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Land Suitability Evaluation for Soybean Using Geographic Information System in Malang District, Indonesia

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Abstract
The objective of the study was to spatially evaluate the suitability of the soybean crop using GIS tools thereby identify the potential to expand the soybean crop cultivation and production based on climate parameters in the Malang area of East Java, Indonesia. The study was conducted from June to July 2014. The location of research carried out at the Laboratory of Engineering of Natural Resources and Environment, Department of Agricultural Engineering, Faculty of Agricultural Technology, Brawijaya University, Malang. The results showed that in the first planting season after the rice crop that begins in March and May, rice field that can be used for growing soybeans consists of 8.896 ha of field (S1), 2.949 ha of S2, 20.744 ha of S3, and 614 ha of N. Rainfed area that can be used to grow soybean consists of 147 ha of S1, 757 ha of S2, 10.645 ha of S3, and 248 ha of N. Dry land that can be used to grow soybean consists of 8.190 ha of S1, 10.789 ha of S2, 68 105 ha of S3, and 8.254 ha of N. Second growing season from June to August all irrigated land, rainfed lowland and upland all soybean planted area cannot (N). The second planting season, which begins in June, and August all irrigated land, rainfed and dryland could not be planted with soybeans except water plus an additional 6.43 mm / day, 9.38 mm / day and 6.85 mm / day with successively increased production in 2699 tons, 4659 tons and 2932 tons.

Keywords: land suitability, soybean production, spatial analysis

Introduction

Soybean is one of important crops in Malang of East Java, Indonesia because of its role as a source of vegetable protein and can be used as an industrial raw material. However, soybean production in Malang is still low to meet the needs of consumption. The largest production of soybean production in this area occurred in the years 2002 – 2006 where the production is only 1.05 t/ha. This corresponds with the low production of soybean in Indonesia. Statistical data of FAO and BPS (Central Bureau of Statistics) showed that the average soybean demand in 2001-2005 amounted to 1.84 to 2.04 million tons, while domestic production is still very low, ranging from 0.67 to 0.81 million tons. Therefore, up to 2006, import of soybean in Indonesia each year around 1.1 million tons per year [1]. The low soybean production in Indonesia is not solely determined by the level of production technology, but it is also determined by the climate in the humid tropics that is not favorable for the growth of soybean [2].

Soybean (*Glycine max* L.) is an important crop grown worldwide, either as stable or commercial crop. Several workers showed that the area for optimal growth of soybean is at 190-357 m [3]. Soybean yield is strongly related to altitude [4]. The lower and the flatter areas have the higher yield [5]. The suitable temperature for soybean is 15–22 °C at emergence, 20–25 °C at flowering, and 15–22 °C at maturity [6][7]. Therefore, the soil and climate conditions can presumably be used to find out how the potential of land suitable for the growth and production of soybean plants in the area of Malang.

The result of previous studies showed that soybean grown in the dry season with irrigation produced higher yield than that grown in the rainy season at the same location. This difference is caused by differences in climatic elements, particularly solar radiation. Soybean planted in the dry season with irrigation can reasonably produce an average of 1.97 t / ha, while in the same location during the rainy season only produces 0.61 t / ha [2]. If a given of land is categorized and utilized based upon its capacity, sustainable agriculture production would be achieved on this land [8]. Therefore, land evaluation is essential to assess the potential and constraints of a given land for agricultural purposes [9].

Land suitability classification process is evaluation of grouping of certain land areas in terms of their suitability for a specific use. Land suitability is defined as the suitability of a certain land type to support a certain land use [10]. Land suitability evaluation is a process of grouping a specific land area to assess the suitability for a defined use [11]. It is thus necessary to apply land suitability results to improve land management for optimum productivity. A wrong decision made on land use may result in the decline crop productivity due to the increase of nematode population, as in the case in Taita, Kenya [12].

Those who use Geographical Information System (GIS) in agriculture recognize that the potential application of GIS in agriculture is large. The GIS system contains a set of procedures that facilitate the data input, storage, manipulation and analysis, and data output to support decision-making activities [13]. However, the GIS user community in production agriculture is small compared to other business sectors. There is a lack of formal opportunities to share applications and innovations of GIS specifically focused on agriculture [14]. Current approaches, based on GIS, spatial analysis and multi criteria analysis are available and are able

to assist in management and decision-making [15]. The main objective of land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period without deterioration, in order to minimize socioeconomic and environmental costs [16]. The Geographical Information System (GIS) offers a flexible and powerful tool as it can combine large volumes of different kinds of data into new datasets and display these new datasets in the form of informative and accessible thematic maps [17]. The FAO guidelines on the land evaluation system [18] are widely accepted for the evaluation. The value of land quality is the function of the assessment and grouping of land types into orders and classes in the framework of their fitness. Generally, land suitability is categorized as suitable (S) and not suitable (N). Whereas, S features lands suitable for use with good benefits, N denotes land qualities that do not allow considered type of use, or are not enough for suitable outcomes [8][19]. Under the present situation, where land is a limiting factor, it is impractical to bring more area under cultivation to satisfy the ever-growing food demand [20]. In other hand, the rapid population growth has caused increased demands for food while soil erosion and extensive deforestation continue [21]. Therefore, successful agriculture is required for sustainable use of soils that significantly determine the agricultural potential of an area.
Land suitability evaluation for soybean crop was not yet done in the region of Malang. In Malang District, soybean is one of leguminous crops grown in paddy fields (irrigated and rainfed paddy fields). Planting is usually done at the end of the rainy season, after the rice harvest. The objective of the study was to spatially evaluate the suitability of the soybean crop using GIS tools thereby identify the potential to expand the soybean crop cultivation and production based on climate parameters in the Malang area of East Java, Indonesia.

Materials and Methods

General Methods

Land suitability evaluation for soybean crop of Malang District was carried out in Laboratory of Natural Resources and Environment, Faculty of Agricultural Technology, Brawijaya University, Malang from June to July 2014. Data used in this study were secondary data covering climate, soybean production and biophysical data. Analysis was done by classifying the data according to the requirements for soybean. The analyzed data were then scored to get the values of land suitability evaluation. The values were then disseminated and classified to obtain maps according to the characteristics present in land suitability classes (rainfall, temperature, soil pH, CEC-clay, organic C, drainage, erosion, effective rooting depth, slope and altitude). Maps obtained were then converted in the form of grid maps using ArcView program.

Study area

Location

The study was conducted in Malang regency from June to July 2014. Malang lies between 112.34'09 " – 112.41'34"E and 7.54'52 ", 2 – 8.03'05 " 11 S in East Java of Indonesia (Figure 1). Malang District with a total area (according to GIS analysis) 356 567 ha consists of 33 districts with 378 villages and 12 urban villages.

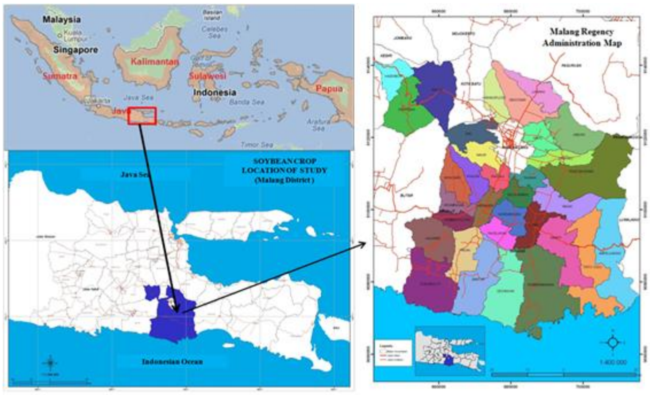

Figure 1. Location of study, Malang District of East Java, Indonesia

Geomorphology

Geological formation which has the largest distribution in Malang area is Volcano deposits of Jembangan, Tengger, and volcanic tuff (Figure 2). Malang has complete relief ranging from plains to the mountains. Soybean generally is found on land with flat relief. Slopes in Malang area is dominated by gentle slopes (8-15%) with an area of 213 752 ha or 60% of the area of Malang (Figure 3).

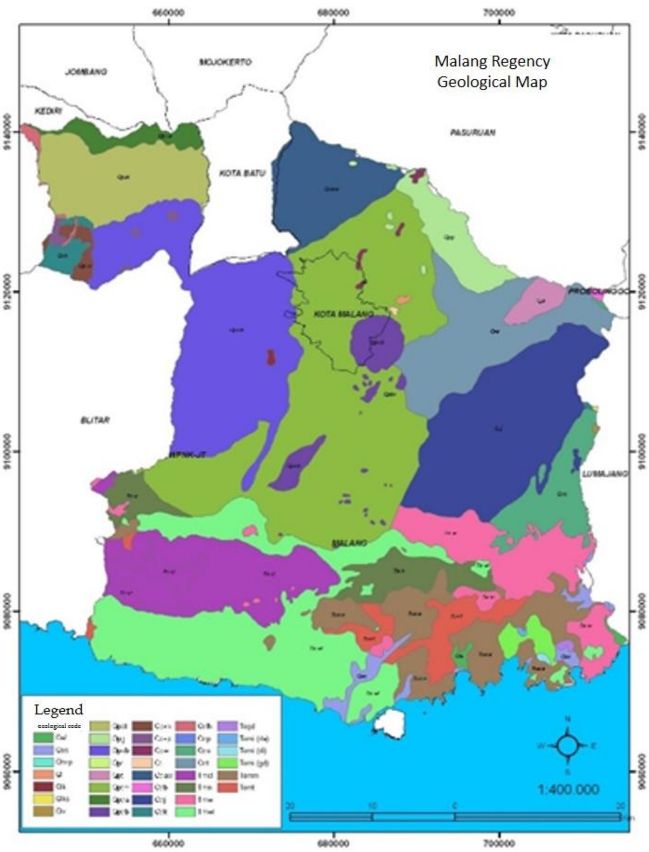

Figure 2. Geological Map

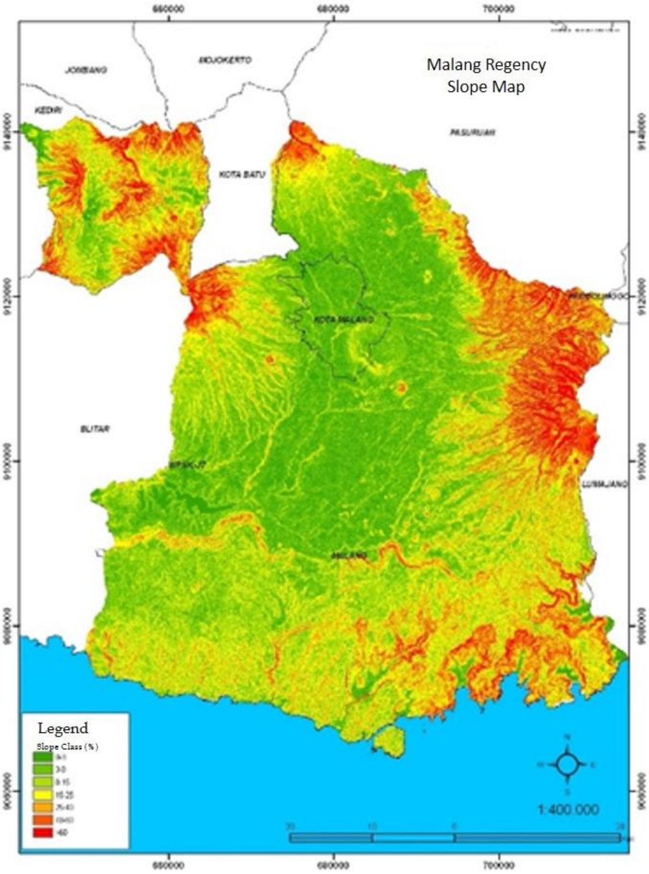

Figure 3. Slope Map

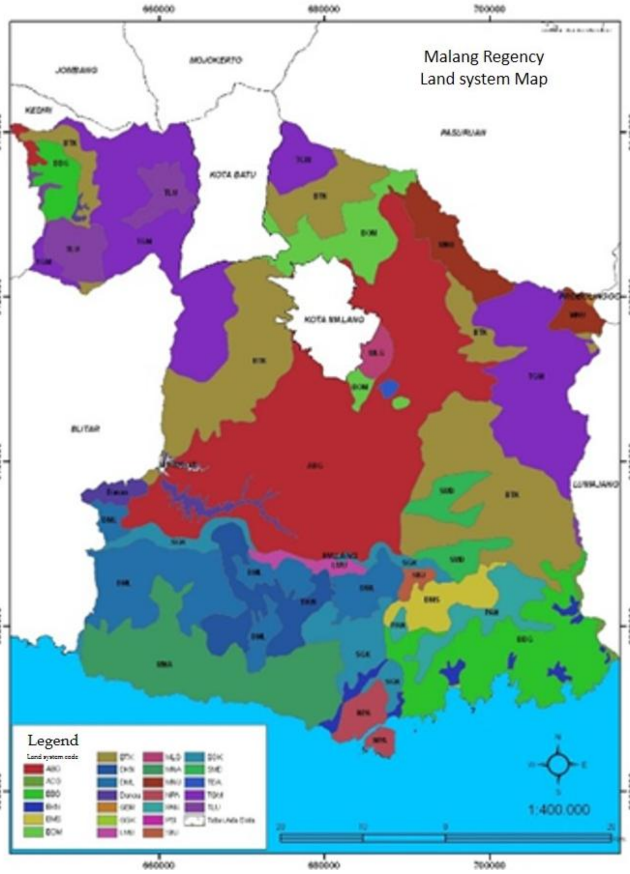

Figure 4. Land System Map

Land systems, land use, and soils

There are five land systems in Malang District, i.e. marine, alluvial, mountains, volcanic and carst. Volcanic system dominates the region, which is about 244 230 ha (70.03% area of Malang) (Figure 4). Attributes of the land systems can derive land characteristics that include oxygen availability (drainage), rooting media (coarse material and soil depth), the danger of flooding (inundation) and land preparation. The existing land use varies greatly in Malang area. Land that can be cultivated extensively is 237 049 ha or 69% of the area of Malang. The land consists of irrigated rice (35,900 ha), rainfed (11 749 ha), home garden (94 134 ha), and plantations (95 266 ha) (Figure 5). If only selected paddy fields (irrigated and rainfed) and dry land that are to be planted with soybeans, there is 164.416 ha of land available for soybean cultivation. There are 18 soil associations with the domination of Inceptisols. Distribution of the soil types is used for the evaluation of the quality and characteristics of the land that includes rooting medium (soil texture and soil depth) and nutrient retention (CEC, and pH of the soil).

Climate

Malang is a cool and dry area. The existing air humidity reaches 72%, with an average temperature range of 23 to 25°C and rainfall of 1833 mm / year with months 4 to 6 wet months. Variations in rainfall ranges from 750 mm / year to 3000 mm / year.

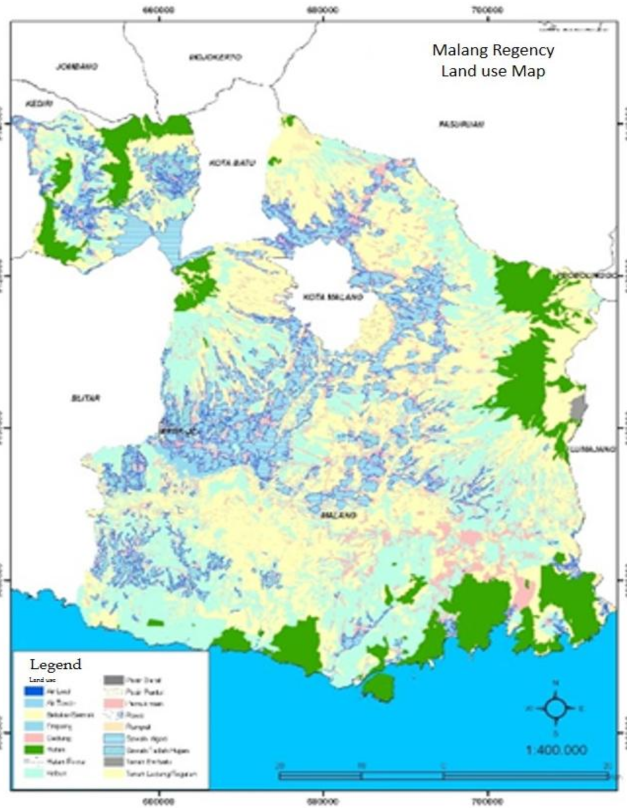

Figure 5. Soil Map

Ecological requirements for soybean

Criteria of plant growth requirements refer to the criteria developed by Djaenudin et al. [22]. Soybean growth cycle is about 120 days long and coincided with the respective period of the rainy season in the study area. Availability of water is very important for the development of soybean during germination period and pod filling [23] [24] in accordance with the first and third months of the growing cycle, respectively. During germination, excess or deficit of water affects the number of plants per area. Moisture deficit is more detrimental to yield in pod filling than at any other stage of growth. When the deficit of water occurs in the first phase of development, soybeans recover better than other plants because they can tolerate short-term of moisture stress in the root system and a relatively long flowering period [24]. The damage to crops caused by drought will depend on the rate of evaporation, the water deficit duration, the stage of development of the plant and the soil types. For maximum yields, 500-750 mm of water is required during the growing season [25], but dry weather is needed for the maturation because excess rainfall presents some limitations [26]. Slight drainage impedance reduces crop yields through the leaves of aging and reduces net photosynthesis. Soybeans grow in both sandy and heavy textured soils with a wide pH range between 5.2 and 8.2.

Land suitability evaluation

Land suitability was done by matching the characteristics of land for soybean growths according to criteria developed by Djaenudin et al. [24]. Assessment of land suitability for soybean crop was done by looking at the actual condition of the field. The actual land suitability evaluation is the evaluation of the suitability of land which only pay attention to the condition of the quality and characteristics of the land at that time, according to the level of management that is practiced by farmers in the region. For evaluation of land for soybean, rainfall criterion used is rainfall in the growing season. As soybean growing season follows paddy rice planting season, then the first growing season of soybean crop is in conjunction with the second cropping season of rice (March-May), while the second planting season of soybean is in conjunction with the third planting season of rice (June - August). Therefore, land suitability evaluation was also conducted on two different seasons.

Results and Discussion

Biophysical conditions

Based on slope, Malang Regency area is divided into four classes of suitability, i.e. Suitable (S1) covering an area of 132 520 ha (37%), Moderately Suitable (S2) covering an area of 81 232 ha (23%), Marginally Suitable (S3) covering an area of 61 268 ha (17%), and Not Suitable (N) covering an area of 81547 ha (23%). Land drainage in Malang District is divided into two classes, i.e. good drainage and somewhat hampered. Good drainage class is dispersed in a location that has ramp to steep slopes, while that of slightly impeded drainage the area often suffer from flooding, particularly in the basin areas or flood plains. Such drainage class is not a problem for soybean and it is still included into the S1 class.

In general, soil solum (soil depth) in Malang not problematic for soybean plants, because it is still deep enough for cultivation. Effective soil depth in the land suitability for soybean is divided into four classes, i.e. Suitable (S1) depth> 75 cm, Moderately Suitable (S2) depth of 50-75 cm, Marginally Suitable (S3) depth of 25-50 cm, and Not Suitable (N) depth <25 cm. Based on data from the effective depth of the soil in each district, it appears that there are no obstacles in the soil depth of Malang lands. Almost 80% of the land area in Malang district included in the Suitable class (S1).

Malang is in the plateau, and generally cultivated land is located at an altitude of 300-600 m above sea level. Therefore, the characteristic of this land is not a problem for soybean crop. Based on the attributes of the land system in the district of Malang is divided into four classes of suitability, i.e. Suitable (S1) covering an area of 144.760 ha (38%), Moderately Suitable (S2) area 179.213 ha (48%), Marginally Suitable (S3) covering an area of 23.103 ha (6%) and Not Suitable (N) covering an area of 29.468 ha (8%). In general, soil texture and soil depth in Malang are not problematic for soybean crop. In general, soil pH and cation exchange capacity (CEC) are not problematic.

Existing temperature data in Malang was only found at a few points only, i.e. Sutami, Sengguruh, Selorejo, Abdul Rahman Saleh and UB stations. As the station locations are difficult to do interpolation, then the information air temperature was predicted using formula Brak, i.e. T = 26.3 - bh, where T = temperatue, b = constants magnitude = 0.006, and h = is the location height. The result of interpolation is presented in using Brak Formula is presented in Figure 7. Based on land suitability criteria of soybean and temperature (Djaenuddin, et al. (2004), the area is classified as Suitable (S1) suitable for soybean crop area is112.060 ha, Moderately Suitable (S2) covering an area of 160 699 ha, marginally suitable (S3) covering an area of 26 628 ha and not suitable (N) covering an area of 76 859 ha. The average rainfall in 1997-2001, 2002-2006, and 2007-2011 were 144.05 mm, 131.7 mm, and 157.6 mm respectively.

Rainfall data were used to calculate the effective rainfall. Variation changes of the effective rainfall will affect the amount of water required for the crop evapotranspiration. By using the Polygon Thiesen, rainy region of each station was predicted. Land suitability criteria according Djaenuddin et al. (2004), is rainfall of 10 days. However, with the limited daily data, the rainfall of 10 days was determined by dividing the monthly rainfall into 3 parts. Soybean growing requirement is Suitable (S1) if the rainfall during the growing period is 350-1000 mm, Moderately Suitable (S2) if rainfall is 250-350 mm or 1100-1600, Marginally Suitable (S3) if rainfall is 180-250 mm or 1600 -1900 mm, and Not Suitable (N) if rainfall <180 mm or> 1900 mm. In the first soybean planting season, soybean is generally grown alongside the second planting season for rice crops around March, while the second soybean planting season, soybean is grown in conjunction with the second planting season for rice crops, around June. Under these conditions, rainfall suitability is also based on the precipitation that falls on every soybean growing season. Based on the rainfall that fell in March to May, all Malang area belongs to the class S2 and S3 no one including the S1 class and class N. Based on the rainfall that fell in June to

August, then the whole region Malang belongs to the class of N only.

Results of analysis using software CropWat evapotranspiration was found that the average evapotranspiration in 1997-2001, 2002-2006, and 2007-2011, in a row is 3.91 mm / day, 4.07 mm / day, and 4.08 mm / day. Soybean crop evapotranspiration was obtained from the crop coefficient value multiplied wit evapotranspiration value. Data of crop evapotranspiration value (Etc) of soybean per 5 year (Table 1) in planting months of July and September, in 1997-2001, 2002-2006, and 2007-2011 are 3.21 mm / day 3.29 mm / day, and 3.35 mm / day, respectively

Table 1. Evapotranspiration (ETc) of soybean

Month	ETc (mm/day)		
	1997-2001	2002-2006	2007-2011
July	3,14	3,31	3,38
August	4,36	4,54	4,54
September	2,13	2,03	2,13
Average	3,21	3,29	3,35

The average humidity throughout Malang is more than 70%, so that the entire Malang district may be classified as Moderately Suitable (S2) for the soybean crop. This parameter seems to be the constraints of soybean growth in Malang. Therefore, Suitable class (S1) for soybean is not found in this area. Malang is located around the equator, so that there is generally no problem with solar radiation, so it can be inserted into the appropriate class (S1)

Actual land suitability of first planting season (March to May).

Results of the evaluation of land suitability in paddy fields (irrigated and rainfed) and upland for soybean crops in Malang in the first growing season is presented in Table 2 and Figure 6. Rainfall in the northern Malang area during the first planting season for soybean causes most of the region is included the S2 class (moderate suitable), S3 (marginally suitable), and N (Not suitable). The rest belongs to the class S1 (suitable) for the soybean crop.

Table 2. Land suitability classes for each land use soybean plants (irrigated and rainfed paddy fields) in Malang in the first growing season (March-May)

Land Use	Land Suitability Classes (ha)				
	S1	S2	S3	N	Total
Irrigated Paddy Field	8.896	2.949	20.744	614	33.204
Rainfed rice fields	147	757	10.645	248	11.796
Upland	8.190	10.789	68.105	8.254	95.338
Total	17.233	14.496	99.494	9.116	140.339

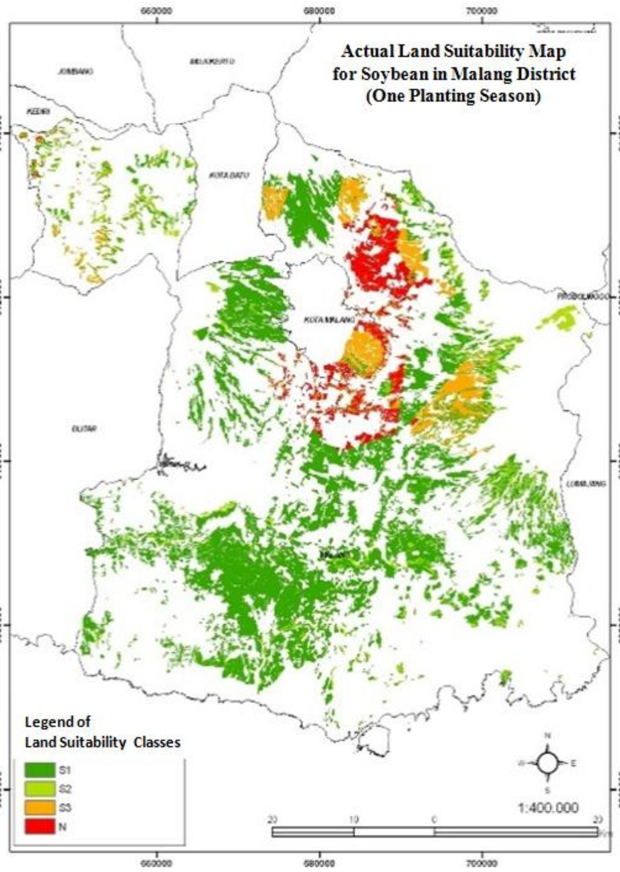

Figure 6. Land suitability for soybean at first planting season (March-May) in Malang District

Actual land suitability of second planting seasons (June-August)

Results of the evaluation of land suitability in paddy fields (irrigated and rainfed) and upland for soybean crops in Malang in the second planting season (June-August) are presented in Table 3, and in Figure 7. In the second planting season, there is no suitable land for soybean plants; all land area is included in N (not suitable) class. The main limiting factor for this is the very low monthly rainfall. The potential land suitability cannot be displayed due to lack of technical irrigated rice spatial data, in particular the discharge of irrigation in the growing seasons 1 and 2.

Table 3. Land suitability classes for each land use soybean plants (irrigated and rainfed paddy fields) in Malang in the second growing season (June-August)

Land Use	Land Suitability Classes (ha)				
	S1	S2	S3	N	Total
Irrigated Paddy Field	-	-	-	95.338	95.338
Rainfed rice fields	-	-	-	11.796	11.796
Upland	-	-	-	33.204	33.204
Total	-	-	-	140.339	140.339

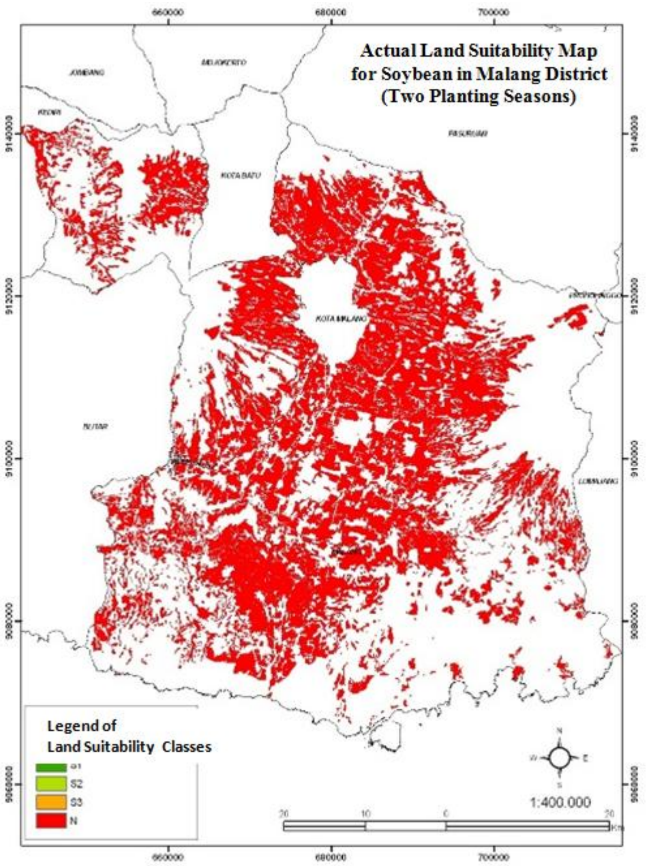

Figure 7. Land suitability for soybean at second planting season (June-August) in Malang District

Effect of changes in water needs on soybean production

Changes in water demand can affect soybean production in Malang district during the past 14 years are presented in Table 4. In the years of 2002-2006 soybean crop water needs was the highest deficient compared with 1997-2001 and 2007-2011. The soybean production in 2001-2006 was also the highest compared with the previous years. The difference in the water requirements of soybean can be caused by changes in the value of evapotranspiration, plant evapotranpiration, and effective precipitation.

Table 4. The effect of changes in water demand for soybean production

Year	Change in water demand (mm/day)	Soybean production (t)
1997-2001	-6,43	2699
2002-2006	-9,38	4659
2007-2011	-6,85	2932

Conclusion

The land suitability for soybean planted after paddy started from March to May are 8.896 ha (S1), 2.949 ha (S2), 20.744 ha (S3) and 614 ha (N), for paddy 147 ha of rainfed (S1), 757 ha (S2), 10.645 ha (S3) and 248 ha (N) for wet land, whereas for dry land are 8.190 ha (S1), 10.789 ha (S2), 68 105 ha (S3) and 8.254 ha (N). The second planting season which begins in June and August for all irrigated land, rainfed and dry land could not be planted with soybean except with added water. Addition of 6.43 mm water / day, 9.38 mm water / day and 6.85 mm water / day increased soybean production of 2699 t, 4659 t and 2932 t, respectively.

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