Fuzzy logic approach in prioritization of crop growing parameters in protected farms: a case in North East India

Amaresh Sarkar*, Mrinmoy Majumder

(*Department of Civil Engineering, National Institute of Technology, Agartala, PIN-799046, Tripura, India*)

Abstract: Global food demand is rising exponentially as the population is increasing. Protected farming is becoming increasingly popular among the farming communities for fast growing vine crops round the year. Consideration of crop growing parameters while designing and maintaining a protected farm is very important for optimal crop growth and profit. Many farmers does not consider all the crop growing parameters and does not know the importance of all factors in the optimal crop growth. In this paper, an attempt has been made to prioritize 12 crops growing parameters using fuzzy approach. 12 crop growing parameters were selected from the literature and scored by four different evaluation methods viz., food consumer importance, expert's importance, farmer importance and food dealer importance. The results revealed that the descending order of relative importance of the 12 crop factors are water quality, light intensity, nutrient availability, crop cultivar, substrate media, daylight length, moisture availability, crop spacing, temperature, air freshness, air circulation and relative humidity respectively. Priority for crop growing factors must be considered while designing and maintaining a protected farm for optimal crop growth and net return.

Keywords: greenhouse, crop factors, optimum crop yield, multi-criteria decision-making (MCDM)

Citation: Sarkar, A., and M. Majumder. 2017. Fuzzy logic approach in prioritization of crop growing parameters in protected farms: A case in North East India. Agricultural Engineering International: CIGR Journal, 19(1): 211–217.

1 Introduction

With the advent of civilization, open field agriculture is facing some major challenges, most importantly decrease in per capita land availability. Eco-friendly solutions to meet food needs are today's seriously concern which is one of the fastest growing sectors in the developing countries. It is a capital-intensive technology, which drastically increases yields and quality of fresh, nutritious food year round and has numerous advantages. Protected farms are a method of growing vine fruits and vegetable crops using mineral nutrient solutions specially designed growing media. This method can be implemented in places where the soil type is not ideal for the desired crop. In addition, the technique can be used in rooftop farming and, therefore, is very useful in areas with limited space such as urban areas (MIT, 2014). There are many factors affecting plant growth and net profit. The suitable high-value vine crops like tomato, cucumber, capsicum, lettuce, cut flowers, strawberry, eggplant, muskmelon etc are suitable for growing in protected farming. Optimal environment for different crop varieties is different (MAFES, 2015). Constructing individual structures for different crop varieties with different optimal environment will be expensive by the marginal and small farmer. Therefore, selecting nearly optimal multi-crops for growing in a single protected farm is highly desirable for the small and marginal grower. Growing food within cities, at the doorstep of the consumers eliminates the need of transportation and therefore reduces greenhouse gas emissions (AVF, 2013). Protected farming allows local crops to be produced year round. The major agricultural problems such as pesticides, pests, deforestation, and soil erosion would be nearly non-existent (Despommier, 2009). Under controlled environment, farming increase crop yields and decrease disease transmission (George, 2014). The crop yield

Received date: 2016-04-12 **Accepted date:** 2017-01-22

***Corresponding author: Amaresh Sarkar**, Department of Civil Engineering, National Institute of Technology, Agartala, PIN-799046, Tripura, India. Tel: 91-9436349675. Email: amaresh.sarkar@gmail.com.

under controlled environment agriculture much higher than the open field agriculture (Banerjee and Adenaeuer, 2014). The controlled environment farming have savings benefits in terms of growing time, nutrient requirements, land requirements and water requirements over open field farming (Meyers, 2010). Commercial protected farming are practicing by Go Green Agriculture in California, Good Life Farms in Indiana, USA (American Hydroponics, 2015). The crops like tomatoes, peppers, cucumbers, strawberries, herbs, watercress, chicory, lettuce are grown hydroponically in large-scale in Thanet Earth farm in Kent, Britain (Thanet Earth, 2015). Sky Greens vertical farm is over 100 mtall tower constructed in Singapore (CNN, 2012). Fast growing nearly all leafy greens are suitable to growing in a same growing environments (Jensen, 2012). An attempt has been made in this paper to prioritize crop growing factors using fuzzy logic approach.

Agricultural modeling and management are complex conceptual processes, where a large number of variables are taken into consideration and interact for system analysis and decision making. Most of the processes in the agricultural sector include the uncertainty, ambiguity, incomplete information and human intuition characteristics. These processes are not only constrained by their environment (e.g., market, climate, seasons, consumer choices), but they are also highly influenced by human factors (stakeholders' perceptions). Fuzzy sets are able to manage and represent uncertainty, andassure that the incomplete information is valued and provide solutions to issues which are crucial in agriculture like fertilization, land degradation, soil erosion and climate variability during planting material selection in physiological analysis. Fuzzy sets have gained constantly increasing research interest in the last 20 years and have found great applicability in the agricultural domain, helping farmers to take right decisions for their cultivated (Papageorgiou et al., 2016). Fuzzy based intelligent irrigation control system could recover water deficiency using wireless sensors. This system access the moisture level of soil and temperature of surrounding area with the help of wireless sensors controlling the sprinkler to irrigate the field within the requirement. To control the irrigation system efficiently, this system consists of soil moisture, temperature sensors, and an intelligent controller using fuzzy logic approach for irrigation (Khan et al., 2014). Fuzzy logic had however been studied since the 1920s, as infinite-valued logic-notably by Łukasiewicz and Tarski (Pelletier, 2000). Several sources have shown and proven that fuzzy systems are universal approximators (Kosko, 1994; Ying et al., 1999). Fuzzy logic has been employed to handle the concept of partial truth, where the truth value may range between completely true and completely false (Novák et al., 1999). Furthermore, hen linguistic variables are used, these degrees may be managed by specific (membership) functions (Ahlawat et al., 2014).

Applications of fuzzy logic in disease management for evaluate the severeness of the disease that had been identified using the symptoms and appearance (Yanget al. 2000; Van der Werf et al., 2013). Application of fuzzy logic in pest management (Dubey, 2013). Application of fuzzy logic in weed management (Yang et al., 2000). Application of fuzzy logic to study and analyze soil (MacMillan et al., 2000; Marks et al., 1995). Application of fuzzy logic in developing expert system for various crops (Prakash, 2003; Roussel et al., 2000; Kolhe, 2011; Hartati, 2010). Evaluation of Agricultural Land Suitability using Application of Fuzzy Indicators (Kurtener et al., 2008). Demonstration of fuzzy modeling of farmers' knowledge (FK) for agricultural land suitability classification using geographic information system (GIS) indicate usefulness of fuzzy modeling in FK-based classification of agricultural land suitability, which could provide useful information for optimum land-use planning (Sicat et al., 2005). Weighted average estimation of land suitability is obtained by composite fuzzy indicator (Burrough, 1989).

2 Methodology

The term fuzzy logic was introduced with the 1965 proposal of fuzzy set theory by Zadeh (1965). Fuzzy logic had however been studied since the 1920s, as infinite-valued logic-notably by Łukasiewicz and Tarski (Pelletier, 2000). Both degrees of truth and probabilities range between 0 and 1 and hence may seem similar at first, but fuzzy logic uses degrees of truth as a mathematical model of vagueness, while probability is a mathematical model of ignorance. Fuzzy logic has been employed to handle the concept of partial truth, where the truth value may range between completely true and completely false (Novák et al., 1999). Furthermore, when linguistic variables are used, these degrees may be managed by specific (membership) functions (Ahlawat et al., 2014).

The fuzzy logic approach is one important methods of MCDM. It provides scientific decision-making in domains where a selection of the best alternative is highly complex (Aruldoss et al., 2013). It combines tangible and intangible aspects to obtain the priorities associated with the alternatives of the problem (Calizaya et al., 2010). The fuzzy method is used when the goals or objectives and the constraints are not of equal importance to the decision-maker (O'Hagan, 2000). The fuzzy values of linguistic relative importance are in the lower and upper limit are 0 and 1 respectively. Fuzzy set is a class that admits the possibility of partial membership in it is called fuzzy set.

Let $X=\{x\}$ denotes a space of objects. Then a fuzzy set A in 'X' is a set of ordered pairs mathematically represented by the equation below Equation (1) and Equation (2). The grade of membership of x in set A ismathematically represented by Equation (3).

$$A=\{\chi,\mu_A(\chi)\} \tag{1}$$

$$\chi \in XA_m \tag{2}$$

$$\mu_A(\chi)\in[0,1] \tag{3}$$

where, $A=\begin{Bmatrix} 1, c \text{ is totally in } A \\ 0, \chi \in A \\ (1,0) \text{ if } x \text{ is partially in } A \end{Bmatrix}$, m represents number of members and $\mu_A(x)$ is the grade of membership of x in set A.

This set is always a continuum of possible choices. Data may be classified as crisp data and fuzzy data. Crisp data has no vagueness or impreciseness. Fuzzy data can be of two types, approximate values and linguistic values (Chaudhuri et al., 2011). Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms. Membership function represents the grade of membership associates with particular groups or a set by a member of that set or group. Determination of membership function in terms of shape and boundary has clear effect on the result of classification performed by fuzzy logic. In the established model, different membership function were formed for input variables. Using Equation (1) and Equation (3), the fuzzy logic different linguistic relative importance membership functions (out put variables) with respective abbreviations is shown Figure 1. Accordigly, the fuzzy logic different linguistic relative importance with respective fuzzy membership value (out put variables are shown in Table 3.

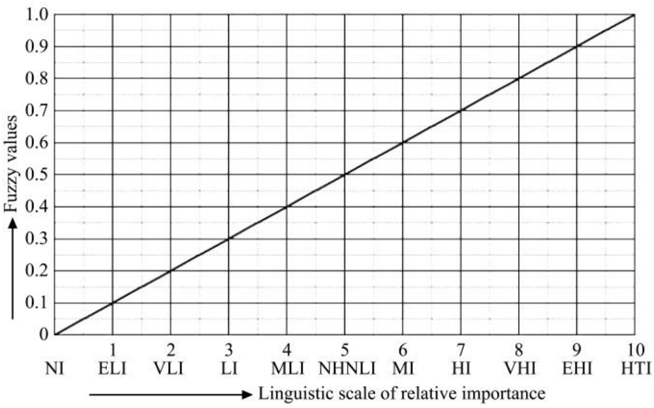

Figure 1 Saaty's fundamental scale of linguistic relative importance

Twelve crop growing parameters viz., air circulation, air freshness, crop cultivar, crop spacing, daylight length, light intensity, moisture availability, nutrient availability, relative humidity, substrate media, temperature, water quality were selected from the literature and scored by four different evaluation methods viz., food consumer importance, expert's importance, farmer importance and food dealer importance. Relative importance of the 12 crop growing factors were collected by four different evaluation methods through face to face questioning to 10consumer household heads, 10 agriculturist, 10 medium farmers and 10food dealers in Tripura state of North Eastern India. The relative importance of 12 crop factors was score by the above four different evaluation methods in a 0 to 10 point scale are shown in Table 1. The relative importance of the four different evaluation methods viz., food consumer importance, expert's importance, farmer importance and food dealer importance were scored as 4, 8, 6 and 2 respectively through a group discussion among five member agricultural professionals. The pairwise comparison matrix of four evaluation methods and their normalized values of importance were shown in Table 2. The graphical representation of scale of linguistic relative importance is shown Figure 1 which is created based on the Saaty's fundamental of relative importance (Saaty, 2008). Fuzzy values of different linguistic relative importances are shown in Table 3. The pairwise comparison matrix of fuzzy linguistic importance of four evaluation methods is shown in Table 4 and the pairwise comparison matrix of fuzzy linguistic values of four evaluation methods and their normalized values of importance is shown in Table 5.

Table 1 Summary of twelve crop factors scores by four different evaluation methods

Crop Criteria	Score of relative importance (0 to 10 point scale)			
	Food consumer importance	Expert's importance	Farmer importance	Food dealer importance
Air circulation	4	5	2.5	2.5
Air freshness	2.5	3.5	2	6.5
Crop cultivar	9.5	8.5	7	5.5
Crop spacing	1.5	4.5	4	2
Daylight length	6	6.5	5	4.5
Light intensity	8.5	5.5	7.5	9.5
Relative humidity	8	1.5	1	0.5
Nutrient availability	7	8	9	7
Moisture availability	3	4	6.5	8
Substrate media	5.5	7.5	8	6
Temperature	3.5	6	4.5	4
Water quality	7.5	9.5	9.5	8.5

Table 2 Pair wise comparisons matrix of four evaluation methods and their normalized values of importance

Methods of evaluation	Group discussion score	Local consumer importance	Expert's importance	Local farmer importance	Food dealer importance	Weightage of parameter	Normalized weightage
Local consumer importance	4	1.00	0.50	0.67	2.00	1.4287	0.2417
Expert's importance	8	2.00	1.00	1.33	4.00	1.6990	0.2875
Local farmer importance	6	1.50	0.75	1.00	3.00	1.5811	0.2675
Food dealer importance	2	0.50	0.25	0.33	1.00	1.2014	0.2033

Table 3 Fuzzy values of different linguistic relative importance

Different linguistic relative importance	Abbreviations	Fuzzy values
Highest important	HTI	1.0
Extremely high important	EHI	0.9
Very high important	VHI	0.8
High important	HI	0.7
Moderately important	MI	0.6
Neither high neither low important	NHNLI	0.5
Moderately low important	MLI	0.4
Low important	LI	0.3
Very low important	VLI	0.2
Extremely low important	ELI	0.1
Nil important	NI	0.0

Table 4 Pair wise comparisons matrix of fuzzy values of linguistic importance by the four different evaluation methods

Evaluation methods	Local consumer importance	Expert's importance	Local farmer importance	Food dealer importance
Local consumer importance	1.00	VLI	LI	VHI
Expert's importance	VHI	1.00	VHI	EHI
Local farmer importance	HI	VLI	1.00	VI
Food dealer importance	VLI	ELI	LI	1.00

Table 5 Pair wise comparisons matrix of fuzzy linguistic values of four evaluation methods and their normalized values of importance

Evaluation methods	Consumer importance	Expert's importance	Farmer importance	Food dealer importance	Weightage of parameter	Normalized weightage
Local consumer importance	1.00	0.2	0.3	0.8	1.2315	0.2466
Expert's importance	0.8	1.00	0.8	0.9	1.3678	0.2739
Local farmer importance	0.7	0.2	1.00	0.7	1.2698	0.2543
Food dealer importance	0.2	0.1	0.3	1.00	1.1247	0.2252

3 Results and discussion

The major challenges of successful protected farming venture are efficient design and monitoring crop growing parameters. A high degree of competence in plant science and engineering skills are required to work together for successfully maintaining of protected farms. The relative ranking of twelve crop factors by fuzzy methods is shown in Table 6. The results revealed that the descending order of relative importance of the twelve crop factors are water quality, light intensity, nutrient availability, crop cultivar, substrate media, daylight length, moisture availability, crop spacing, temperature, air freshness, air circulation and relative humidity respectively. Therefore, priority wise crop growing factors must be considered while designing and maintaining a protected farm for optimal crop growth and net return.

Table 6 Relative ranking of twelve crop factors generated by fuzzy approach

Criteria	Normalized importance of criteria					Normalized importance of Alternatives		Weighted value	Weighted, %	Weighted rank
	Consumer importance	Expert's importance	Farmer importance	Food dealer importance						
Air circulation	0.0491	0.0498	0.0491	0.0491				0.0493	4.9286	11
Air freshness	0.0503	0.0492	0.0486	0.0501				0.0495	4.9509	10
Crop cultivar	0.0501	0.0506	0.0505	0.0501				0.0503	5.0339	4
Crop spacing	0.0495	0.0502	0.0501	0.0497				0.0499	4.9891	8
Daylight length	0.0500	0.0504	0.0502	0.0501		0.2466		0.0502	5.0187	6
Light intensity	0.0511	0.0503	0.0507	0.0510	×	0.2739	=	0.0508	5.0780	2
Relative humidity	0.0485	0.0492	0.0488	0.0489		0.2543		0.0489	4.8863	12
Nutrient availability	0.0505	0.0505	0.0509	0.0504		0.2252		0.0506	5.0589	3
Moisture availability	0.0506	0.0494	0.0502	0.0504				0.0501	5.0147	7
Substrate media	0.0502	0.0502	0.0504	0.0499				0.0502	5.0190	5
Temperature	0.0496	0.0500	0.0497	0.0495				0.0497	4.9694	9
Water quality	0.0509	0.0508	0.0510	0.0506				0.0508	5.0817	1

The crop and variety selection are the first consideration in constructing a protected farm (Bareja, 2011). Most farmers deciding their crops to be grown are mainly based on its marketability (Bareja, 2011). Some farmers are using farm lot, which acquired through inheritance or by purchase. Right decision in the selection of crop growing factors is very important for a successful farming venture. Carbon dioxide and oxygen content in the air are maintained at 0.035% and 21%, respectively inside the structure for optimal crop growth and yield. Air temperatures above 35℃ are generally not suited for crop growth in green houses. Warm-season plants perform best grow at day temperature between 21℃ and 26.6℃ (Kessler et al., 2006). For most crops, the acceptable range of relative humidity is between 50% to 80%; however for plant propagation work, relative humidity up to 90% may be desirable (TANU, 2015). Green house crops are subjected to light intensities varying from 129.6KLux on clear summer days to 3.2 KLux on cloudy winter days. In the blue (0.446-0.500 μm) and red (0.620-0.7 μm) bands, the photosynthesis activity is higher (TANU, 2015). High-intensity low-energy light-emitting diode (LED) lighting has been widely used for maximizing crop growth. The amount of light intensity required varies from plant type to plant type. Halide and sodium metal type light are used by many commercial growers to 'supplement' natural light and to extend the day length. Metal halide lamps give off a 'blue' light which is more suitable for young plants and vegetative growth (Kessle et al., 2006). Generally plants are intolerant of continuous light for 24 h. Therefore, 12 to 14 h of light per day are given to plants (CSUE, 2011).

The substrate must be capable of supporting the root system and holding sufficient moisture and nutrients. It should be free from insects and should allow adequate aeration of the roots and have good drainage qualities (Kessler et al., 2006). Peat is commonly substrates used in protected farms. An inadequate water supply is the most limiting factor to plant growth. The substrate media should be flooded, and subsequently drained to keep the roots moist (Kessler et al., 2006). There are sixteen elements needed for proper plant growth. The optimal nutrient solution contains micronutrients viz., nitrogen (100-250 ppm), phosphorus (30-50 ppm) and potassium (100-300 ppm), sulfur (50-120 ppm), magnesium (30-70 ppm), and calcium (80-140 ppm) and trace elements viz., iron (1-3 ppm), boron (0.2-0.5 ppm), zinc (0.3-0.6 ppm), copper (0.08-0.2 ppm), manganese (0.5-1 ppm), and molybdenum (0.04-0.08 ppm) (Hydrogarden, 2013). Each plant variety has their different optimal pH ranges within which they can grow better. Water quality testing and analysis of irrigation water indicate the amount of different nutrient elements required for optimal crop growth (Trejo-Téllez and Gómez-Merino, 2012). The most crop prefer the pH between 5.5 and 7.5 beyond this range some nutrient elements will be unavailable to the plants (Hydrogarden, 2013).

4 Conclusions

The major challenges of successful protected farming venture are efficient design and monitoring of crop growing parameters. The descending order of relative importance of the twelve crop factors are water quality, light intensity, nutrient availability, crop cultivar, substrate media, daylight length, moisture availability, crop spacing, temperature, air freshness, air circulation and relative humidity respectively. Therefore, priority wise crop growing factors must be considered while designing and monitoring a protected farm for optimal crop growth and net return in the study area.

Acknowledgements

The authors are thankful to the Head, Department of Civil Engineering, National Institute of Technology, Agartala PIN-799046, Tripura, India for providing administrative and financial support for carrying out this research work.

References

Ahlawat, N., A. Gautam, and N. Sharma. 2014. Use of logic gates to make edge svoider robot. *International Journal of Information and Computation Technology*, 4(6): 629–632.

American Hydroponics. 2015. American Hydroponics. American Hydroponics Inc. CA, USA. Availble at: http://american hydroponics.com/meet-some-growers.html. Accessed 22 January 2015.

Aruldoss, M., T. M. Lakshmi, and V. P. Venkatesan. 2013. A Survey on Multi-Criteria Decision Making Methods and Its Applications. *American Journal of Information Systems,* 1(1): 31–43.

Banerjee, C., and L. Adenaeuer. 2014. Up, Up and Away! The Economics of Vertical Farming. *Journal of Agricultural Studies*, 2(1): 40–60.

Bareja, B. G. 2011. Crop agriculture review: Towards an informed application in agriculture and related science. Available at: http://www.cropsreview.com/crop-selection.html. Accessed 14 May 2014.

Burrough, P. A. 1989. Fuzzy mathematical methods for soil survey and land evaluation. *Journal of Soil Science*, 40(3): 477–492.

Calizaya, A., O. Meixner, L. Bengtsson, and R. Berndtsson. 2010. Multi-criteria decision analysis (MCDA) for integrated water resources management (IWRM) in the lake Poopo Basin, Bolivia. *Water Resources Management,* 24(10): 2267–2289.

Chaudhuri, O. K., G. Khot, K. C. Deshmukh, and N. G. Bawne. 2011. Application of fuzzy logic in decision making to optimize the profit in the field of fice cultivation. *International Journal of Applied Mathematics and Applications*, 3(2): 153–165.

CNN. 2012. CNN International Edition, Urban farming looking up in Singapore.CNN International Edition. Available at: http://edition.cnn.com/2012/12/09/business/eco-singapore-vertical-farm/. Accessed 28 January 2014.

Colorado State University Extension (CSUE). 2011. Plant Growth Factors: Light.CMG GardenNotes #142. Available at: http://www.ext.colostate.edu/mg/gardennotes/142.pdf. Accessed 17 May 2014.

Despommier, D. 2009. The Rise of Vertical Farms. Scientific American, INC. Available at: http://mskimsbiologyclass.com/wp-content/uploads/2013/08/The-Rise-of-Vertical-Farms.pdf. Accessed 22 January 2014.

Dubey, S., R. K. Pandey, and S. S. Gautam. Literature review on fuzzy expert system in agriculture. *International Journal of Soft Computing and Engineering*, 2(6): 2231–2307.

George, H. 2014. Growing Up. Massachusetts Academy of Math and Science, USA. Available at: http://www.scientiareview.org/pdfs/245.pdf. Accessed 12 February 2014.

Hartati, S., and S. M. S. Imas. 2010. A fuzzy based decision support system for evaluating land suitability and selecting crops. *Journal of Computer Science*, 6(4): 417.

Hydrogarden. 2013. Guide to Hydroponic System Types. HydroGarden Ltd. Available at: https://www.hydrogarden.com/what-is-hydro.asp. Accessed 17 May 2013.

Jensen, M. 2012. Greenhouse Grower. Meister Media Worldwide. Available at: http://www.greenhousegrower.com/varieties/vegetables/10-vegetable-crops-you-should-consider/. Accessed 4 January 2014.

Kessler J. R., J. D. Williams, and R. Howe. 2006. Alabama Cooperative Extension System. ANR-1151, Eco-farms for Home Gardeners, Auburn University. Available at: http://www.aces.edu/pubs/docs/A/ANR-1151/index2.tmpl. Accessed 14 May 2014.

Khan, F., F. Shabbir, and Z. Tahir. 2014. A fuzzy approach for water security in irrigation system using wireless sensor network. *Science International,* 26(3): 1065–1070.

Kolhe, S., R. Kamal, H. S. Sainid, and G. K. Guptab. 2011. A web-based intelligent disease-diagnosis system using a new fuzzy-logic based approach for drawing the inferences in crops. *Computers and Electronics in Agriculture*, 76(1): 16–27.

Kosko, B. 1994. Fuzzy systems as universal approximators. *IEEE Transactions on Computers*, 43(11): 1329–1333.

Kurtener, D., H. A. Torbert, and E. Krueger. 2008. Evaluation agricultural land suitability:application of fuzzy indicators. *Computational Science and Its Applications-ICCSA*, 2008: 475–490.

MacMillan, R. A., W. W. Pettapiece, S. C. Nolan, T. W. Goddard. 2000. A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic. *Fuzzy Sets and Systems*, 113(1): 81–109.

Marks L. A., E. G. Dunn, J. M. Keller, and L. D. Godsey. 1995. Multiple criteria decision making (MCDM) using fuzzy logic: an innovative approach to sustainable agriculture. In *Proc. the IEEE 3ndInternational Symposium onUncertainty Modeling and Analysisand Annual Conference of the North American Fuzzy Information Processing Society*, 503–508. Los Alamitos, CA, USA, 17-20 March.

Massachusetts Institute of Technology (MIT). 2014. Urban agriculture mission 2014: Feeding the world. Cambridge, MA, USA. Available at: http://12.000.scripts.mit.edu/mission2014/solutions/urban-agriculture. Accessed 12 February 2014.

Meyers, G. 2010. Cityscape farms: Soilless farming. Green Building Elements. Available at: http://www.cityscapefarms.com/soillessfarming. Accessed 12 February 2014.

Mississippi Agricultural and Forestry Experiment Station (MAFES). 2015. Commercial Horticulture, Mississippi State University Extension Service. Available at: http://msucares.com/crops/comhort/various.html. Accessed 4 January 2015.

Novák, V., I. Perfilieva, and J. Močkoř. 1999. *Mathematical Principles of Fuzzy Logic*. Dordrecht: Kluwer Academic Publishers.

Hagan, M. O. 2000. A fuzzy decision maker. *Proc. Fuzzy Logic '93 Computer Design Magazine.* p.M 313

Papageorgiou, E. I., K. Konstantinos, and Z. Dikopoulou. 2016. Fuzzy sets in sgriculture. *Fuzzy Logic in Its 50th Year: New Developments, Directions and Challenges,* eds. C. Kahraman et al., ch. Part III, 211–233. Switzerland: Springer International Publishing.

Pelletier, F. J. 2000. Review of metamathematics of fuzzy logics. *The Bulletin of Symbolic Logic*, 6(3): 342–346.

Prakash, T. N. 2003. Land suitability analysis for agricultural crops: A fuzzy multicriteria decision making approach. M.S. theses. Enschede: The International Institute for Geo-information Science and Earth Observation enschede, geoinformatics.

Roussel, O., A. Cavelier, and H. M. G. V. D. Werf. 2000. Adaptation and use of a fuzzy expert system to assess the environmental effect of pesticides applied to field crops. *Agriculture, Ecosystems and Environment*, 80(1): 143–158.

Saaty, T. L. 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1): 83–98. Available at: http://www.colorado.edu/geography/saaty_2008.pdf. Accessed 28 January 2014.

Sicat, R. S., E. J. M. Carranza, and U. B. Nidumolu. 2005. Fuzzy modeling of farmers' knowledge for land suitability classification. *Agricultural Systems*, 83(1): 49–75.

Tamil Nadu Agricultural University (TANU). 2015. Plant response to greenhouse environments. Available at: http://agridr.in/tnauEAgri/eagriGómez-Merino50/AENG252/lec03.pdf. Accessed 28 January 2015.

Thanet Earth. 2015. How we grow. Thanet Earth Marketing Ltd, Birchington, Kent, Britain. Available at: http://www.thanetearth.com/how-we-grow.html. Accessed 28 January 2014.

The Association for Vertical Farming (AVF). 2013. Why vertical farming? Munich, Germany. Available at: http://vertical-farming.net/en/vf/why/. Accessed on 22 January 2013.

Trejo-Téllez, L. I., and F. C. 2012. Nutrient solutions for hydroponic systems. Hydroponics - A standard methodology for plant biological researches. Available at: http://www.intechopen.com/download/get/type/pdfs/id/33765. Accessed 28 January 2014.

Van der Werf, H. M. G., and C. Zimmer. 1998. An indicator of pesticide environmental impact based on a fuzzy expert system. *Chemosphere*, 36(10): 2225–2249.

Yang, C. C., S. O. Prasher, J. A. Landry, J. Perret, and H. S. Ramaswamy. 2000. Recognition of weeds with image processing and their use with fuzzy logic for precision farming. *Canadian Agricultural Engineering*, 42(4): 195–200.

Ying, H., Y. Ding, S. Li, and S. Shao. 1999. Fuzzy systems as universal approximators, *IEEE Transactions on Systems Man and Cybernetics–Part A Systems and Humans,* 29(5): 508–514.

Zadeh, L. A. 1965. Fuzzy sets. *Information and Control*, 8(3): 338–353.