Mapping High-Potential Areas Using Maximum Entropy Modeling Approach and Constraints Analysis of Pineapple (*Ananas comosus*) Cultivation in Sri Lanka

Wijegunawardhana, A.V.*[1], Abeynayake, N.R.[1] and Kadupitiya, H.K.[2]

[1]*Department of Agribusiness Management, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP), 60170, Sri Lanka*
[2]*Natural Resources Management Centre, Peradeniya, Sri Lanka*

**Corresponding Author:*
Email: ayodyawije@gmail.com

ABSTRACT

Maximum entropy (MaxEnt) modeling is extensively tested high performing quantitative modeling technique which has great potential for identifying best ecological requirement of species based on "presence only data" together with environmental variables. This study was aim to model the high-potential areas for pineapple cultivation in Sri Lanka using MaxEnt model. Total of 215 locations of pineapple cultivation covering whole Sri Lanka and several environmental covariates namely monthly rainfall, monthly mean temperature, Digital Elevation Model (DEM), slope, slope aspect, Normalized Difference Vegetation Index (NDVI) were used as model drivers. The resulting model was validated by using area under the receiver operator characteristic curve analysis. In addition to mapping, a questionnaire survey was conducted with a sample of 60 farmers in four divisional secretariat divisions of Gampaha and Kurunegala districts to explore prevailing conditions and constraints for pineapple cultivation. Highly significant constraints were identified using Wilcoxon signed rank test. Probability prediction map developed by MaxEnt with high predictive power (AUC = 0.913) indicated that some parts of Ampara, Monaragala, Puttalam, Colombo, Kaluthara, Kegalle, Badulla districts as high- potential areas in addition to traditionally pineapple grown districts which are Gampaha and Kurunegala. Wilcoxon signed rank test proved that high cost of inputs, high price of mulching materials, high cost and shortage of labour, high investment, lack of government subsidy facilities, weed problem, threat of mealy bug attack as highly significant production constraints while lack of guaranteed price as the major marketing constraint for pineapple cultivation ($p < 0.05$). This information on high-potential areas important for investors as well as entrepreneurs to take information-based decisions and provide decisive guidance for farmers to expand their cultivation.

KEYWORDS: Environmental covariates (layers), Geographic information system, MaxEnt model, Pineapple cultivation, Probability mapping

Introduction

Pineapple (Ananas comosus) is one of the major commercial fruit crop cultivated in Sri Lanka which has huge potential for export market as it produce some of the finest pineapples in the world (Rupasinghe et al., 2016). Among the world's pineapple producers, Sri Lanka is placed 34th with less than 1 % of total world production and not in a position to meet the growing demand of pineapple in local and international markets due to the lack of quantities and exportable quality (Rupasinghe et al., 2016). Yield and quality of fruits highly depend on the agro-ecological and climatic factors. Therefore, testing of ecological adaptability is a vital factor in the expansion of pineapples in Sri Lanka. Pineapple grow well under temperature range of 18-32 0C and both in the plains and in higher elevations up to 1,000 m from the sea level. Although the pineapple is a drought tolerant crop, it will produce fruit under annual rainfall ranging from 650-3,800 mm (Morton, 1987). Quality of pineapple varies due to growing environment, cultivation technique and variety (Hossain, 2016).

Present extent of pineapple cultivation is 4783 ha (Anon, 2017) and 76 % of the total pineapple production in Sri Lanka is from Kurunegala and Gampaha districts. However, cultivated extent in Kurunegala district has declined gradually while in Gampaha has increased by cultivating almost all available lands (Vidanapathirana et al., 2012). Therefore, it is timely important assignment to find other potential areas (i.e. non-traditional growing regions) for pineapple cultivation to increase the production.

MaxEnt is one of the accurate, increasingly popular and globally accepted machine-learning techniques use for niche modeling to predict the potential distribution of a species (Smith et al., 2012). This approach uses geo-referenced primary occurrence data for species, in combination with digital maps representing environmental parameters (model drivers) to build models characterizing ecological requirements of species (Babar et al., 2012). Predictive performance of MaxEnt is consistently competitive with the highest performing methods due to the relatively insensitivity to spatial errors associated with location data (Baldwin, 2009). Each geographic area is eco-geographically unique; the combination of geology, soil, latitude, longitude, climate, biota, ecological history, and anthropomorphic factors provides a unique range of constraints that define locality, these constraints then act on a species gene pool giving rise to unique patterns of genetic diversity associated with particular geographic locations (Maxted et al., 1995). MaxEnt estimate the target distribution by finding the distribution of maximum entropy subject to the constraint that the expected value of each feature under this estimated distribution matches its empirical average (Phillips et al., 2004). This study was carried out with the aim of mapping high-potential areas for pineapple cultivation in Sri Lanka using MaxEnt model and identify the constraints to promote pineapple cultivation in these areas. This will provide decisive guidance for pineapple growers to expand their cultivation by minimizing negative effects of climate and also important for investors as well as entrepreneurs to take information-based decision such as exploit the possibilities of getting high income by incorporating pineapple cultivation in the present farming systems in high-potential areas.

Methodology

Conceptual Framework

This study involved the pineapple location coordinates and environmental covariates covering whole Sri Lanka. All the environment covariates were derived using digital datasets acquired from free web sources. Google Earth Pro and ArcGIS (V10.3.1) software were used for pineapple location data processing, initial spatial data processing, and final mapping. Spatial analysis and modeling were done using MaxEnt software.

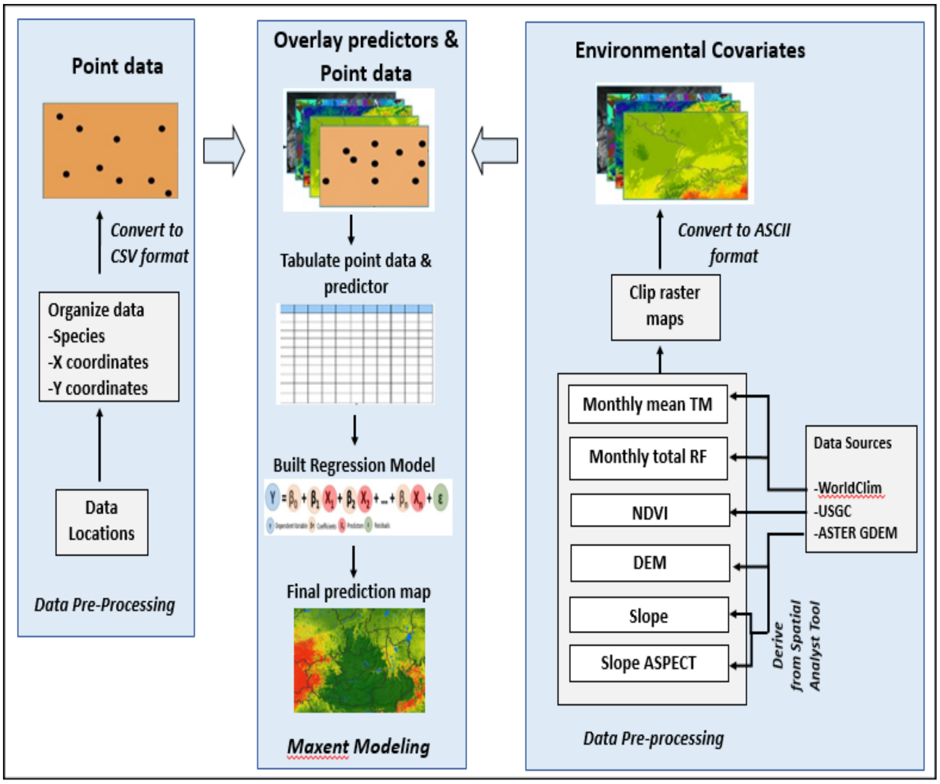

Figure 1: Conceptual Framework

Pineapple point data

GPS survey of 215 Pineapple occurrence data was conducted at several locations of Sri Lanka as shown in figure 2. Primary data was sustained by secondary data, which were collected from various reliable pineapple cultivation reports of department of export agriculture and several agrarian development district offices in Sri Lanka. Point map containing pineapple growing location were prepared with projected (UTM Zone-44N) coordinate system in ArcGIS (V10.3.1) and converted into a comma separated value (CSV) file format before incorporating it into MaxEnt software.

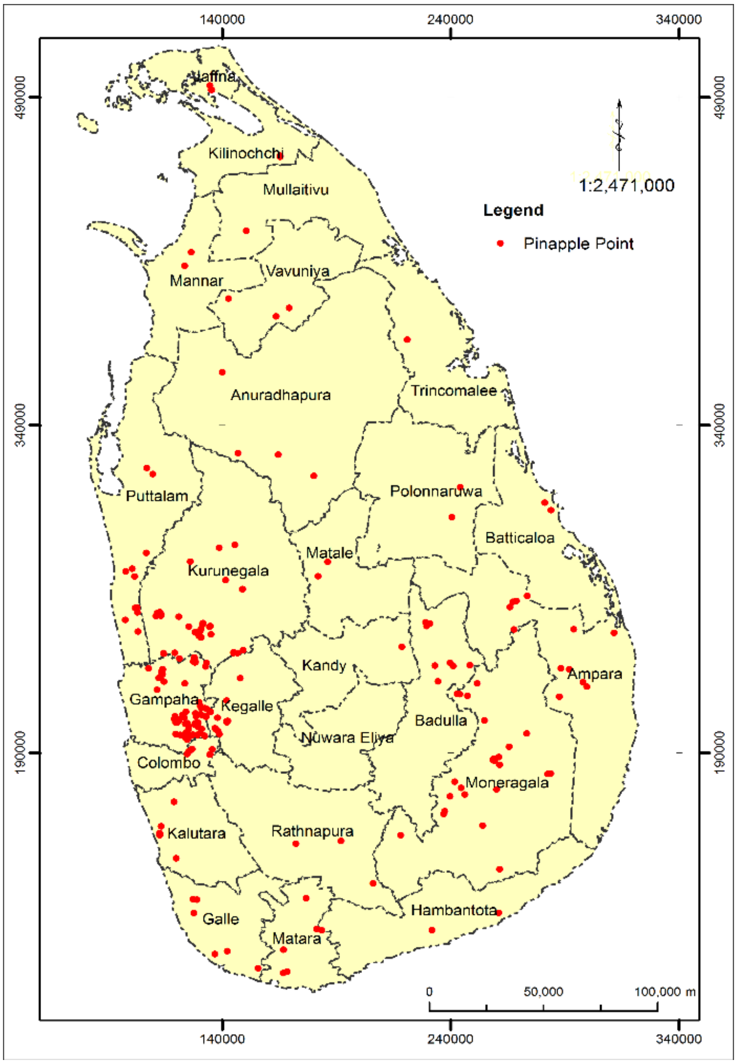

Figure 2: Point map of pineapple cultivation locations

Environmental Covariates

Twenty-four gridded environmental covariates namely monthly mean temperature and monthly rainfall maps (1 km spatial resolution) were acquired from free "worldclim" database which available online at http://www.worldclim.org/bioclim as climatic data. Normalized Difference Vegetation Index (MODIS NDVI) at 250 m resolution was acquired from USGS:http//modis.gsfs.nasa.gov. Due to cloud, 5 years mean data were considered as NDVI. Elevation data as digital elevation model (DEM) was acquired from ASTERGDEM 30 m raster free data set available as http://www. USGS.com. It was a map of surface elevation in meters above sea level at a spatial resolution of 30 m. Slope and slope aspect maps (30 m) were developed in slope calculation tool in ARC GIS spatial analysis tool set with DEM 30 m.

Table 1: Environmental variables used as covariates for spatial modeling

Variable	Description	Range of values	Scale or Resolution	No of layers	Source/ Development method
Tm	Monthly mean temperature (°C)	12.9-30.1	1km	12	www.worldclim.org
RF	Monthly Rainfall (mm)	5-679	1km	12	www.worldclim.org
NDVI	(Infra_Red-Red) /Infra_Red +Red)	-1 to +1	250m	1	modis.gsfc.nasa.gov
DEM	Elevation (m) from above sea level, derived from ASTER GDEM	0-2510m	30m	1	reverb.echo.nasa.gov
Slope	Slope Angle	0 - 75.5 degrees	30m	1	Derived from ASTER GDEM using ArcGIS spatial analyst
Slope Aspect	Slope facing direction (angle clock wise reference to north)	0-360° Slope facing direction	30m	1	Derived from ASTER GDEM using ArcGIS spatial analyst

Spatial Data Processing

All environmental input layers (covariates) were processed to produce set of raster maps with consistent grid snapping in same projected geo-reference (UTM Zone-44N) taking NDVI (250 m) as the base map in Arc GIS software. Then all grid maps were converted into ASCII format using the same software to make compatible spatial data set to use as spatial modeling inputs.

Running the MaxEnt Modeling

Maximum Entropy Modeling version 3.3.3 k acquired from free web sources was employed for the model run for *Ananas comosus* species (Pineapple) with the selected environmental covariates, which were converted in to ASCII format.

Identification of the Constraints of Pineapple Farmers

Data Collection for Survey

Primary data were collected using a structured questionnaire from face to face interview during the period from August to September 2018. Sixty pineapple farmers were selected from four divisional secretariat divisions of Gampaha and Kurunegala districts using the cluster sampling technique (Figure 3).

Data Analysis for Survey

The data were analyzed using both descriptive and inferential statistics. Descriptive analysis was performed to get a clear picture on characteristics of the sample. Wilcoxon signed rank test was employed to identify the significant constraints for pineapple farmers.

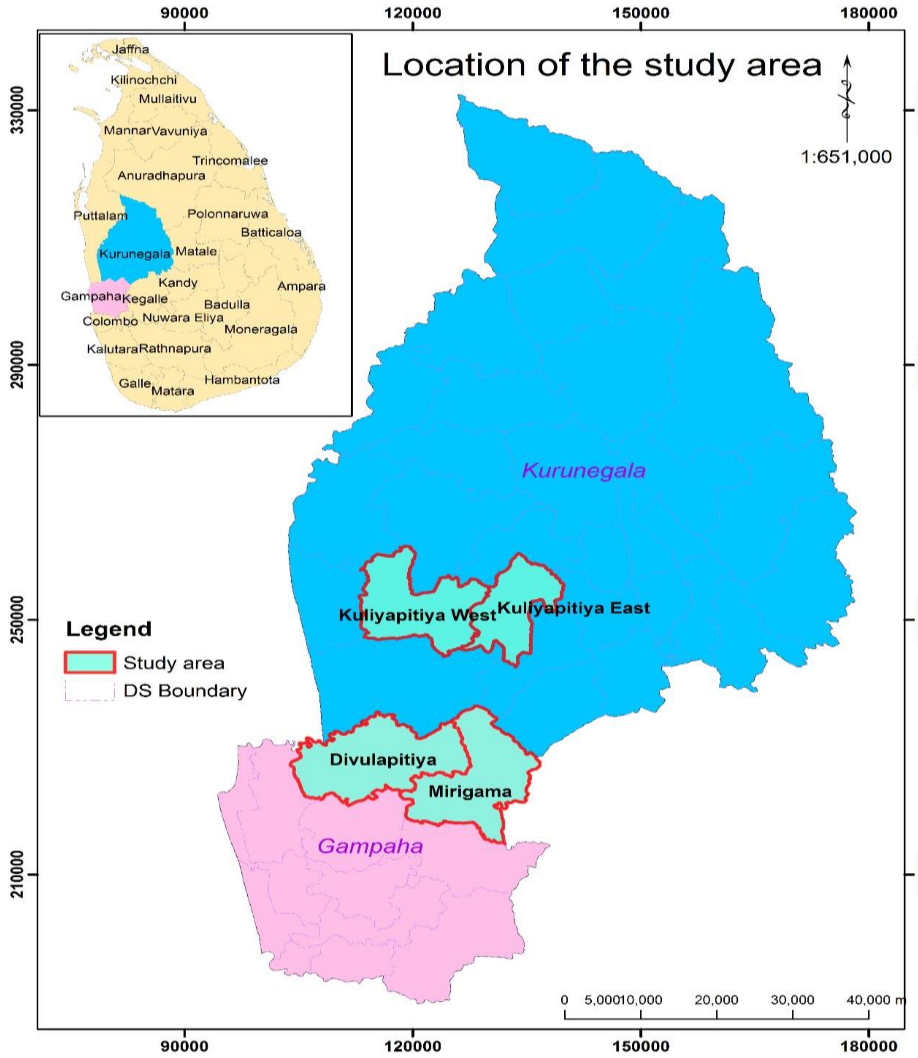

Figure 3: Study area

Results and Discussion

The model was found to have a high predictive power or good discrimination ability with high AUC training value of 0.913 for *Ananas comosus*. The AUC value is good statistical measure to evaluate the discrimination ability of species distribution models. (Kariyawasam et al., 2017).

According to jackknife test (Figure 4), mean temperature in drier months and total rainfall during wet months shows relatively high correlation with pineapple growth. Monthly average temperature during November to February are the most important covariates linked with predictability of best growing locations of pineapple. Although NDVI shows lower predictability individually, when it is omitted, overall predictability will be the lowest when compared with all the other covariates. Slope and slope aspect show weak predictability as covariate for selecting pineapple cultivation locations. These two are the less importance variables for model prediction.

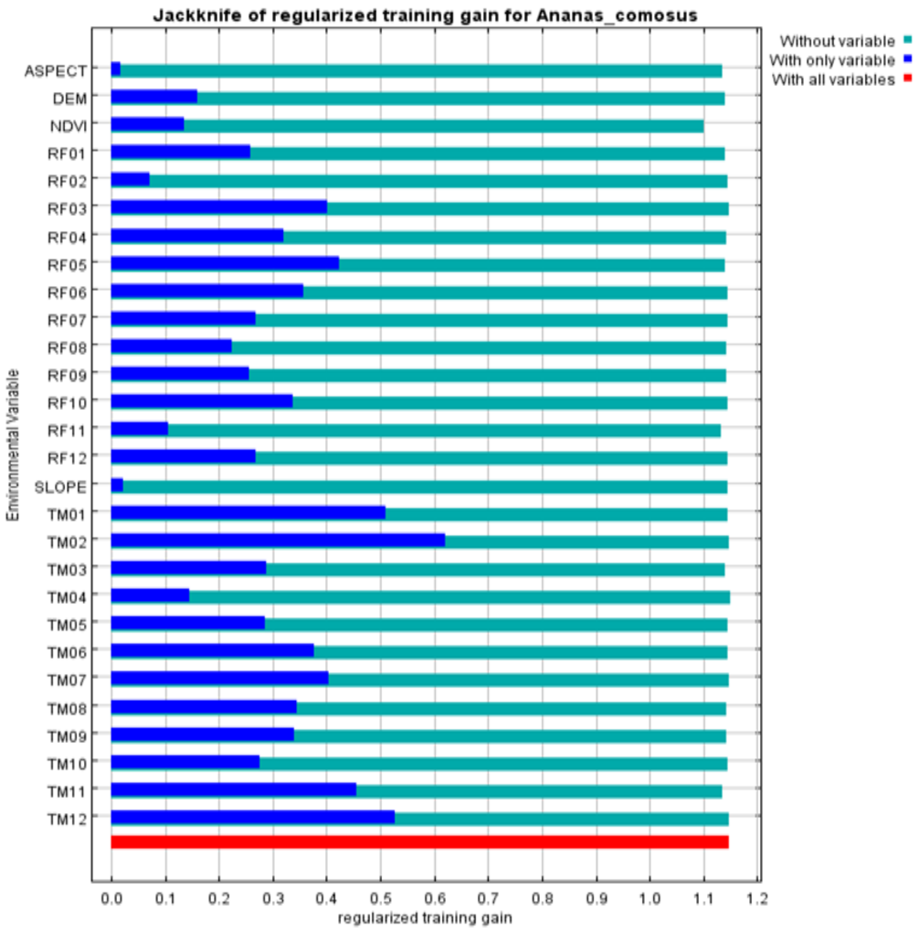

Figure 4. Results of jackknife test of variable importance in the regularized training gain for Ananas comosus. *RF 01- RF12: Monthly rainfall from January to December, TM 01-TM 12: Monthly mean temperature from January to December*

Figure 5. Shows the final Maxent probability prediction map of *Ananas comosus* species based on environmental and geographical variables. High probability of distribution

shows in reddish orange and low to zero probability is represented with light green to dark green. High-potential areas of pineapple cultivation mainly lies in most part of Western, North-Western provinces and some parts of Uva, Eastern, Southern, Sabaragamuwa Provinces of Sri Lanka which is indicated in reddish orange color. Nothern, Central, North Central provinces and some parts of Eastern province show very low potential for pineapple growth which is indicated in dark green color. Areas indicated in Yellow color have a middle potential for pineapple growth.

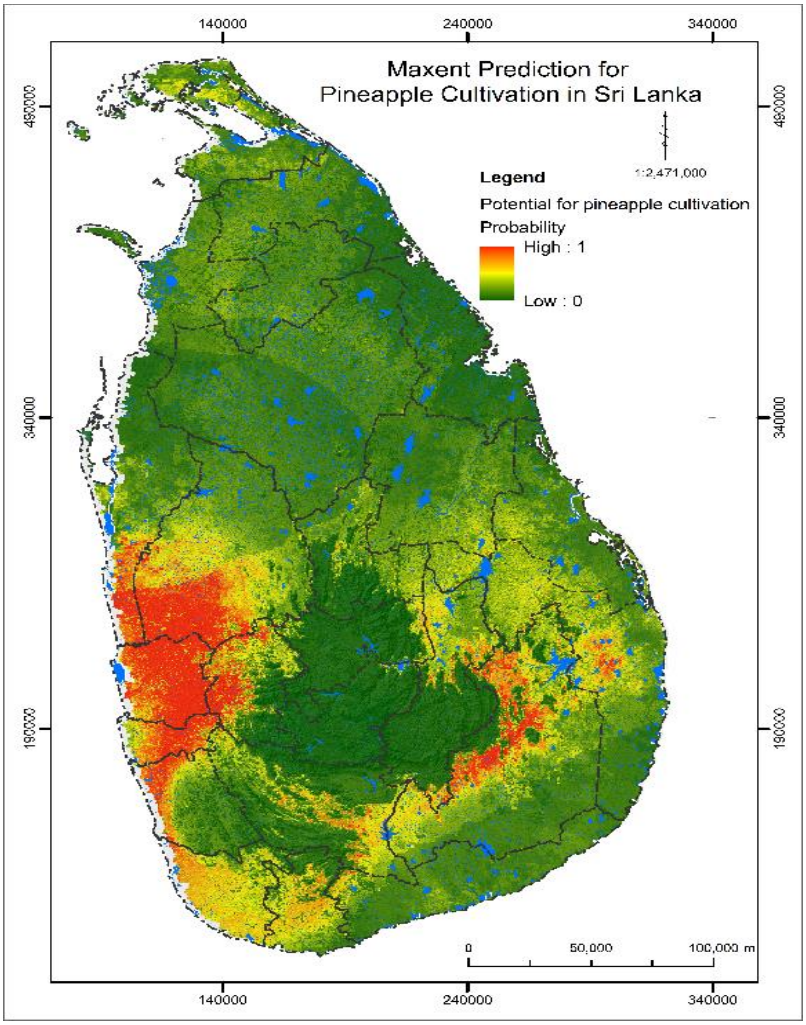

Figure 5: MaxEnt prediction map for pineapple cultivation in Sri Lanka.

In addition to mapping high potential areas of pineapple, a questionnaire survey was conducted to explore the prevailing conditions and constraints related with these areas. Although mapping was carried out for entire country, this survey was carried out only for the Gampaha and Kurunegala districts. These two districts were selected as the majority (76 %) of the total pineapple production in the country is from these two districts.

Basic Descriptive Indicators of Pineapple Farmers

According to the Table 2. Majority of pineapple farmers (37 %) belonged to age category of 60 years or above and 55 % had completed only up to O/L as their highest education level. Land extent of most of the farmers (58 %) for pineapple cultivation varies between 1-5 acres. Forty five percent of the farmers' annual income is more than Rs.100, 000 and pineapple cultivation is an extra income for majority of farmers (70 %). Fifty three percent of the farmers stated that fertilizer is the main cost component of the pineapple cultivation. Although majority (93 %) use chemical fertilizer, most of the farmers (57 %) willing to convert their cultivations into organic cultivation. But out of the total farmers, 31 % mentioned that lack of availability of organic fertilizer is the major problem of organic cultivation. Thirty five percent of the farmers are requesting for monetary subsidy while 25 % of them request for land facilities in order to initiate pineapple cultivation.

Outcomes of Wilcoxon Signed Rank Test

Twenty-four common constraints related to the pineapple cultivation (Table 3.) were identified and they were ranked by the respondents using 5-point Likert scale, where rank 5 indicated the lowest agreement on particular constraints and one indicated highest agreement while 3 indicated neutral view. According to the Wilcoxon sign rank test carried out to find out the significant constraints; C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, and C15 constraints were significant problems ($p < 0.05$) while C16, C17, C18, C19, C20, C21, C22, C23 and C24 were not significant. Some of the major problems are explained below further.

Among the constraints, it is highlighted that both high cost of inputs and lack of subsidy schemes are highly significant production constraints to the pineapple cultivation. It may be mainly due the high price of chemical fertilizers and pesticides used for pineapple cultivation. Despite different form of subsidy schemes have been introduced for many crops by the government, it is surprising to note that many farmers under study were not beneficiary of such schemes. Therefore, it has become serious problem among the pineapple farmers.

Although most of field crops like rice, maize, potato, onion have guaranteed price there is no guaranteed price for fruits and vegetables. It is a major drawback in Sri Lankan agricultural policy. So many pineapple farmers suffer from this problem, as they cannot cover even the production cost.

High labour cost and scarcity have become serious constraints. It may be mainly due to the more job opportunities close to urban areas. High price of mulching materials is another highly significant production constraint. It mainly due to the shortage of coir dust as it is excessively utilized for various industries and export purposes. This has increased the coir dust price and most of the farmers unable to utilize coir dust for mulching purposes due to this high price. These are some major problems addressed with high priority to uplift the pineapple farmers.

Table 2: Descriptive statistics of the sample

Variables	Category	Percentage (%)
Age	30 to 39	8
	40 to 49	27
	50 to 59	28
	60 and over	37
Level of education	Grade 8	5
	O/L	55
	A/L	37
	Degree	3
Extent	Less than 1 ac	17
	1-5 ac	58
	6-10 ac	7
	Above 10 ac	18
Experience	Less than 1 year	5
	1-5 years	43
	6-10 years	22
	Above 10 years	30
Annual income	Rs.10,000-49,999	20
	Rs.50,000-99,999	35
	Rs.100,000 and over	45
Income sources	Major	30
	Extra	70
Highest spent	Fertilizer	53
	Labors	22
	Planting materials	25
Fertilizer type	Chemical	93
	Both chemical and organic	7
Willingness to convert to organic	Yes	57
	No	43
Reason for not willingness	Failures in uniform harvesting	12
	Lack of availability of organic fertilizer	31
	Low productivity	15
	Bulky	19
	High cost	15
	Other	8
Need	Monetary subsidy	35
	Land	25
	Higher prices	3
	Technical knowledge	3
	Quality planting material	17
	Fertilizer subsidy	17

Table 3: Results of Wilcoxon Signed Rank Test

Abbreviation	Constraints	Wilcoxon statistics	P value
C1	Lack of guaranteed price	0.0	0.000*
C2	High investment	112.5	0.000*
C3	High cost of inputs	0.0	0.000*
C4	High labor cost	85.0	0.000*
C5	Lack of labor	216.0	0.000*
C6	Lack of government subsidy scheme	36.0	0.000*
C7	High Price of mulching materials	71.5	0.000*
C8	Weed problem	67.5	0.000*
C9	Not being able to bargain the price	193.5	0.000*
C10	Threat of mealy bug attack	310.0	0.000*
C11	Threat of pineapple wilt disease	344.0	0.001*
C12	Climate change (drought and rainfall)	686.0	0.046*
C13	Less land availability	442.5	0.001*
C14	Lack of technical knowledge	396.0	0.004*
C15	Lack of good varieties	356.5	0.006*
C16	Lack of planting materials	1166.5	0.983
C17	Lack of quality of the fruit	1039.5	1.000
C18	Lack of awareness of potential areas	846.0	0.924
C19	Problems on receiving money from buyers	1523.0	1.000
C20	Post-harvest losses	1006.0	0.998
C21	Lack of storage facilities	1051.0	1.000
C22	Inefficacy of distribution channel	1037.0	0.999
C23	High cost of transportation	1596.0	1.000
C24	Lack of opportunities to sell the final product	1060.5	0.984

*Note: *Significant at 5% level*

Conclusions

This research evaluated the applicability of MaxEnt model for predicting potential areas for pineapple cultivation based on best growing locations and agro-ecological covariates covering whole Sri Lanka. Probability of pineapple cultivation potential was mapped at 250 m ground resolution with a high predictive power (AUC value of 0.913). According to jackknife test, monthly average temperature during November to February are the most important covariates linked with predictability of best growing locations of pineapple and model resulted some parts of Ampara, Monaragala, Puttalam Colombo, Kaluthara, Kegalle, Badulla districts having high-potential for pineapple cultivation in addition to traditionally grown districts which are Gampaha and Kurunegala. Evaluation of constraints in pineapple cultivation shows that, high cost of material inputs, high price of mulching materials, high cost and shortage of labor, high initial investment, lack of government subsidy schemes, less land availability, threat of diseases (wilt and mealy bug), climate change, lack of technical knowledge, weed problem, shortage of good varieties, lack of guaranteed price and low bargaining power are the most critical production and marketing constraints which should be addressed with high priority to uplift pineapple cultivation. Further studies with more covariates and more location data are suggested to improve the accuracy level. This method may be useful to find out the most suitable areas for other crops. Further, map developed by MaxEnt can be used as input data for diverse studies.

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