Variability of Maize Yield Over Different Soil Types and Land Suitability Indices In The Humid Tropics, South Sulawesi Indonesia

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Abstract
An attempt of understanding the influence of land characteristics on crop yields is useful in designing site specific management of land resources. Characteristics of soil and climate in the humid tropics like Indonesia vary considerably among agroecological zones. The primary aim of this study is to assess the correlation between land characteristics and maize yields; and to evaluate the variability of land index over different soil types in the humid tropics of South Sulawesi, Indonesia. As many as 30 soil profiles were made at study area within fourteen different soil types with traditional maize cultivation. A linear regression with Pearson correlation analysis was undertaken to evaluate maize yields at different soil and climate characteristics. It was found that soil pH, base saturation, and organic carbon have a significant correlation with maize yield with R^2 value of 0.705, 0.741, and 0.683, respectively. The analysis also shows that correlation between land suitability index and maize yield reaches an R^2 value of 0.807. The scatter points in the diagram depict a good indication that the higher the land index the better maize yield can be produced in the area under consideration. Suitability analysis indicates that land suitability index (I) value ranges from 11.5 to 55.0, with maize yield from 1.6 ton/ha (*Typic Dystrudepts*) to 5.2 ton/ha (*Typic Haplustalfs*) and parametric suitability classes are S2 (moderately suitable), S3 (marginally suitable), N1 (currently not suitable), and N2 (permanently not suitable).
Keywords: Land suitability index; humid tropics; maize; South Sulawesi

1. Introduction

Geographically, Indonesia islands stretch along the Equator and are located between latitudes 5^0 North and 11^0 South, longitudes 95^0 dan 141^0 East. The region is categorized as a humid tropics that has isohypertermic temperature regime. Soils formed in the humid regimes is generally deep, yellow reddish color, high aluminium saturation, and low fertility, due to the intensive weathering process. The most important external natural factors are solar radiation, temperature, evapotranspiration, and precipitation (Mueller et al., 2010). Soil may provide good characteristics for plant growth if climate, as the main soil forming factors, is in an appropriate range (Lavalle et al., 2009). Using the soil classification system of Dudal Soepraptohardjo (1957), such soil is classified as reddish-yellow podzolic, while according to soil taxonomy system (Soil Survey Staf, 2010), it is classified as *Ultisols* and in a particular case as *Oxisols*. In areas where seasonally dry with ustic soil moisture regime, chemical weathering process is relatively slow, so that the soil adsorption complex is filled with exchangeable bases (especially Ca, Mg and K), makes the soil is slightly acidic to neutral pH.

South Sulawesi, one of the major food-producing provinces in the eastern part of Indonesia produces a large part of maize. This region has varied climate types. According to the criteria of Oldeman (Oldeman, 1977) the climate in South Sulawesi is classified as B1, C1, C2, D1, D2, E1, E2, and E3. Average of maize production in South Sulawesi varies in the range of 3-5 tons/ha. The highest average productivity can be found in the southern region with relatively dry climate, while the lowest productivity is in the northern region with relatively wet (humid). Based on the exploratory map of Indonesia (Subagyo et al, 2000), the main soil types found in South Sulawesi are Inceptisols (48.7 %), Ultisols (25.2 %), Alfisols (9.2 %), Oxisols (2.8 %), Vertisols (3.6 %) and Entisols (5.0 %). These soils occur on different climate, parent material, relief/topography, and landform. According to Soil Survey Manual (USDA, 1951), agricultural development always needs soil suitability evaluation that can be expressed as "productivity rating index" measured on different types of soil. Maize productivity is strongly influenced by the quality/characteristics of the land, including soil and climate. Soil can support plant growth if the soil forming factors such as climate and topography are in an expected range

(Mueller et al., 2010). Type of soil that is formed under a certain pedogenesis process may provide information on the potential productivity of the soil (Mueller et al., 2010). Soils also provide several ecological and social functions (Lal, 2008; Jones et al., 2009). The productivity function is related to the most common definition of soil quality, as "capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, enhance water and air quality, and support human health and habitation (Karlen et al., 1997).

Average of South Sulawesi maize yield is now approximately 4.0 tons/ha (Central Bureau of Statistics, 2011). The soil and climate of South Sulawesi is basically capable of supporting a much higher yield of more than 6 tons/ha (Fauzi et al., 2011). The soil characteristics such as fertility, water availability, and land management have not been to date under consideration by farmers in agricultural development. Land evaluation is thus needed to produce recommendations for appropriate land management according to land potential. To obtain production level according to land potential, crops should be grown under conditions of sufficient water and nutrients, while pest, weed and disease should be controlled (Verdoodt and Van Ranst, 2003). Therefore land suitability classification needs to be taken into account in the development of highly commodity because it is based on knowledge of the requirements of crops, soil characteristics, and soil management (Ande, 2011). The result of land evaluation should reflect not only possible yield, but also more importantly, the ease or difficulty of management of the land parcels for a given purpose and ensuring the land's sustained use for a long period of time (Baja, 2009).

The primary aim of this study is to describe the variability of land suitability index and maize yield on the difference soil types at the humid tropics of South Sulawesi Indonesia. This study also examines the correlation between soil characteristics and maize yield in the study area.

2. Methodology

2.1 Study area and data collection

The study area covers various climate and soil types throughout South Sulawesi where maize is cultivated. It falls within latitudes 0°12' to 8° South and longitudes 116°48' to 122°36' East, approximately. South Sulawesi has a tropical humid climate, characterized by high humidity range between 66.0 % and 86.7 %, mean annual rainfall distribution is 1.500 mm. Mean temperature ranges between 26.5°C and 27.1°C. Agricultural land use type is predominantly arable cultivation with maize. The study area is underlined by carbonat rocks, volcanic breccias, ultra basic rocks, alluvial and sandstone. Ten year metereological data used in this study were collected from 4 climatology stations to determine rainfall, temperature, relative humidity and sunshine hour. The location of study area is presented in Figure 1.

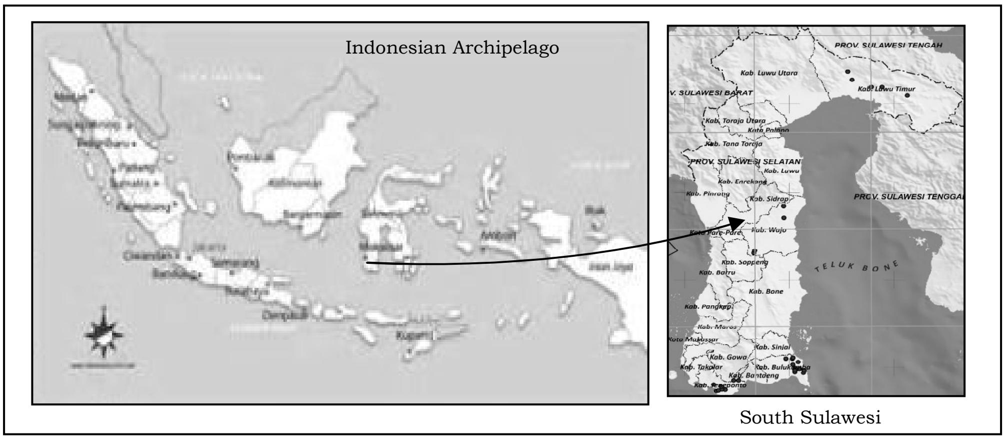


Figure 1. Location of study area (points indicate the location of sampling sites)

2.2 Field Survey and Laboratoy Analysis

Soil characteristics surveyed in 2012 was analyzed using purposive sampling method. Identification of land under traditional maize cultivation in the study area was undertaken during cultivation period (November to February and March to June). As many as 30 farmers (focusing on corn cultivation) from different agroclimatological zones, and 30 representative soil profiles were also made to examine soil horizons. Soil samples were collected and analyzed using standard procedures, as follows. Soil particle size distribution was determined using hydrometer method (Bouyoucos, 1962); soil organic carbon was determined using dichromate oxidation procedure (Walkley and Black, 1934); exchangeable base (Ca, Mg, K, Na) and cation exchange capacity (CEC) were determined with 1 N NH_4OAc, pH 7.0. Soil reaction (pH) was measured in water (1 : 2.5, soil water ratio).

Maize harvested at a randomly determined unit sample of 2.5 x 2.5 sq metres, with 3 replications . The harvested seeds of maize were dried, then weighed and their weights were calculated by using (1) (Baja et al., 2011):

W (tons/ha) = 1.6 x W sample...(1)

2.3 Data Analysis

The soils were classified at a subgroup group level according to Keys to Soil Taxonomy (Soil Survey Staf, 1951). The suitability classification was done separately for each soil unit identified in the survey area. Land suitability evaluation was performed using the parametric method of Sys et al., (1991). The parameters used for land quality calculation include rainfall of growing cycle, mean temperature, relative humidity, length of radiation, slope, drainage, soil physics (texture, depth), soil fertility (pH, organic carbon, CEC, base saturation). In the evaluation, the soil characteristics were then compare with crop requirement of maize (Sys et al., 1993). Land suitability index (I) calculated from the individual ratings was determined using Square Root method (Khiddir, 1986) with using (2):

I = Rmin x √A/100 x B/100 x...(2)

Where I= Land suitability index ; R min = Minimum rating; A, B, ..= Other ratings beside the minimum rating.

2.4 Analysis of correlation

Analysis of correlation was undertaken between land characteristics, land suitability index and maize yield in different soil types in study area using a simple regression methods and a Pearson correlation using SPSS ver 16.

3. Results and Discussions

3.1. Soil Classification

All the pedons were classified at Subgroup levels. Fourteen soil types were found at Subgroup level according to Keys to Soil Taxonomy (Soil Survey Staf, 2010) (Table 1). The pedon classified as *Typic Calciustepts* have a calcic horizon, shallow, high base saturation, horizon A overlying consolidated rock, and soil temperature regime was isohyperthermic. The pedon classified as *Fluventic Haplustepts* have low pH, low CEC, medium organic carbon and base saturation. The pedons classified as *Typic Eutrudepts* have base saturation of more than 60% at depth between 25 cm and 75 cm; *Typic Dystrudepts* have a base saturation less than 60 %. *Oxic Haplustepts* have a CEC of less than 24 cmol (+)/kg clay; *Aquic Haplustepts* have redox depletions with chroma of 2 or less, and also aquic conditions for a certain period of time in normal years.

The pedons classified as *Typic Paleustalfs* and *Typic Paleudalfs* do not show a clay decrease with increasing depth; the matrix of subhorizons have a hue of 7.5YR and chroma of 5, and have an argillic horizon, and high base saturation. Soil moisture regim of *Typic Paleustalfs* is characterized as ustic while *Typic Paleudalfs* is as udic.

The pedons classified as *Typic Haplustults* and *Oxicaquic Hapludults* have an argiliic horizon, and low base saturation. *Oxicaquic Hapludults* are saturated with water in one or more layers within 100 cm of the mineral soil surface.

The pedons classified as *Typic Calciusterts* and *Typic Haplusterts* have Vertisols characteristics which have slickensides and have more than 30 percent clay in the fine-earth fraction either between the mineral soil surface and a depth of 18 cm or in an Ap horizon. Besides that, the pedons have cracks that open and close periodically, and high base saturation. *Typic Calciusterts* have calcic horizons within 63 cm.

Table 1. Soil types at study area

No	Soil Order	Sub Order	GSG*	Sub Group
1.	Inceptisols	Ustepts	Calciustepts	Typic Calciustepts
			Haplustepts	Typic Haplustepts Fluventic Haplustepts Aquic Haplustepts Oxic Haplustepts
		Udepts	Eutrudepts	Typic Eutrudepts
			Dystrudepts	Typic Dystrudepts
2.	Alfisols	Ustalfs	Paleustalfs	Typic Paleustalfs
			Haplustalfs	Typic Haplustalfs
		Udalfs	Paleudalfs	Typic Paleudalfs
3.	Ultisols	Ustults	Haplustults	Typic Haplustults
		Udults	Hapludults	Oxicaquic Hapludults
4.	Vertisols	Usterts	Calciusterts	Typic Calciusterts
			Haplusterts	Typic Haplusterts

*GSG=Great Soil Group

Haplusterts, Calciusterts, Calciustepts, Haplustalfs occupy the gently undulating lower slope, shallow with soil depth ranging from 20 to 65 cm, and well drained. They are found in climatology zones D1, D2, E1 dan E2 according to Oldeman classification (Oldeman, 1977). Their parent materials are limestone and volcanic breccias. Soil depth of *Paleustalfs, Haplustepts, Eutrudepts, Hapludults, Dysrudepts* and *Paleudalfs* ranges from 60 to 170 cm, dominantly on the flat to undulating slope, poor to good drained. Their parent materials are limestone, sandstone, ultrabasic, and alluvium.

3.2. Spatial Distribution of Maize Yields

The results of field study show that maize yield variation ranges from 1.6 ton/ha (*Typic Dystrudepts*) to 5.2 ton/ha (*Typic Haplustalfs*) (Table 2). Figure 2 depicts different maize yields at different soil types (GSG). *Typic Haplustalfs* have highest average maize yields compared with other types of soils. Their parent materials are mostly limestone and volcanic breccias which consist of a large amount of basic cations such as calcium and magnesium. Therefore, soils formed from limestone minerals have high base saturation and the soil pH also tends to be around neutral (Sys, 1977). Soil fertility characteristics like base saturation and soil pH as well as water availability influence maize yield (Calvino, 2003).

Table 2. Spatial distribution of maize yield from different soil Subgroup

No	Coordinat		District	Sub district	Soil type (Subgroup)	Maize Yield (ton/ha)
	Longitudes	Latitudes				
1	119°44'22"	5°38'55''	Jeneponto	Bangkala	Typic Haplusterts	3.5
2	119°51'18"	5°33'13''	Jeneponto	Kelara	Typic Haplustepts	4.0
3	119°38'24"	5°35'44''	Jeneponto	Tamalatea	Typic Calciusterts	2.9
4	119°42'36"	5°38'43''	Jeneponto	Tamalatea	Typic Calciustepts	2.8
5	119°39'44"	5°39'40''	Jeneponto	Tamalatea	Typic Haplustalfs	4.2
6	119°40'48"	5°39'20''	Jeneponto	Tamalatea	Typic Haplustepts	3.8
7	119°42'25"	5°37'5,7''	Jeneponto	Tamalatea	Typic Haplustalfs	5.2
8	119°48'46"	5°33'14''	Jeneponto	Tamalatea	Typic Haplustalfs	4.5
9	120°14'59"	3°45'49''	Wajo	Keera	Fluventic Haplustepts	2.5
10	119°59'32"	4°14'32,5''	Wajo	Sabbangparu	Aquic Haplustepts	1.8
11	119°59'56"	4°13'3,4''	Wajo	Sabbangparu	Typic Paleustalfs	3.1
12	120°15'08"	3°53'10,2''	Wajo	Keera	Typic Haplustepts	2.9
13	120°20'32"	5°25'45,7''	Bulukumba	Herlang	Typic Dystrudepts	2.6
14	120°19'22"	5°23'40,1''	Bulukumba	Herlang	Typic Haplustults	2.1
15	120°22'5"	5°22'1,7''	Bulukumba	Herlang	Typic Haplustepts	2.9
16	120°20'21"	5°27'11,5''	Bulukumba	Herlang	Typic Dystrudepts	2.3
17	120°24'49"	5°28'49,9''	Bulukumba	Bontotiro	Oxic Haplustepts	2.2
18	120°21'18"	5°26'27,4''	Bulukumba	Bontotiro	Typic Dystrudepts	2.5
19	120°22'53"	5°26'12,7''	Bulukumba	Bontotiro	Oxic Haplustepts	2.2
20	120°25'12"	5°27'14,2"	Bulukumba	Bontotiro	Typic Dystrudepts	2.4
21	120°20'24"	5°28'25,6''	Bulukumba	Bontotiro	Typic Haplustepts	2.7
22	120°20'21"	5°27'11,5''	Bulukumba	Bontotiro	Typic Haplustepts	2.8
23	120°15'48"	5°19'55,7''	Bulukumba	Kajang	Typic Dystrudepts	1.6
24	120°19'10"	5°19'59''	Bulukumba	Kajang	Typic Hapludalfs	4.0
25	120°19'30"	5°19'23''	Bulukumba	Kajang	Typic Hapludalfs	3.9
26	121°00'23"	2°31'57''	Luwu Timur	Angkona	Oxicaquic Hapludults	2.2
27	120°48'12"	2°22'45''	Luwu Timur	Kalaena	Typic Dystrudepts	2.0
28	120°50'25"	2°27'33,5''	Luwu Timur	Kalaena	Typic Paleudalfs	3.8
29	121°18'52"	2°37'27''	Luwu Timur	Wasuponda	Typic Paleudalfs	3.7
30	121°05'52"	2°31'58''	Luwu Timur	Wasuponda	Typic Eutrudepts	3.5

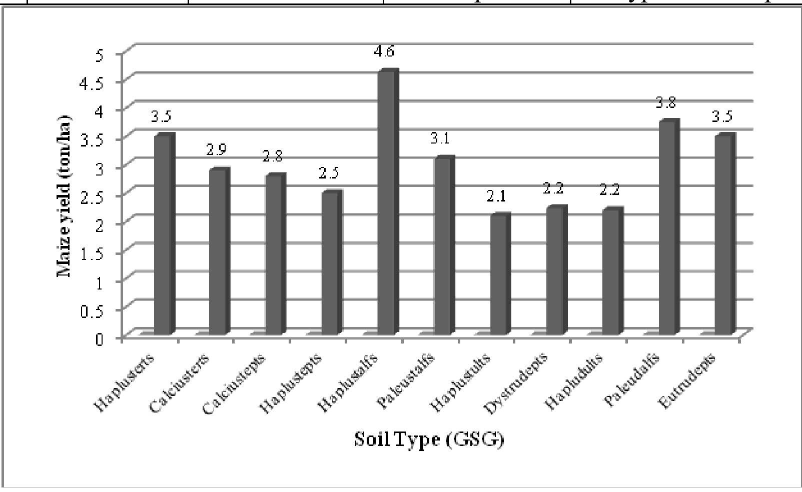


Figure 2 . Average maize yield over different soil types (GSG)

3.3. Correlation between soil characteristics and maize yield

Analysis of correlations between various characteristics of soil with maize yield at different sites show that three soil fertilty characteristics are base saturation, soil pH and organic carbon correlated significantly with maize yield. Kucharik (Kucharik, 2008) also found that maize yield is dependent on soil fertility, fertilizers and inputs such as irrigation.

3.3.1.Correlation between soil base saturation with maize yield

Laboratory analysis shows that soil base saturation varies considerably among land units in the study area, ranges from 12.19 % to 57.14 %. It is recognised that the source of such variation resulted from parent material of each pedons and climate factors. Production of maize cultivated in seasonally dry (ustic moisture regim) with a carbonate and piroclastic material higher than that cultivated in permanently wet with ultrabasic and sandstone parent material. The general relation between climate, particularly rainfall and base saturation is a normal feature (Sys, 1977). Base saturation and pH gradually increase as rainfall decrease. The result of analysis of correlation was generated between soil base saturation content with maize yield in the study area can be seen in Figure 3. The correlation forms the following equation:

$Y = 0.060x + 0.986$ and $R^2 = 0.741$...(3)

Where Y is maize yield and x is the value of soil base saturation. Such a positive correlation indicates that differences of soil base saturation may result in different maize yield.

3.3.2.Correlation between soil pH with maize yield

The soil pH varies considerably among land units in the study area, ranging from 4.5 to 6.79. The result of analysis of correlation between soil pH with maize yield in the study area, can be seen in Figure 3, and the correlation forms the following equation:

$Y = 1.462x – 5.628$ and $R^2 = 0.705$...(4)

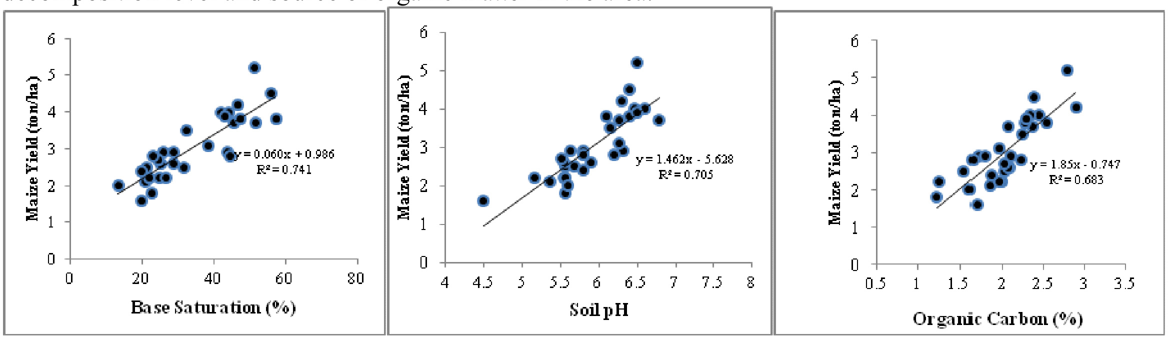
Where Y is maize yield and x is the value of soil pH within 25 cm depth of mineral soil. Such a positive correlation indicates that differences in soil pH may result in a different maize yield. The study zone was classified as humid tropics, a higher weathering and more intensive leaching of bases/nutrients always occurs (Mohr and Van Baren, 1960). Maize yield in the soil pH of more than 6 is higher than that with soil pH less than 6.

3.3.3.Correlation between soil organic carbon with maize yield

Soil organic carbon varies in the study area, ranges from 1.25 % to 2.79 %. In the humid tropics soils of low altitude have normally 0.8 to 1.5 % organic carbon (Sys, 1977). It means that percentage of soil organic carbon in the study area is relatively low. The result of analysis of between soil organic carbon content with maize yield in the study area, can be seen in Figure 3, and the correlation forms the following equation:

$Y = 1.85x – 0.747$ and $R^2 = 0.683$...(5)

Where Y is maize yield and x is the value of soil organic carbon. Organic carbon contents depend on decomposition level and source of organic matter in the area.



(a) (b) (c)

Figure 3. Correlation between soil base saturation (a), soil pH (b), and organic carbon (c) with maize yield at study area

3.3. Land Suitability Index (I)

The results of land suitability analysis show that *I* ranges from 11.5 to 55.0. According to suitability classes in a parametric method (Sys et al., 1991), the indices corresponds to N2, N1, S3 and S2. Furthermore, Table 3 shows the suitability classification of the fourteen soil subgroups in the study area. At the suitability subclass, fertility is low especially CEC, organic carbon, and base saturation. Beside that, factors shallow soil depth (s) limit the suitability of *Typic Calciustepts, Typic Calciustepts* and *Typic Haplusterts*. Limiting factors for *Aquic Haplustepts, Oxicaquic Hapludults* are poor drainage (w) and low fertility (f).

Correlation was tested between *I* and maize yield, and the result can be seen in Figure 4. It forms with the following formula:

$Y = 0.058 I + 1.119$ and $R^2 = 0.807$...(6)

Where Y is maize yield and I is the value of land suitability index.

Table 3. Suitability classification for maize in the study area

No	Soil Subgroup	Order	Class*	Sub-Class**
1	*Typic Calciustepts*	Suitable	S3	S3s,f
2	*Typic Haplustepts*	Suitable	S3	S3s,f
3	*Fluventic Haplustepts*	Suitable	S3	S3s,f
4	*Aquic Haplustepts*	Unsuitable	N1	N1w,f
5	*Oxic Haplustepts*	Unsuitable	N1	N1,f
6	*Typic Eutrudepts*	Suitable	S3	S3f,t
7	*Typic Dystrudepts*	Unsuitable	N2	N2f
8	*Typic Paleustalfs*	Suitable	S3	S3w
9	*Typic Haplustalfs*	Suitable	S2	S2s,f
10	*Typic Paleudalfs*	Suitable	S2	S2f
11	*Typic Haplustults*	Unsuitable	N1	N1f
12	*Oxicaquic Hapludults*	Unsuitable	N1	N1w,f
13	*Typic Calciustepts*	Suitable	S3	S3s,f
14	*Typic Haplusterts*	Suitable	S3	S3s,f

*Class notations: S2: moderately suitable, S3: marginally suitable, N1:currentty not suitable, N2:permanently not suitable
**Subclass notations: t:slope, f:fertility, w:wetness, s:soil physics

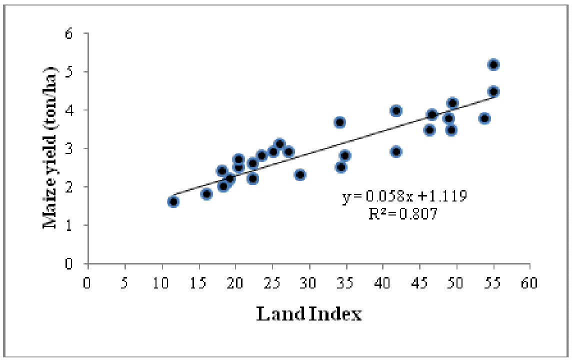


Figure 4. Correlation between Land Index with Maize Yield (ton/ha)

Analysis of correlation shows that there is a good relationship between land suitability index with maize yield with $R^2 = 0.807$. The scatter points have shown a good indication that the higher the land index the better maize yield can be produced in the area under consideration. Land suitability index value represents optimal condition or maximum performance of land characteristics (Sys et al., 1991).

4. Conclusion

Land suitability indices and maize yields for different soil types (at Subgroup level) vary considerably in the study area and significantly correlated. Soil characteristics having significant correlation with maize yield were base saturation, soil pH and organic carbon. The correlation between land suitability index and maize yield over different soil type has shown a good correlation with an $R^2 = 0.807$. Low fertility (f) (CEC, base saturation, organic carbon and pH), shallow soil depth (s), and poor drainage (w) limit the suitability for maize in the study area. The highest maize yield found in *Typic Haplustalfs* (S2s,f), and the lowest was *Typic Dystrudepts* (N2f).

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