

The Effect of Change in Function from Paddy Field to Dry Land on Soil Fertility Index

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ABSTRACT

This research studied the effect of the change in function from paddy field to dry land on the soil fertility index. The research was conducted in Girimarto Sub-district, Wonogiri District, in the Province of Central Java. The five stages of the research were: determination of Land Mapping Units in areas with a change in land use; field survey; laboratory analysis; determination of Minimum Data Sets (MDSs) or Minimum Soil Fertility Index (MSFI); analysis of Soil Fertility Index (SFI). The research results show that the change in function of 231 ha of land in Girimarto Sub-district is due to the topographical factor of the mountain region and the shortage of water. This change in land function has caused an increase in the soil fertility index. Soil fertility in paddy fields is classed as moderate but after undergoing a change in function to dry land, its classification increases to moderate-high. The increase in soil fertility index of dry land is due to the fact that farming patterns on dry land use more animal manure, which has a long-term residual effect on organic matter content. In order to maintain and improve the fertility of paddy field soil, it is necessary to add organic fertilizer as well as inorganic fertilizer.

1. INTRODUCTION

The increase in population density reflects an increase in the need for housing and food. Population growth suppresses agricultural land, in this case related to the increase in built-up land for housing and also intensification of land management to meet food needs. The increase in population indirectly causes changes in land use and also decreases land quality and productivity. Girimarto Sub-district is located in Wonogiri District, Central Java, Indonesia, including one of the Sub-districts facing the problem of land conversion due to population pressure. According to Wuryanta and Susanti (2015), there has been population pressure on agricultural land in the moderate category. The increase in population also causes a water deficit, where the availability of water is not sufficient for both household and agricultural activities. According to the research of Kumalajati et al. (2015), water demand will increase by 3.38% per year, while water availability will decrease by 0.09% per year, and it is predicted that in 2023 there will be a water deficit.

Change in land function refers to the change in use of an area of land (Janah et al., 2017). A change in land function is often associated with changes in soil parameters (Don et al., 2011). Change in land function is also one of the main factors that has a strong impact on climate change (Maharjan et al., 2017). As well as influencing climate, the change of land use or land function also has an effect on soil fertility (Hartemink, 2010; Rolando et al., 2018). Analysis of soil fertility is the key to sustainable planning in a particular area (Khadka et al., 2018). The evaluation of change in land function and land management on soil fertility can use potential indicators such as macro and micro nutrient availability, cation exchange capacity, and soil organic carbon (Cardoso et al., 2013).

Girimarto Sub-district is an area that has more dry land than paddy field. Most of the agricultural land in Girimarto Sub-district is dry land (Murni et al., 2016). The total area of paddy field is 1,691 ha, while dry land covers an area of 2,275.45 ha. The definition of dry land is land used for plant cultivation, which is never flooded or waterlogged, most of the time of the

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year (Wahyunto and Shofiyanti, 2012). The use of dry land for agriculture in Indonesia is generally grouped for yards, moor/fields/gardens, pastures, plantations, timber plants, and uncultivated land. In reality, the activity of change in land function from paddy field to dry land leads to a change in the nutrient content of the soil. Changes in land use are related to changes in soil properties (Willy et al., 2019), both physical, chemical and biological properties. Given that land use changes can lead to a decrease in soil fertility, it is important to understand which specific soil parameters are affected by changes in agricultural land use (Willy et al., 2019).

The evaluation of soil fertility status can provide information to improve strategies and techniques that are effective for achieving sustainable farming in the future (Khaki et al., 2017). Soil Fertility Index (SFI) is the indicator most commonly used to evaluate soil fertility (Yang et al., 2020). Most of the indicators that are used to evaluate the soil fertility index are related to the physical, chemical, and biological properties of the soil (Recena et al., 2019). The determination of indicators of soil fertility is carried out based on the chemical parameters of the soil, including Cation Exchange Capacity (CEC) and Organic Matter (OM) as indicators of soil quality, and macro nutrients including Nitrogen (N), Phosphorus (P), Potassium (K), and Magnesium (Mg), soil pH, and texture (Bagherzadeh et al., 2018; Panwar et al., 2011). In the system of evaluation of soil fertility, the determination of weight values of each index is the main factor that can influence the accuracy of the evaluation (Chen et al., 2020).

This study focused on dry land, namely moor, which is the result of the conversion of rice fields. The moor in Girimarto Sub-district are usually planted with secondary crops such as maize, peanuts and cassava. This is mainly due to the topography of Girimarto Sub-district which is located on a highland plateau, leading to farmers to change the function of paddy field to dry land. Land management efforts are needed in order to maintain and increase soil fertility. The goal of this research is to evaluate soil fertility in areas where there has been a change in land function from paddy field to dry land, and to compare the levels of soil fertility in the two different land types, followed by recommendations for land management in the future.

2. METHODOLOGY

The research was conducted in Girimarto Sub-district, Wonogiri District, in the Province of Central Java, Indonesia, located at 7°42'51.32"-

7°49'19.46" SL and 111°9'49.59"-111°2'29.91" EL, with Karanganyar Sub-district to the north, Sidoharjo Sub-district to the south, Ngadirojo Sub-district to the west, and Jatipurno Sub-district to the east. Girimarto Sub-district is located at an altitude of 40-1,000 m.a.s.l., on undulating terrain with an incline of 14°-45°. The research location covers an area of 6,236.68 ha, of which most of the land is used for agricultural cultivation, including paddy fields and dry land. Approximately 63.6% of the land in Girimarto Sub-district is agricultural land (Wonogiri District Statistic Center, 2020). The research consists of 6 stages: (1) identification of land use change; (2) determination of Land Mapping Units (LMU); (3) field survey; (4) laboratory analysis; (5) determination of Minimum Data Sets (MDS) or Minimum Soil Fertility Index (MSFI); (6) analysis of Soil Fertility Index (SFI).

Changes in land use were identified by observing land use maps in 2012 and 2020 obtained from Google Earth images. Then the mapping of changes in the use of paddy fields to dry land was carried out. The land use change map is used as the basis for determining the Land Mapping Unit (LMU). The LMU were obtained by overlaying several different maps, including a land use change map, a slope map, a map of rainfall, and a map of soil type. The area in the survey consisted of 6 LMU (Figure 1). The sampling points were determined in accordance with the goal of the research. The locations for collecting samples were determined using a method of purposive sampling, by selecting areas with conditions that were representative of the entire research area (Sofiana et al., 2016). Each LMU consists of six sampling points where three points are dry land (conversion from paddy fields) and three points are paddy fields. A total of 36 samples of soil were collected at a depth of 0-30 cm. The collection of soil samples at the location points used the Global Positioning System to find the location points.

A laboratory analysis was carried out to determine the soil fertility index by observing soil physical and chemical properties (Wicaksono et al., 2018). Soil physical properties was texture (pipette method). Soil chemical properties included pH (pH meter with a soil to water ratio of 1.0:2.5), total N (Tot-N) (Kjeldahl method), available P (Av-P) (Olsen method), organic C (Org-C) (Walkley and Black method), exchangeable K (Exch-K) (NH₄OAc 1 N pH 7 extractant, analyzed using Flame Photometer), exchangeable Ca, Mg, and Na (Exch-Ca; Exch-Mg; Exch-Na) (NH₄OAc 1 N pH 7 extractant, analyzed

using Atomic Absorption Spectrophotometer with different wavelengths for each element), cation exchange capacity (CEC) (extract all cations with NH_4OAc 1 N pH 7), Base Saturation (BS) (NH_4OAc

1 N pH 7 extractant, number of exchangeable base cations (K; Ca; Mg; Na) divided by CEC and multiplied by 100%).

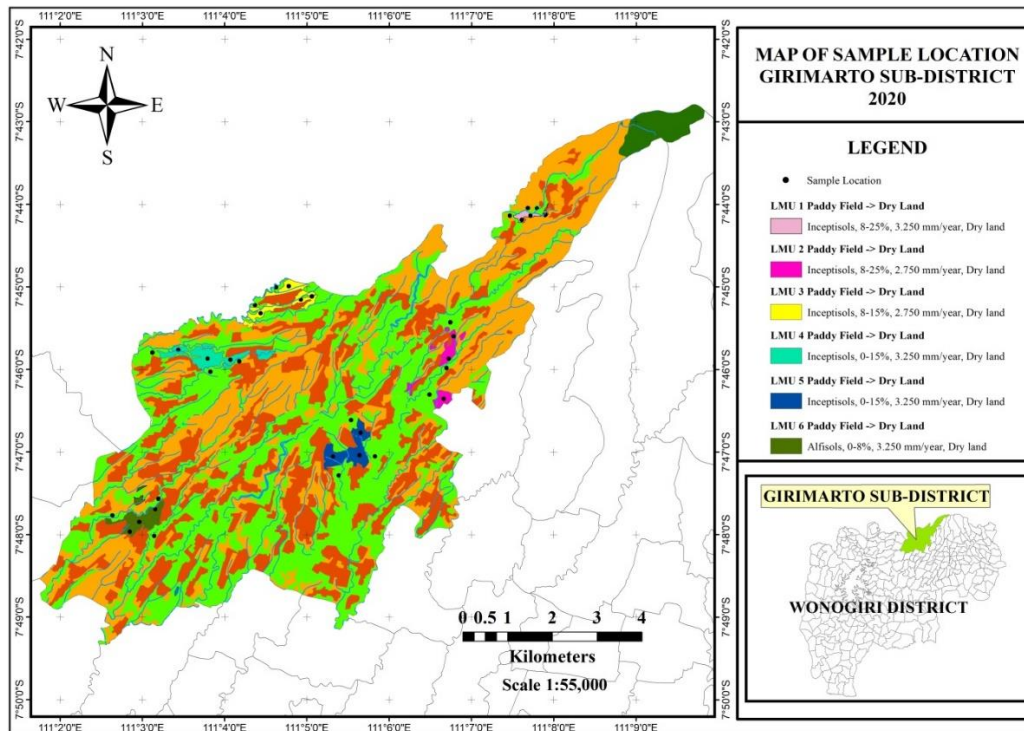


Figure 1. Map of sampling location

The soil fertility index was determined using the data selected from the Minimum Data Sets (MDSs) (Wang et al., 2018). The selection of a MDS that was representative of the soil properties was made based on the results of a Principal Component Analysis (PCA) (Romadhona and Arifandi, 2020). The Minimum Data Set (MDS) is the smallest data obtained through a Principal Component Analysis (PCA), and continues with the Principal Components (PC). The MDS was obtained with a PCA test using a statistical application.

Soil Fertility Index (SFI) is commonly used as a quantitative evaluation of soil fertility (Wang et al., 2018). The calculation of the soil fertility index is the result of the division of the number of weights with the number of Minimum Soil Fertility Index (MSFI) indicators (Mukashema, 2007), using the formula below:

$$\text{SFI} = \left(\frac{\text{Sc}_i}{N} \right) \times 10$$

Where; $\text{Sc}_i = c_j \times p_c$ [$c_j = w_i \times s_i$ and $p_c = \frac{1}{n_c}$]

Description: SFI=soil fertility index (Table 1); c_j =total score weight; Sc_i =total MSFI weights; p_c =appreciation value; N =total MSFI (MDS); n_c =the amount of value used; w_i =weight index; s_i =scoring index (Table 2).

Table 1. Soil fertility index classification

SFI value	SFI class
0.00-0.25	Very low
0.25-0.50	Low
0.50-0.75	Moderate
0.75-0.90	High
0.90-1.00	Very high

Source: Bagherzadeh et al. (2018)

The SFI scores were used to compare the fertility index of paddy field with that of dry land, so that recommendations can be made about future land management. Paired t-test was used to determine the effect of land use on SFI, as well as correlation analysis to determine the relationship between SFI and soil fertility indicators.

Table 2. Scoring index for each indicator

Indicator	Unit	Scoring index (Soil Research Institute, 2009)				
		1	2	3	4	5
Tot-N	(%)	<0.1	0.1-0.2	0.21-0.50	0.51-0.75	>0.75
Av-P	(ppm)	<5	5-10	11-15	16-20	>20
Exc-K	(me/100g)	<0.1	0.1-0.3	0.4-0.5	0.6-1.0	>1.0
Exc-Ca	(me/100g)	<2	2-5	6-10	11-20	>20
Exc-Mg	(me/100g)	<0.3	0.4-1	1.0-2.0	2.1-8.0	>8.0
pH	-	4.5-5.5	5.5-6.5	6.6-7.5	7.6-8.5	>8.5
Org-C	(%)	<1	1-2	2-3	3-5	>5
CEC	(me/100g)	<5	5-16	17-24	25-40	>40
BS	(%)	<20	20-40	41-60	61-80	>80

3. RESULTS AND DISCUSSION

3.1 Change in land function

Change in land function cannot be separated from human activity (Li et al., 2017), nor can it be separated from various natural factors such as topography and climate, and especially drought (Rahman et al., 2017) (Table 3). The results of

research by Rahmawati et al. (2019) show that Wonogiri District has low rainfall, which has the potential to cause drought and a continuous decline in water supply. Girimarto Sub-district is located at an incline of 14°-45° which makes it difficult to access the water needed to irrigate paddy field in this mountain area.

Table 3. Distribution of change in land function from paddy field to dry land

LMU	Location (Village)	Area (ha)	Land use change
1	Bubakan	8.7	Paddy field to dry land
2	Semagarduwur	33.3	Paddy field to dry land
3	Giriwarno	41.4	Paddy field to dry land
4	Giriwarno and Jatirejo	54.1	Paddy field to dry land
5	Tambakmerang	50.7	Paddy field to dry land
6	Waleng and Doho	42.8	Paddy field to dry land
Total Area		231.0	

Shortage of water is the primary reasons why paddy fields relying solely on rainfall have been forced to be transformed into dry land, which is ultimately used for growing other crops. The change in land function from paddy field to dry land in Girimarto Sub-district has led to the cultivation of peanuts, cassava, and corn, using a multi cropping system in which more than one type of crop is grown on the same area of land, while in other places banana trees are also grown at the edge of the land. Rice requires an average rainfall of 200 mm/month or more, with a distribution of four months to grow well (Paski et al., 2017). Meanwhile, the rainfall in Girimarto Sub-district is less than 200 mm/month, and this condition lasts for six months (Figure 2).

The reduced availability of water affects

agricultural activities. Girimarto Sub-district is included in the Keduang watershed, where the results of research by Kumalajati et al. (2015) stated that the availability of water in 2018 decreased by 0.32% from 2013. The reduced availability of water can lead to a water deficit. The research results of Sanjaya (2020) in the villages of Bubakan, Semagarduwur, and Tambakmerang show a water deficit, where the amount of water available is less than the amount needed. This shortage of water in the Girimarto Sub-district has led to a change in function from paddy field to dry land. This change in function has occurred in six villages in the Girimarto Sub-district, namely the villages of Bubakan, Semagarduwur, Giriwarno, Jatirejo, Tambakmerang, and in an area between the villages of Welang and Doho.

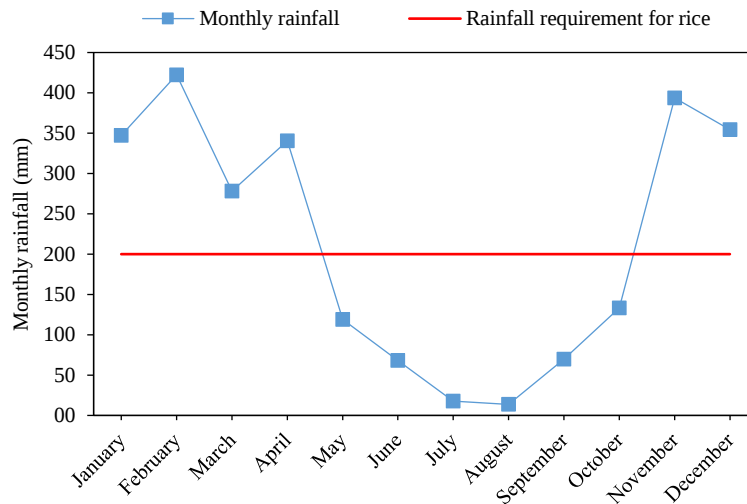


Figure 2. Average monthly rainfall in Girimarto Sub-district year 2012-2017 (Source: [Wonogiri District Statistics Center, 2021](#))

3.2 Soil parameters

According to the results of the laboratory analysis of the parameters total N, available P, exchanged K, organic C, pH, Ca, Mg, CEC, and BS, the data for paddy field and dry land in every LMU showed a change in the content of these elements in the soil, as presented in [Table 4](#). From the various parameters, organic C shows quite a sizeable change,

with organic C in dry land being higher than in paddy field. This is due to the continuous use of animal manure on dry land, which can increase the organic matter content, and this is the main key to success in dry land cultivation. Organic C is closely related to soil fertility level ([Lal, 2013](#)). The organic C content can be seen from the amount of organic matter in an area of land ([Ringgih et al., 2018](#)).

Table 4. Soil chemical properties on paddy fields and dry land for each LMU

Land use	Tot-N (%)	Av-P (ppm)	Exch-K (me/100g)	Exch-Ca (me/100g)	Exch-Mg (me/100g)	pH	Org-C (%)	CEC (me/100g)	BS (%)
Paddy field 1	0.30	3.49	0.30	2.34	0.63	6.14	1.13	25.15	19.06
Paddy field 2	0.32	3.42	0.41	1.87	0.90	6.26	0.90	28.04	18.38
Paddy field 3	0.30	4.39	0.41	4.47	1.06	6.11	1.33	34.92	26.36
Paddy field 4	0.23	2.91	0.28	1.72	0.52	6.24	0.52	23.99	15.62
Paddy field 5	0.23	3.72	0.44	2.19	0.83	5.90	1.04	26.63	18.58
Paddy field 6	0.29	3.66	0.40	3.45	0.61	6.37	1.01	27.46	24.19
Dry land 1	0.25	3.08	0.38	2.19	0.97	6.18	2.99	34.26	18.81
Dry land 2	0.26	3.80	0.31	4.38	0.64	6.13	2.84	37.31	19.02
Dry land 3	0.36	3.88	0.55	3.98	1.18	6.17	3.41	41.66	20.55
Dry land 4	0.18	3.37	0.36	1.57	0.80	5.84	2.36	28.51	14.31
Dry land 5	0.28	3.39	0.36	4.20	1.01	6.16	3.05	41.91	18.17
Dry land 6	0.25	3.72	0.34	2.21	1.03	6.11	3.32	33.54	14.34

In the parameter CEC, a higher value is seen in dry land than paddy field. The CEC value is influenced by organic C content and the types of clay forming minerals in the soil. The higher the organic C content, the higher the CEC. As stated by [Ringgih et al. \(2018\)](#), the difference between CEC values in dry land and paddy field is largely influenced by the amount of organic matter present in the soil, which explains why

a higher organic C value will be accompanied by a higher CEC value.

3.3 Soil fertility index

The results of the PCA analysis produced four PCs with an eigenvalue >1, which were selected as the main components, and six indicators as the MDS with the highest weight value for each PC, which were

used to determine the soil fertility score. The PCA analysis generated the Minimum Soil Fertility Index (MSFI) which represents all the soil fertility indicator values used (Prastiwi et al., 2021). For PC 1 there were two indicators that represented the highest weight values for soil fertility, namely Ca and CEC. For PC 2, a single indicator was chosen to represent the soil fertility value, namely base saturation (BS). For PC3, 2 indicators were selected that represented the fertility value with with highest weight, namely pH and total N which showed mutual correlation, while for PC4, a single indicator was chosen that displayed a high weight value, namely organic C (Table 5).

Table 5. Results of PCA

Eigenvalue	2.7491	1.7430	1.3294	1.0988
Proportion	0.3050	0.1940	0.1480	0.1220
Cumulative	0.3050	0.4990	0.6470	0.7690
Variable	PC1	PC2	PC3	PC4
pH	-0.017	-0.116	0.684*	0.471
Tot-N	0.289	-0.314	0.411*	-0.196
Av-P	0.357	0.220	-0.145	-0.222
Exch-K	0.318	-0.072	0.235	-0.632
Org-C	0.352	-0.186	-0.487	0.366*
Exch-Ca	0.422*	0.325	0.132	0.325
Exch-Mg	0.403	0.207	-0.044	-0.057
CEC	0.466*	-0.382	-0.022	0.207
BS	0.079	0.711*	0.175	0.069

Note: CEC=cation exchange capacity, BS=base saturation *=MDS

The analysis of soil fertility index (Table 6) shows a SFI for paddy field classed as moderate, while for dry land the SFI classed as moderate to high. A decrease in soil fertility in paddy field can occur due to a loss of nutrients from the soil. It is the culture of rice farmers to use a lot of inorganic fertilizer which is easily absorbed by crops and is lost through washing and denitrification. The disproportionate use of man-made fertilizer with a high concentration also creates an imbalance of nutrients in the soil, which can lead to the deficiency of other nutrients.

According to Adi et al. (2017), the use of chemical fertilizer with a high nutrient content is not always beneficial. The use of this synthetic fertilizer encourages nutrient loss, environmental pollution, and causes damage to nature. The research results of Nabavi-Pelesaraei et al. (2018) show that the use of chemical fertilizer also has an impact on the environment. Kai et al. (2020) also state that the

excessive use of chemical fertilizer has the potential to affect the environment, causing a decrease in microorganisms and water pollution. One of the consequences of using inorganic fertilizer is a decline in nutrient content in the soil, which in turn leads to a decrease in soil fertility. In rice cultivation, this can cause very high drainage of nutrients through the transportation in crops.

The results of the Paired t-test analysis showed that changes in land use from paddy fields to dry land had a significant effect on increasing SFI (t-value=6.53; p-value=0.000; n=36). Changes in the use of paddy fields to dry land significantly increase C-Organic (t-value=13.77; p-value=0.000; n=36), exchangeable Ca (t-value=2.94; p-value=0.009; n=36) and CEC (t-value=6.87; p-value=0.000; n=36). C-Organic, exchangeable Ca and CEC were also significantly positively correlated with SFI (p-value<0.05; n=36).

The increase in soil fertility index of dry land is due to the fact that farming patterns on dry land use more animal manure, which has a long-term residual effect on organic matter content. The key to successful cultivation on dry land is the use of animal manure. The application of animal manure to corn crops has a highly significant effect on the residual product and effect in the following season (Suntoro et al., 2018). Farmers are often unaware of the important role of organic matter in connection with soil fertility. Therefore, efforts can be made to maintain soil fertility by adding sufficient organic matter. According to Suntoro et al. (2020), the use of organic fertilizer from livestock can be implemented to preserve and improve soil fertility. The research of Cruz-Paredes et al. (2017) shows that animal manure can increase soil pH and CEC, which is beneficial for increasing soil fertility. Ahmad et al. (2015) also state that organic matter is an important source of nutrition for increasing soil fertility. The research of Yu et al. (2020) finds that the result of continuous application of organic matter to paddy field over a period of 10 years can significantly increase the content of organic C, biomass microbes, and active organic C. The addition of animal manure to dry land has a long term residual effect that lasts until the following season. According to Arisana et al. (2017), the use of animal manure as organic fertilizer on dry land is more effective for increasing soil fertility because of its micro and macro nutrient content.

Table 6. SFI of paddy field and dry land for each LMU

Paddy field																
MSFI	Proportion	Cumulative	Wi	Si each sampling point												
				1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1
Exch-Ca	0.305	0.769	0.1983	1	1	1	1	1	1	1	1	1	1	1	1	1
CEC	0.305	0.769	0.1983	3	3	4	3	3	5	4	4	4	3	3	4	4
BS	0.194	0.769	0.2523	1	1	1	1	2	1	2	2	1	1	1	1	2
pH	0.148	0.769	0.0962	2	2	2	3	2	2	2	2	2	2	2	2	2
Tot-N	0.148	0.769	0.0962	3	2	3	3	3	3	3	3	3	3	2	3	3
Org-C	0.122	0.769	0.1586	2	1	2	1	2	1	2	1	2	1	1	2	1
Cj				1.84	1.59	2.04	1.78	2.10	2.08	2.29	2.14	2.04	1.69	1.59	1.88	2.04
nc				5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Pc (1/nc)				0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Sci (Cj × Pc)				0.37	0.32	0.41	0.36	0.42	0.42	0.46	0.43	0.41	0.34	0.32	0.38	0.41
N				6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
SFI (Sci/N) × 10				0.61	0.53	0.68	0.59	0.70	0.69	0.76	0.71	0.68	0.56	0.53	0.63	0.68
SFI each LMU				0.61			0.66			0.72			0.57			0.71
SFI Class				Moderate			Moderate			Moderate			Moderate			Moderate

Dry land																
MSFI	Proportion	Cumulative	Wi	Si each sampling point												
				1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3	5.1
Exch-Ca	0.305	0.769	0.1983	1	1	1	1	1	1	1	1	1	1	1	1	1
CEC	0.305	0.769	0.1983	4	4	5	4	4	5	4	4	5	4	4	4	4
BS	0.194	0.769	0.2523	1	2	1	1	2	1	2	2	1	1	1	1	1
pH	0.148	0.769	0.0962	2	2	2	2	2	3	2	2	2	2	2	2	2
Tot-N	0.148	0.769	0.0962	3	2	3	3	2	3	3	3	3	2	2	3	3
Org-C	0.122	0.769	0.1586	4	3	3	3	4	3	4	3	4	3	2	3	4
Cj				2.36	2.36	2.40	2.20	2.52	2.50	2.61	2.45	2.56	2.10	1.95	2.20	2.40
nc				5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Pc (1/nc)				0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Sci (Cj × Pc)				0.47	0.47	0.48	0.44	0.50	0.50	0.52	0.49	0.51	0.42	0.39	0.44	0.48
N				6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
SFI (Sci/N) × 10				0.79	0.79	0.80	0.73	0.84	0.83	0.87	0.82	0.85	0.70	0.65	0.73	0.80
SFI each LMU				0.79			0.80			0.85			0.69			0.83
SFI Class				High			High			High			Moderate			High

4. CONCLUSION

The change in land function that has taken place in Girimarto Sub-district on an area of 231 ha is due to the topographical factor of the mountain region and the shortage of water, which has led to a change in land function from paddy field to dry land. The soil fertility of paddy field in Girimarto Sub-district is classed as moderate while that of dry land is classed as moderate to high. The factor that has the greatest influence on soil fertility is the difference in soil nutrient content, especially organic matter, Ca and cation exchange capacity. Increased efforts need to be made to maintain and improve soil fertility, and especially the organic matter content in paddy field soil. The use of man-made fertilizer or chemical fertilizer needs to be balanced with the use of animal manure, which can provide an alternative solution for increasing the amount of organic matter contained in the soil. Changes in the use of paddy fields to dry land with good land management can increase soil fertility, increase land productivity and maintain the sustainability of agricultural production.

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