening optimization studies have been focused on optimizing the economic value of the agricultural lands and none of these studies have addressed the socio-ecological aspect of home gardening and have not paid attention to enhancing social and environmental benefits through maximizing the species richness within the available garden area. However, according to the literature, it is discovered that profit is not the main motivation of most Sri Lankan gardeners [6,15]. Therefore, the interference of similar studies on crop selection is not suitable under the concept of the Sri Lankan home gardening context. When considering the significant characteristics of home gardens, it is clear that home gardens require a high amount of species density, and high plant diversity such as staples, vegetables, fruits, and medicinal plants, and also the main objective is home consumption [1,16]. Moreover, rather than generating profit, gardeners pay attention to improving health, enhancing food and nutritional security, social equity and gender balancing, preserving indigenous knowledge and building integrated societies, recycling water and waste nutrients, controlling shade, dust, and erosion, maintaining or increasing local biodiversity, enhance pollination and provide habitats for wildlife [1,16]. Consequently, the main motivation of this study is to accumulate the non-economic value of home gardens into consideration and provide new insight to optimize home gardens based on species richness within the available garden area using a mathematical and computational approach. Understandably, a home garden is a complex land use system mainly controlled by the gardener's perspective. The expected outcome of the garden can vary based on the gardener's desire. Therefore, instead of the economic value of the garden, this research anticipates the social and environmental benefits (food, medicine, ornamental, etc.) of home gardens and paid more attention to the gardener's preference for plant species. Considering the factors of available garden area, the benefits of each plant variety, and the gardener's desire for plant selection, this study suggests two different mathematical models under two scenarios: GA for the first scenario and ILP for the second scenario. The objective of the first scenario is to maximize the number of plant varieties within an available land area based on the gardener's minimum requirement of plants in each variety. The second scenario is to maximize the plantation area while allocating the optimum number of plants in each variety. As a powerful meta-heuristic, GA is well known for its capability in handling complex optimization problems and contributes to many studies in different fields. It has been observed that GA has been used in several agricultural research but not specifically in research associated with gardening. Since scenario 1 deals with a large number of plant varieties and the plant selection process, GA is considered in this research because of its easy representation and efficient calculations. Initially, GA is used as an experimental approach and it worked well for this application. Therefore, GA is accepted in solving this problem due to its simplicity and efficient calculation even though it deals with a large number of plant varieties. Furthermore, this will be an opening for the comparative analysis of MHAs in home gardening optimization based on the socio-ecological benefits of home gardens which is hard to address using the mathematical application. ILP model is a deterministic approach that can be highly used in crop selection and it has been revealed by the prior studies that the ILP model provides effective and efficient results in optimization [17,18] but has not been considered for home gardens optimization under socio-ecological aspects. Due to the simplicity and effectiveness of both well-known approaches, this research proposes a combination of two models under two different scenarios for a new perspective on home gardening optimization.

2. Materials and Methods

This section is followed by a detailed explanation of how the research was operationalized based on accumulated materials, collected data, and proposed methods. Both primary and secondary data relating to 154 plant varieties [19]–[22] have been collected to implement the model. GA and ILP models have been proposed under two different scenarios, based on the space requirement of the initial plant selection. Two possibilities have been taken into consideration when a gardener performs the initial plant selection.

I. The space requirement for the initially selected plant varieties exceeds the available plantation area.
II. The space requirement for the initially selected plant varieties does not cover the available plantation area.

Based on the scenarios, the flow of the study has been organized as indicated in Figure 1.

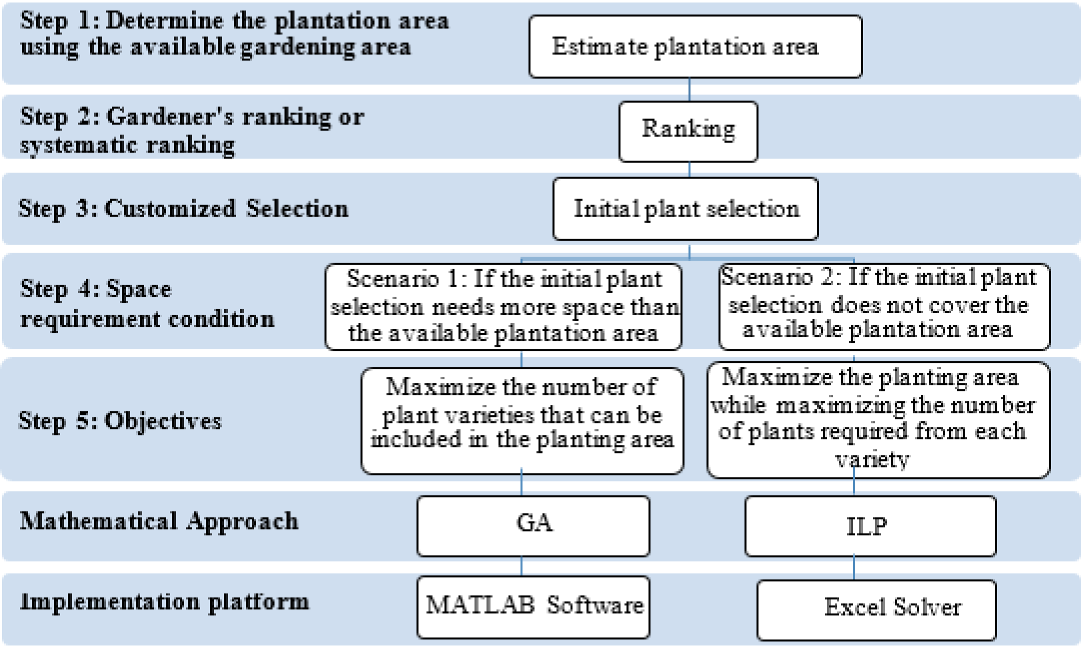


Figure 1: diagram of the research process.

2.1. Calculate the circulation area of the garden

Available plantation area is one of the key inputs of both models. Consequently, in this study, the plantation area was estimated by assuming gardeners may use 1 m × 2 m size raised gardening beds and allow a 1-ft distance (approximately 30 cm) between two gardening beds. The total plantation area was calculated using equations (1) and (2) provided by [23].

$$N.S.F.+C.A = U.S.F. \quad (1)$$

$$C.A. = C.F. \times U.S.F \quad (2)$$

In this study $N.S.F.$ (Net Square Feet), $C.A.$ (Circulation Area), and $U.S.F.$ (Usable Square Feet) were calculated in m^2 and redefined based on this study. Where,

$N.S.F.$: Plantation area (Area required for planting beds)

$C.A.$: Circulation area around the garden

$U.S.F.$: Usable area/ Garden area (Area required only for gardening purposes without buildings, pools, etc.)

$C.F.$ (Circulation Factor) gives the factor of circulation which was used to determine the circulation area out of the total usable area [23].

Calculate $C.F.$ by considering the dimension of one planting bed,

$N.S.F. = 1\ m \times 2\ m = 2\ m^2$

$C.A. = 2 \times (2.3\ m \times 0.15\ m) + 2 \times (1\ m \times 0.15\ m) = 0.99\ m^2$

$U.S.F. = 2.99\ m^2$; By equation (1)

$C.F. = 0.33$; By equation (2)

The selected area for the implementation consists of 112 m^2 of the garden area and the plantation area was determined as 75 m^2 using equations (1) and (2) based on the total garden area and the received $C.F.$ value (0.33).

2.2. Perform plant ranking

A home garden is a complex system that requires more attention to selecting the most suitable plants for the available plantation area. The plant ranking procedure is essential to narrow down the selection of plant varieties for a home garden due to the high availability of plant species. Even though most of the ranking methods have been proposed for the plant ranking process, few of these methods can apply to home garden plants [24]. Therefore, a new ranking procedure was proposed in this study to select the best plant varieties for a home garden and used in the initial population selection phase in GA.

$i: Plant\ code\ (i = 1,2,3,\cdots,154),$

$j: Type\ of\ need\ (j = 1,2,3,4,5,6,7)$, where

$j = 1: Need\ for\ vegetable, food\ ingredient, or\ spice$
$j = 2: Need\ for\ fruit$
$j = 3: Need\ for\ medicine$
$j = 4: Need\ for\ flower\ or\ ornamental\ plant$
$j = 5: Need\ for\ firewood$
$j = 6: Need\ for\ shade$
$j = 7: Need\ for\ timber$

$k: Usable\ part\ of\ the\ plant\ (k = 1,2,3,4,5)$, where

$k = 1: Leaves$
$k = 2: Stem, bark, stalk$
$k = 3: Fruit\ or\ seed$
$k = 4: Flowers, flower\ bud, or\ flower\ stem$
$k = 5: Roots, tubers, bulbs, rhizome$

$v_{i,j}$: $weight\ of\ the\ needs\ satisfied\ by\ plant\ i$

$u_{i,k}$: $weight\ of\ the\ usable\ parts\ of\ plant\ i$

$x_i = \sum_{j=1}^{7} v_{i,j}$, $where\ x_i\ is\ the\ total\ weight\ of\ satisfying\ the\ needs\ of\ plant\ i$

$y_i = \sum_{k=1}^{5} u_{i,k}$, $where\ y_i\ is\ the\ total\ weight\ of\ usable\ parts\ of\ the\ plant\ i$

If the selected plant variety is not a creeper-type (herb, bush, tree, etc.), the area needed for that variety was obtained by,

$z_i = minimum\ number\ of\ plants\ need\ in\ variety\ i \times\ space\ requirement\ for\ one\ plant\ in\ a\ variety$

If the selected plant type is a creeper (pennywort, etc.), then it was determined as,

$z_i = minimum\ area\ required\ for\ the\ plant\ variety\ i$

The minimum number of plants of each plant variety/ minimum area of creeper-type plants was hypothetically decided and it depends on the gardener's requirements. Nevertheless, z_i was defined as the minimum total area needed for plant variety i. Assuming the gardener does not have any specific requirements for the home garden whether it is used for food, medicine, or any other purpose, equal weights were allocated for satisfying the required needs of the plants. If the gardener needs to obtain specific benefits from the garden, it is suggested to provide higher weight for those types of plants.

Therefore,

$$v_{i,j} = \begin{cases} 1, & if\ need\ j\ is\ satisfied \\ 0, & otherwise \end{cases}$$

$$u_{i,k} = \begin{cases} 1, & if\ that\ part\ of\ the\ plant\ is\ useful \\ 0, & otherwise \end{cases}$$

$$\boldsymbol{f(x_i, y_i, z_i) = (x_i + y_i)/z_i} \qquad (3)$$

Where $\boldsymbol{x_i + y_i}$ provides the accumulated value by plant variety $\boldsymbol{i}$ and $\boldsymbol{f(x_i, y_i, z_i)}$ provides the value obtained by the plant within the unit area. The highest value for $\boldsymbol{f(x_i, y_i, z_i)}$ indicates the most suitable plant variety for the garden and receives the highest value in ranking.

2.3. The process under scenario I

Scenario 1: If the initial plant selection required more space than the available plantation area, then the objective of this study is to maximize the plant varieties that can be included in the garden to obtain high diversity. GA was proposed to achieve this objective.

2.3.1. Initial Plant selection for scenario 1

For the first case study for scenario 1, the initial plant selection was carried out based on the agro-ecological zone (low-country wet zone) where the selected study area is located and 80 plant varieties (from 154 plant varieties) in that agro-ecological zone were selected as the initial selection, which is presented in Table 1.

Table 1: Initial plant selection for case 1.

Plant code	Plant name	Minimum Number of plants/ space (m^2)	Plant code	Plant name	Minimum number of plants/ space (m^2)
5	Balloon-vine	1	84	Eggplant	3
8	Spinach	3	85	Banana	2
10	Butterfly pea	1	86	Cassava	2
12	Lima bean	3	87	Brinjal	3
16	Country Potato	2	90	Anthurium	20
19	Cassia tora	5	91	Cosmos	10
21	Ginger	2	94	Hibiscus	1
25	Turmeric	2	95	Coco-yam	2
26	Orchid (pigeon)	1	96	Barberton-daisy	10
27	Sweet potato	1	97	Leichhardt	1
28	Lantana	1	98	Lilly-pilly	1
33	Taro	1	100	Aerial yam	3
34	Ladies fingers	5	102	Golden shower	1
37	Coriander	5	103	Hog plum	1
40	Winged beans	1	106	Namnam/ Cynometra cauliflora	1
41	Sri Lankan Mulberry	1	108	Bilimbi/ Averrhoa bilimbi	1
46	Balsam	10	109	Fig	1
47	Night flowering jasmine	1	110	Soursop	1
50	Bitter gourd	3	115	Black pepper	2
52	Arrowroot	5	118	Sugar apple	1
55	Crape jasmine	1	119	Guava	1
56	Queen Sago	1	120	Lime	1
57	Indian pennywort	1*1	121	Sorrowless tree/Ashoka	1
58	Indian sarsaparilla	2	125	Rose-apple	1
59	Grater yam	1	127	Star fruit	1
60	Sessile joyweed	1*1	128	Batoko plum/ lovi-lovi	1
61	Horse purslane	1*1	129	Bullock’s heart/ Wild sweetsop	1
64	Canereed/ Costus speciosus	1	130	Malay rose-apple	1
65	Ixora	1	131	Mango	1
66	Cinnamon	1	133	Coconut	1
67	zinnias	10	134	Governor’s plum/ Coffee plum	1
69	Bottle gourd	1	136	Jackfruit	1
71	Cucumber	1	139	Canistel	1
72	Snake gourd	1	143	Lanson	1
73	Air yam	1	144	Indian gooseberry	1
76	Lasia	1*1.5	146	Avacado	1
77	Marigold	6	148	Rambutan	1
78	Pineapple	3	149	Breadfruit	1
81	Hummingbird tree	1	150	Mangosteen	1
82	Marvel of Peru	2	151	Garcinia cambogia	1

2.3.1. Application of GA

Plant code, space requirement, the minimum number of plants in each variety, plant value, and the estimated available plantation area are provided as the input variables of the algorithm and each trial consists of 50 runs. The main steps followed by the algorithm are presented below.

Procedure:

Step [1]. **[Start]** Generate the initial population of *n* chromosomes (plant mix) based on the ranking.

1.1. Include each variety in the plant mix at each locus with a selection probability which is obtained by ranking.

1.2. $Selection\ probability = Rank\ of\ variety / Sum\ of\ ranks$

1.3. If a randomly generated number for each locus is lesser than or equal to the selection probability, then include that variety into the plant mix of the initial population.

1.4. Chromosomes are represented using binary representation.

1.5. Population size (n) is proportional to the size of the chromosome. Hence n was given as $k \times chromosome$ size.

Step [2]. **[Fitness]** Evaluate the fitness of each plant mix in the population.

2.1. $f(\alpha_i)$: Number of plant varieties (Number of species) included in the plant mix i.

2.2. $fitness = w_i \cdot f(\alpha_i)$, where

2.3. $w_i = 1$, if $space\ requirement\ for\ plant\ mix\ i \leq Plantation\ area$

2.4. $w_i = 0.1$, if $space\ requirement\ for\ plant\ mix\ i > Plantation\ area$

Step [3]. **[New Population]** Create a new population by repeating the following steps *m* times until the new population is complete; where *m* is the number of iterations.

3.1. [Selection]: Parent selection using the rank selection method.

3.1.1. Select two chromosomes from the population according to their fitness.

3.2. [Cross over]: Cross over the parents (parent plant mix) to form a new offspring (new plant mix) with a crossover probability. If no crossover was performed, the offspring is an exact copy of the parents.

3.2.1. Use single-point crossover with some probability.

3.2.2. Use a random single crossover point.

3.3. [Mutation]: Mutate new offspring using the “flipping bits” operator at each locus with a mutation probability.

3.4. [Accepting]: Place new offspring in a new population and after completing the off-spring population apply elitism by replacing the least fitted plant mix of the off-spring population with the most fitted plant mix in the parent population.

Step [4]. **[Replace]** Use the newly generated population for a further run.

Step [5]. **[Test]** If the end condition is satisfied (Number of iterations), stop and return the best solution in the current population.

Step [6]. **[Loop]** Otherwise go to step 2.

In this scenario, the number of plant varieties for the best fit run[a] has been obtained as the optimum plant mix. Parameters can highly affect the final solution of GA. Therefore, the parameters were selected by trial and error method in this study. The number of iterations/generations was decided based on the anytime curve, which provides insight into the optimal solution along with the computational time/number of generations. Crossover and mutation probabilities for GA were determined through sensitivity analysis by performing 100 runs of the algorithm for different parameter combinations which were selected through the prior studies [25] and obtained the best value provided by each parameter combination through trial and error. Population size was maintained as a constant ($k \times chromosome\ size$) within each hypothetical example and k was decided by trial and error method. The fitness function of the algorithm was determined based on the diversity indices for assessing plant diversity [26]–[28] and if the constraint is violated, then the fitness is provided as $0.1 \cdot f(\alpha_i)$, to reduce the selection of poor solutions.

2.4. The process under scenario 2

Scenario 2: If the initial plant selection does not cover the available plantation area, then the objective of this study was focused to maximize the planting area by maximizing the number of plants in each initially selected plant variety.

2.4.1. Initial plant selection for scenario 2

The second case study was performed based on both the agroecological region of the selected garden area (low-country wet zone) and the ranking procedure. Hence, the top 20 plants of the ranking belonging to the low-country wet zone were selected as the initial selection which is presented in Table 2.

Table 2: Initial plant selection for scenario 2.

Plant code	Plant name	Plant code	Plant name
5	Ballon vine	28	Lantana
8	Spinach	33	Taro
10	Butterfly pea	34	Ladies fingers
12	Lima bean	37	Coriander
16	Country Potato	41	Sri Lankan Mulberry
19	Cassia tora	40	Winged beans
21	Ginger	47	Night flowering jasmine
25	Turmeric	46	Balsam
26	Orchid (pigeon)	50	Bitter gourd
27	Sweet potato	52	Arrowroot

2.4.2. Application of ILP Model

[a] The best fit run is obtained by selecting the run which provides the maximum fitness for a trial.

If the decision criteria of the second scenario (required space for initial plant selection < available plantation space), have been satisfied, then the problem is solved using model 2. To fulfill this objective, the ILP model has been proposed and implemented by an Excel solver under the Branch and Bound method.

Procedure:

Inputs:

1. Space requirement for one plant in each selected plant variety $(\boldsymbol{s_1}, \boldsymbol{s_2}, \cdots, \boldsymbol{s_n})$.
2. Available plantation Area.
3. The minimum number of plants required from each selected variety.

Variables: Number of plants needed from each selected plant variety to maximize the planting area $(\boldsymbol{a_1}, \boldsymbol{a_2}, \cdots, \boldsymbol{a_n})$.

Objective: Maximize the planting area.

$\boldsymbol{Max = a_1 \cdot s_1 + a_2 \cdot s_2 + \cdots + a_n \cdot s_n}$, where $\boldsymbol{1 \leq n \leq 20}$

Constraints:

1. $\boldsymbol{a_1, a_2, \ldots, a_n \geq Minimum\ number\ of\ plants\ required\ based\ on\ the\ gardener's\ request}$
2. $\boldsymbol{a_1, a_2, \ldots, a_n \leq Maximum\ number\ of\ plants\ required\ based\ on\ the\ gardener's\ request}$
3. $\boldsymbol{a_1 \cdot s_1 + a_2 \cdot s_2 + \cdots + a_n \cdot s_n \leq Available\ plantation\ area}$
4. $\boldsymbol{a_1, a_2, \ldots, a_n} \in \mathbb{Z}^+$

3. Results and Discussion

3.1. Results for scenario 1-GA

The hypothetical example performed under scenario 1 contains 80 plant varieties that have been selected within the low country wet zone. To satisfy the minimum plant requirement of each variety indicated in Table 1, the garden should have at least 1338.9 $\boldsymbol{m^2}$ plantation area. Nevertheless, the area selected for this study consists of only 75 $\boldsymbol{m^2}$ for the plantation purpose which is not adequate for the all initially selected plant varieties. Therefore, the best plant combination which has the highest plant richness (highest number of plant species) was determined by implementing GA. According to the results obtained throughout all 50 runs which include 100 iterations, 53 plant varieties have been obtained as the optimum plant mix that can be planted within the available plantation area. This optimum plant mix required 74.99 $\boldsymbol{m^2}$ of space for plantation purposes and the result is highly compatible with the available plantation area (75 $\boldsymbol{m^2}$). The final MATLAB output of the optimum plant mix has been presented in Table 3.

Table 3: Optimum plant mix for case 1.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Plant code	5	8	10	12	16	19	21	25	26	27	28	33	34	37	40	41	46	47
No.	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Plant code	50	52	55	56	57	58	59	60	61	64	65	66	67	69	71	72	73	76
No.	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	
Plant code	77	78	81	82	84	85	86	87	90	91	94	95	96	98	100	102	106	

Furthermore, the best fitness value of each iteration of the best fit run was obtained to check the behavior of the convergence. Over some time/ number of iterations, a smooth converging curve that has reached a maximum fitness value of 53 can be observed. Figure 2 provides a better understanding of the convergence behavior of the model.

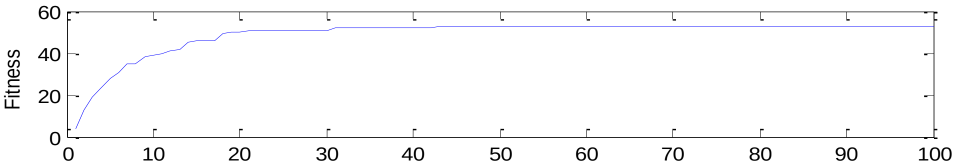


Figure 1: Best fitness with iterations for the best fit run.

3.1.1. Sensitivity Analysis

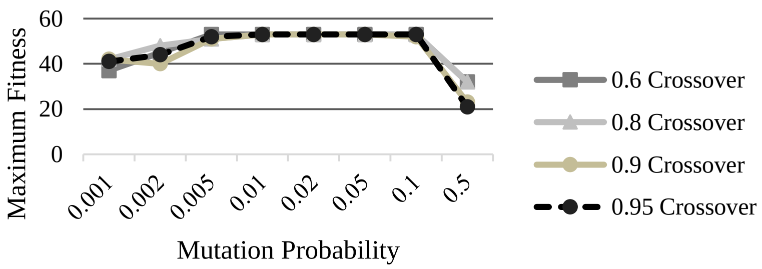
To have the optimum results of the algorithm, the best parameter combination was selected by trial and error method using different combinations of parameter values. Based on the received results, the population size, crossover probability, and mutation probability were determined as 160, 0.95, and 0.05, respectively. The selected parameter values have been used to obtain the final output.According to the sensitivity analysis, it is clear that the mutation probability has a higher impact on the optimal solution than the crossover probability in this scenario.The behavior of the optimal solution for the different combinations of mutation and crossover probabilities is presented in Table 4.

The presented results in Table 4 are further elaborated in Figure 3. Figure 3(A) presents the behaviour of the maximum fitness of the best fit run for the different combinations of mutation and crossover probabilities while Figure 3(B) presents the minimum fitness and Figure 3(C) presents the average fitness values for the best fit run in each parameter combination. According to Figure 3(A), 0.01, 0.02, and 0.05 mutation probabilities provide maximum fitness value. Nevertheless, the concave behaviour of the graphs that are presented in both Figure 3(B) and Figure 3(C) indicates that the best fitness value is provided by the 0.05 mutation probability. Furthermore, the imbricate lines of the fitness presented in each figure: 3(A), 3(B), and 3(C), stipulate that crossover probability does not highly affect the fitness value in this case.

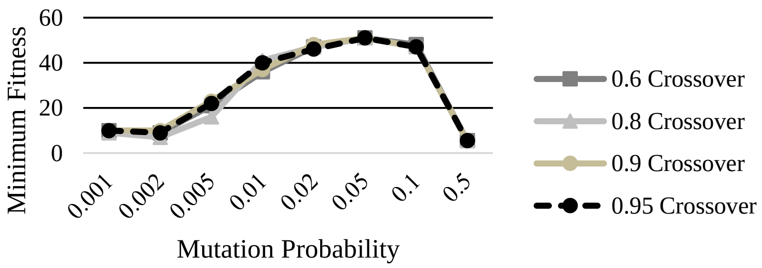
Table 4: The impact of mutation and crossover probabilities on the optimal solution.

Crossover			0.6	0.8	0.9	0.95
Mutation Probability	0.001	Min	10	9	10	10
		Avg	23.13	23.41	22.11	24.27
		Max	37	42	42	41
	0.002	Min	9	7	10	9
		Avg	25.34	24.96	26.13	26.35
		Max	45	48	40	44
	0.005	Min	21	16	23	22
		Avg	39.37	38.98	39.53	39.07
		Max	53	51	51	52
	0.01	Min	36	41	37	40
		Avg	48.65	47.85	48.22	47.32
		Max	53	53	53	53
	0.02	Min	47	47	48	46
		Avg	51.37	51.18	51.59	51.44
		Max	53	53	53	53
	0.05	Min	51	51	51	51
		Avg	52.7	52.71	52.66	52.75
		Max	53	53	53	53
	0.1	Min	48	47	47	47
		Avg	49.96	49.7	49.8	49.74
		Max	53	53	52	53
	0.5	Min	5.5	5.5	5.5	5.5
		Avg	6.528	6.255	5.97	5.944
		Max	32	32	23	21

(A)



(B)



(C)

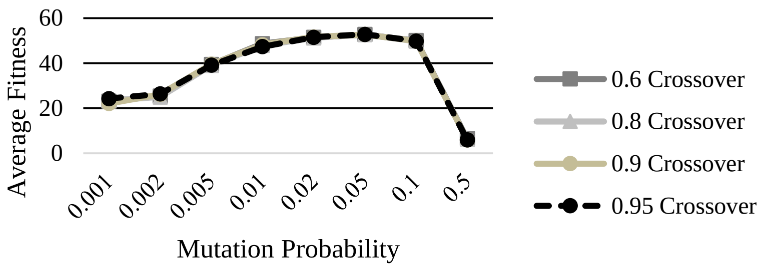


Figure 3: Mutation probability vs. Fitness of best run for A = Maximum fitness[b], B= Minimum fitness[c], and C= Average fitness[d]

The number of iterations/generations is another key indicator that can affect the optimal solution of the algorithm. If the algorithm has a less number of generations, it will cause a suboptimal solution and otherwise, it will increase the computational time. Anytime curve is one way of determining the optimal number of iterations based on time and fitness as presented in Figure 4. Termination conditions of the algorithm can be determined through this curve. Therefore, this study performed the algorithm initially with 100 iterations, based on case 1 under scenario 1 (including 80 plant varieties) and using 154 plant varieties as the second case under scenario 1.

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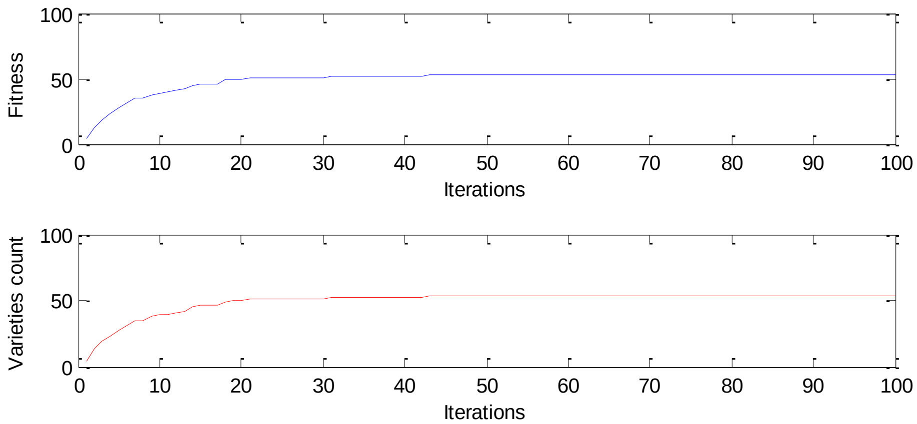
(A)



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[b] Maximum fitness is selected from the 100 iterations that belong to the best-fit run
[c] Minimum fitness is selected from the 100 iterations that belong to the best-fit run
[d] Average fitness is selected from the 100 iterations that belong to the best-fit run

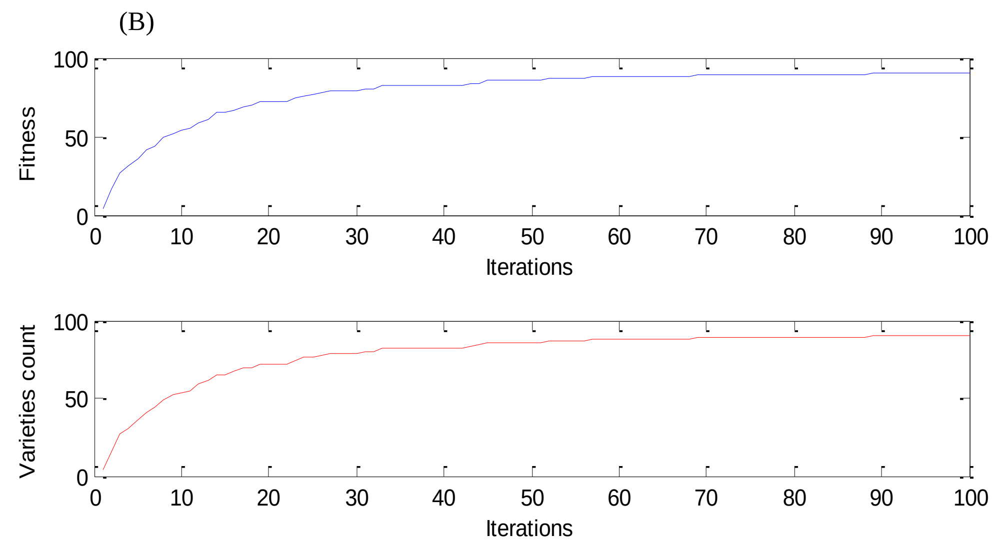

Figure 4: The behavior of the anytime curve for A = case I under scenario 1 and B = case II under scenario 1

Figure 4(A) shows the steady convergence behavior after approximately 50 iterations. However, Figure 4(B) shows the improvements until it reaches around 100 iterations. Therefore, the number of iterations of this algorithm cannot be determined in general and it is case-based. Moreover, population size is another key factor to be considered because the higher population sizes for smaller chromosome lengths may increase the computational time and conversely, a lesser number of population sizes for higher chromosome lengths can cause premature convergence. Consequently, optimal population size needs to be determined. Hence, this algorithm was performed by considering the population size as proportional to the chromosome length. The population size was determined based on computational time and fitness value. The best fitness was received when the proportional constant (k) equals 2. Therefore, the hypothetical example performed under scenario 1, which includes 80 plant varieties as the initial selection contains 160 chromosomes as the population size. Besides the parameter selection, this study has focused on applying the concept of elitism. According to the comparison between with and without elitism in the algorithm, it was revealed that the anytime curve when applying elitism received a more smooth curve than without the presence of elitism. The smoothness of the curve indicates the fluctuations of the solution. If the curve presents a very smooth behavior, it implies that the solution does not differ frequently. Therefore, it was identified that applying the elitism concept can impact the results. Figure 5 presents the behavior of the anytime curve for these two incidents and it clearly presents the result does not fluctuate frequently with the presence of elitism in the algorithm.

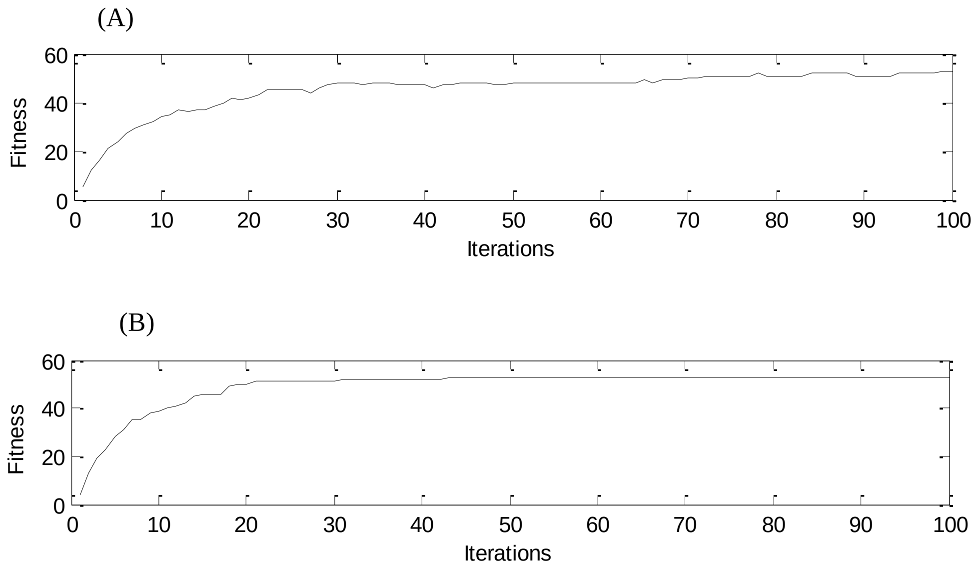

Figure 5: Fitness value on each iteration for A=without elitism and B= with elitism

3.2. Results for Scenario 2-ILP

The top 20 plants belonging to low country wet zone have been applied to implement the ILP model under scenario 2. The space requirement for the minimum number of plants in all selected varieties covers only 6.46 m^2 of the available plantation area (75 m^2). Therefore, Table 5 provides the output of the optimal plant mix which was received to maximize the total plantation area based on the minimum and maximum requirements of each selected variety. According to the results that have been obtained by the Excel solver output, it was observed that the optimal plant mix needs a 74.97m^2 plantation area. Understandably, this plant combination fully utilizes the available plantation area. Consequently, this is a very effective and efficient way of plant mix selection if there are complex situations like the high availability of plant combinations.

Table 5: Optimum plant mix for scenario 2.

Plant code	5	8	10	12	16	19	21	25	26	27
Number of plants	2	5	1	3	2	10	20	50	5	5
Plant code	28	33	34	37	41	40	47	46	50	52
Number of plants	10	10	30	50	2	5	2	20	4	10

3.2.1. Sensitivity analysis

Moreover, the details of the slack and surplus values have been included in Table 6. Slack values indicate the unused number of plants within a given variety and surplus values present the number of plants exceeding the minimum requirement of that plant variety.

Table 6: Sensitivity analysis for ILP.

Constraint Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Slack or Surplus	1	2	0	0	0	5	18	48	4	4	9	9	25	45	1
Constraint Number	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Slack or Surplus	4	1	10	1	5	0	45	1	17	3	0	30	0	0	0
Constraint Number	31	32	33	34	35	36	37	38	39	40	41				
Slack or Surplus	0	0	0	0	0	0	0	0	0	0	0.0264				

4. Conclusion

Plant selection is a highly significant step in the home gardening optimization procedure. Nevertheless, none of the prior studies have provided a significant contribution to home gardening optimization in a socio-ecological context. Consequently, the main objective of this study focused on optimizing the limited garden area to enhance species richness within the garden and utilize the available garden area based on the gardener's requirements. GA and ILP models have performed well in this concept and highly satisfied the objectives while increasing the efficiency and effectiveness of plant mix selection. GA contributes to enhancing the diversity of the garden with the most suitable plants based on the gardeners' perception while the ILP model optimizes the available plantation area. Furthermore, because of the randomness in GA, several combinations of plant mix can be obtained and it is useful for crop rotation in the garden. Therefore, this application is highly supportive for the garden planners to have a better plant mix for the garden while optimizing the land area. This study can be improved as applicable to any region in any country with minor modifications and can be further expanded as a multi-objective optimization problem with a modified fitness function based on several factors. Furthermore, this application can be further improved and implemented as a mobile app that allows gardeners to evaluate the value or diversity of their gardens and optimize it by themselves according to their perspective. However, this study concerns only the horizontal space utilization of the home garden and does not address the vertical space utilization in home gardens which is highly encouraged in urban areas. Furthermore, the space required for each plant variety can slightly vary according to several factors such as region, different plant forms of the same species, cultivars, and other natural factors that can affect the growth of a plant.

References

[1]. D. H. Galhena, R. Freed, and K. M. Maredia, "Home gardens: a promising approach to enhance household food security and wellbeing," *Agric. Food Secur.*, vol. 2, no. 1, p. 8, Dec. 2013, doi: 10.1186/2048-7010-2-8.

[2]. A. W. Drescher, R. J. Holmer, and D. L. Iaquinta, "Urban homegardens and allotment gardens for sustainable livelihoods: Management strategies and institutional environments," in *Tropical Homegardens: A Time-Tested Example of Sustainability*, vol. 3, B. M. Kumar and P. K. R. Nair, Eds. Dordrecht: Springer Netherlands, 2006, pp. 317–338.

[3]. D. K. N. . Pushpakumara, B. Marambe, G. L. L. P. Silva, J. Weerahewa, and B. V. R. Punyawardena, "A review of research on homegardens in Sri Lanka: the status, importance and future perspective," *Trop.*

Agric., vol. 160, pp. 55–125, 2012, [Online]. Available: https://www.researchgate.net/publication/236117466.

[4]. M. Buddhi *et al.*, “Vulnerability of homegarden system to climate change and its impacts on food security in South Asia,” 2011. [Online]. Available: https://www.apn-gcr.org/wp-content/uploads/2020/09/3ddf57b875774091a38f95bdfee0b6c9.pdf.

[5]. L. G. D. S. Yapa, “Contribution of Home Gardens to Household Food Security in Sri Lanka: A Comparative Study on Wet Zone and Intermediate Zone,” *J. Soc. Sci. Humanit. Rev.*, vol. 3, no. 3, p. 124, Sep. 2018, doi: 10.4038/jsshr.v3i3.11.

[6]. T. T. Ranasinghe, “Manual of low/no-space agriculture -CUM-Family Business Gardens (FBG),” Resource Centres on Urban Agriculture and Food Security and International Water Management Institute, 2009.

[7]. S. Chetty, “Studies in heuristics for the annual crop planning problem,” University of KwaZulu-Natal, South Africa, 2012.

[8]. M. Felix, M. Judith, M. Jonathan, and S. Munashe, “Modeling a Small Farm Livelihood System using Linear Programming in Bindura, Zimbabwe,” *Res. J. Manag. Sci.*, vol. 2, no. 5, pp. 20–23, 2013, [Online]. Available: www.isca.in.

[9]. G. Buzuzi and A. N. Buzuzi, “A Mathematical Programming Technique to Crop Mix Problem on a Farm in Mutasa, Manicaland Province, Zimbabwe,” *SSRG Int. J. Econ. Manag. Stud.*, vol. 5, no. 11, pp. 6–10, 2018, doi: 10.14445/23939125/ijems-v5i11p102.

[10]. N. Patel, M. Thaker, and C. Chaudhari, “Agricultural land allocation to the major crops through linear programming model,” *Int. J. Sci. Res.*, vol. 6, no. 4, pp. 519–522, 2017.

[11]. J. Ward and J. Symons, “Optimising crop selection for small urban food gardens in dry climates,” *Horticulturae*, vol. 3, no. 2, p. 33, May 2017, doi: 10.3390/horticulturae3020033.

[12] . O. Adekanmbi, O. Olugbara, and J. Adeyemo, “An investigation of generalized differential evolution metaheuristic for multiobjective optimal crop-mix planning decision,” *Sci. World J.*, vol. 2014, pp. 1–8, 2014, doi: 10.1155/2014/258749.

[13]. J. Adeyemo and F. Otieno, “Optimizing planting areas using Differential Evolution (DE) and Linear Programming (LP),” *Int. J. Phys. Sci.*, vol. 4, no. 4, pp. 212–220, 2009.

[14] . J. A. Adeyemo and F. A. O. Otieno, “Optimum crop planning using multi-objective differential evolution algorithm,” *J. Appl. Sci.*, vol. 9, no. 21, pp. 3780–3791, 2009, doi: 10.3923/jas.2009.3780.3791.

[15] . M. Glavan *et al.*, “The economic performance of urban gardening in three European cities – examples from Ljubljana, Milan and London,” *Urban For. Urban Green.*, vol. 36, no. October, pp. 100–122, 2018, doi: 10.1016/j.ufug.2018.10.009.

[16]. G. A. S. Ginigaddara, *Sri Lankan home gardens and household food security*. Rajarata University of Sri Lanka, 2019.

[17]. P. H. H. P. N. De Silva, G. H. J. Lanel, and M. T. M. Perera, “Integer Quadratic Programming (IQP) Model for Cut Order Plan,” *IOSR J. Math.*, vol. 13, no. 02, pp. 76–80, Mar. 2017, doi: 10.9790/5728-1302027680.

[18]. M. T. M. Perera and G. H. J. Lanel, “A Model to Optimize University Course Timetable Using Graph Coloring and Integer Linear Programming,” *IOSR J. Math.*, vol. 12, no. 05, pp. 13–18, May 2016, doi: 10.9790/5728-1205031318.

[19]. Export Development Board, “Industry Capability Report-Sri Lanakan Floriculture Sector,” 2019. [Online]. Available: https://www.srilankabusiness.com/publications/industry-capability-reports/.

[20]. Export Development Board, “Industry Capability Report-Spice and Concentrates,” 2020. [Online]. Available: https://www.srilankabusiness.com/publications/industry-capability-reports/.

[21]. Export Development Board, “Industry Capability Report Fresh Fruit & Vegetable,” 2019. [Online]. Available: https://www.srilankabusiness.com/publications/industry-capability-reports/.

[22]. U. Rajapaksha, *Traditional Food Plants in Sri Lanka*. Hector Kobbekaduwa Agrarian Research and Training Institute, 1998.

[23]. United States General Services Administration, *Circulation: defining and planning*. Washington, DC, 2012.

[24]. M. Amberber, M. Argaw, and Z. Asfaw, “The role of homegardens for in situ conservation of plant biodiversity in Holeta Town, Oromia National Regional State, Ethiopia,” *Int. J. Biodivers. Conserv.*, vol. 6, no. 1, pp. 8–16, 2014, doi: 10.5897/IJBC2013.0583.

[25]. A. Hassanat, K. Almohammadi, E. Alkafaween, E. Abunawas, A. Hammouri, and V. B. S. Prasath, “Choosing mutation and crossover ratios for genetic algorithms-a review with a new dynamic approach,” *Information*, vol. 10, no. 12, 2019, doi: 10.3390/info10120390.

[26]. R. Peet, “The Measurement of Species Diversity,” *Annu. Rev. Ecol. Syst.*, vol. 5, no. 1, pp. 285–307, 1974, doi: 10.1146/annurev.es.05.110174.001441.

[27]. R. Neelamegam, S. Roselin, A. M. A. Priyanka, and V. M. Pillai, “Diversity Indices of Home Garden Plants in Rural and Urban Areas in Kanyakumari District, Tamil Nadu, India,” *Sch. Acad. J. Biosci.*, vol. 3, no. 9, pp. 752–761, 2015.

[28]. R. Ponce-Hernandez, P. Koohafkan, and J. Antoine, “Assessing carbon stocks and modelling win-win scenarios of carbon sequestration through land-use changes,” Rome, 2004. [Online]. Available: https://www.fao.org/3/y5490e/y5490e.pdf.