Journal of Developments in Sustainable Agriculture 4: 165-172 (2009)

GIS-Based Neural Network Modeling to Predict Suitable Area for Beetroot in Sri Lanka: Towards Sustainable Agriculture

P.K.S.C. Jayasinghe[1]* and Masao Yoshida[2]

[1] United Graduate School of Agricultural Science, Tokyo University of Agricultural and Technology, Saiwai-cho 3-5-8, Fuchu, Tokyo 183-8509, Japan

[2] Faculty of Agriculture, Ibaraki University, Chuou 3-21-1, Ami, Ibaraki 300-0393, Japan

In this research, neural network technology with a Geographical Information System (GIS) was used to carry out land suitability analysis for beetroot. The suitability evaluation of beetroot (*Beta Vulgaris*) was based mainly on the methods described by the Food and Agricultural Organization (FAO). Study area of this research was in the upcountry of Sri Lanka. Soil properties, meteorological data, current land use and slope accessibility were considered as important factors to identify potential lands for beetroot. Average annual temperature and precipitation (1961-1990 data), topographic, soil and land use maps of the study area were used for the study. Crop requirement criteria were collected from a literature review and from the Department of Agriculture, Sri Lanka. Paper maps were scanned and screen digitized to prepare thematic layers (maps) and then converted to raster format and reclassified. Reclassified layers were converted to ASCII format. The Levenberg-Marquardt (LM) algorithm was used to perform the Artificial Neural Network (ANN) modeling. Finally, a suitability map was prepared according to the given criteria with four suitability categories; namely, highly, moderately, marginally and not suitable. According to the final suitability map of ANN modeling, 10.43%, 31.66% and 7.96% of lands fell respectively under highly, moderately and marginally suitable categories. The results revealed that there was no, "not suitable" land parcel in the present study area. According to these results, we conclude there is moderate potential for growing beetroot in the upcountry of Sri Lanka.

Key words: Land suitability, neural network, beetroot, GIS, Sri Lanka

Introduction

In recent decades, there has been impressive growth of population in the planet. To fulfill the demand of the increased world population for agricultural products, intensifying the production rate is tried in different ways. Currently available natural resources are continuously being declining and may not be sufficient to fulfill the needs of the future generation. Therefore, for few decades, the world's concern is being focused towards sustainable agriculture. To improve agricultural production in a sustainable way, systematic and efficient management of farming practices are essential. The main idea of the sustainable agriculture is to make use of optimum available natural resources for efficient agricultural production. In order to fulfill these principles of sustainable agriculture, identifying the best suited lands for specific crops is the key factor in the agriculture field. Land suitability analysis has to be carried out in such a way that the local needs and conditions are reflected well in the final decision (Jayasinghe, 2008).

Food and Agricultural Organization (FAO) reported that (1978) a specific agricultural use on land that is most suitable according to agro-ecological potentialities and limitations is the best way to achieve sustainability. This challenge facing

Received: September 28, 2009, Accepted: December 9, 2009

*Corresponding author's current address: United Graduate School of Agricultural Science, Tokyo University of Agricultural and Technology, Saiwai-cho 3-5-8, Fuchu, Tokyo 183-8509, Japan.

Tel: +81-29-888-8688, (Mobile) +81-90-3595-0036, Fax: +81-29-888-8525, E-mail: subashjp@yahoo.com

agriculture, particularly in developing countries, is to increase productivity without causing ecological damage. To establish sustainable agriculture, it is necessary to provide proper recognition of land abilities and allocating of them to the best and most profitable for food production. Therefore, to identify the best suitability lands for vegetable crops using modern data mining technologies such as neural network is vital importance in achieving sustainable agricultural systems, which balance productivity and environmental protection.

Artificial Neural Networks (ANN) is an effective tool for suitability analysis in a Geographical Information System (GIS) environment (Sui, 1993). Integration of artificial neural network technologies with GIS has archived considerable progress during the last decade. The ANN plays significance role as spatial data mining technique for handling vast amount of data in GIS environment (Skidmore *et al.,* 1997). At present, wide variety of research has been conducted to explore the potential applicability of ANN for spatial data analysis including land suitability analysis (Zhou, 1996). The integration of GIS and ANN provide a potential mechanism to lower cost of analysis of natural resource information by reducing the amount of time spent interpreting data (Malczewski, 2004).

At present, the major issues of the beetroot cultivation in Sri Lanka are the increasing cost of production and yield of the production is not sufficient to fulfill the people's demand. As a tropical country, beetroot growth is difficult for fairly light temperature particularly other parts of the country except of study area. Available arable lands in Sri Lanka are very limited as a small island. Thus, the sustainable and efficient use of land resources is an important issue for agricultural development of the country. Some farmers use environmentally harmful methods such as, high rate chemical fertilizers that favored maximizing production. Farmers of rural areas are still using traditional farming methods (e.g.: soil tillage) and low technology for farming practices. Some farmers cannot achieve the potential yield because of low input. The other problem is that farmers are not financially fulfilled to pay for consultation, new equipment, information etc. Increase of Beetroot production would greatly benefit to the economy of the country. Moreover, generation of employment and income of farmers are mainly attributed to develop the rural economy and the standards of living of rural people. Therefore, the main objective of this study is to identify suitable land area for beetroot in up country of Sri Lanka using GIS and ANN technologies. This evaluation is based on the method as described by FAO (1976) for land suitability evaluation for crops in terms of suitability ratings from highly suitable to not suitable based on climatic and terrain data and soil properties cropwise.

Overview of Beetroot

Beetroot originated in the Mediterranean regions of Europe and North Africa. Sciencetific name of beetroot is *Beta vulgaris.* Beetroots are grown as cool season vegetables. This is globe shape, red color vegetable. The root growth occurs most significantly at cool night season due to lower respiration rates, which allows for the accumulation of carbohydrates. Modern cultivars are classified according to the shape, color and time of maturity. Beetroot is a great source for healthy sweetness and homegrown vegetables.

Materials and Methods

Overview of Artificial Neural Network

The neural networks present a structure similar to the one of the human brain. ANN is a type of parallel computer technology that consists of a number of smaller processing elements joined together. These processing elements are called nodes. Nodes are usually organized into neuron layers; an input layer where data are presented to the network, an output layer where that holds the response of the network to a given input, and hidden layer which is located between input layer and output layer. The processing elements in these different layers are either partially or fully interconnected. This combination of the processing elements linked to each other with connection weights and connections are associated with a corresponding weight based on the strength of the connection (Rosenblatt, 1958; Yiannis *et al.,* 2008; Gonzalez, 2008).

Multilayer network models are classified as feedforward networks (Yanfang, 2002). The input layer neurons receive input patterns from the external environment and propagate them into the first

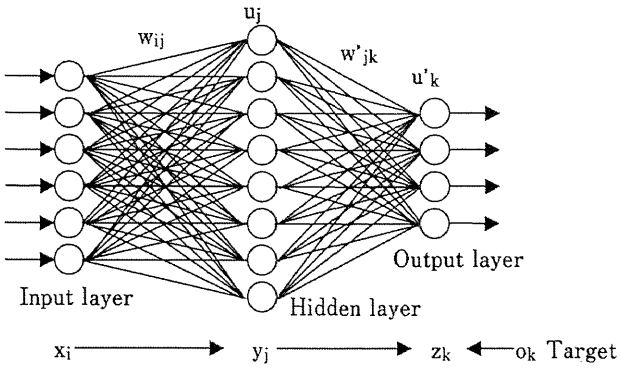

Fig. 1. Basic architecture of ANN modeling

Table 1. Production of beetroot in upcountry and other areas of Sri Lanka

2006 Yala season*	Prod./M.T.
Up country	8,688
Other areas	5,101
2005/2006 Maha season*	
Up country	7,936
Other areas	2,027

*Two seasons per year, locally called Yala and Maha.
Source: Statistics Department of Sri Lanka (2007).

hidden layer neurons. In this layer any data processing is not carried out. Input values distributed from each of the input layer neurons are multiplied by each of the adjustable connection weights linking the input layer neurons to hidden layer neurons. At each neuron in the hidden layer weighted input values are summed and a bias value is added (Hornik, 1989). Then combined input value is passed through a nonlinear transfer function like sigmoid or hyperbolic tangent to obtain the output value of the neuron (Gonzalez, 2008; Blamire, 1996). This output value is an input for the neurons situated in the following layer. Finally, the output layer neurons produce the output value of the network model (Fun, 1996) (Fig. 1).

Study Area

Upcountry (locally called) of Sri Lanka was selected as study area for the research. The upcountry is covered by four districts, namely Kandy, Matale, Nuwareliya and Badulla districts. Sri Lanka is an agricultural economic and many of agriculturally important crops are grown in the country. Growing seasons are mainly determined by influenced of two monsoons rainfall which are the north-east monsoon in November to February and the south-west monsoon from May to September. However, vegetables are grown throughout the year with the help of other types of rainfall and irrigations. Land area of the study area is 8,535 km^2 and the most economically important crop is tea. However, this is the major beetroot growing area of the country (Table 1) (Dept. statistics, Sri Lanka, 2007). The mean annual rainfall varies from 1,000 mm to over 4,000 mm. The temperature varies from 12℃ to 25℃ in a year.

Climatic condition of Sri Lanka is suitable for growing crops with wide diversity. The majority of the population involved in agriculture sector and most of them are small scale farmers. To develop of rural economy, vegetable production sector provides important contribution to the country. Considering the limited land resources in Sri Lanka, identifying suitable lands would be one of the key factors to increase the vegetable production of the country and as well as rural farmers can be moved for sustainable agricultural practices.

Data Sources

The identification of beetroot growing requirements is the most important task for this evaluation. Crop requirements criteria (Table 2) were collected from literature review, regional experience and from the Department of Agriculture, Sri Lanka (Department of Agriculture, Sri Lanka, 2009).

Average annual rainfall (1961-1990 data), average annual temperature (1961-1990 data) and topography maps were obtained from International Research Institute for Climate and Society (IRI) (2008). Soil (Panabokke, 1996) and land use (UDA, Sri Lanka 2008) maps of the study area were utilized for the study. Each of these factors was considered as a thematic layer in the GIS database.

GIS-Based ANN Modeling

The methodology of the GIS-based neural network modeling for development of crop-land suitability analysis consists of three stages. These three stages are connected by data preparation, ANN model performance and out put generation.

Table 2. Crop requirement criteria for beetroot

	Classes			
	1 (Highly Suitable)	2 (Moderately Suitable)	3 (Marginally Suitable)	4 (Not Suitable)
Soil pH	6-8	4-6	4-2	Other values
Soil Texture	Sandy loam/ Sandy clay loam	Clay loam/loam	Loamy sand/ sandy clay	Clay/Sand
Soil Drainage	Well drainage	Moderately drainage	Poor drainage	Very poor drainage
Soil OrganicC (C%)	>5	3-5	2-3	<2
CEC ($cmol_c kg^{-1}$)	>15	10-15	5-10	<5
Soil P (ppm)	>8	8-6	6-4	<4
Slope (%)	<15	15-30	30-60	60<
Temperature (℃)	15-18	18-24	24-26	Others values
Rainfall (mm)	1,500-2,000	1,000-1,500	2,000-2,500	>2,500

Stage One: Data Preparation

Paper maps of rainfall, temperature, soil, land use, and topography were scanned and screen digitized by help of ArcView GIS application. Digitized soil map was used to derive soil properties maps (Senarath and Dassayayake, 1999a, 1999b, Dassanayake and Hettiarachchi, 1999, Dassanayake *et al.,* 2005, De Silva *et al.,* 2005, Dassanayake and De Silva, 2005, Panabooke, 1996) as the separate soil layers (pH, texture, drainage, organic C, soil P, CEC (Catain Exchange Capacity)). Topographic map was used for the preparation of slope map by using Triangular Irregular Network (TIN) model.

Created thematic layers (vector format) were converted into the raster format. All the raster thematic layers were prepared and imported into the ArcView 9.2 application. The reclassify function of spatial analysis tool in ArcView 9.2 was used to reclassify the all layers based on suitability rank as shown in Table 2. The reclassification process allows the user to bring the dataset to a common scale. The details flow of the data pre-preparation methodology is presented in Fig. 2.

The methodology of the neural network based GIS modeling for development of suitability analysis is shown in Fig. 3. Above prepared reclassified raster layers were exported to ASCII format using import/export facilities in ArcView 9.2. A VB (Microsoft Visual Basic) program was used to convert exported ASCII data file into the data format suitable for neural network modeling. The nine GIS data layers now become the nine processing

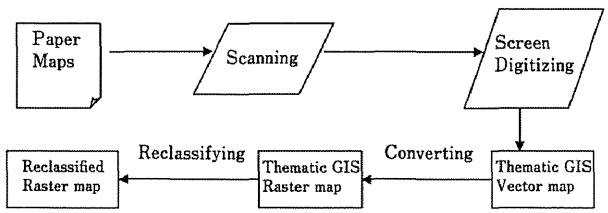

Fig. 2. Diagram of data pre-preparation methodology

elements in the input layer of the ANN.

Water bodies, Tea, Rubber and Coconuts plantation, and dense forests in the land use layer and Lithosols, erosional remnants and rocky areas in the soil layer were assigned as restricted areas for the analysis (49.96%).

Stage Two: ANN Modeling

The training of neural network is the most critical step in ANN modeling. The ANN model was trained using randomly selected data while the remaining data was utilized for testing of the network performance. Alyuda Neurointelligence application was used to implement the LM algorithm. The LM algorithm was applied to calculate the weights between the input layer and the hidden layer, and between the hidden layer and the output layer, by modifying the number of hidden node and the learning rate. Optimal number of nodes in the hidden layer was identified by changing different networks. The LM method took much longer time to train an ANN model compared with other

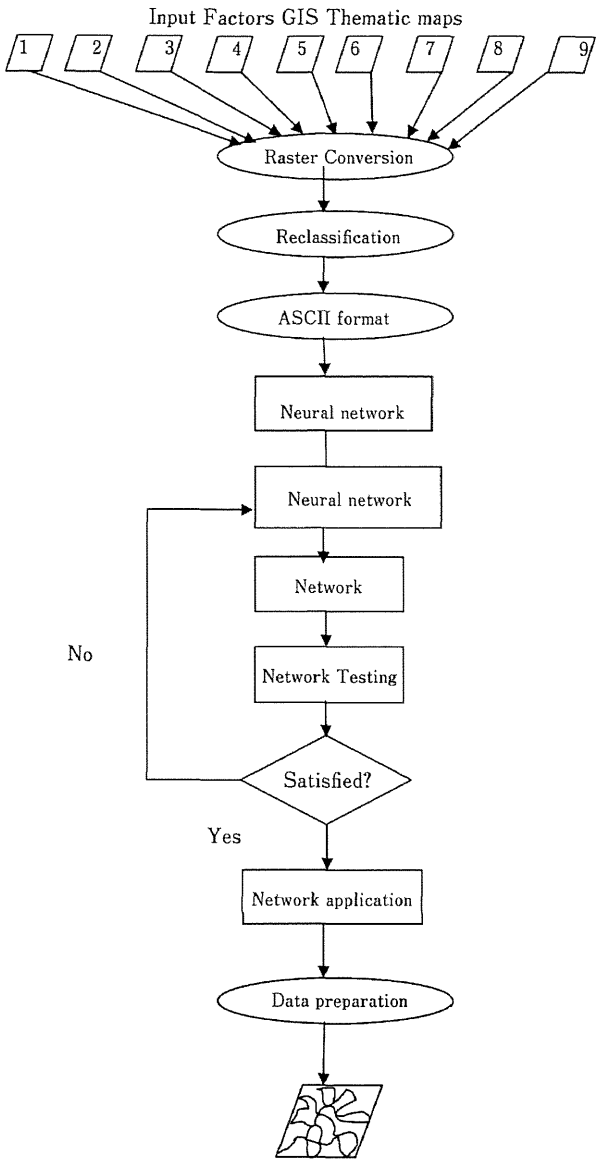

Fig. 3. Methodology of ANN modeling

methods such as resilient back-propagation method. In this study, Root Mean Square Error (RMSE) and Mean Error (ME) were used to assess the model accuracy with iteration time. The model prediction with lower RMSE and ME was considered to be a successful model (Hornik, 1991). After a fairly long period of experiments, optimal network structure was identified.

Training results indicate that the best ANN model for predicting suitable area for beetroot was a 9-22-4 network structure because of low RMSE and ME (Table 3). When the number of hidden layer was less than 22, the network scale was too small and model prediction accuracy was low. When the number of hidden layer was greater than 22, the model could be over-fitted. When the model was over-fitted, the training accuracy was high but the prediction accuracy can be decreased (Chan *et al.*, 2006). The output pattern of the ANN modeling is presented in Table 4.

Table 3. ANN model trained by LM algorithm

ANN structure*	ME	RMSE
9-8-4	−0.43	4.2
9-12-4	−0.46	6.4
9-14-4	−0.44	5.1
9-16-4	−0.42	3.8
9-18-4	−0.44	5.5
9-20-4	−0.43	3.6
9-22-4	−0.42	3.2
9-24-4	−0.44	5.4
9-26-4	−0.46	6.3

*Network structure input layer-hidden layer-output layer.

Finally, based on this analysis, it is concluded that the network structure, training method and training times greatly impact to identify suitable ANN model. Therefore, this experiment found that a 9-22-4 network structure trained by the LM algorithm was the best ANN model for the prediction of beetroot production according to the given input criteria (Fig. 3).

Stage Three: Out Put Generation

After development of ANN architecture (9-22-4) by LM algorithm through the training file, entire study area was evaluated using Alyuda Neurointelligence application. The result was then converted back to the GIS format for the output process. The thematic mapping functions of ArcGIS were used to prepare final evaluation map based on the evaluation results from the neural network modeling. This thematic map was used to calculate suitable area for beetroot.

Results and Discussions

The prepared land suitability map for beetroot is presented in Fig. 4 and Table 5. Result showed that 10.43% land area was under highly suitable catego-

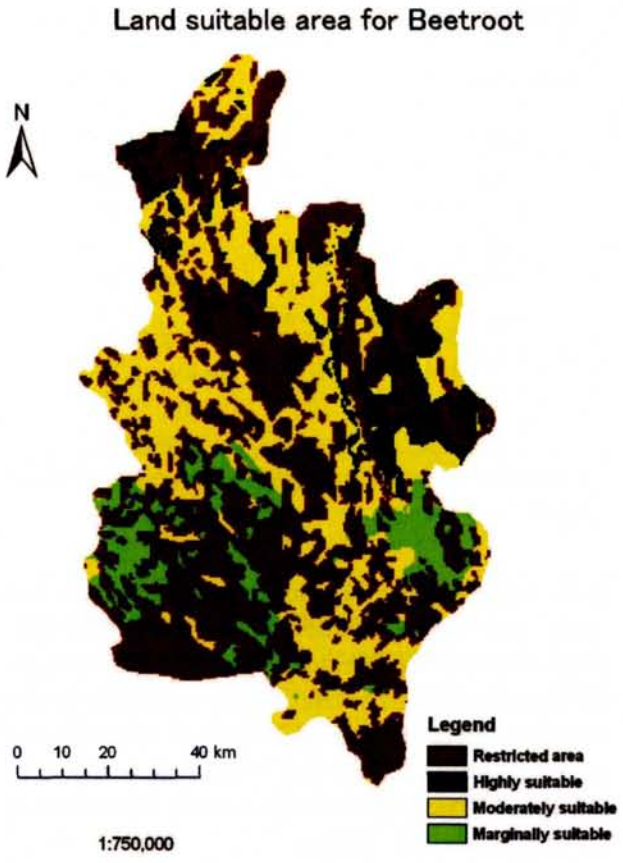

Fig. 4. Land areas suitable for beetroot

ry. The majority of the land (31.66%) was moderately suitable. According to the given criteria, the analysis revealed that 7.96% of current lands fall to under marginally suitable category. The final result map confirmed that "not suitable" land parcels were not available in the present study area.

According to the final results, the ANN model has identified number of highly suitable land parcels in the Badulla and Matale districts. This ANN model found about 5% (out of 10.43%) highly suitable lands in Badulla district. Badulla district is one of the largest beetroot growing areas of the country. Climatic condition of this areas are playing important role to growing beetroot and therefore, it is revealed that the farmers have already identified this area as a suitable area for beetroot by their practical knowledge. The highly suitable areas for beetroot were mainly located close to home garden and other plantations. Soil characteristics of the highly suitable class were mostly sandy loam and well drainage. Soils in the highly suitable class were also non-acidic (pH 7 to 8) as well as moderate total C (3 to 5%) and CEC (10 to 15 cmol (+) kg^{-1}). Moderately suitable land parcels are expanded through the study area. Therefore, this study reveals that there are some possibilities for growing beetroot by improving the quality of land. For example, if soil fertilizer is not sufficient, farmers can apply compost or green manure instead of high chemical fertilizer. The results of ANN model showed that marginally suitable land areas were found in the mountain slope at high elevation and less water recourses area of southeast part. Because this region had low water sources for agricultural activity relating to the current condition in supplementary water factor. In this case, if irrigation is established in the region, the environmental effects in water sources are not necessarily unfavorable as well as some soil properties may be improved in terms of soil organic matter, soil drainage.

This research used the available spatial information for the identification of suitable area for growing beetroot. Crop-land suitability analysis can be regarded as a relatively difficult task due to large number of factors and large volume of data that may be required for the determination. Many input of the GIS based land suitability are the maps of criteria, which are representing the complex, continuous and uncertain information in a simple manner. Nowadays, many methods can be used to

Table 4. Output pattern of the ANN sample

Highly suitable	Moderately suitable	Marginally suitable	Not suitable
1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 5. Land suitability results for beetroot

Suitable Classes	Land Area (ha.)	%
Highly Suitable	89003.93	10.43
Moderately Suitable	270222.34	31.66
Marginally Suitable	67905.94	7.96
Not Suitable	0.00	0.00
Restricted area	426367.79	49.96
Total land area	853500.00	100

make the suitability analysis, such as sieve mapping method, landscape unit method and cartography map overlay method. But new approach of this research was that, we integrated spatial data mining method for GIS-based land suitability evaluation. Compared with neural network-based GIS and traditional GIS-based cartography modeling, fault tolerant ability of ANN is greatly higher than cartography modeling. In neural network approach, when errors occur in the final result, the user can easily identify and correct them. Users can refine the results progressively by improving the quality of the training samples. If user has any new evidence about the suitability of a site, he could add it to the training samples. If user finds an error in a training sample, he could remove or edit it. Then user needs merely to retrain the neural network. Therefore, neural network methods are dynamic and compatible with the human cognitive process.

Identification of suitable crop lands using modern technologies might be affected to prevent of environmental harmful farming practices as well as it is significantly helped to enhance the food productions. The traditional and indigenous knowledge for sustainable land use farming are especially in resource-poor, low-input farming systems. Unfortunately, all of these methods come with dangerous environmental side effects which can not only harm local ecosystems and animals, but even the people who consume the produce treated with these methods.

Conclusions

This paper presents application of the ANN modeling with GIS technology to predict the potential area for beetroot based on nine crop requirement factors. The ANN model based on LM backpropagation algorithm was developed, which has a 9-22-4 network structure. This result suggests that the neural network based-GIS modeling can be powerful alternative approach toward automated spatial decision making.

This study has demonstrated the capabilities of using neural network, GIS and field data for identifying potential sites for beetroot. According to the results of the study, it can be concluded that upcountry of Sri Lanka is moderately potential for growing beetroot. In addition to that, it is recommended that field checking should be carried out to verify the obtained results. Furthermore, socio-economic factors have to be given due consideration to increase its usefulness. It is therefore recommended that more work be carried out to refine the model and to include other related ancillary data like socio-economic factors. This investigation provides information at a regional level that could be used by farmers to select growing beetroot instead of other crop patterns. As well, decision-making regarding growing beetroot could be based not only on the information provided by this ANN model, but also on other aspects such as; production supports (by local and central governments), marketing, technological level, economic evaluation, in addition to local customs, which are also highly important. As a developing country, Sri Lanka, these kinds of research are required to expand the vegetable production which would raise the social and economic life of the farmers in the area.

Today, Sustainable agricultural practices involve a variety of approaches. Sustainable agriculture address many environmental and social concerns, but it offers innovative and economically viable opportunities for growers, laborers, consumers, policymakers and many others in the entire food system. This paper was an effort to emphasize on identification of crop-land suitability which is significantly support to cover up several main goals of sustainable agriculture. Which are satisfy human food needs, enhance environmental quality and the natural resource, make the most efficient on-farm resources, sustain the economic viability and finally, enhance the quality of life for farmers and society as a whole. Therefore, further research of crop-land suitability is essential to make the most efficient use of nonrenewable resources for farm practices and which may help to bring the farming community for sustainable agriculture.

At present, most of the researches are being concerned on global warning and climate change. The climate change impact potentially significant to vegetable production. Therefore, future crop-land suitability research will be concerned on that issue too and this kind of researches is required to drive local farmers towards sustainable agriculture.

Acknowledgements

We sincere thank to agricultural extension offi-

cers of present study area for their numerous help to success this study and Dr. D.A.L. Leelamanie, Faculty of Agriculture, University of Ruhuna Sri Lanka for her valuable input.

References

Blamire, P.A., 1996. The influence of relative sample size in training artificial neural networks. Int. J. Remote Sens. 17 (1), 223-230.

Chan, Z., S.H., Ngan, H.W. and Rad, A.B., 2006. Short-term ANN load forecasting from limited data using generalization learning strategies. Neurocomputing 70 (1-3), 409-419.

Dassanayake, A.R. and Hettiarachchi, L.S.K., 1999. Soils of the Up County wet zone. In: Mapa, R.B., Somasiri, S. and Nagarajah, S., (Eds.), Soils of the Wet Zone of Sri Lanka., Soil Science Society of Sri Lanka, Peradeniya, Sri Lanka, pp. 122-138.

Dassanayake, A.R., Somasiri, L.L.W. and De Silva, G.G. R., 2005. Soils of the Low Country Intermediate zone. In: Mapa, R.B.,Dassanayake, A.R., Nayakekorale, H. B., (Eds.), Soils of the Intermediate Zone of Sri Lanka., Soil Science Society of Sri Lanka, Peradeniya, Sri Lanka, pp. 53-117.

Dassanayake, A.R. and De Silva, G.G.R., 2005. Soils of the Up Country Intermediate zone. In: Mapa, R.B., R.B., Dassanayake, A.R. and Nayakekorale, H.B., (Eds.), Soils of the Intermediate Zone of Sri Lanka., Soil Science Society of Sri Lanka, Peradeniya, Sri Lanka, pp. 149-164.

Department of Agriculture Sri Lanka, 2008. Agriculture Technologies: http://www.agridept.gov.lk/index1.php, accesed December 12, 2008.

Department of Meteorology Sri Lanka, 2009. Agro-meteorology data: http://www.meteo.gov.lk, accessed January 20, 2009.

Department of Statistics Sri Lanka, 2007. Agricultural and Environment Statistics Division, Highland crops time series data: http://www.statistics.gov.lk/agriculture/hcrops/index.html, accessed December 12, 2008.

Food and Agriculture Organization (FAO, Rome), 1978. Report on the Agro-ecological Zones Project. World Soil Resources, Report 48, Rome, Italy.

Food and Agriculture Organization (FAO, Rome), 1976. A frame work for land evaluation, Soils Bulletin No. 32. Rome, Italy.

Fun, M.H., 1996. Training modular networks with the Levenberg-Marquardt Algorithm. IEEE International Conference on Neural Network, 3-6 June. Vol. 1, pp. 468-473.

Gonzalez, M.P. and Zapico, J.L., 2008. Seismic damage identification in buildings using neural networks and modal data. Comp. Struct. 86, 416-426.

Hornik, K., 1989. Multilayer feedforward networks are universal approximators. Neural Networks 2 (5), 359-366.

Hornik, K., 1991. Approximation capabilities of multilayer feed forward network. Neural Network 4 (2), 251-257.

International Research Institute for Climate and Society (IRI, New York) 2006. Climate predictions and applications for Sri Lanka.

Jayasinghe, P.K.S.C. and Machida, T., 2008. Web-based GIS online consulting system with crop-land suitability identification. Agr. Inform. Res. 17 (1), 45-51.

Malczewski, J., 2004. GIS-Based Land-use suitability analysis: a critical overview. Prog. Plann. 62 (1), 3-65.

Panabokke, C.R., 1996. Soils and Agro-Ecological Environments of Sri Lanka, Natural Resource Series No. 2. Natural Resources, Energy and Science Authority of Sri Lanka, Colombo, pp. 35-101.

Rosenblatt, F., 1958. The perceptron. A probabilistic model for information storage and organization in the brain. Psychol. Rev. 65 (6), 386-408.

Senarath, A. and Dassanayake, A.R., 1999a. Soils of the Low Country Wet zone. In: Mapa, R.B., Somasiri, S., Nagarajah, S., (Eds.), Soils of the Wet Zone of Sri Lanka., Soil Science Society of Sri Lanka, Peradeniya, Sri Lanka, pp. 37-91.

Skidmore, A.K., Turner, B.J., Brinkhof, W. and Knowles, E., 1997. Performance of a neural network: mapping forests using GIS and remotely sensed data. Int. J. Photogra. Eng. Remote Sens. 63 (5), 501-514.

Sui, D.Z., 1993. Integrating neural networks with GIS for spatial decision making. Oper. Geograph. 11 (2), 13-20.

Urban Development Authority, Sri Lanka (UDA), 2008. Land use map, http://www.uda.lk, accessed November 04, 2008.

Yanfang, L. and Limin, J., 2002. The application BP network to land suitability evaluation, Geo-spatial Info. Sci. 5 (1), 55-61.

Yiannis, T., Lagaros, N.D., Psarropoulos, P.N. and Georgopoulos, E.C., 2008. Simulating the seismic response of embankments via artificial neural networks: Ad. Eng. Soft. 40 (8), 640-651.

Zhou, J. and Civco, D.L., 1996. Using genetic learning neural networks for spatial decision making in GIS: In. J. Photogra. Eng. Remote Sens. 62 (11), 1287-1295.