Evaluating Land Suitability using Fuzzy Logic Method

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Abstract

A system for evaluating land suitability using fuzzy logic method has been developed. The system determining a degree of delimitation, land ratings, suitability classes, and their actual land suitability subclasses of given land characteristics. The main parts of the evaluation process, which included in the fuzzy inference engine of the knowledge based system, are fuzzification and defuzzification. They are discussed partly in this paper to show how the system works.

The results of shows that the system can evaluate the land suitability for different types of crops of given land characteristics or vise versa. The evaluated rating indicates the degree of suitability for crops to be cultivated on a given land area with the existing conditions.

Keywords : *Knowledge-Based System, Land Evaluation, Fuzzy*

1 Introduction

Land evaluation is a process for predicting land suitability class of a given area. It is very important for agriculture, especially in determining which crops are appropriate for a given area, or alternatively, given crops, what types of soil is appropriate to plant in. Land evaluation can be automated using a computer system, a fuzzy knowledge based system, which emulate the decision-making process of an agriculture expert.

There are several knowledge-based system have been developed for land suitability evaluation. For example, EXGIS is a system integrating expert system shell designed for manipulating knowledge on land use suitability for agricultural purposes with GIS, a commercial computer package from ARC/INFO (Yialouris *et al.*, 1997). It is a rule-based expert system for land and climate suitability evaluation in southern part of Greece. Five crops are considered maize, olive, tomato, wheat, and grape. Another example is ALES (Rossiter & Armand, 1997, a computer program for land evaluation, both physically and economically, following the method of Food and Agriculture Organization (FAO). This research focuses on developing a fuzzy knowledge-based system for physical land suitability for food crops.

2 Architecture of the knowledge based system

The structure of the knowledge based system for land suitability evaluation consists of two major parts: the development environment and the consultation environment such as shown in Figure 1.

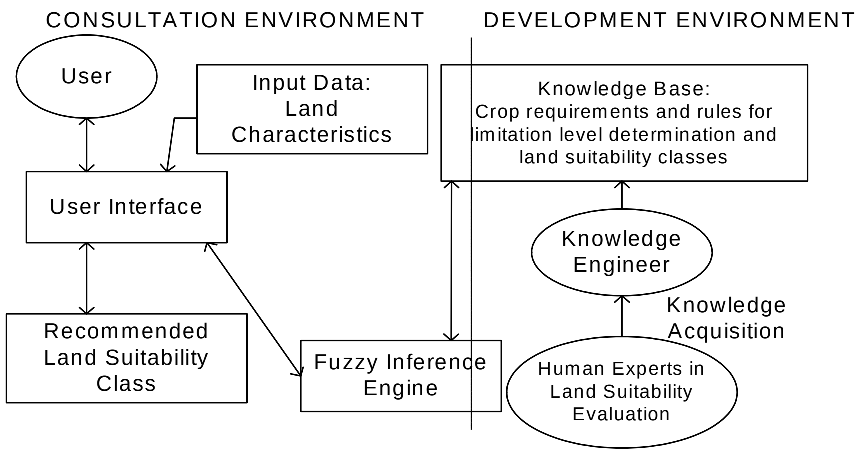

Figure 1. The structure of the knowledge based system for land suitability evaluation

The knowledge of this system is about the requirements for different types of crops (food, horticultural, industrial or estate, and spicy crops) and is taken from Soil and Agro climate Research Center, Bogor. This knowledge has also been collected and well documented by researchers of Puslitbangnak (Center of Research Development for Animal Production) dan Puslitbanghort (Center of Research for Horticultural Development) (Djaenudin et al, 2000).

The land suitability classes are evaluated using the limitation method regarding number and intensity of limitations. The evaluation is carried out using fuzzy inference method. Under the limitation method, the land characteristics (or qualities) are compared with the requirements data for a specific crop. Then, the land classes are defined according to the number and the intensity of limitations. Limiting method suggests first evaluation of climatic limitations. Land suitability class determination on climatic limitation is based on the most severe one (Sys et al, 1991).

According to the FAO (Food and Agriculture Organization) framework there are two suitability orders: *Suitable* and *Not Suitable* and three suitability classes: *very suitable* (S1), *moderately suitable* (S2), and *marginally suitable* (S3). Table 1 shows the types of the limitation and their corresponding land characteristics. The knowledge representation technique used for this system is production rule. The knowledge is represented in the form of IF-THEN. There are two groups of IF-THEN rules, i.e. for determining the limitation level and for determining land suitability class. The premise part of the rule can be a fuzzy preposition or non-fuzzy preposition which is related to land characteristic group, while the conclusion part is related to limitation level.

3 Inference Engine

This component is essentially the brain of the knowledge based system that provides methodology for reasoning about information in the knowledge base and on the working memory for formulating conclusion. The reasoning mechanism takes place in the inference engine according to then facts received from the user interface.

Land suitability class is determined through a two-phase inference based on input data expressed as crisp value and fuzzy set. First, inference process is done to set the limitation level, and secondly it is done to determine the suitability class of the land. These two processes are depicted in Figure 2.

Table 1. Limitations and land characteristics being used.

Limitation	Land Characteristics
climate	average temperature, rainfall, air humidity
Landscape and soil Topography Wetness Physical soil Soil fertility Salinity and alkalinity	 slope flooding , drainage texture, coarse fragments, soil depth soil CEC (Land KTK), pH, bases saturation, C-Organic Salinity, alkalinity
Land preparation	surface rock, folded drown of rock

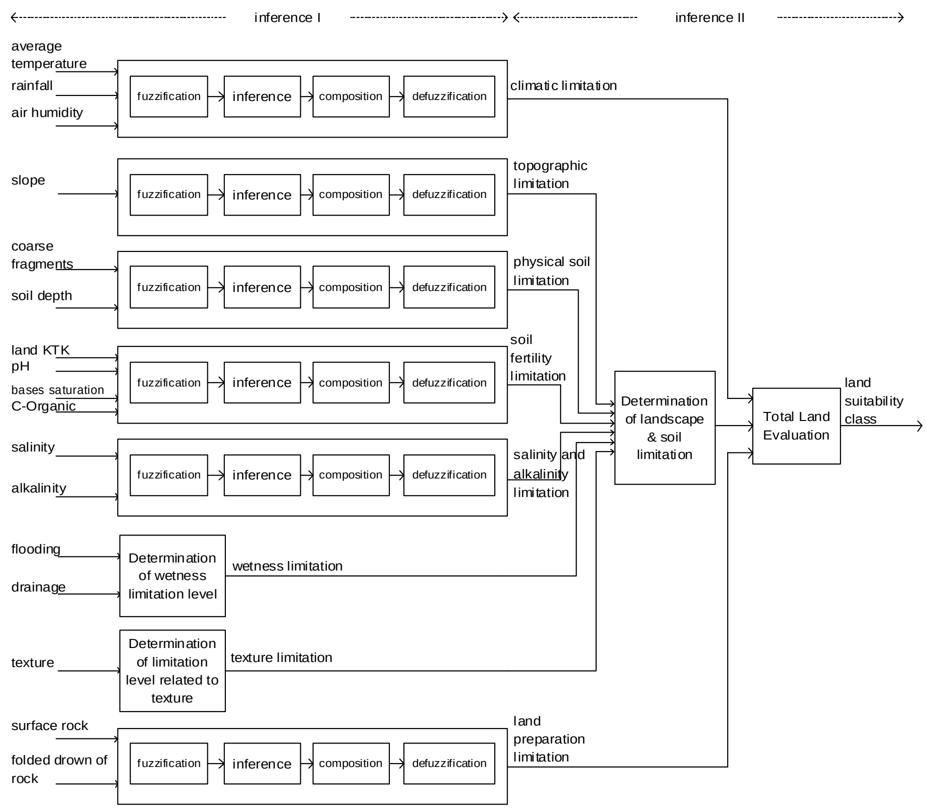

Figure 2. Inference process

3.1 Phase I Inference

In phase I inference, limitation level is concluded from inputted values of land characteristics. For land characteristics expressed as linguistic variables, *i.e.* characteristics related to climate, topography, physical soil (except soil texture), soil fertility, salinity and alkalinity, and land preparation, limitation level is obtained from fuzzy inference. For illustration, a portion of the inference process to set these limitation levels based on input of crisp values, associated with climate, is illustrated in Figure 3.

Based on fuzzy inference, there are four phases in limitation level setting from crisp value input, namely fuzzification, inference, composition, and defuzzification. Inference method adopted in the present research is *min*, while *max* is used for the composition. Combination of the two is known as *max-min* inference. This method is widely used in inference engine using fuzzy system due to its easiness in computation (Wang, 1997). Defuzzification method used in the study is center average defuzzifier. It is easier to implement compared to the other two, center gravity and maximum defuzzifier.

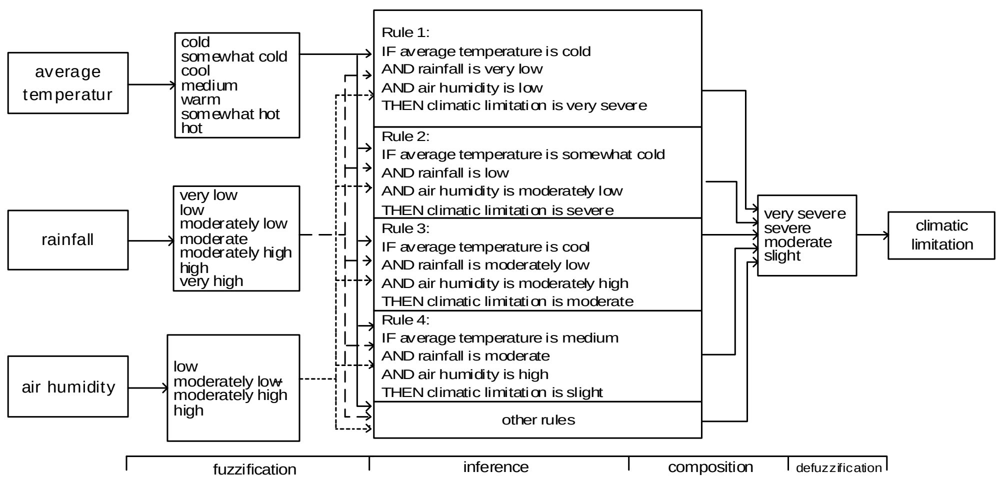

Figure 3. Determination of limitation associated with climate.

3.2 Fuzzification

Group membership function of each land characteristics takes trapezium shape, determined based on overlapping interval of plant requirement data. The general form of membership function is depicted in Figure 4, its equation is not shown here.

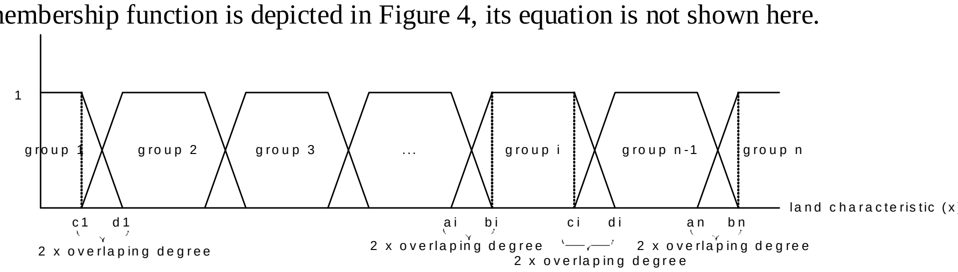

Figure 4. General form of land characteristic membership function.

The membership function of groups of average temperature for asparagus is depicted in Fig. 5, and defined completely (Sitanggang, 2002). This shows that average temperature value is within *medium* group with membership level of 1 if the value lies within (18.5, 24.5] interval. This interval is obtained by narrowing the requirement interval of average temperature for the medium group, i.e. [18, 25].

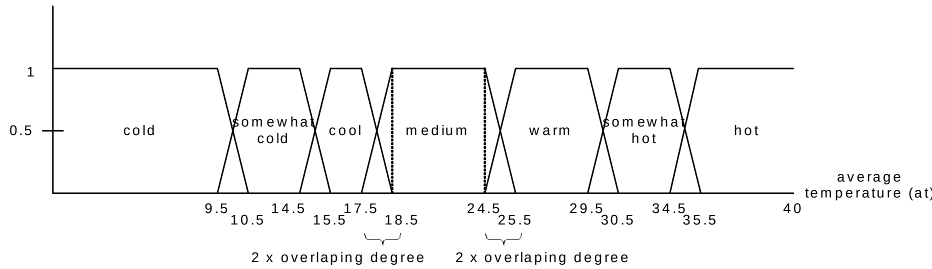

Figure 5. Membership function of groups of average temperature for asparagus.

The membership functions for the other land characteristics is similarly determined as it is done for average temperature, and they can be seen in (Sitanggang, 2002). The membership function for limitation level determined from limitation rating *r* with overlap 5 is shown in Figure 6. All equations defining the membership function for the land characteristics are not shown here, but are written in (Sitanggang, 2002).

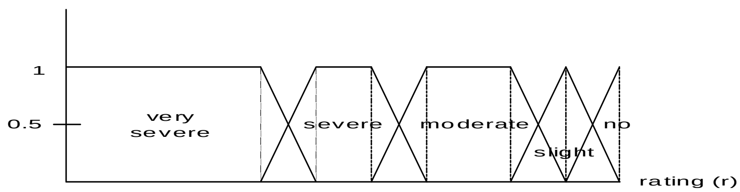

Figure 6. Membership function for group of limitation level.

As an illustration of the fuzzification process, an example of data input of land characteristics related to the climate is

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- Average temperature    : 29.75 °C
- Rainfall               : 1996 mm
- Air humidity           : 40 %
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From group membership function of average temperature, rainfall, and air humidity, the membership value of input data in each group can be computed. The membership value of average temperature data input is in *warm* and *somewhat hot* areas. Similarly, membership value for rainfall data input is in the areas of *medium* and *moderately high*. The membership value for air humidity data input is *high* area. These membership values are as follows:

Average temperature (*at*): $\mu_{warm}(29.75) = 0.75$, $\mu_{somewhat\_hot}(29.75) = 0.25$.

Rainfall (*rf*): $\mu_{moderate}(1996) = 0.6$, $\mu_{moderately\_high}(1996) = 0.4$.

Air humidity (*ah*): $\mu_{moderately\_high}(40) = 1$.

Using rules for setting climatic limitation level (Sitanggang, 2002), we come to the following rules:

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Rule 1: IF at is warm AND rf is moderate AND ah is moderately high
  THEN climatic limitation is moderate
Rule 2: IF at is warm AND rf is moderately high
  AND ah is moderately high THEN climatic limitation is moderate
Rule 3: IF at is somewhat hot AND rf is moderate
  AND ah is moderately high THEN climatic limitation is severe
Rule 4: IF at is somewhat hot AND rf is moderately high
  AND ah is moderately high THEN climatic limitation is severe
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By applying min operator to the above rules, the truth values of the premises are obtained as depicted in Figure 7.

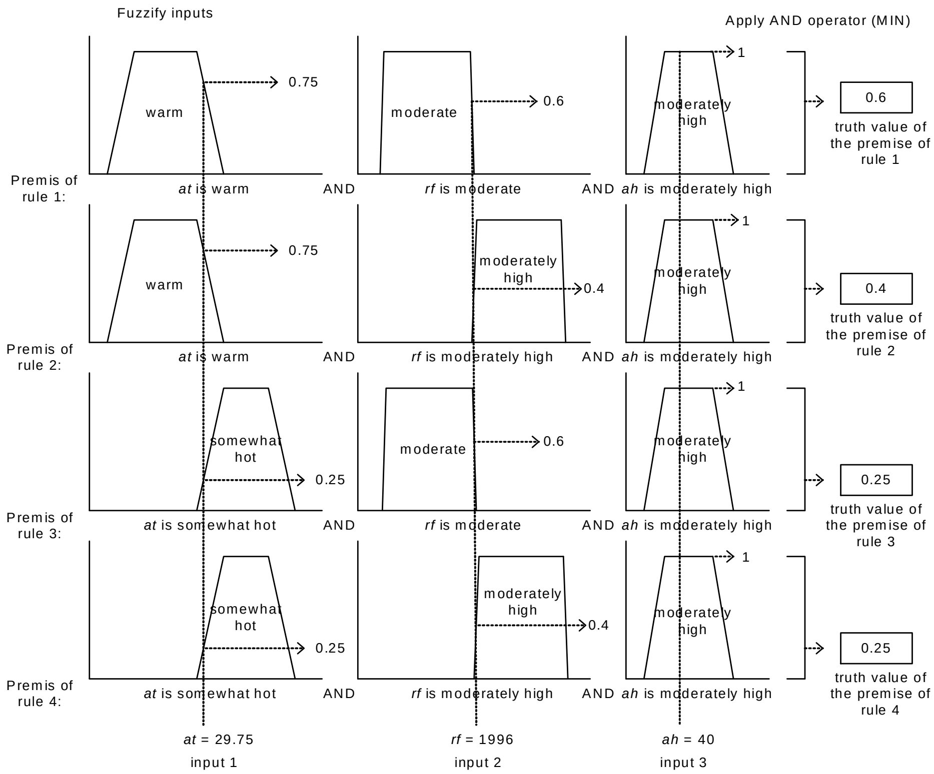


Figure 7. Fuzzification process of crisp input data.

3.3 *Min* Inference

The membership function of the limitation level is derived from the generated rules, truncated at the height corresponding to the computed truth premise value using the respective rule such as shown Fig. 8.

3.4 *Max* Composition

The climatic limitation rating crisp data.is obtained using *max* composition method, which is composited from maximum points of all fuzzy sets generated from the results of min inference such as shown in Fig. 8. The membership function produced from composition process is as follows:

$$\mu_{\text{Output}}(r) = \begin{cases} \dfrac{r-35}{10}, & 35 < r \le 37.5 \\ 0.25, & 37.5 < r \le 57.5 \\ \dfrac{r-55}{10}, & 57.5 < r \le 61 \\ 0.6, & 61 < r \le 84 \\ \dfrac{90-r}{10}, & 84 < r \le 90 \\ 0, & \text{otherwise} \end{cases}$$

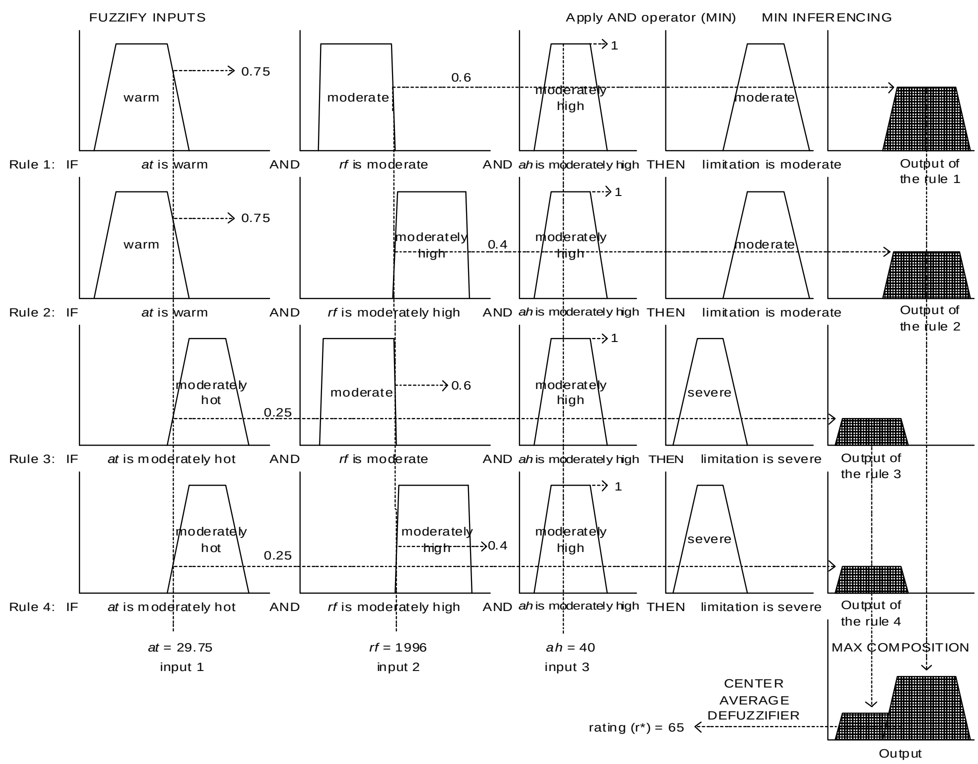


Figure 8. Inference process for determining climatic limitation rating crisp data.

3.5 Defuzzification

Fuzzy sets produced from composition process are converted into crisp form through center average defuzzifier method. Center of fuzzy sets of rule 1, 2, 3, and rule 4 outputs (Figure 8) respectively are $\bar{r}^1 = 72.5$, $\bar{r}^2 = 72.5$, $\bar{r}^3 = 50$, $\bar{r}^4 = 50$, with height $w_1 = 0.6$, $w_2 = 0.4$, $w_3 = 0.25$, $w_4 = 0.25$. Center average defuzzifier method computed limitation rating related to the climate (r^*) as follows:

$$r^* = \frac{72.5\times 0.6 + 72.5\times 0.4 + 50\times 0.25 + 50\times 0.25}{0.6 + 0.4 + 0.25 + 0.25} = 65.$$

From limitation level membership function we obtain $r^* = 65$, belonging to *medium* group with membership level $\mu_{medium}(r^*) = 1$.

Rating of limitation related to topography, physical soil (except soil texture), soil fertility, salinity and alkalinity, and land preparation can be obtained in the same way as it is shown for the climate

4 Results

The fuzzy system outputs rating and level of limitation, land suitability class and its actual sub-class according to the land characteristics given by the user. The input data can be expressed either in crisp values or in fuzzy sets. As an example, given a set of crisp input data such as shown in Fig.9, the system results in the total land evaluation is

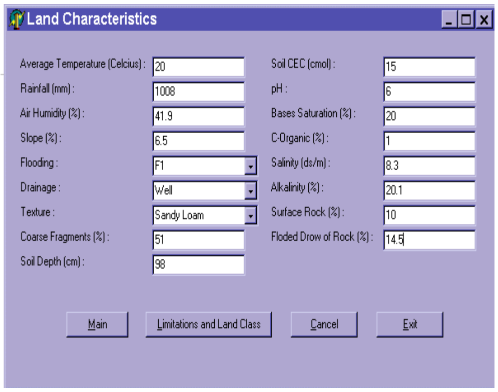


Figure 9 Example of crisp input data

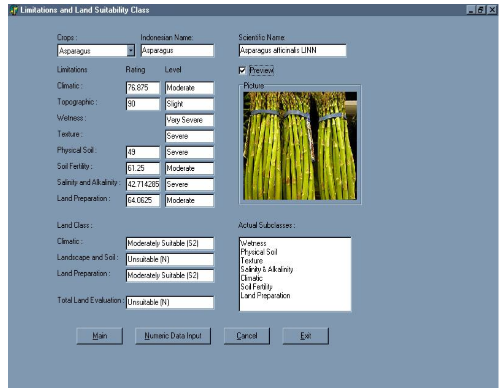
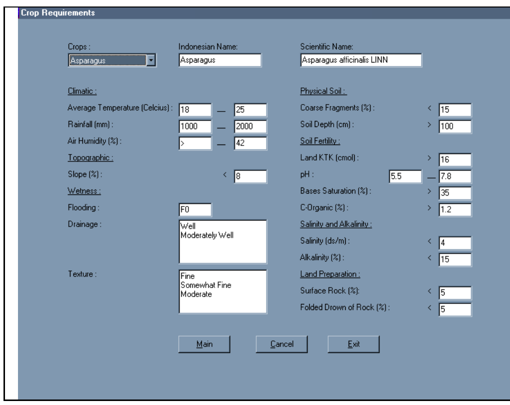


Figure 10 Example of output



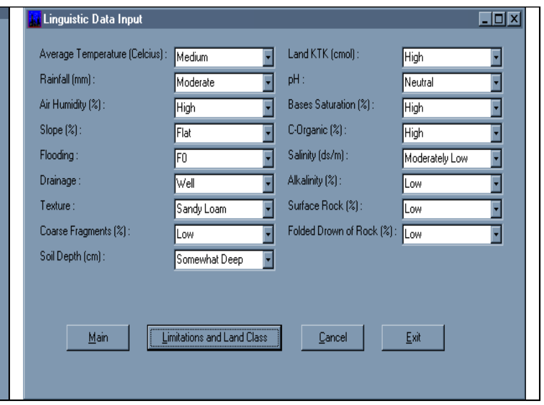


Figure 11 Crop requirements

Figure 12 Example of fuzzy input data

Table 4. Land suitability class associated with climate, landscape, soil for crisp input data

Climatic Class	Crops	Landscape and soil Class	Crops
S1	--	S1	--
S2	Asparagus, Aster, Star Fruit, Gladiolus, Corn, Citrus, Peanut, Soybean, Cananga, Quinine, Klengkeng Fruit, Mango, Rose, Pineapple, Bitter Melon, Papaya, Tuberosa, Strawberry, Tobacco, Sweet Potato	S2	--
S3	Spinach, Bean, Durian Fruit, Mung Bean, Long Bean, Cinnamon, Radish, Water Melon, Cucumber, Banana, Cantaloupe, Egg Plant, Tomato, Carrot	S3	Broccoli, Corn, Cotton, Cinnamon, Soybean, Cabbage, Pepper, *Gnetum gnemon*, Water Melon, Cucumber, Nutmeg, Bitter Melon, Cantaloupe, Egg Plant, Tomato, Sweet Potato
N	Apple, Broccoli, Cotton, Cabbage, Pepper, *Gnetum gnemon*, Nutmeg, Petsai, Leaf mustard, Lettuce, Tea.	N	Apple, Asparagus, Aster, Spinach, Star Fruit, Bean, Durian Fruit, Gladiolus, Citrus, Mung Bean, Long Bean, Peanut, Cananga, Quinine, Klengkeng Fruit, Radish, Mango, Rose, Pineapple, Papaya, Petsai, Banana, Leaf mustard, Tuberosa, Lettuce, Strawberry, Tea, Tobacco, Carrot

Not Suitable (N) for crop of asparagus such as depicted in Fig.10. It is *marginally suitable* (S3) for corn, cinnamon, soybean, water melon, cucumber, bitter melon, cantaloupe, egg plant, tomato, and sweet potato such as shown in Table 4. Table 4 indicates the land suitability class for each crop related to climate as well as landscape and soil. The system is also capable of showing requirements of a given crop. Figure 11 shows the asparagus crop's requirements are given by the system. Another example is shown in Figure 12, the set of fuzzy input data results in the total land evaluation is *moderately suitable* (S2) for crop of asparagus.

5 Remarks

The developed system has been evaluated by the experts from Faculty of Agriculture both Gadjah Mada University and Soil and Agro climate Research Center Bogor, the result shows that it is capable of determining the land suitability class given the characteristics of the land, therefore, it can determine the appropriate crops to be cultivated. In addition, the system is also capable of determining the appropriate land characteristic for a given types of crops.

Fuzzy inference method can represent and manipulate agriculture knowledge that is incomplete or vague and can be used to determine land limitation rating. The rating value is used to determine limitation level of the land. At the similar limitation level for different types of crops, the rating value is used to determine what the most suitable crops to cultivate for the existing condition of the land. The greater the rating value the more suitable crop for land of interest.

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