Modelling banana yields to evaluate land use in Thailand.

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Figure 1. Banana (Kasetsart 2)

Abstract: Crop modelling in Thailand presents challenges to both farmers and researchers. Farmers want to increase production, reduce costs, and remain profitable under variable climate and economic conditions. Researchers want to match soils, climates, and crop growth and give sound management advice. PLANTGRO - a generic system for predicting growth of plants was used to predict the performance of a new variety of banana (Kasetsart 2) grown in four different environments in Thailand.

Observational data of bananas from 4 farms with different climate and soil types were used to initialize the model. Two farms from the Tak and Nakorn Sawan Provinces in the lower northern part of Thailand. Temperatures in these regions ranged from 30-39 º C (mean maximum) and 20-27º C (mean minimum), precipitation ranged from 1100 – 1500 mm per year and soil type is of a silty texture. Two farms from Chanthaburi and Rayong Provinces on the eastern coast of Thailand. Temperatures in these regions ranged from 30-35 º C (mean maximum) and 22-27º C (mean minimum), precipitation range from 1400 – 2200 mm per year and soil type is of a loamy texture. The model predictions of banana yields were compared with observed yields for the year 2007.

Model predictions of banana yields at Nakorn Sawan, Tak and Rayong agreed with the observed field data. The predicted yields were 19.83, 19.35 and 14.66 and the actual yields were 19.5, 18.5 and 13.75 tonnes/ha at Nakorn Sawan, Tak and, Rayong, respectively. However, model predictions of banana yields from the Chanthaburi Province were under-estimated. The predicted yield was 14.15 tonnes/ha and the actual yield was 22.12 tonnes/ha at Chanthaburi. The Chantaburi under-estimation probably occurred because farmers's in that region had good management skills i.e. irrigated 30 liters/day and supplied optimum fertilizer levels. The results also showed that the most severe limiting factors in Tak and Nakorn Sawan provinces were base saturation and water availability while in Rayong and Chanthaburi they were pH and water availability. The most suitable planting periods are June, May, January, and September at Tak, Nakorn Sawan, Rayong and Chanthaburi, respectively.

PLANTGRO succeeded in simulating banana yields in Nakorn Sawan, Tak and Rayong Provinces with different environments. The results were used to assess banana production yields to evaluate land use. The Automated Land Evaluation System (ALES) was used to quantify actual constraints to banana production as an aid in land evaluation. Integration of the results from PLANTGRO, ALES and present land use were used to determine possible lands for new banana production in the Wangchow District in the Tak province.

Keywords: *Crop modelling, Automated Land Evaluation System*

1. INTRODUCTION

Land evaluation and land use planning are often handicapped by a lack of suitable information on the performance of candidate species (or cultivars, provenances, etc.) under different climates, soil types, and management strategies. Often the problem is not so much the absence of information but rather deficiencies within available decision support systems that rely on empirical models calibrated to plot-based data. Such decision support systems are unable to utilize alternate sources of information, such as informal data and expert knowledge. However, expert systems and other approaches enable such data to be incorporated into models that are compatible with prevailing planning systems.

Systems approaches are an appropriate means for meeting the complex challenges facing managers of agricultural systems. Crop modelling can play a significant part in systems approaches, by providing a powerful capability for scenario analyses. Crop modelling has developed extensively over the past 30 years such that a diverse range of crop models is now available. However, it is argued that the tendency to distinguish between so-called "scientific" and "engineering" challenges and approaches in crop modelling has constrained the maturation of model development and application. Consideration is therefore given here to effective crop modelling that combines a scientific approach that enhances understanding with an applications orientation that retains a focus on prediction and problem-solving. The major issue in effective crop modelling is therefore seen as how to achieve the appropriate balance between simplicity and complexity in combining the biological, physical, and prediction requirements for each specific task. Avoidance of unnecessary complexity and maintaining transparency of design are considered as guiding principles.

Given a comprehensive crop model with robust predictive capability, there are many opportunities for applications ranging from research into management practices to crop improvement. In a controlled environment of protected cultivation, seeking optimal combinations of environmental control and crop management strategies to maximize profitability is feasible, using optimization algorithms in conjunction with controlled experiments including climate and soil controlled with crop models. It is argued that a participatory approach that includes managers as partners in this process is required to effect change.

1.1. PLANTGRO

PLANTGRO (Hackett and Vanclay, 1997) is a package designed to help assess the suitability of a species for a site, by ranking that species' performance on a qualitative scale from 0-9. It uses information on 20 environmental variables reflecting factors as diverse as day length and soil pH. The plant's response to each of these factors is expressed as a simple relationship, which is used with site-specific soil and climate data to estimate limitations to plant growth. PLANTGRO is somewhat unusual amongst plant-growth prediction systems in that it can use informal data and personal knowledge to supplement more formal experimental data. Thus PLANTGRO may be particularly helpful in providing preliminary growth estimates for species (plants and trees) and sites for which no formal data or empirical models are available. Although intended only to indicate the suitability of a given site species combination, empirical trials suggest that the suitability index provides a reasonable indication of growth potential, the correlation between predicted and observed height growth being as high as 80% (Hackett and Vanclay, 1997). PLANTGRO can be calibrated for new situations, by providing appropriate soil, climate, and species files. These can be compiled from plot-based data, casual field observations, or expert knowledge.

1.2. The Automated Land Evaluation System (*ALES*)

The ALES (Rossiter and Wembeke, 1997), is a computer program that allows land evaluators to build expert systems that can evaluate land according to the method presented in the Food and Agriculture Organization's publication "Framework for Land Evaluation". It is intended for use in projects, or regional-scale land evaluations. The ALES was developed at Cornell University from 1986-1996 and is still distributed by Cornell. It is supported by the program author, D.G Rossiter, who moved to International Institute for Geo-information Sciences and Earth Observation (ITC), Enschede in the Netherlands in 1997. Although ALES is a DOS program which has not been updated since 1996, it is still a rich expert system environment and continues in use as part of the land evaluator's toolkit. Evaluators build their own *expert systems* with ALES, taking into account local conditions and objectives. The ALES is not by itself an expert system, and does not include by itself any knowledge about land and land use. The ALES is a *framework* that allows evaluators to encapsulate their own expertise and local knowledge.

1.3. Banana Kasetsart 2

Banana (*Musa* spp.) is an economically important plant in the humid tropical lowlands that produces fruit year-round. There are many banana cultivars grown commercially. The ASEAN member countries actually have almost identical commercial clones, but different common names. However, only bananas with improved AA diploids (*Musa* AA Group) namely 'Kluai Khai' in Thai, or what we call banana Kasetsart 2 were used in this study (Figure 1). The cultivar was developed by Department of Horticulture, Kasetsart University in the year 1998- 2001 by tissue culture technique followed by treatment of 20 grays (1 gray = 100 rads) of gamma irradiation. The Kasetsart 2 banana (K2B) arose from a mutation in the 6^{th} generation. The K2B banana exhibits higher growth, yield, and fruit quality. The K2B banana flowers at 310 days after planting and its finger shape is oval (Figure 1). The total soluble solid (TSS) of K2B is about 25.6 %. The K2B banana is higher in pulp firmness (1.69 N/cm^2), which is easy to be transported for export.

This paper describes the application of PLANTGRO to predict yields of K2B in 4 different locations, namely: Tak and Nakorn Sawan Provinces in the lower northern part of Thailand and Chanthaburi and Rayong on the eastern coast of Thailand. The ALES was then used to quantify actual constraints on K2B in the present land use system as an aid in land use planning.

2. MATERIALS AND METHODS

2.1. Study sites description

The study was carried out in farmers' fields in four provinces (Figure 2) namely: Tak, Nakorn Sawan Chantaburi and Rayong.

1. *Tak study site.* Tak is located 426 km from Bangkok in the north-west of Thailand, at 15º,N, 99ºE. It is 1,162 metres above sea level. Mean annual rainfall in the area is about 1,100 mm over an annual mean of about 103 rain days. The average annual highest temperature is between 36.50 – 40.40 º C and the average lowest temperature is between 9.70 – 13.90 º C. Relative humidity ranges from 69 to 75 %. Soils in the site are formed from semi-recent alluvium, that occurs on river levees and alluvial fans. The local topography ranges from nearly flat to slightly undulating landscape. It was established as Kamphaeng Phet series (Kp) and is a member of fine silty, mixed isohyperthermic Ultic Haplustalfs (Soil survey staff, 2003). They are very deep soils characterized by brown, dark brown loam, or silt loam A horizon, overlying a brown, dark brown, or dark yellowish brown silt clay loam, or silty loam argillic B horizon. The surface soil is moderately acid to neutral , and strongly to slightly acid in the subsoil.

2. *Nakorn Sawan study site.* This site is located in the lower North some 240 km from Bangkok and lies on 15.80 º N, 100.16 º E.. Soils are formed from recent alluvium and occur on the flat terrain of higher parts of river and stream levee. Slopes are less than 2 %. It was established as Chiang Mai series (Cm) and is a member of loamy, mixed, non-acid, isohyperthermic Typic Ustifluvents (Soil survey staff, 2003). They are very deep, stratified, and characterized by brown or greyish brown or dark brown silt loam or silty clay loam C horizon. Textures of the subsoil are silty with distinct mottles. Reaction is medium acid to neutral. The climate zone of Nakorn Sawan is savanna with an average temperature of 25-32 º C. The highest temperature is around 38 ºC in April, the rainy seasons may last from May to October, where total the precipitation is around 1,120 mm/year with 102 rainy days and winter starts from November to January with an average temperature of 24-29 ºC.

3. *Rayong study site.* Geographically Rayong is located on the east coast of Thailand. It is about 180 kilometres from Bangkok and lies on 12.40 º N, 101.16 º E. Soils are formed from alluvial over marine deposits on coastal plain, where relief is level to

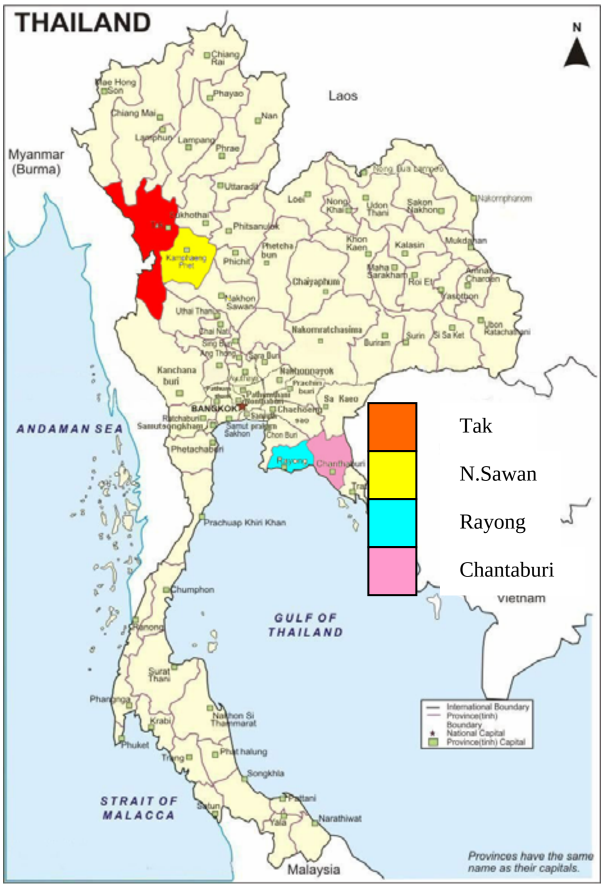

Figure 2. Study sites

nearly level and 0-2 % slope. It was established as Chon Buri series (Cb), a member of fine-loamy, mixed, semiactive, isohyperthermic Typic Endoaqualfs (Soil survey staff, 2003). They are very deep, dark greyish brown, or greyish brown loamy surface (A horizon) overlying a light gray, light brownish gray, or pinkish gray sandy clay loam argillic B horizon. The sand fraction is medium to coarse. The colours are dark brown, dark reddish brown, or yellowish red surface, yellowish brown and red subsoil with mottled throughout the profile. Soils are moderately acid to slightly acid (pH 6.5-8.0), over strong to very strong acid. Climate zone of Rayong is savanna with an average temperature of 26-30 ^{o}C. The highest temperature is around 32 ^{o}C in April, the rainy season is from May to October, where total precipitation is around 1950mm/year with 105 rainy days. Winter starts from November to January, with an average temperature of 21-23 ^{o}C.

4. *Chanthaburi study site.* Chanthaburi is situated on southeast of Thailand, approximately 230 km. from Bangkok and lies on 12.61 ^{o} N, 102.11 ^{o} E. It covers an area of 6,338 square-kms. Soil derived from granite or equivalent rocks and occurred on granitic terrain. Relief is gently undulating to undulating (2-12%). Elevation is 30 centimetres above mean sea level. It was established as Khlong Nok Kratung series (Knk), a member of fine-loamy kaolinitic, isohyperthermic Typic Kandiudult (Soil survey staff, 2003). They are very deep dark brown, very dark grayish brown, or brown coarse sandy loam surface (A horizon) overlying a light brown or pale brown medium and coarse sandy loam, or sandy clay loam B horizon. Sand grains usually increase in size with depth of soils and they are very strong in acid (pH 4.5-5.5) at surface and very strong (pH 4.5-5.0) in the subsoil. The climate zone of Chanthaburi is monsoon with an average temperature of 27-28 ^{o}C. The highest temperature is around 33 ^{o}C in April, the rainy season lasts from May to October, where total precipitation is around 2800 mm/year with 106 rainy days and winter starts from November to January with the temperature of 19-21 ^{o}C in average.

2.2. Study method

This modelling study was part of the project titled "Supply management to ensure quality of the fruit selected through the Thai produce and grain branding project: the case of small banana (Kluai Khai)" (Silayoi et al. 2008). The PLANTGRO crop model was used to predict the yield of K2B while the ALES decision tree was used to assess suitability of all sites. The result was then combined to evaluate if the land in Wangchow District, Tak Province was suitable for a K2B plantation.

- Data collection: Primary and secondary data of relative factors and variables of K2B were collected i.e. climate, soil and topography of the areas which were used as the database in PLANTGRO and ALES. Selected variables were grouped into environmental factors on the basis of their specific relationship with the assessment of land suitability for K2B, namely: soil property, topography, and climate. These environmental factors were basically different in their dependence on land suitability.

- Determination of classes of variables: The classes of variables were determined following Sys, C. et. al. (1993) namely: climate, soil, nutrients, yields (Table 1.).

- Determination of restricted areas: land in Wangchow District in Tak Province where prediction and actual yields are similar was then evaluated. Land use map and soil map in the year 2007 was used to determine restricted area for K2B. Urban and any construction, forest , water body, slope complex and miscellaneous lands in land use map and slope complex (SC), alluvial complex (AC), alluvial fan complex (AFC) and rock land (RL) in soil map were classified as permanently not suitable (N2).

Table 1. Landscape and soil requirement for banana: modified from Sys. C. et. al. (1993)

Classes	Climate		Slope %	Drainage	Soil characteristics					Saline (dS/m) Alkaline (%)
	Ann.Rain (mm)	Mean (^{o}C) ann.Te			Texture	Fertility				
						CEC Clay	BS	pH H_2O	OC	
S1	>1500	18-22	0-2	Mod-good	SiCL, CL,SiL ,SC,L	16-24	35->50	5.8-7.5	>2.4	0-2 0-4
S2	1250-1500	16-18	2-4	Imperfect	SCL	16(-)	20-35	4.2-5.6 7.5-8.0	2.4-1.5	2-4 4-8
S3	1000-1250	14-16	4-6	Poor	SL, LS	16(+)	<20	5.2-4.5 8.0-8.2	1.5-0.8	4-6 8-12
N	<1000	<14	>6	Poor	fS,S,cS	-	-		<0.8	>6 >16

S1 = Suitable , S2= Moderately suitable , S3= Marginally suitable , N= Not suitable (N1 = Not Suitable (improvable) , N2 = Not suitable (permanent), SiCL = Silty clay loam, CL= Clay loam, SiL = Silt loam, SC = Sandy clay, SL = Sandy loam, L = Loam, fS = Fine sand, cS = Coarse sand, S = Sand

- Determination of land utilization types (LUT's): LUT's of K2B were defined as either moderate or high input. The moderate input includes application of low fertilizer, mechanized weeding, and soil tillage and artificial drainage whereas the high input means application of high fertilizer, mechanized weeding and soil tillage, artificial drainage, and adequate irrigation.
- Assessment of land suitability for K2B: ALES was used to assess suitability of K2B in each soil unit while PLANTGRO was use to predict yield in both moderate input and high input. The results were combined to assess K2B suitability classes.
- GIS application: overlaying of existing land use map and yield maps identified possible land for K2B plantation in the future.

3. RESULTS

3.1. PLANTGRO and ALES Output

PLANTGRO predicts yield whereas ALES assesses suitability classes of moderate input soils and high input soils (table 2).

Table 2. Yield prediction by PLANTGRO and suitability classes by ALES compared to actual yield.

Sites	Soil series	ALES output	Yield (tonnes/ha)				
			PLANTGRO Prediction				Actual Yield (tonns/ha)
			Moderate input	Class	High input	Class	
Tak	Kp	S3c	20.51	S3	30.14	S1	18.52
Nakorn Sawan	Cm	S3m/p	19.83	N1	19.35	N1	19.53
Chanthaburi	Knk	S3b/p	14.15	N1	29.30	S2	22.13
Rayong	Cb	N1	14.66	N1	16.85	N1	13.75

C= Cation Exchange Capacity,m= Rainfall, p= Phosphorous, b=Base saturation, d=Drainage, N1=Not suitable (improvable)
Yield level: S1=>30 ton/ha, S2=25-30 ton/ha, S3=20-25 ton/ha, N=<20 ton/ha.

Kp (Kamphaeng Phet), Cm (Chiang Mai), Knk (Khlong Nok Kratung), and Cb (Chon Buri)

Model predictions of K2B in moderate input soils at Tak, Nakorn Sawan and Rayong sites were in broad agreement with the actual field data. However, model predictions at Chanthaburi were under-estimated which probably occurred because farmers in that province had good management practices in applying 30 litres/day of irrigation water along with optimum fertilizer. Results show that predicted yields of K2B were 20.51, 19.83 and 14.66 tonnes/ha, while actual yields were 18.52 19.53 and 13.75, tonnes/ha at Tak, Nakorn Sawan and Rayong, respectively. The predicted yield was 14.15 tonnes/ha and actual yield was 22.13 tonnes/ha at Chanthaburi. It was also observed that the relative good agreement between predicted and observed yields for Tak, Nakorn Sawan and Rayong provinces was in a savanna climate. While the under prediction in Chanthaburi province occurred in a monsoon climate.

Under high input, the predicted yields of K2B of 30.1, 19.4, 29.3 and 16.9 tonnes/ha in Tak, Nakorn Sawan, Chanthaburi and Rayong, respectively suggests that Kp and Knk soils in Tak and Chanthaburi can be improved but the Cm soils in Nakorn Sawan cannot be improved. The Cb soils in Rayong were assessed as N1 by ALES and improvement would be rather difficult.

According to ALES, the current soils Kp, Cm, and Knk were marginally suitable, but Cb was not suitable for K2B. Only the yields on current Kp soils agree with those predicted by ALES.

3.2. Land evaluation

Lands of the Wangchow District in Tak Province which covers about 1,227,886 km^2 were evaluated by combining PLANTGRO and ALES within a GIS environment. To produce soil suitability maps, yields and land use maps were considered and used as input to the GIS system.

Yield maps of moderate input and high input soils were overlaid with a land use map to produce land suitability classes maps for K2B. PLANTGRO predictions based on soil types: Ps, Sp, Kp, and Mr which were classified as marginally suitable (S3) can be improved to be suitable (S1) while soil types Pc and Tm which were marginally suitable (S3) can be improved to moderately suitable (S2) in high input condition. Lands of soil types Tw, Rb, and Pp were still in the moderately suitable class (S2) in high input condition. Lands of soil units Cu, Sin, and Ty were classified as unsuitable (N1) (Table 3). All the maps are shown in figure 3.

Table 3. Yield prediction by PLANTGRO and suitability classes by ALES at Wangchow District, Tak Province.

No.	Symbol for Soil	Soils	ALES output	PLANTGRO Yield Prediction (Tonnes/ha)			
				Current soils	Yield levels	Improved soils	Yield levels
1	Ps	Pusana	S3tm	21.22	S3	31.14	S1
2	Sp	San Pa Tong	S3pm	21.23	S3	30.14	S1
3	Kp	Kamphaeng Phet	S3c	20.05	S3	30.14	S1
4	Tw	Tab Kwang	S3mc	25.68	S2	25.68	S2
5	Cu	Chan Thuek	N1	19.00	N	21.38	N1
6	Mr	Mae Rim	S3Tm	21.23	S3	30.14	S1
7	Pc	Pak Chong	S3mc	24.44	S3	25.68	S2
8	Rb	Ratch Buri	S3md	25.68	S2	25.68	S2
9	Pp	Phon Pisai	S3mc	25.68	S2	25.63	S2
10	Sin	Singh Buri	N1	18.16	N	18.16	N1
11	Tm	Ta Muang	S3tm	21.23	S3	25.68	S2
12	Ty	Ta Yang	N1	21.23	N	21.23	N1

t=Texture, m= Moisture, c=CEC (Cation Exchange Capacity), d= Drainage, p= Phosphorous, de=Soil depth
Yield levels: S1=>30 tonnes/ha, S2=25-30 tonnes/ha, S3=20-25 tonnes/ha, N=<20 tonnes/ha.

4. DISCUSSION AND CONCLUSION

Integration of the results from PLANTGRO and ALES in the Wangchow District indicates that K2B plantations are feasible. The results also show that high levels of soil improvement (high input) on marginal land (10.27% of the area) increase the probability of K2B production on marginal land. However a moderate level of soil improvement does not increase the probability of K2B production. (Table 4.)

Table 4. Land suitability classes for K2B in Wangchow District, Tak Province, Thailand.

Area (km^2)		%	Area (km^2)		%
Suitability Class	Mod. input		Suitability Class	High input	
Suitable (S1)	-	-	Suitable (S1)	117,018	9.53
Moderately suitable (S2)	183,948	1.49	Moderately suitable (S2)	27,382	2.23
Marginally suitable (S3)	125,963	10.27	Marginally suitable (S3)	-	
Not suitable (improvable): N1	25,940	2.11	Not suitable (improvable): N1	25,940	2.11
Not suitable (permanent: N2	125,963	86.13	Not suitable (improvable): N2	125,963	86.1
Total	1,227,886	100	Total	1,227,886	100

Table 5. Possible land and soil types for new Kasetsart 2 banana (K2B) plantations.

Possible land for K2B	Soil types	Area (km^2)
P1	Ps, Sp, Kp, Mr	106,219
P2	Tm, Tw, Rb, Pp	98,570
N	Paddy rice restricted areas	1,023,097
Total	-	1,227,886

P1 – first priority; P2- second priority. N= Not possible

See Table 3. for definition of soil type abbreviations

It was found that the area of suitable class (S1) is mainly covered by soil series Pusana (Ps), Sanpatong (Sp), Kamphaeng Phet (Kp) and Mae Rim (Mr). Although they are upland soils i.e. good for K2B production some sections of the land are being used for rice production. The first priority (P1) for possible areas to be planted for K2B production are the areas of suitable class except those that are used for paddy rice (9.2% of S1) which cover 106,219 km^2. The second priority (P2) are the areas that are moderately suitable (S2) under high inputs, they cover the areas with the soils Ta Muang (Tm), Tab Kwang (Tw), Ratch Buri (Rb) and Phon Pisai (Pp), excluding paddy lands, which cover about 98,570 km^2 (Table 5).

The integration of information among current land use types, land suitability assessment, and crop modelling made it possible to find new locations for K2B plantations effectively.

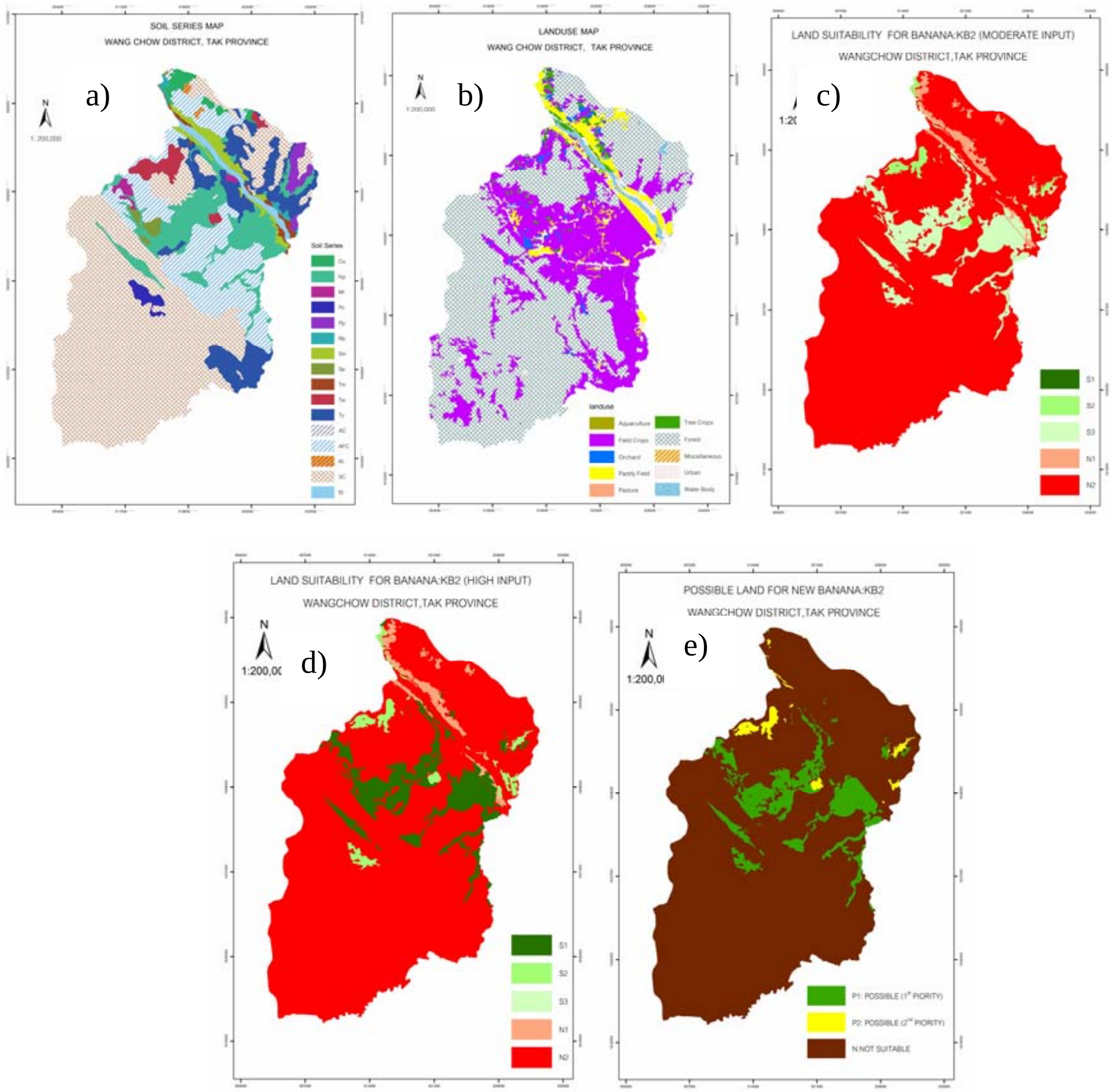

Figure 3. a) soil map, b) land use map, c) suitability classes (moderate input), d) suitability classes (high input), e) possible lands for banana (KB2)

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