

Land Suitability Index for Estimating Sugar Cane Productivity in the Humid Tropics of South Sulawesi Indonesia

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ABSTRACT

This research was completed using mixed qualitative and quantitative methods. Field surveys were executed in sugar cane plantation throughout South Sulawesi Indonesia. Land suitability analyses were performed using a parametric approach with Storie's index equation followed up with correlation analysis using the Pearson correlation. Results revealed that the period for sugarcane crop growth in the humid tropic relatively dry regions of South Sulawesi Indonesia lasted for the months of November to July. The land suitability for sugar cane in the research location was moderately suitable (S2c) and marginally suitable (S3c, S3s, S3s,f and S3c,w) with limiting factors such as relative humidity during crop maturation phase, the duration of sunlight, soil depth, soil texture, soil pH and soil drainage. Land suitability index at the research location ranged from 25.2 to 55.0; sugar cane yields ranged from 30.3 to 62.0 Mg ha⁻¹ year⁻¹. Pearson correlation coefficient (r) between LSI with cane and sugar productivity were 0.81 and 0.84 respectively, signifying the strength of the correlation between the two values. This also indicates that land suitability index can be estimating the potential crop yield in the humid tropicsthat relatively dry climate regions.

Keywords: Humid tropics, land suitability index, sugar cane

ABSTRAK

Potensi sumber daya lahan dapat dinilai dengan menggunakan metode evaluasi lahan dengan pendekatan yang tepat. Penelitian ini bertujuan untuk (1) karakterisasi kondisi tanah dan iklim peternakan tebu di daerah tropis yang relatif kering; (2) mengevaluasi kesesuaian lahan perkebunan tebu di daerah tropis yang relatif kering untuk tebu; (3) menganalisis hubungan antara indeks kesesuaian lahan (LSI) dengan produktivitas tanaman tebu. Penelitian ini menggunakan metode campuran kualitatif dan kuantitatif. Survei lapang dilakukan di perkebunan tebu di Sulawesi Selatan. Analisis kesesuaian lahan dilakukan dengan menggunakan pendekatan parametrik dengan persamaan Indeks Storie diikuti dengan analisis hubungan LSI untuk tanaman tebu menggunakan korelasi Pearson. Hasil penelitian menunjukkan bahwa periode pertumbuhan tanaman di perkebunan tebu di daerah tropika basah yang relatif kering berlangsung selama bulan November sampai Juli, topografi datar sampai bergelombang, tekstur halus, drainase yang baik, solum tanah dangkal sampai sedang, pH tanah agak masam sampai netral, kapasitas tukar kation dan kejenuhan basa tinggi, kandungan bahan organik sedang dan salinitas rendah. Kesesuaian lahan untuk tanaman tebu di lokasi penelitian tergolong cukup sesuai (S2c) dan sesuai marjinal (S3C, S3s, S3s, f dan S3C, w) dengan faktor pembatas seperti kelembaban relatif selama fase pematangan tanaman, lama penyinaran matahari, kedalaman tanah, tekstur, pH tanah dan drainase tanah yang buruk. Indeks kesesuaian lahan di lokasi penelitian berkisar 25.2 sampai 55.0; hasil tebu berkisar 30.3 sampai 62.0 ton tebu per hektar. Koefisien korelasi Pearson (r) antara LSI dan hasil tebu basah dan gula adalah 0.81 dan 0.84, secara berturut-turut. Hal ini menandakan kekuatan korelasi antara LSI dan hasil tebu atau gula. Ini juga menunjukkan bahwa indeks kesesuaian lahan dapat digunakan sebagai penduga potensi hasil tebu di daerah iklim tropika basah yang relatif kering.

Kata kunci: Indeks kesesuaian lahan, tebu, tropika basah

INTRODUCTION

Crop productivity is highly dependent upon three main determinants, soil and climate (FAO

2007), as well as land management practices (Meyer and van Antwerpen 2010). Sugarcane requires specific conditions to be able to grow and produce optimally. Sugarcane can grow and reach optimal crop production in various types of soil as long as the soil has good structure, aeration, and solum which allows the roots to grow to depths of at least 60 cm

(Sys *et al.* 1993). Most external natural factors are solar radiation, temperature, evapotranspiration and precipitation (rain) (Mueller *et al.* 2010; FAO 2007). This is in line with the opinion of Bindraban *et al.* (2000) that the performance of the plant is largely influenced by several key factors, among others, radiation, water and nutrients. In addition to climate, soil characteristics also greatly affect the productivity of the plant. However, the soil will support crop growth when climate is a soil-forming factor in the expected interval value (Murray *et al.* 1983; Mueller *et al.* 2010). South Sulawesi is one of the major producing province sugar cane in Indonesia where the crop is prioritized in relatively dry, tropical climates, such as Camming and Arasoe (District of Bone) and District of Takalar. Based on the data from PT Perkebunan Nusantara (PTPN) XIV South Sulawesi, in 2013, the sugarcane yield of the three regions vary between 20 and 80 Mg ha⁻¹ year⁻¹. Additionally, the percentage of brix in the three sugarcane-producing regions were, respectively, 7.0%, 7.5% and 9.8%. Sugarcane yield differences in these three areas is probably a result of the diversity of land characteristics related to both soil and climate.

Optimal and sustainable production can be achieved if land use planning is according to land evaluation results (Gong *et al.* 2012). Various land suitability classification methods are widely used in Indonesia, both manual and computerized, among them: region capability classification (Soepraptohardjo 1970); land suitability evaluation (FAO 1976), land evaluation computer system (Wood and Dent, 1983) and automated land evaluation system (Rossiter and Wambeke 1997). However, the existing methods are often showing vary results in the assessment of land suitability classes for the same test location. Sevani *et al.* (2010) modified the FAO's limit value (FAO 1970) by integrating an expert system, but the results of the validation in the field have not provided statistically significant results. Consequently, it is necessary to modify the method for estimating the potential of land as influenced by specific conditions based on the actual yields of plants in the field which is expressed in the form of land suitability index values using parametric multiplicative approach.

Therefore, the study goals were to: (1) characterize the soil and climate of sugar cane plantations in relatively dry, tropical climates in South Sulawesi Province of Indonesia, (2) evaluate the suitability of sugarcane plantations in relatively dry, tropical climates for the development of sugar cane, and (3) analyze the relationship between the land

suitability index (LSI) with the productivity of sugarcane.

MATERIALS AND METHODS

Study Scope

This study used mixed qualitative and quantitative methods. Qualitative methods were used to determine land suitability classes, while quantitative methods were used in determining the optimal results and marginal land unit analyzed. Observation and description of the soil profile and soil sampling were conducted in three sugar cane regions in the province of South Sulawesi, Indonesia: Camming, Arasoe, and Takalar (Figure 1).

A total of 32 soil profiles were made and observed and a description for each profile was created based on analysis. Analysis of soil samples was performed in the Laboratory of Chemistry and Soil Physics of the Soil Science Department, Faculty of Agriculture, Hasanuddin University and Soil Laboratory, Soil Research Station in Maros, South Sulawesi, Indonesia. Equipment used in the study consisted of a set of survey tools such as GPS, munsel soil color charts, compass, abney level, a computer equipped with Microsoft Office 2007 and SPSS version 16 software as well as tools for the analysis of soil samples such as pH meter, hydrometer, atomic absorption spectrophotometer, and flamephotometer.

The materials used include topographic maps, soil maps, map of sugar cane plantation, climatological data, yield data from sugar cane plantation. Profile point determination based on the results of overlapping maps of soil, topographical maps, maps of plantation and crop production range mapping by using Arc GIS ver 10.3. Sugarcane yield was separated into four divisions: between 0 and 20 Mg ha⁻¹, between 20 and 40 Mg ha⁻¹, between 40 and 60 Mg ha⁻¹, between 60 and 80 Mg ha⁻¹. Overlapping of the maps produced 32 units of observation. At each profile, soil samples were taken for analysis in the laboratory. Climate data was obtained from three climatological stations near the plantation areas.

Sampling and Soil Analysis

The parameters observed in this study were the characteristics of climate, soil, and terrain. Climatic characteristics consisted of: rainfall, temperature, humidity, and duration of sunshine. The characteristics of the soil and terrain consisted of, among others, slope, drainage, waterlogging, 3 fraction soil texture, soil structure, soil depth, surface

rocks, cation exchange capacity, the amount of exchangeable base cations, salinity, organic carbon.

Study Stage

This study consisted of several stages: Determination of the growing period using Equation 1. The growing period is the month that the precipitation greater than half evapotranspiration and a temperature of more than 6.5 °C (FAO 1996; Choudhury and Jansen 1998).

$$P \geq \frac{1}{2} ETP \dots\dots\dots(1)$$

Notes:

- P = precipitation (mm)
- ETP = evapotranspiration (mm)

Free surveys performed at the 32 representative soil profiles (10 profiles in Takalar, 12 in Camming and 10 in Arasoe) were also made to examine soil horizons. In each observation unit, a soil samples were taken for analysis in the lab. Soil profile description referred to the Soil Survey Manual (Soil Survey Staff 1993). The type of soil was determined in accordance with the soil taxonomy system as described in Keys to Soil Taxonomy 12th Edition (Soil Survey Staff 2014).

Calculation of land and climate suitability index using a parametric approach, Storie’s equation (Storie 1978), as shown in equation 2 and 3. Furthermore, the results of the calculation of the value of LSI were adjusted to the criteria of land suitability classes in accordance to Sys *et al.* (1991) which classifies land units into the following orders: highly suitable (S1), is moderately suitable (S2), the marginally suitable (S3) and currently not suitable (N) for LSI values that are >75 to 100, between 50 and 75, between 25 and 50, and between 0 and 25, respectively.

$$Ic = a \times \frac{b}{100} x - \frac{c}{100} x \dots\dots\dots(2)$$

if 25 < Ic < 92,5 then climate rating = 16.67 + 0.9 Ic

if Ic < 25, then climate rating = 1.6 × Ic

$$IKL = A \times \frac{B}{100} x - \frac{C}{100} x \dots\dots\dots(3)$$

Note:

- Ic = climate index
- a, b, c, = climate characteristic rating
- A, B, C, = land characteristic rating (climate and soil)
- LSI = Land Suitability Index

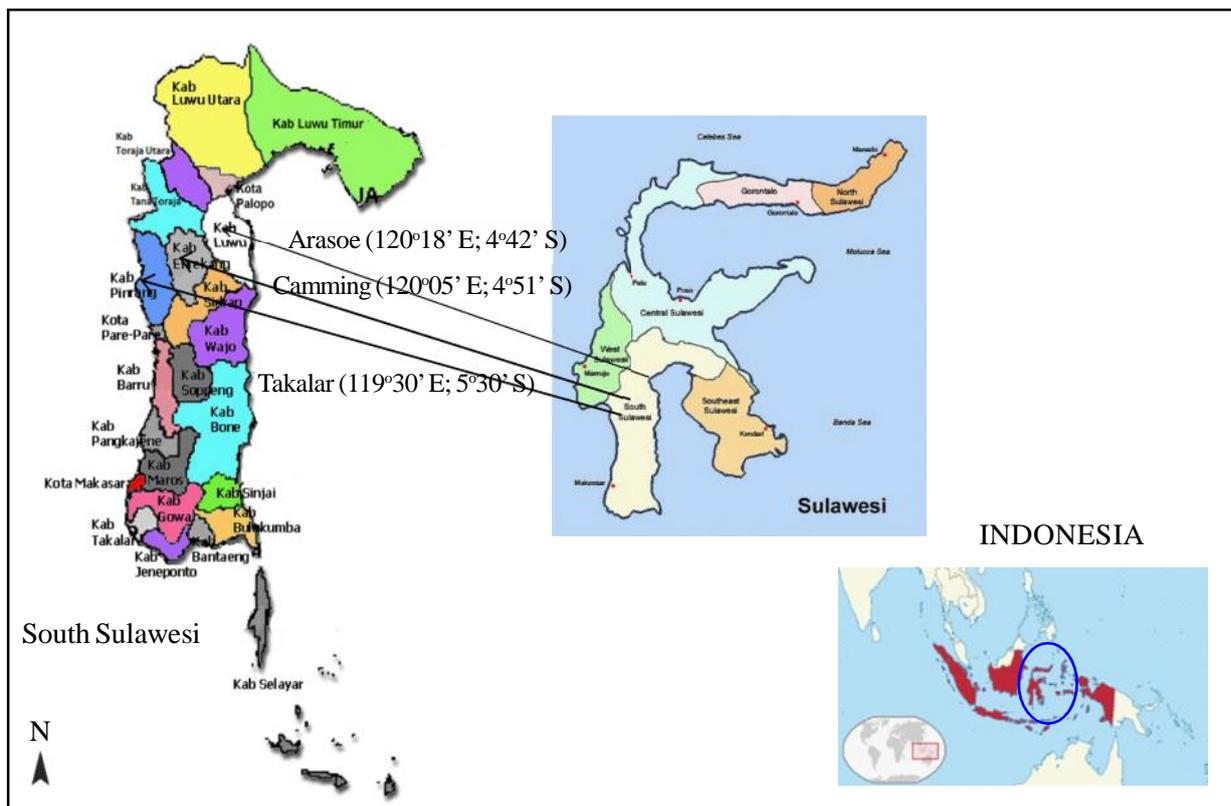


Figure 1. Map of the research sites.

Table1. Climate suitability index in the research location for the period of November – June/July.

| Climate Characteristics | Rating LSI | | |
|--|------------|-----------|-----------|
| | Takalar | Camming | Arasoe |
| Precipitation of vegetative stage (mm) | 94.1 | 93.7 | 90.5 |
| Precipitation of maturation stage (mm) | 95.5 | 92.6 | 93.6 |
| Mean day temperature for vegetative stage (°C) | 96.2 | 92.2 | 90.3 |
| Annual average temperature (°C) | 100 | 100 | 100 |
| Sunshine: hours/year | 94.5 | 80.0 | 74.5 |
| Relative humidity of maturation stage (%) | 73.0 | 70.0 | 70.0 |
| Climate Suitability Index (Ic) | 59.6 (S2) | 44.8 (S3) | 39.9 (S3) |

Yield predictions were determined as described in Sys *et al.* (1991), which for the S1 class an LSI >75%; S3 if LSI is somewhere in the range of 40% above and 10% below the marginal results, S2 for LSI values between S1 and S3, and N for all LSI values under S3. Marginal results signify that total profits are balanced/equal to the total expenditure (Vargahan *et al.* 2011). The definition of optimal results was set based on Sys *et al.* (1993) stating that sugar cane crop yields for commercially grown plants on irrigated lands should reach 110 Mg ha⁻¹ yr⁻¹.

Data Analysis

Calculation of the correlation between LSI and sugar cane productivity using Pearson correlation with a coefficient ranging from 0 – 1. The closer the value was to 1 the stronger the correlation between the two values. Pearson's correlation analysis was performed using SPSS Versi 16.

RESULTS AND DISCUSSION

Climate and Soil Characteristics

The growing period at three study sites ranged from 240 days from November to July in Takalar and 273 days from November to June in Camming and Arasoe. Knowing the growing period for the crops is important in determining the appropriate moment for planting to reduce the risk of drought and optimize crop yield (Allen *et al.* 1998). Based on the precipitation data of the last 15 years (1999-2013), the average annual precipitation at the 3 research locations ranged between 1.600 and 2.000 mm per year, with 8 months of rain and 4 months of dry season; according to Oldeman this climate is classified D2 with an average air temperature of 25.9°C, the average humidity is 85.8% with an average minimum and maximum temperatures of 22°C and 33°C, respectively.

Field observations and soil sample analysis results showed that sugar cane plantations in these

regions were generally located at an altitude of 56 to 510 m above the sea level, had a slope ranging from 0 to 15%, poor to good drainage, surface rock concentration ranging from 1 to 10%, soil depth ranging between 50 and 100 cm, soil textures of silty clay loam, sandy clay loam, silty loam, clay, clay loam, pH value ranged from 5.8 to 6.2, cation exchange capacity clay ranged from 42.7 to 186.6 cmol kg⁻¹ clay, base saturation ranged from 47.41 to 83.34%, amount of base - a base exchange ranged from 8.98 to 18.63 cmol kg⁻¹ soil, organic

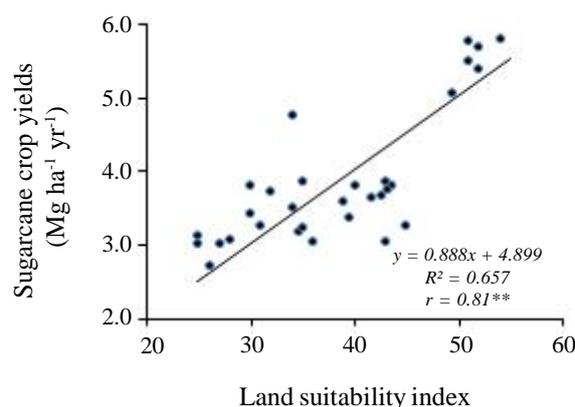


Figure 2. Relationship between LSI and sugarcane crop yields.

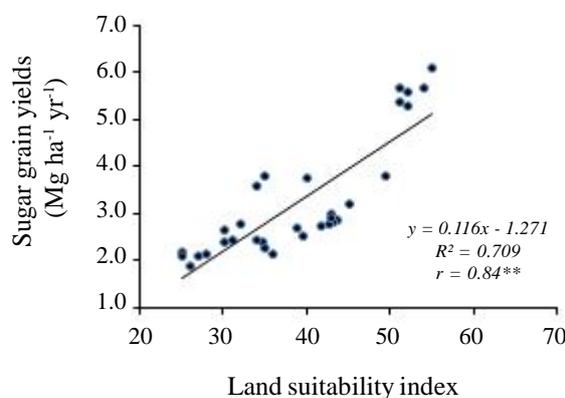


Figure 3. Relationship between LSI and sugar grain yields.

Table 2. Land suitability index, crop yields, land suitability classification for sugarcane at research sites.

| Land Unit | Soil type (<i>Soil Taxonomy</i>) | Land suitability index | Land suitability classification | Cane production (Mg ha ⁻¹ yr ⁻¹) | Sugar production (Mg ha ⁻¹ yr ⁻¹) |
|-----------|---------------------------------------|------------------------|---------------------------------|--|---|
| TA1 | Typic Haplustalfs | 55.0 | S2c | 62.0 | 6.1 |
| TA2 | Typic Haplustalfs | 51.0 | S2c | 55.0 | 5.4 |
| TA3 | Typic Haplustepts | 35.1 | S3s | 38.7 | 3.8 |
| TA4 | Typic Haplustepts | 40.3 | S3s,f | 38.3 | 3.8 |
| TA5 | Typic Haplustalfs | 51.1 | S2c | 57.8 | 5.7 |
| TA6 | Typic Haplustepts | 52.0 | S2c | 54.0 | 5.3 |
| TA7 | Typic Haplustepts | 43.1 | S3s,f | 30.5 | 3.0 |
| TA8 | Typic Haplustalfs | 52.4 | S2c | 57.0 | 5.6 |
| TA9 | Typic Haplustepts | 45.1 | S3s | 32.9 | 3.2 |
| TA10 | Typic Haplustepts | 54.2 | S2c | 58.0 | 5.7 |
| C1 | Typic Haplustepts | 43.6 | S3c | 38.3 | 2.9 |
| C2 | Typic Haplusterts | 43.1 | S3c | 37.8 | 2.8 |
| C3 | Typic Haplustepts | 39.5 | S3c | 34.0 | 2.6 |
| C4 | Typic Haplustepts | 38.9 | S3c | 36.0 | 2.7 |
| C5 | Typic Haplustalfs | 34.6 | S3c | 32.0 | 2.4 |
| C6 | Typic Haplusterts | 42.6 | S3c | 37.0 | 2.8 |
| C7 | Typic Haplustalfs | 41.6 | S3c | 36.5 | 2.7 |
| C8 | Typic Haplustepts | 31.0 | S3c | 32.9 | 2.5 |
| C9 | Typic Haplustepts | 49.4 | S3c | 50.9 | 3.8 |
| C10 | Typic Haplustalfs | 34.0 | S3c | 47.8 | 3.6 |
| C11 | Typic Haplustepts | 32.2 | S3c | 37.3 | 2.8 |
| C12 | Typic Haplustepts | 43.4 | S3c | 38.9 | 2.9 |
| AR1 | Typic Haplustalfs | 30.2 | S3c | 38.2 | 2.7 |
| AR2 | Typic Haplustepts | 35.3 | S3c | 32.4 | 2.3 |
| AR3 | Typic Haplustepts | 25.4 | S3c | 31.4 | 2.2 |
| AR4 | Typic Haplustalfs | 30.1 | S3c | 34.5 | 2.4 |
| AR5 | Typic Haplustepts | 26.0 | S3c,w | 27.2 | 1.9 |
| AR6 | Typic Haplustepts | 36.0 | S3c | 30.6 | 2.1 |
| AR7 | Typic Haplustalfs | 34.0 | S3c | 35.1 | 2.5 |
| AR8 | Typic Haplustepts | 27.2 | S3c,w | 30.3 | 2.1 |
| AR9 | Typic Haplustepts | 28.1 | S3c | 31.0 | 2.2 |
| AR10 | Typic Haplustepts | 25.2 | S3c,w | 30.4 | 2.1 |

Note: *c=climate; w=wetness; f=fertility*

carbon ranged from 2.1 to 2.4%, and salinity ranged from 0.42 to 1.11 dS m⁻¹.

Based on the observations and analysis of the soil sample profiles in the laboratory, using a soil taxonomy classification, the soil at the research locations could be classified as Typic Haplustepts, Typic Haplustalfs and Typic Haplusterts. Typic Haplusterts soil was found only in Camming, whereas Typic types Haplustalfs and Typic Haplustepts were found in all locations.

Climate Suitability

Analyses on climate suitability at the research locations returned results of moderately suitable (S2) and marginally suitable (S3) with limiting factors of sunshine radiation and relative humidity. Climate

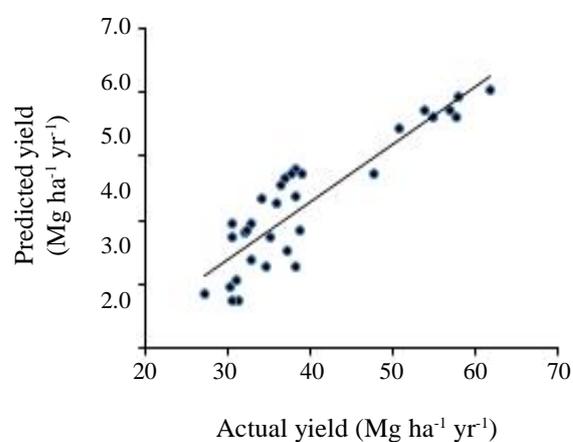


Figure 4. Comparison of actual crop yields with crop yield prediction.

suitability index calculation results for the period of November to June at all three locations can be seen in Table 1.

Land Suitability

The climate and soil are very important environmental factors that influence the growth and sugar cane crop yields. Qualitative analyses returned results showed that the land in the research sites fell under the category of moderately suitable (S2c) and marginally suitable (S3c, S3c,w, S3s,f, S3s) for sugar cane crops with climate-related limiting factors such as high relative humidity during maturation period (for all locations), lack of sunshine duration (in Arasoe and Camming), poor drainage at some observation points usually situated in lowlands (Arasoe), clay soil texture at the subsoil (Camming and Arasoe), shallow solum depth (<50 cm) in several places in Takalar, and slightly acidic soil in Takalar.

Correlation between Land Suitability Index and Sugar Cane Yield

Land suitability index values determine the classification of land suitability for a given location. By knowing the LSI value one can predict the crop production potential of a location. The highest LSI value was 55.0 in sugarcane plantations in Takalar, the lowest LSI value was 25.2 found in sugarcane plantations in Arasoe. Highest cane and sugar crop yields were found in the land plot with the greatest LSI in Takalar producing 62.0 Mg ha⁻¹ yr⁻¹ of cane and 6.1 Mg ha⁻¹ yr⁻¹ of sugar. The lowest crop yields for cane and sugar were 27.2 Mg ha⁻¹ yr⁻¹ and 2.1 Mg ha⁻¹ yr⁻¹, respectively, located in Arasoe. The relationship between land index, land suitability index, and crop productivity can be seen in Table 2 and Figure 2 below.

Figure 3 shows that sugar yield in research locations were predominately lower than 4 Mg sugar ha⁻¹ yr⁻¹. The highest average sugar production was slight greater than 4 Mg sugar ha⁻¹ yr⁻¹ in plantations in Takalar with land suitability index classification of S2. Conversely, the lowest yearly average was less than 3 Mg sugar ha⁻¹ yr⁻¹ found in Arasoe that land suitability analyses classified as S3. Such low crop yields in Arasoe appear to be influenced by the lack of sunshine radiation due to cloudy conditions and water tables closer to the soil surface resulting in poor drainage than in other locations.

Figure 3 also shows that there is a strong positive correlation between the land suitability index value with the crop yield of a particular location. This can be seen in the values of $r = 0.81$ (significant at p

<0.01) and $r = 0.84$ (significant at $p < 0.01$) which show that the greater the land suitability index the larger the crop yield for that location is. These results are confirmed by the correlation analysis between actual crop yields and crop yield predictions (Figure 4) which showed a strong correlation where value of $r = 0.89$ (significant at $p < 0.01$).

Quantitative analysis showed that optimal estimation of sugarcane crop yields cultivated for commercial use on irrigated land was greater than 82.5 Mg ha⁻¹ yr⁻¹, marginal sugarcane crop yields were 27.5 Mg ha⁻¹ yr⁻¹ (B/C ratio = 1), so that lands categorized S3 produced 30.25 to 38.5 Mg ha⁻¹ yr⁻¹, S2 land produced >38.5 to 82.5 Mg ha⁻¹ yr⁻¹, and lands categorized N produced <30.25 Mg ha⁻¹ yr⁻¹. These results are in accordance with the actual crop yields at the research locations which ranged from 25.2 to 62.0 Mg ha⁻¹ yr⁻¹. These results show that in regions with land characteristics resembling the agroecology of sugarcane plantations in South Sulawesi that is humid tropical/relatively dry, flat to wavy topography, Typic Haplustalfs, Typic Haplustepts and Typic Haplustersts, sugarcane crop yield predictions can be performed using land suitability analysis and these results can be duplicated in regions with similar climate and land characteristics as those found in sugarcane plantations in South Sulawesi.

The climate of the research locations was quite suitable for the cultivation of sugar cane, classified either moderately suitable (S2) or marginally suitable (S3) for the planting period of early November with a relatively high humidity as a limiting factor of >70% during the maturation period. Relative humidity during maturation period for all locations was greater than 80% which was an inhibiting factor in the maturation period of the plant. According to Sys *et al.* (1993), optimal sugar cane growth occurs if the relative humidity is lower than 60% during maturation period. High humidity can result in low sugar cane yields and decreased resistance to disease (Samui and Kukarani 2003;). Hoogenboom (2000) examined the influence of various weather factors including maximum and minimum relative humidity of various crops in tropical regions of Nigeria, found that humidity played a large influence in crop yields, including sugar cane.

In addition to the humidity in the maturation period, the duration of sunshine radiation during maturation period could also be a limiting factor in crop yield in Camming and Arasoe that tend to be cloudy. The role of solar radiation is not solely on the photosynthesis process alone but it is important also to hormonal photo reaction (Monteith 1972).

According to Cardozo and Sentelhas (2013), the formation of sugar is inhibited by cloudy weather on the day and night. When the weather is cloudy during the day, the process of photosynthesis is hampered; consequently the number of tillers in each clump is reduced. Cloudy weather occurring in the night time increases the air temperature and plant respiration rate, thus, the accumulation of sugar in the stem decreases. In addition to humidity and solar radiation, the temperature and precipitation also affect the yield (Kumar 1984), but in this study, temperature and precipitation were not limiting factors in the areas of study. This shows that the influence of climatic factors on the growth and production of sugarcane (Samui and Kukarani 2003).

The results of biophysical evaluation of research sites were consistent with the results of Naidu (2002) in several sugarcane plantations in India showing that the growth of roots, stems, and sugar cane yield declined in the subsoil with the texture of fine clay dominant, potentially swelling and shrinking, rocky and poor drainage. Such conditions limit the production of sugar cane. Another point raised by Getaneh and Negi (2014), namely drought in sugarcane plantations could seriously inhibit plant growth in shallow soil. Deep soil has the ability to store a larger volume of water than the shallow soil (Blackburn 1984). Soils with high clay concentrations and shallow could still have water storage capability (Meyer and van Antwerpen 2010). In addition to soil depth and texture, soil drainage was also a limiting factor for crop growth in many research sites, particularly in the Arasoe region. Sugarcane can withstand the presence of water puddles for a maximum of 2 weeks, but such conditions invite diseases, such as fungi, viruses, and bacteriae (Sys *et al.* 1993).

CONCLUSIONS

Land suitability index at the research location ranged from 25.2 to 55.0; sugar cane yields ranged from 30.3 to 62.0 Mg ha⁻¹ yr⁻¹. Pearson correlation coefficient (r) between LSI with cane and sugar productivity were 0.81 and 0.84, respectively, signifying the strength of the correlation between the two values. Sugarcane plantation productivity in the humid tropics relatively dry climate with land characteristics resembling to those found in South Sulawesi Indonesia can be predicted using land suitability index.

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