MODEL TROPICAL LEGUME TREES FOR REVERSING SOIL DEGRADATION AS A SOLUTION FOR INCREASING RURAL FARMERS INCOME BY GIS ANALYSIS A CASE STUDY – MEEGAHAKIVULA, SRI LANKA

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Commission II, WG II/4

KEYWORDS: Photogrammetry, GIS, Agriculture, Crop, Soil, Developing Countries, Change Detection, Prediction

ABSTRACT:

Poverty in rural areas of developing countries is one of the major global issues. Economic growth in rural areas of Sri Lanka has been significantly lower than in the urban areas, especially around Colombo and principally excluded the agricultural sector. A considerable proportion of rural livelihoods still depend mainly on agriculture, facing soil degradation and erosion. An important contribution towards a sustainable development of rural areas in Sri Lanka is thus to improve soil quality to enable sustainable agricultural development. Meegahakivula is one of such area has been selected to investigate and is highly undulated. The area is investigated in an interdisciplinary approach by three partners such as agronomy, socioeconomic and Photogrammetry, Remote Sensing and Geographic Information System (GIS). The incorporation of *Gliricidia sepium* leaves as green manure is believed to improve soil quality by rising both soil nitrogen and organic matter content. The by-products of the trees contribute to an improved income. The socioeconomic component deals with the potential enhancement of income and its importance within the farming systems. Incorporation of *Gliricidia sepium* in lands with different slopes categories will be analyzed by use of image processing in photogrammetric techniques including the integration of spatial data with agronomic and socioeconomic data in GIS.

1. INTRODUCTION

1.1. Introduction to the Area

During the last decades Asia experienced a tremendous economic transition and development; although many parts of Asia gained "visible in a significant reduction in poverty", some regions were bypassed by the "economic miracle". Today, more than two third of the world's poor live in Asia whereof South Asia accounting for nearly half of these. Poverty alleviation and economic development on this continent is a major issue for the global community. Agricultural growth contributed significantly to the economic development over the last decades. Nevertheless poverty remains basically a rural problem with 80-90% of the poor living in rural or remote areas (IFAD 2002). The most common feature of rural poverty in Asia is landlessness or limited access to land. Poor rural households can be characterized by various economic, demographic and social features. Deprived rural households tend to have larger families, are less educated and suffering from higher unemployment. Also they are short of basic amenities such as piped water supply, sanitation and electricity. Due to their remote access to credit, inputs and technology is limited. These facts help to explain why other constraints such as lack of market information, business and negotiation experiences divests them of the power to interact on equal terms with other – generally stronger – market forces (IFAD 2002).

The World Bank's poverty map exercise for Sri Lanka (World Bank 2007) showed that poverty incidences are correlated to spatial and geographic attributes such as geographical isolation, measured by distance to the nearest market or city.

The growth in Sri Lankan economy excludes the agricultural sector, resulting in a declining importance in terms of national income and agricultural employment. Nevertheless a large part of the population still relies on agriculture for their livelihood. Narayan and Yoshida 2005 argue that the stagnation in agriculture seems to be an important contributing factor to the persistence of poverty in rural and estate areas

Meegahakivula is a typical example for the poor tropical farming community. As identified, this can be suggested as low external input agriculture system. Even though this area consider as intermediate zone, where annual rainfall is in between 1250 mm – 2500 mm, rain fall confined to two distinct seasons. This leads to prolong dry season from June to September which causes cropping and living impossible. Moisture dependency is one of the intermediate conclusions that made after first minor season model crop experiment. Because of this, most of the farmers reluctant to go for a crop in minor season which means only less than 50% of the farming community able to cultivate in one season. It is totally a rain fed cropping system. Framers own large extent of land doing some crop rotation and most of the times their shifting the cropping fields inside the land while keeping some parts to fallow. This is a common way of developing the soil fertility in this region. Land tenure issues coming in the reasons of soil degradation where farmers do not adopt any measures to upgrade the soils with changing land ownership situations. Sometimes farmers do not use extra bit of fertilizer in such situations. By considering all these type of aspects there is a need of low cost and low resources utilizing solution which has some influence to in long run to address this problem.

The area is greatly undulated with the height difference between 150 m – 600 m above Mean Sea Level (MSL) and hence the selected focal points in the area are in different categories of slopes. Considering the all of the above situations, the area selected for this multidisciplinary approach research is highly suitable.

1.2. Background and Objectives in Socioeconomic Context

A private development program introduced *Gliricidia sepium* cultivation, teaching farmers to use the leaves as green manure and the use of compost in production. The benefits of the venture are not only based on *Gliricidia*, but also on enabling farmers to gain profits from extension services where they are thought to use composts and getting various incentives as free seeds, seedlings, water tanks, animals etc.

The program has been a success resulting in an increased supply of wood. The over-supply led to the idea of establishing a value-chain where the wood is delivered to a dendrothermal power plant to increase farmers' income. As the value-chain has not been established successfully other livelihood improvements have to be considered. Farmers are facing the problem that a short-term increase of production by enlarging the area is virtually impossible and technological intensification is limited due to economic constraints and risk considerations. Farmers need to develop strategies changing the flows of cash and goods, the factors modifiable in short-term. Here only two possible strategies are briefly sketched. First, a decrease of farmers' dependence on the supply side of the market through an increased self-sufficiency by diversification of their production, which leads to more cash remaining in the households enabling investments. Second, an increased integration into the market leads to an increase of cash availability which could be reinvested. All potential strategies bear respective risks and chances depending on the available resources, skills and the economic and market development.

The socioeconomic project component strives for two major goals: First, evaluating the economic effects of the program and the measures implemented and second, to understand why the farmers participate.

To evaluate the effects of the program a profound understanding of all flows of cash and goods within, between as well as out of and into the farming systems is necessary. Furthermore, only based on sound understanding of the processes characterizing the farming systems, analyses of farmer's participation in the program is possible. The design of the study considers the characteristics of the development program where incentives are only provided if farmers cultivate following the required production practices. This fact calls for a separate analysis of the motivation for participation and a study on objective factors for *Gliricidia* adoption. Farmer's subjective utility will be assessed to analyze their motivation for participation. The assessment of farmer's aims for future development helps to understand the subjectively perceived effects of the program for the household's development. A logit model on the other hand is used to find objective factors affecting *Gliricidia* adoption. For both analyses the sample, including both program participants and non-participants, is divided into two sub-samples.

The described analyses are accompanied by a one-year survey. It assesses, on monthly basis, information on household labor allocation, income from agriculture and non-agriculture activities as well as consumption figures. This combined information is used for modeling farming systems, defining strategies and to derive figures for various economic indicators as productivity, labor intensity, efficiency, etc.

1.3. Background and Objectives in Agronomic Context

Meegahakivula, the region we are concentrated or the actual research site can be considered as a typical tropical land with marginal productivity. The land was under shifting cultivation with annual food crops and tobacco for many years. With successive reduction of the yields the tobacco cultivation shift from this site to another location and people in this area left alone with barren landscape and poor soils. Since the vegetation cover was not there the land subjected to severe erosion during that time making the condition even severe. The region is characterised by high gradient. Most of the lands in these slopes provide evidence for the erosion taken place for last few decades. Soil degradation and the erosion are two factors that show a positive correlation. Soil degradation implies long term decline of in soil productivity and its environment moderating capacity. The process of soil degradation is accelerated by the erosion (Lal, 2001).

Gliricidia sepium (Jacq.) is a tropical legume species from Central America (Yucatan) which has identified as suitable for the introduction as tree in cropping systems, due to its good coppicing tolerance (Simons *et al,* 2004). It is especially suitable for smallholder farmers for generating extra income by selling the wood to dendrothermal electricity units (Wise and Cacho, 2005). Although there are species such as *Leucaena*, *Tithonia* and *Erythyna*, farmers do adopt to grow *G. sepium* due to easiness of propagation, adaptability and its multipurpose use. The N-fixing ability of the *G. sepium* is relatively low. Gliricidia able to fixed 13 kg/ha/yr (MacDicken, 1994) when comparing to the other species in adopt by farmers.

Soil organic matter is an important component in farming. Tropical soils are known to be consist with low amount of organic matter it rarely exceed 4% (Jenkinson, 1990). Without soil organic matter, a concrete risk in tropical cropping systems, the earth's surface would be sterile (Syers and Craswell, 1995), because it acts as a reservoir of carbon, nutrient and energy. Improved management of soil organic matter is best achieved by mimicking natural systems; these minimize carbon removal and maximize *in situ* residue and nutrient recycling, both of which are identified as important components of sustainable cropping systems (Craswell and Lefroy, 2001).Therefore *Gliricidia sepium* has a beneficial influence on this farming system and need to be understood in a comprehensive approach. This approach of producing energy for the region with the renewable *Gliricidia* wood chopping as energy source is of tremendous value to the people of the region, who are in a situation of desperation.

The project started with the establishment of trees, principally *Gliricidia sepium* in predetermined blocks or around the fence lines for the development of the degraded lands. The planting of *Gliricidia* proved be a success as the species was adapted to the local ecophysiological conditions. However, there was an excess of fuel wood that farmers could not dispose off, and this was a setback in promoting the adoption of *Gliricidia*, even though the species played a significant role in improving the soils.

In this study there are three main concerns. First is to identify the possible pattern of soil degradation with respect to the terrain characters of region. Secondly use of *Gliricidia sepium* leaves as green manure and tree itself as an intercropped legume tree for the remediation of low soil fertility and nutrient removal due to soil erosion. Third part is to identify and confirm the soil replenishing ability of *Gliricidia sepium* as it adds organic matter to soil in direct and indirect ways which leads to enhance the soil productivity and sustainability.

1.4. Use of Geographic Information System

This research intends to identify the effect of *Gliricidia sepium* for reversing the soil degradation of the area and subsequently identify the changes of rural farmers' income generation due to the increase of yield and the selling of wood chip production. As there are many kinds of data in different resolutions and time scales, which have to be integrated in one system, the adequate solution is the use of GIS with its ability to handle different types of data for storing, integrating, manipulating, and analysing. GIS plays a major role of spatial data handling combine with their aspatial data that can be used as an easy decision making tool for this kind of application instead of using tradition mapping system as the soil degradation is depending on many factors such as slope, elevation, aspect, land use, etc. that can be easily handled in GIS. Additionally, there are many kind of tools are available for spatial data handing in GIS ArcToolBox.

This paper focuses on developing a GIS based decision making tool to identify the pattern that the *Gliricidia sepium* can be incorporated in different slope and related categories to increase the soil fertility and subsequently the income.

2. DATA

2.1. Socioeconomic Data

For the socioeconomic dimension, a big variety of data with different time frames is necessary. Demographic data about the households like family size, education level and the age of family members, housing conditions, the land area, animal possessions and general information on income were assessed between January and April 2008. This assessment has no time dimension, only the situation on the date of the interview was of relevance.

To get a picture of the household activities like farming, labor allocation, consumption, sales as well as income, a one-year survey has been designed. The idea is to gain sound knowledge about the flows within, between out of and into the farming systems covering the seasonality of agricultural production. The survey each month which started on the 15th October 2007 is being distributed to the farmers until end of 2008. The data is assessed in different time dimensions. Labor allocation, including the income earned in case of off-farm work is assessed daily. Food consumption is filled weekly for both all consumption of farm products and products bought on the market, indicating also prices. Income from public and private aid, animal and plant sales and exceptional income is completed on monthly basis. This is also the case for data on value and amount of different production inputs, tools and equipment and utilities like water, electricity education and others.

The results from the assessment of utility and the Logit-model will be integrated into the GIS as well again as values without time dimension.

2.2. Agronomic Data

In this research agronomic component is responsible for providing all necessary data on soil, crops, farms, history of cropping and potential of cropping in studying area. At the beginning of the program, farms were identified as the focal points in different terrain categories in different clusters of the village. Data for all three disciplines will produce using identified focal points as the base.

Once focal points are selected the characteristics of each location will be identified base on the needs of the different disciplines. As agronomist, topography of the terrain (slope inclination, length and orientation) determines the risk of water erosion. The examination of the soil physical properties, soil profile, i.e., the depth of the A horizon, its bulk density and its texture, which are all altered due to selective transport and deposition of soil particles of different size during erosion events, will be used as indicators for the loss of top soil. The soil pH and the soil contents of phosphorous, potassium and carbon (as an indicator of organic matter) will be used as soil fertility indices. In order to identify the effect of N supply by *Gliricidia* for the available field crops in farming system an onfarm experiment activity is include to the research activities.

The evaluation of the response to the factors described later will allow to answer whether: a) N fertility is a major consequence of soil degradation (response of the field crops to N fertilizer on sites without *Gliricidia*); b) *Gliricidia* loppings can substitute N fertilizer supplies; c) to which extent *Gliricidia* loppings reduce production costs (mineral N fertilizer substitution) (with addition of green leaves at rate of 3 Mt/ha) or increase income (yield of field crops); d) the modification of these responses by terrain characteristics. Fertility implications and productivity measures will be identified by cultivating two model crops as in major season Maize (*Zea mays* L.) and minor season Mungbean (*Vigna radiata* (L.) Wilczek). Other than that each focal point (farm) consist with and detailed description about cropping pattern, cropping history, *Gliricidia* planting pattern and the ways and quantities of using, crop and tree composition and use of external inputs.

For the better understanding and based on the hypothesis that intensified nutrient and crop management at home garden level separate set of experiment will carry out simultaneously with the field trials. In 30 home gardens selected out from focal points, analyzed separately for its soil characters in detail, plant composition, and productivity of model crops under home garden conditions and rooting habits of model crops.

Data that produce by agronomic group will integrate to the GIS system to produce information on effect of terrain on soil degradation, impact of *Gliricidia* for reversing soil degradation and maintain sustainable production and environmental stability after incorporating *Gliricidia* to the system.

2.3. Spatial Data

All available data such as aerial images acquired in the year 1999 with the 1:27,000 scale, topographic maps in the scales of 1:10,000 and 1:50,000 prepared in 1995 and 1996 respectively and 1:10,000 GIS data coverage including transport, hydrology, buildings, important places, land use, contours, utilities and administration boundaries of the project area were collected from the Survey Department of Sri Lanka.

These aerial images will be used to develop a Digital Terrain Model (DTM) to obtain the necessary topographic parameters for agronomist such as slope inclination, length and orientation of focal points for their soil analyzing.

Slope, aspect, hill shade and contours have been generated using Digital Terrain Model (DTM) obtained by aerial photographs. The generation of DTM and Orthoimage are done by Satellite Imagery Precision Processing (SAT-PP) software developed by the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology, ETH Zurich that has the ability to generate more reliable and accurate DTM. The DTM has been generated in 1 m grid spacing and the orthoimage has been generated with 25 cm resolution. The available transportation, hydrological features, buildings, important places around the area, and land use coverage have been integrated to the system. These all spatial data have been linked with their attribute data.

The selected all focal points were surveyed by using Global Positioning System (GPS) and integrated to system.

3. GIS DATA MODELING AND DATA ANALYZING

3.1. GIS Data Model

There are 14 entities which have been identified such as Family, Farmer, Focal Point, Soil Fertility, Animal, Income, Gliricidia, Fertilizer, Family Labor, Production, Expenditure, External Labor, Other Work, and Weather.

Their relationships have been established by using relationship matrix and subsequently their cardinality and attributes with primary and foreign keys were identified. Accordingly, a GIS data model is developed and shown in Figure 1.

For example, if considered the entity Family, it has 4 relationships with other 4 entities such as Farmer, Labor, Income, and Expenditure. In reality there is a relationship between Family and Farmer with cardinality will be “A Family has zero or more Farmers”, but in this case it will be “A Family has one or more Farmers”, because all focal points own by the families have their own farmers. However, there is no difficulty to make relationship with zero or more. The other 3 relationships with cardinality are “A Family has zero or more Labors”, “A Family has zero or more Income”, and “A Family has one or more Expenditure”.

All entities have relevant attribute tables. For example, the Focal Point entity has 13 attributes relevant to the project objectives such as Farmer ID, Cluster ID (This is for identification of the focal point that is placed in which cluster), SADP (This is for identification of whether the focal point is included or not in the **S**ustainable **A**griculture **D**evelopment **P**rogram), Land Use, Slope Percentage, Slope Type (This is for categorizing the slope percentage ranges in to 3 categories), Area, Perimeter, Hill Shade, Aspect, Family ID, and Land Title. The primary key of this attribute table is Farmer ID.

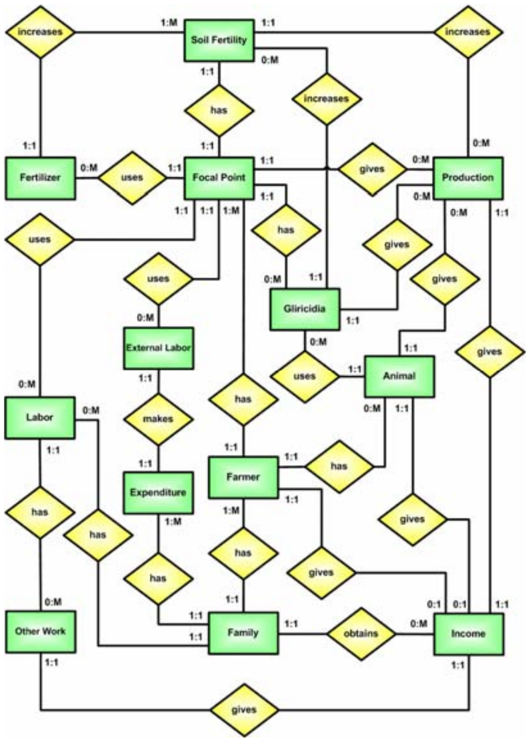
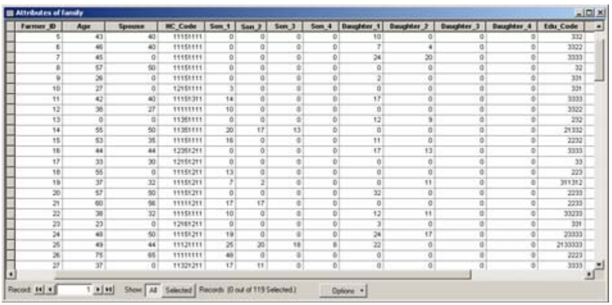


Figure1. GIS Data Model.

3.2. Data Integration

The socioeconomic data will be collected for the period more than one year commencing from 15th October 2007 until the end of 2008. These data are in different time scales (weekly, monthly) except the demographic data. There are many attributes in these socioeconomic data. The given data sets have been restructured relevant to the attribute tables defined in the GIS data model. For example, the demographic data table imported to the system is given the Figure 2.



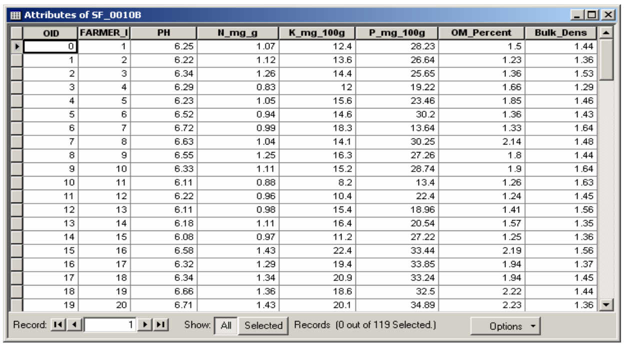
Attributes of Family

Farmer_ID	Age	Spouse	HC_Code	Son_1	Son_2	Son_3	Son_4	Daughter_1	Daughter_2	Daughter_3	Daughter_4	Edu_Code
5	43	40	11151111	0	0	0	0	10	0	0	0	332
6	46	40	11151111	0	0	0	0	7	4	0	0	3322
7	45	0	11151111	0	0	0	0	24	20	0	0	3333
8	57	50	11151111	0	0	0	0	0	0	0	0	32
9	26	0	11151111	0	0	0	0	2	0	0	0	331
10	27	0	12151111	3	0	0	0	0	0	0	0	331
11	42	40	11151311	14	0	0	0	17	0	0	0	3333
12	38	27	11111111	10	0	0	0	0	0	0	0	3322
13	0	0	11351111	0	0	0	0	12	9	0	0	232
14	55	50	11351111	20	17	13	0	0	0	0	0	21332
15	53	35	11151111	16	0	0	0	11	0	0	0	2232
16	44	44	12351211	0	0	0	0	17	13	0	0	3333
17	33	30	12151211	0	0	0	0	0	0	0	0	33
18	55	0	11151211	13	0	0	0	0	0	0	0	223
19	37	32	11151211	7	2	0	0	0	11	0	0	311312
20	57	50	11151211	0	0	0	0	32	0	0	0	2233
21	60	56	11111211	17	17	0	0	0	0	0	0	2233
22	38	32	11151111	10	0	0	0	12	11	0	0	33233
23	23	0	12161211	0	0	0	0	3	0	0	0	331
24	48	50	11151211	19	0	0	0	24	17	0	0	23333
25	49	44	11121111	25	20	18	8	22	0	0	0	2133333
26	75	65	11111111	48	0	0	0	0	0	0	0	2223
27	37	0	11321211	17	11	0	0	0	0	0	0	3333

Record: 1 Show: All Selected Records (0 out of 119 Selected.) Options

Figure 2. Family Data.

Agronomic data will also be collected in different time scales for soil fertility and cropping potential. Presently available soil fertility in the depth ranges 0 – 10 cm, 10 – 20 cm, 20 – 30 cm and 30 – 60 cm data including pH value, bulk density and percentages of Nitrogen (N), Phosphorus (P), Potassium (K), and organic matter have been integrated to the system. Figure 3 below shows the soil fertility data in 0 – 10 cm depth.


Attributes of SF_0010B

OID	FARMER_I	PH	N_mg_g	K_mg_100g	P_mg_100g	OM_Percent	Bulk_Dens
0	1	6.25	1.07	12.4	28.23	1.5	1.44
1	2	6.22	1.12	13.6	26.64	1.23	1.36
2	3	6.34	1.26	14.4	25.65	1.36	1.53
3	4	6.29	0.83	12	19.22	1.66	1.29
4	5	6.23	1.05	15.6	23.46	1.85	1.46
5	6	6.52	0.94	14.6	30.2	1.36	1.43
6	7	6.72	0.99	18.3	13.64	1.33	1.64
7	8	6.63	1.04	14.1	30.25	2.14	1.48
8	9	6.55	1.25	16.3	27.26	1.8	1.44
9	10	6.33	1.11	15.2	28.74	1.9	1.64
10	11	6.11	0.88	8.2	13.4	1.26	1.63
11	12	6.22	0.96	10.4	22.4	1.24	1.45
12	13	6.11	0.98	15.4	18.96	1.41	1.56
13	14	6.18	1.11	16.4	20.54	1.57	1.35
14	15	6.08	0.97	11.2	27.22	1.25	1.36
15	16	6.58	1.43	22.4	33.44	2.19	1.56
16	17	6.32	1.29	19.4	33.85	1.94	1.37
17	18	6.34	1.34	20.9	33.24	1.94	1.45
18	19	6.66	1.36	18.6	32.5	2.22	1.44
19	20	6.71	1.43	20.1	34.89	2.23	1.36

Record: 1 Show: All Selected Records (0 out of 119 Selected.) Options

Figure 3. Soil Fertility (0 – 10 cm Depth).

In spatial context, orthoimage, digital terrain model, hill shade, aspect, road network, important places relevant to the project objectives, water features, buildings data and surveyed focal points with there attributes were included into the GIS. The following diagrams give the overview of different kind of spatial data integration in GIS

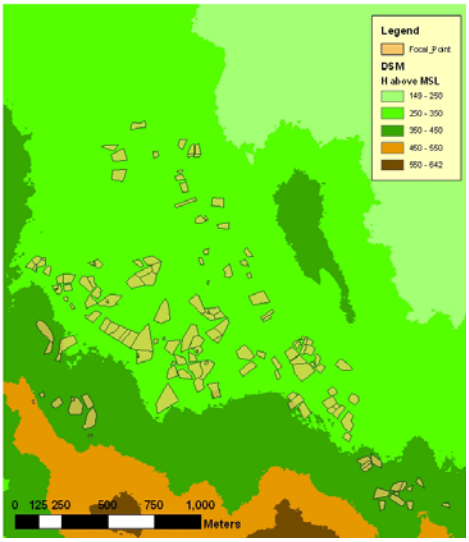


Figure 4. Focal Points with DSM.

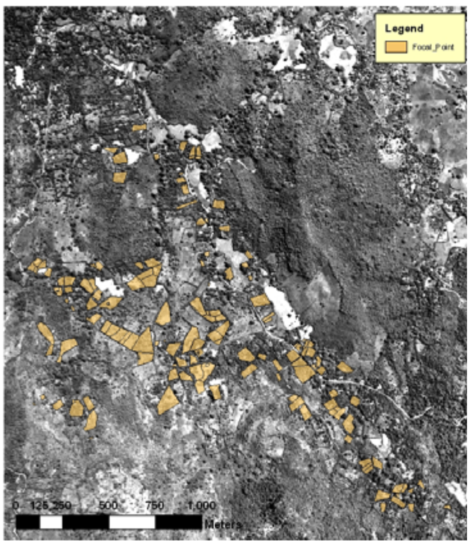


Figure 5. Focal Points with Orthoimage.

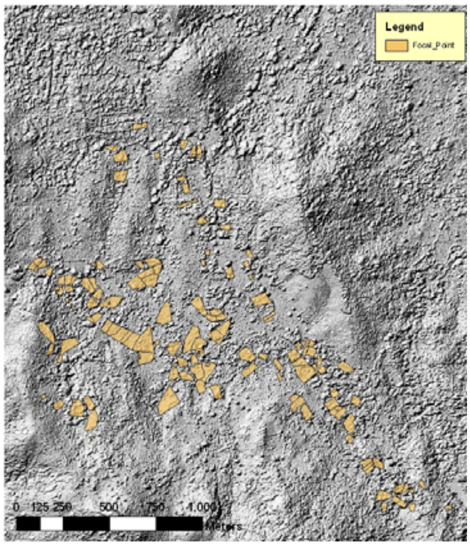


Figure 6. Focal Points with Hill Shade.

3.3. Data Analyzing

Factors affecting adoption of *Gliricidia sepium* cultivation will be analyzed by a logit model where the probability of adoption by farmers depend on a vector of independent variables and a vector of unknown parameters. The assessment of the utility derived from project participation in general is based on interviews consisting of three main steps. The first step is to assess the actual situation followed by the most important positive and negative changes and the aims for the future. The subjective aims combined with some possible strategies for development elaborated by the researcher based on the information of the household to a set of aims for future development. These aims are listed and rated by the farmer. In a first round, farmers get 100 points to weigh the different aims regarding importance to them. In the second round, they are asked to indicate on a defined scale to which degree this aim has been fulfilled. Multiplying the number of the weight and the delta in fulfillment of the aim provides the relative importance of that respective aim to the overall expected utility derived from project participation which is defined by the sum of all fractions of the utility characterized by the aims. The GIS provides as central storage unit enabling access to relevant data necessary to deduce the variables affecting adoption and information and data required for aims respective strategy development. By comparing figures between the different household relative advantages are revealed. The GIS contributes towards an integrated understanding about the farming systems in an aggregated, regional dimension.

The farming systems will be characterized by land use, soil conservation measurements (e.g. contour planting, terraces, etc.), and agricultural practices (e.g. tillage intensity, fertilizer use, crop protection, the method of planting trees etc.). Crop productivity, as a global index of the level of soil degradation, will be determined in normalized plots (same agricultural input, the same varieties used for the model crops) on all surveyed sites. In addition cropping history of the land will use to develop basic knowledge on land use of the site and to set up suitable experiment sites for research requirements. All the parameters above will be determined at different terrain positions (bottom, middle and top slope) within a single site, as these can be expected to be at different risks of soil degradation by water erosion. Site characteristics will be determined once, at the beginning of the study, while crop yields will be recorded for two years (two minor and two major crop seasons). Soil properties will be accessed for the second time after the fourth crop harvest. Obtained data from this process will analyze using multivariate statistical procedures i.e. multiple regressions, principle component analysis and variance component analysis. Mainly SAS (SAS Institute Inc, Cary, NC, USA, 1999) and other appropriate graphic tools will use in this process.

Information obtain from above analysis feed to GIS base to develop comprehensive model which enables us to understand the usefulness of *Gliricidia sepium* to upgrade degraded farming system.

4. CONCLUSIONS AND RECOMMENDATIONS

Agronomists expect to develop some models based on their data to use in wider range of tropical regions that similar to Meegahakivula region. First is to identify the possible relationship between the terrain characters on soil degradation. Also the possible explanation using other parameters like cropping history, land use and crop management. Then relate the soil degradation to the soil properties to identify the basic needs to be address by incorporating *Gliricidia sepium*. Second is to model measure the ability of *Gliricidia sepium* leaves to macro and micro nutrients to crops as a substitute to synthetic fertilizers. Production of economically viable crop by substituting synthetic fertilizers using green manures and other agronomic aspects in cost effective manner to help the farming livelihood. Third is to evaluate the sustainability of the adoption process of *Gliricidia sepium* to maintain the soil nutrient status without exhaustion because of continuous cropping. This modeling needs at least two years to identify the possible parameters of land productivity, sustainability of integration and environmental stability.

The economists expect to gain insight why farmers do participate or not. The analysis is believed to provide knowledge about the farming systems and their direct environment. This is extremely valuable in a time with the increased instability on markets and raising food prices – factors outside of the system of a single farmer, not influenced by their operational and strategic decisions.

GIS data model has been completed and need more data sets to go for data analyzing.

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