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Evaluation of productivity of potatoes in Nuwara Eliya and Badulla districts with the aid of GIS techniques

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Abstract

GIS based model was used as spatial biophysical model to evaluate productivity of potatoes in Nuwara Eliya and Badulla Districts. A field survey was conducted in central hills of Sri Lanka under field conditions in *yala* and *maha* seasons during 2003-2005. Results revealed that fresh tuber yield performance of potatoes varied markedly as a function of seasonal climatic variations, soil chemical properties and applied cropping systems. The *yala* season being relatively drier than *maha* season produced a remarkably higher potato tuber yield than that of *maha* season during 2003-2005. It was also observed that paddy field grown potato plants were free from bacterial wilt disease whereas late blight was the major destructive disease. Reduction in tuber yield was positively correlated with wilt and late blight diseases. According to the composite scores in GIS model the highest score was recorded in Welimada in *maha* season. However, Medawela recorded the lowest value due to deviation from optimum soil pH. In *yala* season the highest composite score was recorded in Boralanda which is compatible with benefit to cost ratio of Boralanda. In both *yala* and *maha* seasons composite scores and average fresh tuber yield were positively correlated in all clusters. According to the results the average highest yield during three year period (2003 -2005) was recorded in Boralanda and Welimada clusters in *yala* and *maha* seasons respectively. Results of the present study revealed that Granola produced higher yields constantly for the six seasons throughout the study period under climatic conditions of central hills of Sri Lanka.

Key words: Productivity, GIS model, tuber yield, cropping systems

1. Introduction

Potato (*Solanum tuberosum* L) is a cool-season vegetable that ranks with wheat and rice as one of the most important staple crops in human diet around the world. Potatoes are not roots but specialized underground storage stems called "tubers". At present potatoes are extensively cultivated in highlands ofNuwara Eliya district and midlands of Badulla district. The potato is a highly profitable crop for farmers in

Nuwara Eliya and Badulla districts, however the average productivity of potatoes in Sri Lanka is about.12 t/ha, and it is comparatively lower than the productivity of India (16 t/ha). The cost of production is very high (Rs.40-50/kg) since seed potatoes are very expensive (Rs.80-100/kg) and accounts for more than 50% of the total cost of production (Nugaliyadde, 2003). Mazeen *et al.*(2002) reported that there were 9000 ha of land under potato cultivation in Sri Lanka, mainly in Badulla and Nuwara Eliya districts and to a lesser extent in lower elevations.

The major potato growing seasons in Nuwara Eliya district is *"yala"* (February –May) and minor season is *"maha"* (September – December). Planting is avoided during May -July because of heavy wind and rain, and in December and January due to night frost. In Nuwara Eliya district imported seed potato is used to produce the *yala* season crop while for the second crop (*maha*), *yala* produced tubers are used for planting. Potatoes are also widely cultivated in Badulla district during *yala* and *maha* seasons, in *"yala"* (May – August) in paddy fields following rice harvest and in *"maha"* (November –February) in highlands. In the Badulla district also imported seed potato is used for *maha* season crop whereas *yala* planted crop is grown from the seed tubers harvested in *maha* season.

Nugaliyadda *et al.* (2005) reported that the annual potato productivity during last decade remained at an average of 12 t/ha due to non-availability of good quality, disease free seeds of desirable varieties at the correct time for planting. The production is not sufficient to meet the demand of the country. Productivity is determined by the trend in adoption of technology such as selecting high yielding and disease resistant varieties, irrigation methods, fertilizer and pest and disease management conditions. Poor adoption of technology increases cost of production and gives a low profit margin.

Pests and diseases cause economic losses to growers, and result in increased prices of products to consumers. It has been estimated that 11.8% of the total food produced in the world is lost due to diseases before the harvest of the crop. With regard to potatoes, 21.8% of potato crop is lost due to diseases (Babu and Malathy, 1998).

Study area and its physiographical environment

The study area (Central hill country) falls within intermediate and wet climatic zones of Sri Lanka which receive average annual rainfalls of 1500-2250 mm and >2500 mm, respectively. Mean annual temperature of the study area belongs to two zones ranging between 15 –22 (Badulla) and 10-15 ^{0}C (Nuwara Eliya). Agro-ecological regions of the study area are Up-Country Wet Zone (1,2,3) and Up-Country Intermediate Zone (1,2,3). Geomorphological features of the area are mainly high elevated ridges and mountain ranges, plateau and undulating plains and basinal structures. Examples are Uva Basin, Pidurutalagala ridge, Horton Plain, High Plain and Idalgashinna-Ohiya ridges. The relief of the area is over 900 m.

Application of Geographic Information System for evaluation of potato cultivation in Sri Lanka

Land evaluation is a basic technique and often used for land-use planning and for estimating land productivity for a selected crop. Different empirical modelling approaches to predict land productivity for crops under the wide range of weather and soil conditions have been described. Most of these models are designed to use available climatic and soil information as statistical averages and generalized crop phenology. A production situation is a hypothetical land-use system, with one or only a few relevant land characteristics and/or land qualities, and the calculated production is not an actual value, but a potential production (Pratummintra *et al.*, 2002).

However, modelling and handling of geographic data for decision making is very important in any aspect; specially in agricultural sector, if there is a user friendly method for decision making, it is the most worthwhile exercise. Therefore, Geographical Information System (GIS) plays a remarkable role in the Agriculture sector. GIS is a set of computer tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world. GIS has become quite popular and its use in all countries is still growing. Handling the variability in climatic conditions and soil information can be approached through the use of GIS. By using GIS techniques, it is possible to produce thematic maps as an out put, with information on the impact of differences in climate and soil on land productivity for a specific crop.

In Sri Lanka, potato cultivation is restricted to very few districts and to small clusters, and it is not easy to maintain a database and model them. However, in this study it was aimed to use GIS as a modern, computer based, powerful tool for modelling potato cultivation in Sri Lanka in order to assess the land, environment and seasonal variance in Nuwara-Eliya and Badulla districts. All factors, which are important for potato cultivation are studied and analysed to determine significant effects on the production.

2. Materials and Methods

Field survey

Five clusters were selected from Nuwara Eliya and Badulla districts on the basis of harvesting pattern, climatic conditions and other geographical parameters for evaluation of productivity of potatoes. The five clusters were named as Nuwara Eliya, Welimada, Boralanda, Haputale and Medawela (Figure 1). Thereafter the field survey was carried out in *yala* and *maha* seasons in 2003 and 2005, with 80 potato farmers in Nuwara Eliya and Badulla districts in the up-country where potatoes are cultivated extensively; there was about 5747 ha of land under potato cultivation in these two districts. The selected 80 farmers were interviewed by using a comprehensive questionnaire. Farmers were selected randomly by talking to villagers and looking at cultivated fields. Most fields were small and ranged from 0.1 – 0.2 ha.

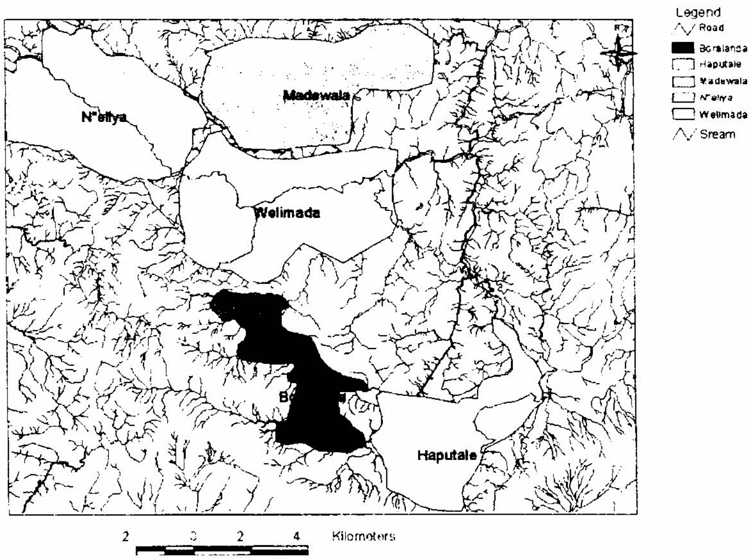


Fig 1. Cluster map of potato growing areas

The information on the production was collected by interviewing farmers and inspecting their fields during growing seasons. Regular monitoring was done in selected fields in the study area. Information on seed potato, variety, cropping system, time of planting, pest and disease management, irrigation, harvesting, yield, selling prices and constraints were recorded using a structural questionnaire. The profitability analysis of potatoes and percentage share of each constraint were also calculated. The ground truth data on potato cultivation in 2003 were collected by the available data taken from farmers in the study area and they were used to compute the productivity in 2003.

Soil Properties

Sampling and soil preparation

Soil samples were taken randomly from 0 –20 cm depth from each experimental site covering uplands and lowlands (paddy fields) where potato has been grown. All samples were sieved through 2.0 mm sieve separately. Sub-samples of each soil were air dried and analysed for chemical and physical properties.

Chemical properties of soils

Soil analysis for available nutrient status

An air-dried soil sample (5.0 g) was weighed and mixed with 0.5N HCl and shaken overnight. Then the mixture was filtered into 100 ml volumetric flask and diluted up to 100 ml and the resultant filtrate was used for analysis of N, P, K, Ca and Mg. Total

N was determined after adding 1:1 HCl to the filtrate and measuring photochemical absorbance using UV-Visible spectrophotometer. Total P was determined by colorimetric method with Ammonium Vandomolybdate. K, Ca and Mg were determined using an Atomic Absorption Spectrophotometer (AAS).

Organic carbon in soils

Modified Walkely and Black method (1965) was used to measure organic carbon of the soils.

Soil pH was measured with a glass electrode using a soil: water ratio of 1: 2.5.

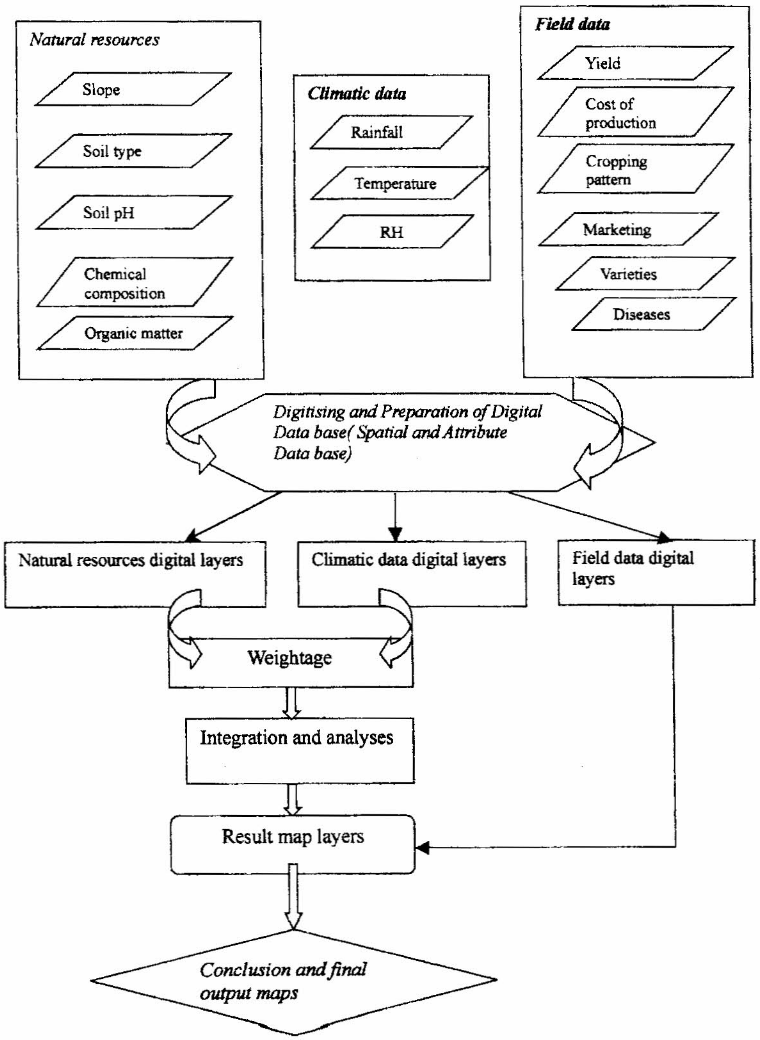


Fig 2. GIS based crop production model

GIS Procedure

Following data were used for GIS analysis

Available data

1:10,000 and 1:50,000 topographic maps published by Survey Department of Sri Lanka (1996).
Aerial photographs of 1:20,000 (1999) from the Survey Department of Sri Lanka.
Geological map (1:100,000), published by Geological Survey and Mines Bureau (1998)
Daily and monthly rainfall and temperature data from the Department of Meteorology, Sri Lanka.
Agro-ecological zones of Sri Lanka.

Secondary Data

Soil Chemistry.
pH.
Soil texture, types, and moisture content.
Cultivation data (variety, cost, yield, diseases, seasons).

Procedure

The topographic map of the study area was scanned and geo-referenced.
On screen digitising was done and following digital map layers were prepared:

Vector map of contour with attribute.
Vector map of Cluster boundary (5 clusters).
Road map (vector).
Drainage map (vector).

Aerial photographs were studied using standard Mirror Stereoscope and potato-growing areas were demarcated.

Following map layers were prepared using processed secondary data

Polygon map of rainfall.
Polygon map of benefit to cost ratio.
Polygon map of soil chemistry.
Raster map of slope.
Polygon map of soil nutrients.

Suitable links between spatial and attribute data were created
Data analysis and overlay operations were made.
Weighting, rating and classifying suitability factors were done.
The four suitability aspect maps were combined into a composite suitability map by simple addition of the suitability weighting system. Weighting could be applied when all aspects did not have an equal importance.

Table 1. Weighting of parameters

Class code	Class	Score in map suit-score						
		Rainfall mm *Maha*	Rainfall mm *Yala*	Potassium ppm	Phosphorus ppm	Organic matter %	C:N	pH
1	Unsuitable	>850	<200	<100	1000-1450	<1.0	<6.0	<5.0&>6.1
2	Marginally suitable	400-500	200-300	100-200	500-600	1.0-1.5	6–10	5.0 - 5.3
3	Suitable	700-800	300-400	200-250	600-800	1.5-3.0	>12.0	5.3 - 5.5
4	Highly suitable	500-600	>400	>250	800-1000	>3.5	10-12	5.5 - 6.0

pH

The optimum pH is about 5.5 –6.0. Very acidic soils make small potatoes.

Rainfall

Higher rainfall affects the tuber yield because it is favourable for occurrence and spread of late blight. Too much of water or too little water will affect tuber number, size and quality.

Potassium (K)

The potato is a heavy feeder in terms of potassium. (Peet,www.cals.ncsu.edu/)

Phosphorus (P)

The potato is a heavy feeder in terms of phosphorus. (Peet,www.cals.ncsu.edu/), but phosphorus has an antagonistic effect on uptake of K by plants.

Organic matter

Application of 10 –12 t/ha of well rotted cattle manure or compost in furrows before planting will improve the growth and increase the yield.

Nitrogen (N)

N must be carefully managed to provide adequate but not excess amounts. The usual ratio of carbon to nitrogen in the majority of cultivated soils is between 1-12. Narrow ratios are not common in most productive soils. Ratios above 12 are common in nitrogen deficient soils (Allison, 197

3. Results

The survey revealed that farmers in Nuwara Eliya district grew potatoes in lowlands twice a year in both y*ala* and *maha* seasons and in uplands only in *maha* season. Vegetables were grown in between potato cultivations in Nuwara Eliya district. Farmers in Badulla district grew potatoes in lowlands once a year after harvesting rice and in uplands only in *maha* season. They grew vegetables in uplands before growing *maha* season potato crop. Major vegetable types grown in potato farms were beans, cabbage, carrots, leeks, beetroot, radish and salad leaves.

Table 2. Cropping systems adopted by farmers

District	Season	Land class	Cropping pattern	Irrigation
Nuwara Eliya	*Yala*	Lowland	Veg.-potato-veg-potato	Rain water
	Maha	Upland	Veg.-potato-veg.	Rain water
Badulla	*Yala*	Paddy fields	Paddy-potato-veg.	Irrigation
	Maha	Upland	Veg.-potato-veg.	Rain water
	Maha	Upland	Fallow-potato	Rain water

*Veg.=Vegetables

Varieties Grown in Nuwara Eliya and Badulla districts

Though the Department of Agriculture has recommended a number of potato varieties for cultivation in Sri Lanka the main grown commercial varieties were Granola, Desiree, Lyra, Raja, Binella and Arnova. Granola was the popular one among farmers because its potential for high yield and relatively short time required for tuber maturity despite relatively low resistance to late blight.

The average yield performance of the potato varieties grown in *yala* and *maha* seasons over three years (2003 – 2005) at five clusters are tabulated separately (Tables 3 and 4).

Table 3. Yield performance of potato varieties during *yala* season in 5 clusters (t/ha).

Yala					
Variety	N'Eliya	Welimada	Boralanda	Haputale	Medawela
Granola	24.0	23.4	28.1	20.0	21.0
Lyra	20.0	16.3	-	-	--
Raja	-	-	-	-	-
Desire	-	15.0	-		-
Arnova	-	21.3	-	-	-
Binella	-	-	27.5	-	-
Ricolta	-	-	-	18.8	-

Table 4. Yield performance of potato varieties during *maha* season in 5 clusters (t/ha).

Maha					
Variety	N'Eliya	Welimada	Boralanda	Haputale	Medawela
Granola	20.4	21.4	21.5	20.6	13.3
Lyra	-	20.3	-	-	-
Raja	15.0	-		-	-
Desire	-	21.7	-	20.0	12.5
Arnova	-	-	-	22.5	-
Binella	-	-	17.5	7.5	-

The highest yield was recorded from Granola in all the clusters in *yala* season while Binella showed the second best performance. In *maha* season Granola recorded the highest yield in three clusters except Welimada and Haputale where Desiree and Arnova recorded the highest yield respectively. It was also observed that there was no remarkable yield difference among the three high yielding varieties. Granola, Desiree and Arnova performed well under rainfed conditions. The variety showing the highest average tuber yield was selected as the most suitable variety for the location and the season.

Soil chemical properties

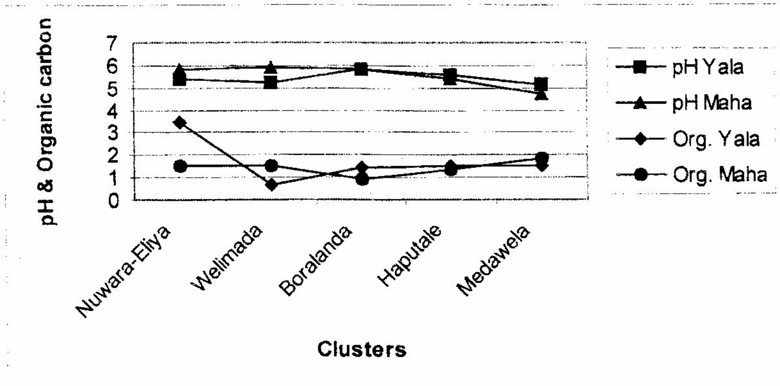


Fig 3. Mean soil pH and organic carbon % in different clusters

It is evident from the results that there is no significant difference between lowland and upland soil pH in different clusters (Figure 3). All soils were acidic in reaction and low in organic matter except Nuwara Eliya lowlands. Results also show that all soils were within the suitable pH range for potato cultivation (5–6) except Medawela uplands, which had a soil pH less than 5.

Rainfall pattern

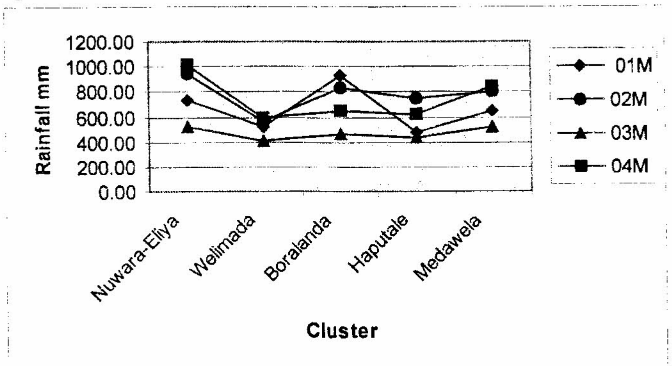


Fig 4. Rainfall over *maha* seasons in different clusters

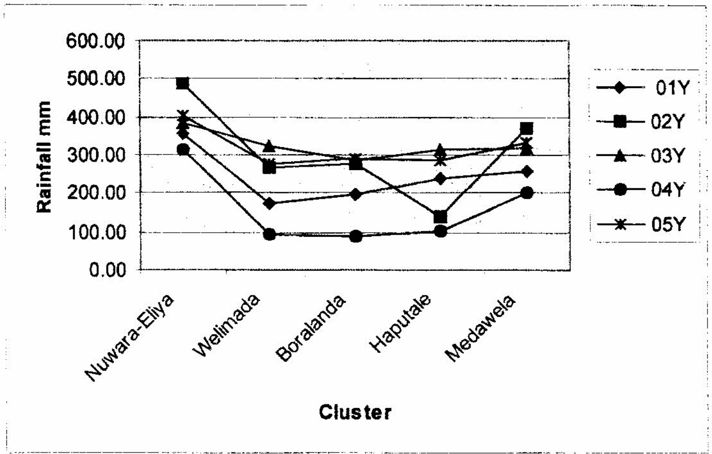


Fig 5. Rainfall over *yala* seasons in different clusters

Rainfall pattern of the years showed that heavy rainfall was experienced during *maha* seasons than *yala* seasons (Figures 4 and 5). *Maha* season is a wet season with a weekly average of 4 –5 rainy days (Babu, 2005).

Fresh tuber yield performance of the potato varied with seasons (Figures 6). Generally the *yala* season, being relatively drier than the *maha* season produced a remarkably higher potato tuber yield than that of wet *maha* season irrespective of soil nutrient levels.

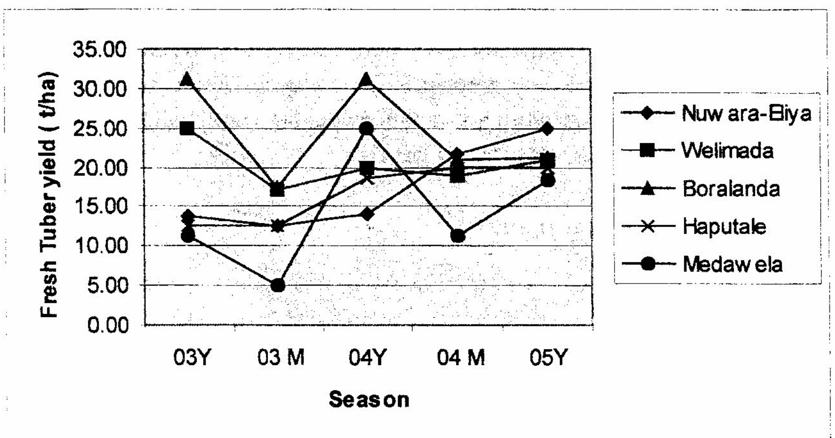


Fig 6. Average tuber yield in different clusters over seasons

According to the composite scores in GIS model (Figures 7 and 8) the highest score was recorded for Welimada in *maha* season (22). This is because Welimada received favourable rainfall, soil pH, amounts of organic matter and nitrogen during growing seasons. However, Medawela recorded the lowest value (10) due to deviation from optimum soil pH, and lack of availability of P and K to the plants. In *yala* season the highest composite score (17) was recorded in Boralanda which is compatible with benefit to cost ratio of Boralanda. Haputale and Nuwara Eliya (15) had lower scores due to excess nitrogen and calcium, which affect tuber yield in lowlands.

In both *yala* and *maha* seasons composite scores and average fresh tuber yield are positively correlated (Figure 6,7 and 8). It is evident from the results that the average highest yield during three-year period (2003 –2005) was recorded in Boralanda and Welimada in *yala* and *maha* seasons, respectively

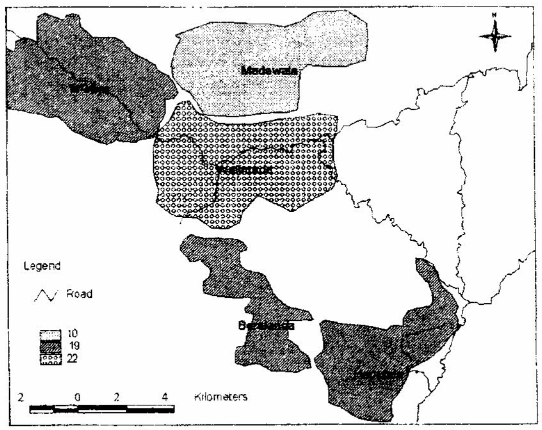
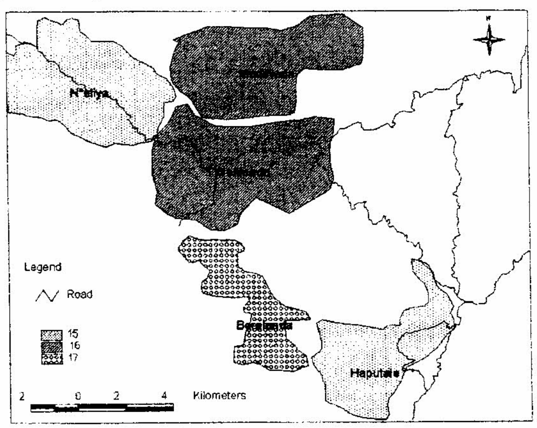


Fig 7. Composite map of *maha* season



Fige 8. Composite map of *yala* season

Occurrence of diseases

Following diseases were observed in both districts during the study period
Early blight of potato caused by *Alternaria solani.*
Late blight of potato caused by *Phytophthora infestans.*
Bacterial wilt of potato caused by *Ralstonia solanacearum.*

Bacterial wilt was reported in upland grown crops in both districts at different damage levels. Some potato fields were badly affected by wilt and caused remarkable yield loss. It was also observed that paddy field grown potatoes were free from bacterial wilt, and late blight was the main destructive disease in those potatoes (Table 5). It was also observed that all commercial varieties were susceptible to late blight and wilt during *maha* season, which could be attributed to the decrease in productivity.

Table 5. Effect of diseases on fresh tuber yield (t/ha)

Village	Variety	Diseases	Fresh tuber yield t/ha	Land use
Katumana	Granola	Late blight	12.5	Carrot-potato
Suwadelpola	Raja	Wilt and seed rot	5.0	Bean - potato
Dikkapitiya	Granola	Tuber rot	12.5	Fallow - potato
Mirahawaththa	Granola	Blight, wilt	12.5	Cabbage potato
Kalubululanda	Binella	Blight	15.0	Radish-potato
Haputale	Desiree	Blight .wilt	7.5	Bean-potato
Uvaparanagama	Granola	Blight, wilt	11.3	Fallow- potato
Uvaparanagama	Desiree	Blight	10.0	Paddy-potato
Uvaparanagama	Granola	Blight, seed rot	5.0	Paddy-potato

Granola fresh tuber yield remained 20 –28 t/ha in *yala* season (Table 3) i.e. 8-12 kg of marketable tubers from each kilogram of seed planted. The diseases have severely affected tuber yield (Table 5), which in turn reduced the net profit to the farmer.

Marketing

Majority of farmers sell their products to Pettah, Haputale and Keppetipola market and a few sell to private dealers at the farm gate. The selling prices were recorded separately for 5 different clusters.The cost of cultivation was calculated in each season in each cluster using expenditure over potato growing period excluding labour inputs. Since labour inputs were shared among family members of farmers at different levels, labour cost cannot be estimated.

The income from potato cultivation was calculated by multiplying average price and average production. The income and cost data for seasons from 2003 to 2005 were used to calculate benefit to cost ratio of each cluster (Figures 9 and 10)). These data were used to study seasonal price fluctuations and yearly fluctuations.

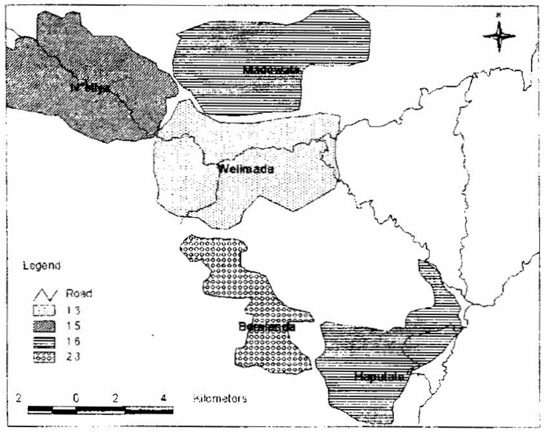


Fig 9. Map of benefit to cost ratio in *yala* season

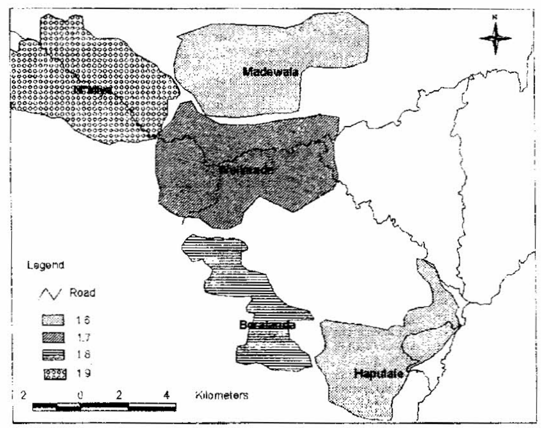


Fig 10. Map of benefit to cost ratio in *maha* season

4. Discussion

The crop yield is determined by irrigation, fertilizers, crop protection measures and cropping systems. Therefore, the above parameters imply that crop yield vary from field to field within the same cluster and a generalised productivity model for the entire locality may not give benefit to all categories of farmers in the potato growing area.

Water supply is one of critical factors that limit the extent of potato cultivation in the up-country. In hills where potatoes are planted in *maha* season, it is difficult to regulate moisture content because potatoes have to be grown as a rainfed crop. Research and agronomic practices have revealed that irrigation at the time of tuber initiation leads to an appreciable improvement in the potato yield. Fertilizer is another expensive input, second only to the seed cost in potato cultivation.

Optimum fertilizer application for maximum yield under different agroecological conditions will help farmers tremendously to reduce cost of production, which is the key factor affecting net income.

Currently a wide range of new varieties is being assessed for suitability for cultivation in up-country (Babu *et al.*, 2005). According to the survey the main variety cultivated during study period was Granola. It is extensively cultivated because it is early maturing (60-75 days), high yielding and produces a high proportion of large sized tubers. However, the main reason for its popularity is due to slower rate of seed degeneration, due in part to its resistance to potato cyst nematode (Batt, 1999). Though Granola was popular among farmers, it is susceptible to late blight and wilt diseases. Further, Granola and Binella in Boralanda cluster were comparable in terms of yield, showing their suitability to up-country intermediate zone for *yala* season in lowland cultivation, whereas Granola, Desiree and Arnova are suitable for *maha* season in upland cultivation. Results of the present study revealed that Granola produced higher yield constantly for the six seasons throughout the study period under climatic conditions of central hills of Sri Lanka.

In Badulla district, *yala* season potatoes are planted in flood irrigated paddy fields in which most of the wilt causing bacteria in the soils are killed due to anaerobic condition and most potato crops are free from wilt disease (*R.solanacearum)*. Babu (1998) reported that 21.8% of the total potato crop is lost by potato diseases. Raja, Escot and Maranka varieties possess high level of late blight tolerance. Hillstar possesses high level of resistance to late blight. Since farmers have to purchase whatever seed potatoes available in the market during planting time, they do not have an option to get suitable disease resistant varieties at the planting time. Most farmers applied recommended fungicides and protectants in time and managed to minimise disease level and to keep the loss below an economic injury level. Meanwhile, some farmers were unable to protect their crop from late blight spread due to heavy rain, which was beyond farmers' control. Bacterial wilt was also reported in upland grown crops in both districts at different damage levels. Some potato fields were badly affected by wilt and caused remarkable yield loss.

Use of GIS for modelling of potato cultivation in Sri Lanka is a fairly complicated exercise, because the parameters which affect potato production very often do not show linear relations. Available literature and our filed information were used to classify and give weights for the parameters. Because of heterogeneous nature of soil, climatic conditions and all other physical parameters, modelling of the productivity and land suitability is not an easy task. However, with the help of statistical analysis, the data were generalized. Therefore, some deviations from the ground truth data can be observed in composite weight maps.

Most of farmers in Nuwara Eliya and Badulla districts are small scale farmers, therefore performance data are mostly heterogeneous. Since the field data vary from season to season in different clusters it would be more accurate if the number of sites and seasons were increased for the research. Parameters used in the GIS model and the scoring systems were mostly based on our research findings and available literature. There are many more factors to be considered such as climatic and soil properties.

However, the productivity is also constrained by inappropriate varieties, especially for disease resistance, the high cost of planting material, fertilizer and pesticides, inefficient farming practices and poor infrastructure especially transport, which increase production and marketing costs. Benefit to cost ratio can be increased by reducing cost of production, providing incentives as well as by establishing a proper marketing system. Provision of disease resistant, good quality seed will increase the tuber yield and net return to the grower.

5. Acknowledgements

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