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Crops Plantation Planning Respecting Climate Changes: Fuzzy-Based Approach

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Abstract

Objectives: Commonly, agriculture in many areas of the world represents an example of fields that are affected hardly by climate changes. This work attempts to find and rank candidate plantation plans of a given set of crops that can be planted in a specific area with regard to the climate change. **Methods/Statistical Analysis**: This work represents a fuzzy-based approach. Firstly, a prediction process takes place in order to predict the incoming year values of climate variables like temperature, humidity and sun shining. In consequence, the crops climatic requirements are represented using the flexibility of fuzzy set theory. After that, the year under planning is scanned to find the more suitable plantation periods for each crop. Finally, the proposed approach finds a set of candidate plantation plans each is associated with an overall suitability degree greater than a predefined threshold. **Findings:** Many previous works attempt to find the more suitable areas for planting a specific crop or to modify the plantation dates to be more suitable. These works don't care about the consequent planted crops in the same area which almost affect the overall outcome of the plantation process. In contrary, the proposed approach gives a ranked set of candidate plantation plans based on their overall suitability degrees. Accordingly, it helps farmers in selecting the more suitable plantation plan respecting climate change. **Application/Improvements: A**n application is built respecting the proposed approach. Its database includes the area historical climatic data and the crops climatic requirements. The application starts predicting the incoming year climatic values. Consequently, it finds each crop suitable plantation periods which are used to get the candidate plantation plans with an overall suitability degree. An illustrative case study is presented showing the added value of the proposed approach compared with some other previous ones.

Keywords: Climate Change, Crops Plantation Planning, Crops Requirements, Fuzzy Set Theory, Prediction

1. Introduction

Climate change represents a crucial real-life problem that affects most aspects of our life. In the field of crops plantation, it is very essential to find some strategic planning for the plantation process in a given area in order to maximize the overall plantation process profitability. Such need becomes critical as a result of the ongoing change in climate especially on the temperature degree, humidity and sunshining. In order to satisfy such need, the crops suitable requirements that include uncertainty in some cases should be handled. Modeling of such requirements from climate variables can be through the flexibility of fuzzy set theory. Accordingly, some essential needs for crops plantation planning appeared to cope with such progressive change in climate. This work presents a fuzzy-based approach for crops plantation planning in an area respecting the prevailing change in climate.

1.1 Agriculture and Climate Change

Nowadays, climate change represents one of the most impacting issues in many aspects of the world like agriculture. The effect of climate change on agriculture is noticeable since most crops need specific climate requirements for growing and yielding. So, the change in climate makes planting some crops needs to adjust the plantation dates, if it is possible, to satisfy the crop climatic requirement. On the other hand, such change in climate may make a specific area appropriate for planting new untraditional crops. Accordingly, agriculture needs more search efforts to cope effectively with such climate change.

1.2 Plantation Planning

Commonly, planning is a process for an organization for defining a working strategy, or direction of the organization, and making decisions on allocating the resources needed to accomplish such strategy. It may also control mechanisms for managing the implementation of the strategy. Strategic planning becomes important in organizations during the 1960s and still has an essential aspect of strategic management. It is executed by strategic planners or strategists[1]. It is essential for plantation planning to find and evaluate each candidate period to plant a specific crop in a given area. Yet, this requirement resembles a challenging task due to the uncertainty nature of the crop climatic requirements that almost are described using human-like terms like around, more or less and some other uncertain terms. Such task can be achieved efficiently by benefit from the flexibility of using fuzzy set theory when modeling uncertain information like crops suitable requirements.

1.3 Flexibility of Fuzzy Set Virus Crisp Set

Generally, a traditional crisp set has sharp boundaries that makes an element belongs totally to it or does not belong to it at all. For example, a crisp set of moderate temperature degree includes the temperature degrees belong to the closed interval [22, 38]^{O}C as shown in Figure 1. Accordingly, a temperature degree of 21.9 or 38.1^{O}C does not belong to such a set although they are very closed to the set left and right boundaries respectively. Such situation motivates the appearance of fuzzy set theory that allows partial membership values of elements in a set. Figure 2 shows an example of a trapezoidal fuzzy set depicted in (1). Generally speaking, fuzzy set theory was initiated by[2]. Since then, many researches and applications in many fields have been achieved. Fuzzy queries have appeared in the last years to cope with the necessity to soften the Boolean logic in database queries[3]. A fuzzy query system enables users to select data from a database using human linguistic words which are qualitative by nature[4]. This area of research is still interesting as there are needs for more improvements of existing approaches.

$$\mu_t(x) = \begin{cases} 0 & x \prec 10 \\ (x-a)/(b-a) & 10 \le x \prec 22 \\ 1 & 22 \le x \prec 38 \\ (d-x)/(d-c) & 38 \le x \prec 50 \\ 0 & x \ge 50 \end{cases} \tag{1}$$

Where $\mu_t(x)$ represents the matching degree of temperature x to the fuzzy set "Moderate temperature" and a, b, c and d have the values 10, 22, 38 and 50 respectively.

The goal of this paper is to propose a fuzzy based approach for selecting the more suitable periods for planting a specific crop at a specific location given the agro-climatic historical database for such location. In consequent, such approach helps in strategic planning for crops plantation in a specific location respecting the changes in climate variables in the nearly coming years.

The rest of this paper is organized as follows: The second section introduces the related work. The proposed approach is presented in the third section. The fourth section shows an illustrative case study. The discussion is presented in the fifth section. The sixth section shows the conclusion.

2. Related Works

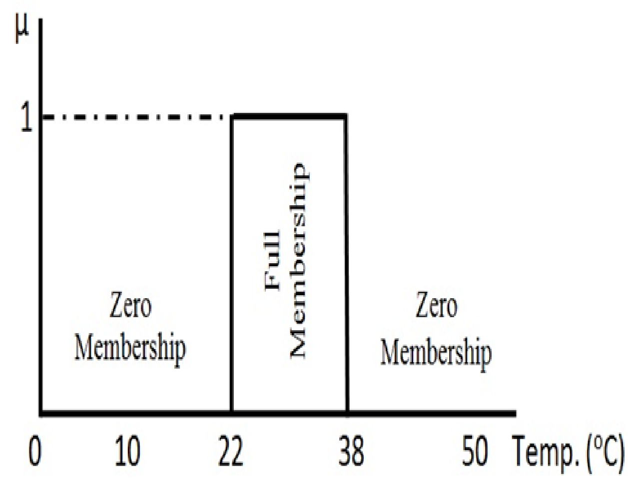

Figure 1. Linguistic value "Moderate temperature" defined as a crsip set with sharp boundaries.

Many approaches have been proposed for the problem of the affection of climate changes on agriculture. Some approaches aimed mainly to show the impact of climate change on crop production like[5,6]. As water resources are one of the most important parameter in plantation process, an approach has been proposed aiming to adapt

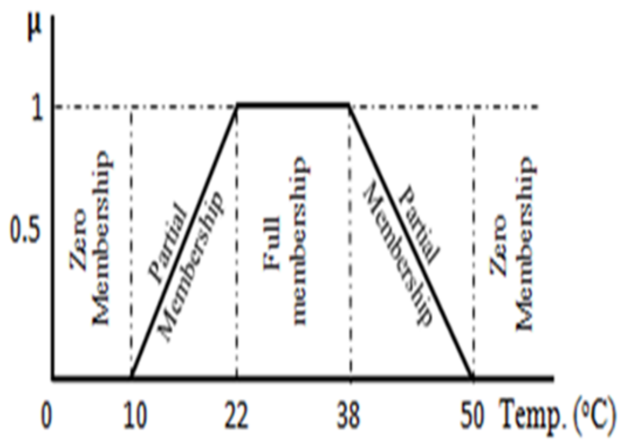

Figure 2. Linguistic value "Moderate temperature" defined as a fuzzy set with smooth boundaries.

crop planting dates to climate changes like in[7,8]. Another approach for crop yield forecasting was presented in[9] to map the relations between climate data and crop yielding. It is based on time series data of the crops and weather. Some approaches use the average values of climate data like in[9]. Other approaches have been proposed such as Fuzzy-based Decision Support Systems for evaluating land suitability and selecting the more suitable crops to be planted is provided as in[10,11]. Also, the authors of[12] developed a fuzzy rule based system for evaluating land suitability and selecting the appropriate crops for it. Unfortunately, all of the above approaches remedy from missing an overall view about the plantation plan of a given area. In other words, it is good to find the more suitable areas for planting a given crop or modifying the plantation dates in some areas. But it is very essential to take into consideration the other planted crops in the same area. Changing traditional plantation dates for some crops may cause shifting for plantation dates of other crops. Such process may prevent some origin crops from planting in same area at all or reduces the suitability of the new plantation dates. Unfortunately, many crops have minimum and maximum survival values of climate variables that should be considered. Also, the works presented in[13-16] attempt to find more suitable plantation periods for planting a given crop in a specified area. Although all of these works contributes to enhance the plantation process with respect to the changes in some climatic and environmental changes, there still a need for a flexible approach that gives reliable plantation plans respecting the ongoing change in climate.

This paper proposes a fuzzy based approach for strategic planning of crops plantation dates respecting climate change. Based on the available historical climatic data and the candidate crops requirements for Alexandria governorate in Egypt, the proposed approach gives a set of candidate suitable plantation plans which are ranked according to the overall suitability for each plan.

3. The Proposed Approach

Commonly, the proposed approach benefits from the flexibility of fuzzy set theory that allows partial matching degrees of elements to a set in a human-like fashion. In fact, there are no rigid boundaries of crops suitable requirements of climate variables like temperature and sun shining. Yet, there are tolerant smooth boundaries of the appropriateness degrees of a climate variable to a given crop. Accordingly, fuzzy sets are very suitable for representing the requirements of crops plantation process in a flexible and reliable manner. Consequently, climate requirements for the underlined crops are fuzzily defined and stored in a database for crops requirements. On the other hand, the historical agro-climatic data like sunshining, temperature and humidity for a set of most recent previous years is stored in another agro-climatic database. Such data is used to predict the climate variables values in the next years that are under agriculture planning. The architecture of the proposed approach is depicted in Figure 3. It consists of three main modules: the first one is responsible for defining the appropriate climate requirements for each crop; the second module is responsible for predicting climate data of the next incoming years; and the last one is concerned with setting a set of candidate plantation plans for the specified area. The following subsections present these modules.

3.1 Weighted Climate Data Prediction Module

This module aims mainly to predict the climate data for the nearly incoming years. The input of this module is the available historical agro climatic data for a set of previous years for the specified location. A weight is computed for each year indicating the impact of each year in the prediction process. That is the more recent year the higher the impacting weight and vice versa. On the other hand, the output represents the predicted agro climatic data for a set of incoming years. Commonly, it starts preparing its

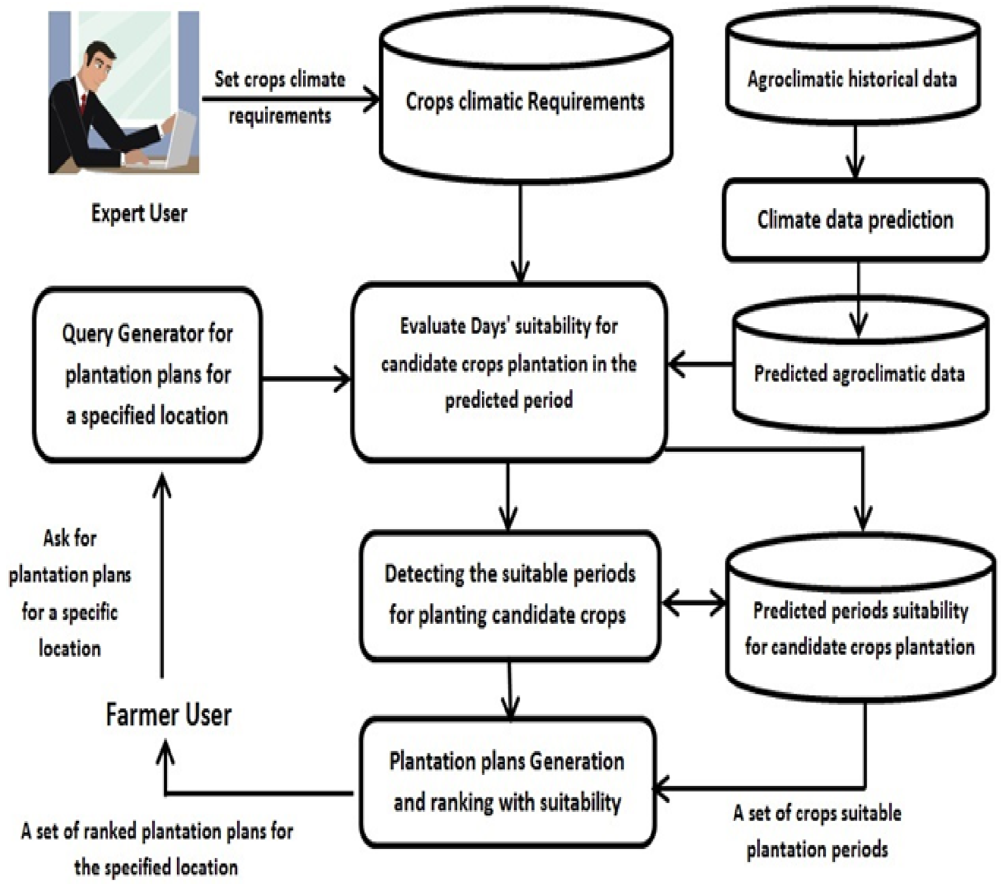

Figure 3. The architecture of the proposed approach.

input of historical data by excluding the extreme values and estimating the missed ones if any for the underlined area. Consequently, Algorithm 1 is used to predict the values of climate variables for the under-planning incoming year using an enhanced version of climatology prediction, a climate forecasting technique[16]. In this algorithm, the more recent year the more impacting one in the prediction process.

Algorithm 1: Weighted climate data prediction.
Inputs: The historical climate data for a set of previous years N.
Outputs: The predicted climate data for next incoming year Y_m.
Begin:

Let $T = \sum_{i=1}^{n} i$

//where T is used for weighting years in the prediction process and $n = |N|$
For each year Y_i in N

Compute the prediction weight W_i of year Y_i:

$$W_i = (|N| - (Y_m - Y_i) + 1) / T$$

End for
For each day D_i in the next year Y_m

$$Y_m(D_i) = Y_1(D_i) * W_1 + Y_2(D_i) * W_2 + \ldots + Y_n(D_i) * W_n$$

End for
End

3.2 Crops Requirements Fuzzy Modeling Module

This module enables to mathematically define the suitable climate requirements for each crop. It is used to gather the crops climatic requirements from the agricultural experts and refine it to define the suitable plantation requirements of each affecting climatic variable such as temperature, humidity and sunshine. Such requirements are used to generate suitability fuzzy membership functions for the specified crop. For example, the requirements of potatoes crop specified in[17] can be represented in a very flexible manner using the more detailed trapezoidal membership function shown in Figure 4 and as depicted in (2). In other words, the suitability requirements of temperature degrees, for example, for crop C_i can be represented using the trapezoidal fuzzy membership function with the following rules:

- x is the most suitable temperature degree with full matching degree for each temperature x in [*b, c*],
- x is a highly acceptable suitable temperature degree with relatively a high suitable, more half, partial matching degree for each temperature x in either [*(a+b)/2*, b[or]*c, (c+d)/2*], and
- x is a less acceptable suitable temperature degree with relatively a low suitable, less half, partial matching degree for each temperature x in either]*a, (a+b)/2*] or *[(c+d)/2, d*[, and
- x is a catastrophic temperature degree if $x \geq d$ or $x \leq a$.

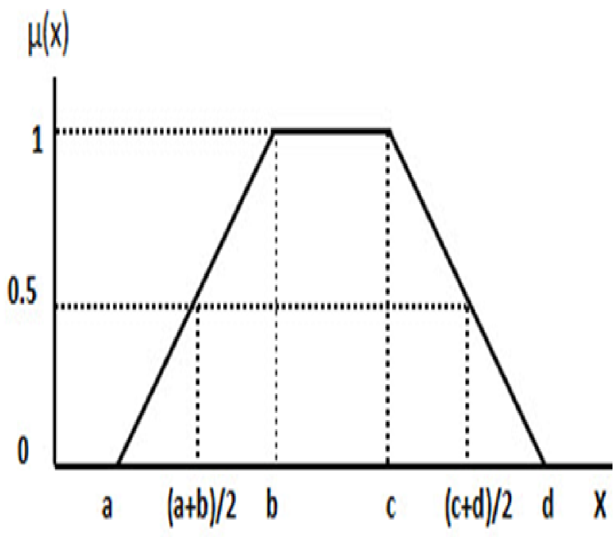

Figure 4. Trapezoidal fuzzy membership function.

$$\mu_t(x) = \begin{cases} 0 & x \leq a \\ (x-a)/(b-a) & a \prec x \prec (a+b)/2 \\ 0.5 & x = (a+b)/2 \\ (x-a)/(b-a) & (a+b)/2 \prec x \prec b \\ 1 & b \leq x \leq c \\ (d-x)/(d-c) & c \prec x \prec (c+d)/2 \\ 0.5 & x = (c+d)/2 \\ (d-x)/(d-c) & (c+d)/2 \prec x \prec d \\ 0 & x \geq d \end{cases} \quad (2)$$

Where $\mu_t(x)$ represents the membership degree of each element x in the universe of discourse *a, b, c* and *d* are the function control points.

3.3 Days Suitability for Crops Plantation Module

This module is responsible for evaluating the suitability of each day for planting a specific crop respecting the predefined requirements set by the expert. It uses the climatic requirements of the crops and the predicted climate data for the nearly coming years of the specified location as inputs. In consequence, it evaluates the suitability of each day for planting each candidate crop. This module consists of three phases as follows:

3.3.1 Phase 1: Evaluate the Availability of Each Candidate Crop Requirements

This phase retrieves the suitability fuzzy membership functions for each candidate crop that were defined in the previous module. This phase benefits from the flexibility of fuzzy set theory with smooth boundaries to represent the suitable requirements of climate variables for a crop. In this phase, a set of fuzzy membership functions are defined stating the how much each value in a climatic variable is suitable for the growth of a specific crop.

3.3.2 Phase 2: Suitability Degree Computation

This phase evaluates the overall suitability degree for each day in the candidate period. Generally, the defined fuzzy membership functions are used to map each climate variable value to a suitability degree reflecting how much it is perfect to the plantation process of the crop. Accordingly, the overall evaluation takes place according to the predefined fuzzy membership functions of crops requirements and the predicted climate data of the under planning year. In this work, each climate variable has an importance or affecting factor (α). So, the overall suitability value is computed by fuzzy landing the weighted suitability values of the effecting climate variables on the crop plantation. Accordingly, the suitability membership value (S) of any day for the plantation of a specific crop is computed as depicted in (3).

$$S = \alpha_t * S_t + \alpha_h * S_h + \alpha_s * S_s \quad (3)$$

Where S represents the overall suitability, and are the suitability of temperature, humidity and sunshining respectively, α_t, α_h *and* α_s are the effecting or importance factors for temperature, humidity and sunshining respectively with the constraint that $\alpha_t + \alpha_h + \alpha_s = 1$.

Consequently, the suitability of a period P_j for planting crop C_i can be computed as depicted in (4).

$$S(P_j, C_i) = \sum_{k=1}^{n} S(D_k, C_i) / n \quad (4)$$

Where $S(D_k, C_i)$ is the suitability of day D_k for planting crop C_i and n is the number of days in period P_j.

Consequently, the computed suitability degrees of the candidate plantation periods for the specified crop are stored in the agro-climatic database.

3.3.3 Phase 3: Determining and Optimizing Crops Suitable Periods

This phase is concerned with selecting the period if it has a suitability degree equal to or more than the accepted threshold for such sub period. Consequently, an optimization process takes place aiming to maximize each the suitability degrees of the selected periods as possible. It takes place by shifting the period to left or right then reevaluates its suitability degree. In other words, the optimization can easily achieved by removing N days from the beginning of a period and adding N days to the end of the period, and vice versa, and reevaluate the modified period suitability as explained in the previous phase. Finally, a set of ranked suitable plantation periods for each crop is obtained. Each plantation period is described by the crop name, start date, duration and its suitability degree.

In fact, determining each crop suitable plantation periods at a given area is not the satisfactory objective in this research. Instead, finding complete suitable crops plantation plans for an area within a specified plantation period is the main objective. Such plantation plans help farmers and governments to manage and optimize the overall agriculture economy in the specified areas.

3.4 Candidate Plantation Plans Generation Module

This module aims mainly to find the more suitable plantation plans for a given area respecting both of climate change and candidate crops requirements. As presented in Algorithm 2, the input of this module is the union of suitable plantation periods sets of candidate crops that can be planted in the area under planning. The processing takes place by finding the more suitable sequence of such plantation periods with an overall length in days less that the period under planning. On the other hand, the output is a set of plantation plans with a suitability measure for each plan. It starts by generating all valid plantation plans that satisfy mainly the following conditions:

- There is no overlapping between any two plantation periods within the same plantation plan since the plantation process will takes place on the same area.
- The overall period of the plantation plan must not exceed the period under planning.
- Each plantation plan has an overall average suitability that is more than or equal a predefined threshold value.
- Generally, an intermediate period between each two consequent crops plantation periods is taken into account. This is very essential for plowing, ventilation and preparing the land for planting the consequent crop in the plantation plan.
- In consequence, the resulted plantation plans are ranked respecting their suitability degrees. Commonly, there are possible to scenarios for obtaining the candidate plantation plans as presented in the following subsections.

Algorithm 2. Candidate plantation plans generation.
Inputs: A set of n crops under planning $C = \{C_1, C_2, C_3, ..., C_n\}$, predicted climate data for the considered year and crops requirements including temperature suitability S_t, humidity suitability S_h and sunshine suitability S_s, the length of period under planning PL and a main crop MC may be specified.
Output: A set of candidate plantation plans respecting climate suitability and the life time of crops.
Begin:

For each crop C_i in the crops set C

Evaluate each day D_j suitability for planting crop C_i such that:

$$S(D_j, C_i) = \alpha_t * S_t(D_j, C_i) + \alpha_h * S_h(D_j, C_i) + \alpha_s * S_s(D_j, C_i).$$

Find the set of suitable plantation periods with suitability ≥ θ, a predefined threshold, such that:

$$SP_{C_i} = \{P_j \mid S(P_j, C_i) \geq \theta \ and \ |P_j| \geq lifetime(C_i)\}$$

Where $|P_j|$ denotes the number of days n in the period and

$$S(P_j, C_i) = \sum_{k=1}^{n} S(D_k, C_i) / n$$

Where $S(D_k, C_i)$ is the suitability of day D_k for planting crop C_i

End for

Construct the set G of all suitable plantation periods of all crops such that:

$$G = \bigcup_{i=1}^{n} SP_{C_i}$$

Where $n = |C|$ is the number of crops under planning.

Generate a set of candidate plantation plans CPP such that:

If $MC \neq \{\Phi\}$ then

$$CPP = \{CPP_i \mid CPP_i \subset G \wedge MC \in CPP_i \wedge length(CPP_i) < PL \wedge \forall CPP_j \in G \ then \ CPP_i \cap CPP_j = \Phi\}$$

Else

$$CPP = \{CPP_i \mid CPP_i \subset G \wedge length(CPP_i) < PL \wedge \forall CPP_j \in G \ then \ CPP_i \cap CPP_j = \Phi\}$$

End If

End

The proposed approach considers two scenarios of generating crops plantation plans. The first one generates the candidate plantation plans given a crop as a main crop that should appear in each generated plantation plan. The second scenario considers all candidate plantation plans that are ranked with their overall suitability. These scenarios are presented in the following subsections.

3.4.1 First Scenario: Specifying a Main Crop

In this scenario, a main strategic crop is specified that must be included in each resulted plantation plan for the specified area. The proposed approach considers all candidate plantation periods for such crop. It takes each of suitable plantation periods for the specified strategic crop and search for the suitable plantation periods for the other crops until finding all alternative plantation plans. Consequently, a set of candidate plantation plans including such a crop is obtained. For example, assuming that the specified main crop is C_i, then this scenario starts determining all candidate plantation periods for crop C_i. After that, it finds all plantation plans including any of candidate plantation periods for crop C_i with the constraint that the overall plan period is less than or equal to the period under planning. The average suitability degree is computed for each plan indicating how much each plan is efficient assuming that the average suitability represents the other face of crops average productivity.

3.4.2 Second Scenario: Find Each Candidate Plantation Plan with an Overall Suitability Greater than a Specified Threshold

This scenario concentrates on the overall suitability degree for the generated plantation plans. There is no restriction on the crops set included in each generated candidate plan. The average suitability of the resulted plantation plans must be more than or equal to a predefined threshold value. The overall suitability of each plan represents an important factor on the expected yielding which represents a measure of the plan profitability. Accordingly, the set of results plantation plans includes all combinations of crops suitable plantation periods that have average suitability greater than or equal a specified threshold value. In fact such scenario helps discovering unusual crops for planting in the area under planning that may have higher outcomes compared with traditional ones.

4. An Illustrative Case Study

This case study illustrates an example of generating a set of plantation plans for a set of candidate crops at Alexandria governorate in Egypt respecting the climate change and the crops suitable plantation requirements. The historical agro-climatic data are considered for the last five years from 2012 to 2016 for Alexandria. Such data includes temperature, humidity and sunshining, the most impacting climatic variable on planting the crops under study. Algorithm 1 is used to predict the values of such climatic variables at the next year, 2017. As stated in the algorithm, the most recent year the more impacting on the prediction process and vice versa. The climatic requirements of the specified crops presented in[17-18] are set using the trapezoidal membership function due to its flexibility to represent such requirements. Figure 5 shows the representation of the suitable temperature for maize crop. It is obvious that the ideal temperature degree for planting maize crop is from 27 to 35°C. Such suitability decreases gradually as the temperature decreases from 27°C or increases over 35°C.

On the other hand, the suitability of humidity and sunshining climate variables for planting maize crop is shown in Figure 6–7 respectively. Accordingly, a humidity less than or equal to 30% is very ideal. In contrary, as the humidity increases over 30% the suitability of planting maize decreases gradually. Also, the ideal suitable sunshining hours for planting maize are from 12 to 14 hours. In the same way, the climate requirements of the candidate crops are set and stored in the crops requirements database.

In consequence, the process of finding and evaluating the suitable periods for planting each crop in the set of candidate crops takes place. This process searches for each suitable series of days to plant each crop. As a result, each crop has a set of candidate suitable periods for its plantation process respecting both of its requirements and life time.

Each suitable period is associated with a suitability degree stating how much it satisfies the requirements of

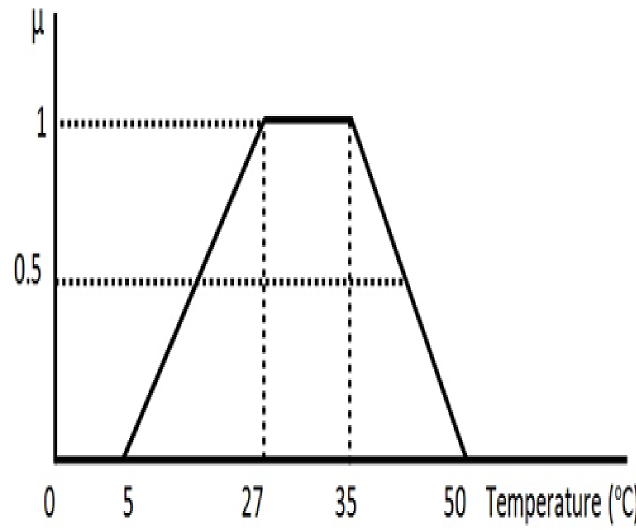

Figure 5. Temperature suitability for maize crop.

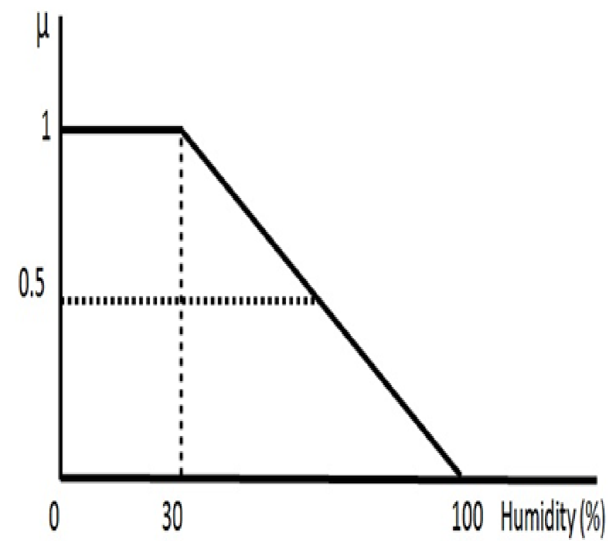

Figure 6. Humidity suitability for maize crop.

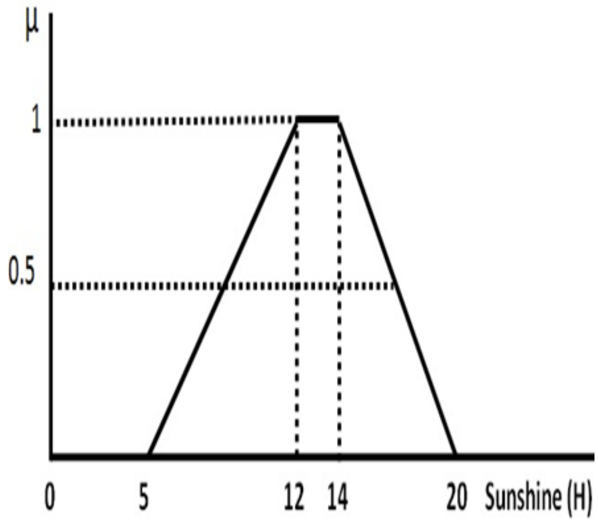

Figure 7. Sunshining suitability for maize crop.

the crop plantation process. The suitability degree of each period represents the average of the weighted suitability of days of the period using (2). The most suitable plantation periods in the result set for the candidate crops are presented in Table 1 as shown, some crops have just one suitable period and some others have many suitable periods. Also, there are some overlapping cases between different crops suitable plantation periods. According to the resulted set of most suitable plantation periods for each crop, the generation of plantation plans takes place as follows:

4.1 First Scenario: Specifying a Main Crop

In this case study, the wheat crop are selected as a main crop. The resulted plantation plans are as presented in Table 2. Figure 8 shows the plantation sequence of plan 2.

Table 1. A set of most suitable candidate plantation periods for the crops under planning

Crop Id	Crop Name Life Time	Period Id	Start Date	Start Date (365)	Suitability (%)
C1	Wheat 160	1	1 Jan.	1	92.37
		2	22 Jan.	22	95.33
		3	12 Feb.	43	96.21
		4	24 Dec.	341	90.56
C2	Potatoes 90	1	15 Sep.	258	82.2
		2	15 Oct.	288	85.2
		3	1 Nov.	305	84.8
C3	Squash 100	1	10 Jan.	10	83.19
		2	14 Feb.	45	86.16
		3	19 Oct.	292	85.5
		4	1 Nov.	305	83.08
C4	Maize 120	1	16 Jun	16	94.5
		2	15 May	135	90.11
		3	24 Mar.	83	80.22
C5	Bean 90	1	5 Mar.	64	95.4
		2	26 Mar.	81	90.1
		3	1 Oct.	274	96.19
		4	22 Oct.	295	96.79
		5	12 Nov.	316	91.38
C6	Soy 110	1	12 Feb.	43	92.125
		2	5 Mar.	64	95.4
		3	1 Oct.	274	96.185
		4	22 Oct.	295	96.79
C7	Turnip 45	1	27 Oct.	300	84

As shown in the results, all plantation plans include wheat as a main crop. These plans represent alternatives that can be adopted by famers with respect to each plan suitability degree. Accordingly, it helps finding the more suitable plantation plan in a given area that includes the specified main crop.

Table 2. A set of resulted plantation plans respecting wheat as a main crop

Plan Id	Consequent Crops in the Plan	Plan Suitability (%)	Duration (Days)
Plan 1	Wheat[1 – 161] => Maize[165-285] => Bean[295-20]	93.09	384
Plan 2	Wheat[341 – 136] => Maize[137-257] => Bean[274-364]	92.32	388
Plan 3	Wheat[341 – 136] => Maize[145-265] => Bean[274-364]	92.29	388
Plan 4	Wheat[1 – 161] => Maize[165-285] => Squash[292-27]	89.33	391
Plan 5	Wheat[1 – 161] => Maize[165-285] => Potatoes[288-13]	89.23	377
Plan 6	Wheat[1 – 161] => Maize[165-285] => Potatoes[305-30]	89.09	394
Plan 7	Wheat[1 – 161] => Maize[165-285] => Turnip[300-345]	88.83	344
Plan 8	Wheat[1 – 161] => Maize[165-285] => Squash[305-40]	88.52	404
Plan 9	Wheat[341 – 136]=>Maize[137-257]=>Potatoes[258-348]	87.66	372
Plan 10	Wheat[341 – 136] => Maize[145-265] => Turnip[280-325]	87.56	349

Table 3. A set of resulted candidate plantation plans with intermediate period ≤ 18 days

Plan Id	Consequent Crops in the Plan	Plan Suitability (%)	Duration (Days)
Plan 1	Maize[20 – 140] => Maize[145 – 265] => Bean[274 – 364]	93.6	344
Plan 2	Wheat[1 – 161] => Maize[165 – 285] => Bean[295 – 20]	93.09	384
Plan 3	Wheat[341 – 136] => Maize[137 – 257] => Bean[274 – 364]	92.32	388
Plan 4	Bean[316 – 41] => Soy[43 – 153] => Maize[165 – 285]	91.21	334
Plan 5	Bean[64 – 154] => Maize[165 – 285] => Turnip[300 – 345]	89.84	281
Plan 6	Bean[74 – 164] => Maize[165 – 285] => Turnip[300 – 345]	89.84	281
Plan 7	Wheat[1 – 161] => Maize[165 – 285] => Squash[292 – 27]	89.33	391
Plan 8	Squash[292 – 27] => Soy[43 – 153] => Maize[165 – 285]	89.25	358
Plan 9	Potatoes[258 – 348] => Bean[74 – 164] => Maize[165 – 285]	89.24	318
Plan 10	Wheat[1 – 161] => Maize[165 – 285] => Potatoes[288 – 13]	89.23	377
Plan 11	Potatoes[288 – 13] => Soy[43 – 153] => Maize[165 – 285]	89.15	338
Plan 12	Potatoes[305 – 30] => Soy[43 – 153] => Maize[165 – 285]	89.01	345
Plan 13	Maize[20 – 140] => Maize[145 – 265] => Turnip[280 – 325]	88.87	305
Plan 14	Wheat[1 – 161] => Maize[165 – 285] => Turnip[300 – 345]	88.83	344
Plan 15	Soy[43 – 153] => Maize[165 – 285] => Turnip[300 – 345]	88.75	302
Plan 16	Squash[305 – 40] => Soy[43 – 153] => Maize[165 – 285]	88.44	345
Plan 17	Wheat[341 – 136] => Maize[137 – 257] => Potatoes[258 – 348]	87.66	372
Plan 18	Wheat[341 – 136] => Maize[145 – 265] => Turnip[280 – 325]	87.5	349

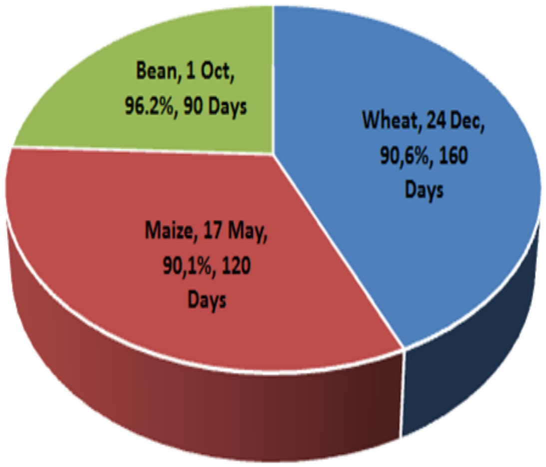

Figure 8. A chart representing plan 2 with an average suitability 92.32% resulted in the first scenario.

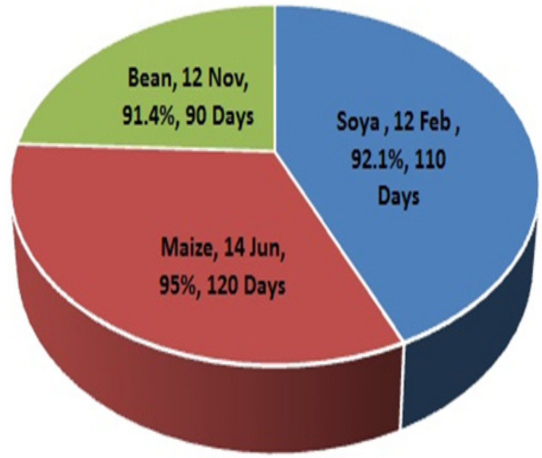

Figure 9. A chart representing plan 4 with an average suitability 92.8% resulted in the second scienario.

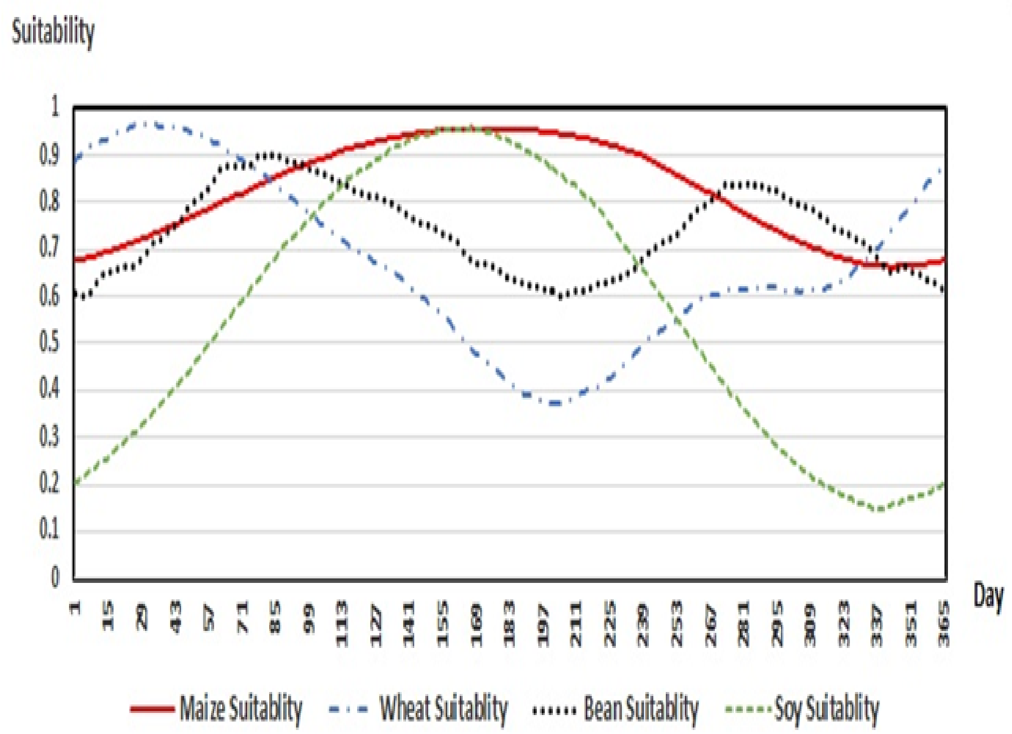

Figure 10. Days suitability for the candidate crops Maize, Wheat, Bean and Soya.

4.2 Second Scenario: Find Each Candidate Plantation Plan with an Overall Suitability Greater than a Specified Threshold

Table 3 shows a set of candidate plantation plans with an overall suitability greater than 87.59 and an intermediate period less than 18 days. On the other hand, Figure 9 shows the sequence of planting these crops as represented in plan 4 while Figure 10 shows the days suitability for the candidate crops maize, wheat, bean and soy. In this scenario, the overall suitability degree can be used to select a plantation plan as such suitability degree indicates the degree of productivity of yielding of the plan crops. Accordingly, such set of plantation plan includes all combinations of disjoint crops suitable plantation periods that have an overall suitability greater than the specified threshold value. Such alternative plantation plans make it easy for farmers to select the more suitable plantation plan respecting the climate change and the suitability measure for each plan.

5. Discussion

The results of the illustrated case study show the added value of the proposed approach against previous ones. It gives a set of alternative plantation plans for farmers to choose the more suitable one of them respecting the ongoing change in climate. Hence, it helps protecting the plantation process from catastrophic damage resulted from changes in climate. The proposed approach allows specifying a major crop that should be included in the resulted plantation plans. On the other hand, it allows obtaining all valid plantation plans with suitability greater than a given threshold value. Also, the proposed approach enables the user to set a maximum value of the intermediate period between each two consecutive crops in the resulted plans. Table 4 shows a comparison between the proposed approach presented in this work and some other related ones.

6. Conclusion

Generally, agriculture represents one of the most effected aspects in our life of changes in climate. As a result, the plantation process for many crops needs to be adjusted respecting both time and location in order to cope with such changes in climate. This work presents a fuzzy-based approach for planning crops plantation with respect to the ongoing changes in climate. Such approach aims to give a more suitable plantation plans aiming to increase the yielding of crops plantation. Also, it helps in avoiding catastrophic damage for crops plantation by determining the most suitable periods for planting each candidate crop. The proposed approach benefits from the flexibility of fuzzy set theory to define the suitable climate requirements for each candidate crop. Consequently, the more suitable periods for each crop in the incoming year are determined. After that, a set of plantation plans respecting the set of candidate plans are generated in two scenarios. In the first scenario, a main crop is selected representing an essential crop. So, any resulted candidate plan should include it. On the other hand, the second scenario generates a set of plantation plans having an overall suitability degree greater than a predefined threshold.

Table 4. A comparison between the proposed approach and a set of other previous related approaches concerning enhancing crops plantation respecting climate changes

Related Work	Inputs	Outputs
Consideration of Climate Conditions in Reservoir Operation Using Fuzzy Inference System (FIS)[1]	The climate variables that affect the availability of water	A cropping schedule bytaking into account the effects of different climate conditions on water availability
A Crop Model and Fuzzy Rule Based Approach for Optimizing Maize Planting Dates in Burkina Faso,West Africa[6]	The average values of climatic data and the climatic requirements of the maize crop	The more suitable plantation date for maize crop
Crop Yield Forecasting by Adaptive Neuro-Fuzzy Inference System [8]	Historical weekly climatic and yield data	A prediction of rice yielding
Fuzzy query approach for crops planting dates adaptation with climate changes[13]	Climatic variable values and crops climatic requirements	A set of candidate plantation periods for the specified location and crop
Fuzzy based approach for discovering crops plantation knowledge from huge agro-climatic data respecting climate changes[15]	Climatic data and the requirements from water and climatic variables	A set of suitable plantation periods for the specified crop with a follow-up of water requirements and a list of predicted diseases that can harm the crop in each plantation period
The proposed approach	Climatic historical data of a given area and the climatic requirements of the crops under planning	A ranked set of crops plantation plans associated with a suitability degree. Such plans may include a strategic crop if required.

Commonly, each resulted candidate plantation plan is associated with an overall suitability degree. Also the intermediate periods between each two consequent plantation process is considered to be less than or equal a specified threshold. Such suitability degree indicates how much each plantation plan is suitable in the specified area. Also, such suitability can be used as productivity or yielding measure assuming that all other requirements of plantation such as soil requirements and water are satisfied. Accordingly, this work gives an overall suitability measure for the plantation year life cycle for all available candidate plantation plans. Thus, a farmer becomes able to select the plantation plan that satisfies his/her needs.

7. References

1. Humid RO, Mohammad AA, Mohammad AH. Consideration of Climate Conditions in Reservoir Operation Using Fuzzy Inference System (FIS). British Journal of Environment & Climate Change. 2013; 3(3): 444-63. Crossref
2. Zane L. Fuzzy sets. Information and Control. 1995; 8:338-53.
3. Salam MA, Mahmood MA, Awad YM, Hazman M, Bendary EN, Hassanien AE, Tolba MF, Saleh SM. Climate Recommender System for Wheat Cultivation in North Egyptian Sinai Peninsula. Proceedings of the Fifth International Conference on Innovations in Bio-Inspired Computing and Applications IBICA. 2014; p. 121-30. Crossref.
4. Branco A, Evsukoff A, Ebecken N. Generating fuzzy queries from weighted fuzzy classifier rules. ICDM workshop on Computational Intelligence in Data Mining. 2005; p. 21-8.
5. Defang NJ, Manu I, Bime MJ, Tabi O, Defangn HF. Impact of climate change on crop production and development of Muyuka subdivision - Cameroon. International Journal of Agriculture, Forestry and Fisheries. 2014; 2(2):40-5.
6. Moussa W, Patrick L, Seydou B. A Crop Model and Fuzzy Rule Based Approach for Optimizing Maize Planting Dates in Burkina Faso, West Africa. Journal of Applied Meteorology and Climatology. 2017; 53:598-613.
7. Mohaddes SA, Mohayidin MG. Application of the Fuzzy Approach for Agricultural Production Planning in a Watershed, a Case Study of the Atrak Watershed, Iran. American-Eurasian Journal of Agricultural & Environmental Sciences. 2008; 3(4):636-48.
8. Kumar P. Crop Yield Forecasting by Adaptive Neuro Fuzzy Inference System. Mathematical Theory and Modeling. 2011; 1(3):1-8.
9. Hartati S, Sitanggang IS. A Fuzzy Based Decision Support System for Evaluating Land Suitability & Selecting Crops. Journal of Computer Science. 2010; 6(4):417-24. Crossref.
10. Rajeshwar GJ, Bhalchandra P, Khmaitkar SD. Predicting Suitability of Crop by Developing Fuzzy Decision Support System. International Journal of Emerging Technology and Advanced Engineering. 2013; 3(2):1-9.
11. El-Boraie G, El-Raman A. Optimizing water use efficiency of wheat under South Sinai condition (Wadi Sudr). Journal of Agricultural Science Mansoura University. 2009; 34(12):11477-88.
12. Gadallah AM, Mohamed AM, Hefny HA. Fuzzy Query Approach for Crops Planting Dates Optimization Based on Climate Data. International Conference on Advanced Machine Learning Technologies and Applications. 2014; p. 436-45. Crossref.
13. Mohammed AH, Gadallah AM, Hefny HA. Fuzzy query approach for crops planting dates adaptation with climate changes. 9th International Conference on Informatics and Systems. 2014; p. 52-60.Crossref.
14. Gadallah AM, Mohammed AH. Fuzzy-based approach for reducing the impacts of climate changes on agricultural crops. Handbook of research on machine learning innovations and trends. IGI Global. 2017; p. 272-94. Crossref.
15. Fuzzy based approach for discovering crops plantation knowledge from huge agro-climatic data respecting climate changes. Available from: https://www.springerprofessional.de/en/fuzzy-based-approach-for-discovering-crops-plantation-knowledge-/15583660. Date accessed: 02/04/2018.
16. Yadav S. Climatic conditions for growing wheat. Important India. Avialable from: https://www.importantindia.com/12612/climatic-conditions-for-growing-wheat/. Date accessed: 02/04/2018.
17. Kenanaonline: Wheat plantation-suitable climate. Available from: http://kenanaonline.net/page/1966. Date accessed: 14/10/2017.
18. Central Administration for Agricultural Extension. Available from: https://caae-eg.com/index.php/2012-12-25-10-49-19.html. Date accessed: 27/03/2014.