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Assessment of Soil Degradation Based on Soil Properties and Spatial Analysis in Dryland Farming

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ABSTRACT
Dryland farming, managed intensively, with the input of chemical fertilizers exceeding the dose threshold, can cause soil degradation. Degraded soil affects low environmental carrying capacity and soil and water conservation. Researchers conduct soil tests on agricultural land to address this issue, especially those that apply a continuous cropping system. This study aimed to examine soil properties to determine the conditions of soil degradation in dryland farming. The method integrates spatial analysis with Geographic Information Systems (GIS), field surveys, and laboratory soil samples analysis. The spatial data used to map the potential for soil degradation includes land use, slope, rainfall, and soil type. Integrating spatial and laboratory data, such as soil physical, chemical, and biological properties results in soil degradation status conditions representing the actual conditions in the field. This study found that there were three classes of soil degradation successively, namely mild, moderate, and high. There are two statuses of soil degradation, including non-degraded and light soil degradation status. The soils with a mild degree of degradation are due to the limiting factors of permeability, fractional composition, and total porosity. Some actions that can be taken include planning soil degradation prevention measures by utilizing soil degradation potential maps that have been made for areas with high soil degradation potential. For the sites with a status of soil degradation, efforts are made to start carrying out soil improvement actions in accordance with conservation principles to reduce the soil degradation that occurs. Moreover, organic matter is added to degraded and potentially degraded soils to increase the stability of soil aggregates and water-carrying capacity.

Keywords: soil degradation, geographic information systems, dryland farming, soil properties.

INTRODUCTION

Environmental problems are so complex at the end of this decade. The latest research mentions that there are indications of climate change with the surface urban heat islands phenomenon (Sunarta et al., 2022). Other problems are the increasing number of buildings in urban areas implications for the degraded green areas (Sunarta and Saifulloh, 2022a), increased air pollution due to dense industrial activities, tourism and other human activities which have implications for increasing greenhouse gas emissions (Sunarta and Saifulloh, 2022b). This research investigates from a different perspective as an effort to monitor the environment. Environmental monitoring carried out from the dry land agriculture sector. The latest research states that the high rate of deforestation is due to changes in the function of forest areas to agricultural land (Goulart et al., 2023). Such conditions certainly have implications for low carbon absorption, which is essential in mitigating climate change (Araujo et al., 2023). Low carbon stocks and absorption are caused by low green vegetation cover (Bordoloi et al., 2022), because basically the largest carbon stocks derived from plant biomass (Ahirwal et al., 2021). Low biomass has implications for other environmental problems, one of which is the potential for land degradation. Researchers examined this phenomenon on dry land farming, in the Baturiti Agrotourism Area, Tabanan Regency, Bali Province. The area has forest land cover associated with dry land agriculture. In practice, in the field, farmers cultivate agricultural commodities on steep slopes, and invaded part of forest land for agricultural activities.

Biomass production that is managed without regard to conservation principles, such as the use of annual crop cultivation land on steep slopes and the continuous use of synthetic chemicals at doses that exceed the limit, will cause changes in the basic properties of soil, resulting in damage to the soil. Standard criteria for soil damage are needed to determine the actual status of land damage in the field. The potential for soil damage in a field can be determined through spatial data analysis using geographic information system (GIS) technology. The Indonesian government seeks to prevent and control soil damage by issuing Government Regulation of the Republic of Indonesia Number 150 of 2000 concerning Control of Soil Damage for Biomass Production. For this reason, researchers are interested in analyzing soil damage on dry land in Baturiti District.

The main problem in dry land agriculture is the vulnerability to land degradation due to erosion and slope (Dariah et al., 2004). Baturiti District has the potential for soil loss erosion, landslides, especially on the land with steep slopes (Trigunasih and Saifulloh 2022; Diara et al., 2022). Management of agricultural land in Baturiti District tends to apply conventional farming systems compared to the management of organic systems so that it affects microbes in the soil (Mayasari et al., 2019).

Conventional agriculture tends to carry out farming systems using chemical fertilizers to achieve high production so that it is expected to increase farmers' income (Pradnyawati et al., 2021). On the basis of the food balance data, Tabanan Regency experienced a deficit in three commodities: shallots, garlic and large chilies. The decrease in the yield of some of these commodities can indicate a decrease in land productivity due to damage to the soil. Therefore, it is necessary to conduct a study regarding the potential and status of soil damage in the area to carry out damage control and countermeasures for potential damage to the area.

STUDY AREA

Studies on soil degradation were carried out in several areas in Indonesia (Fig. 1a), which are regionally located in the Province of Bali (Fig. 1b)

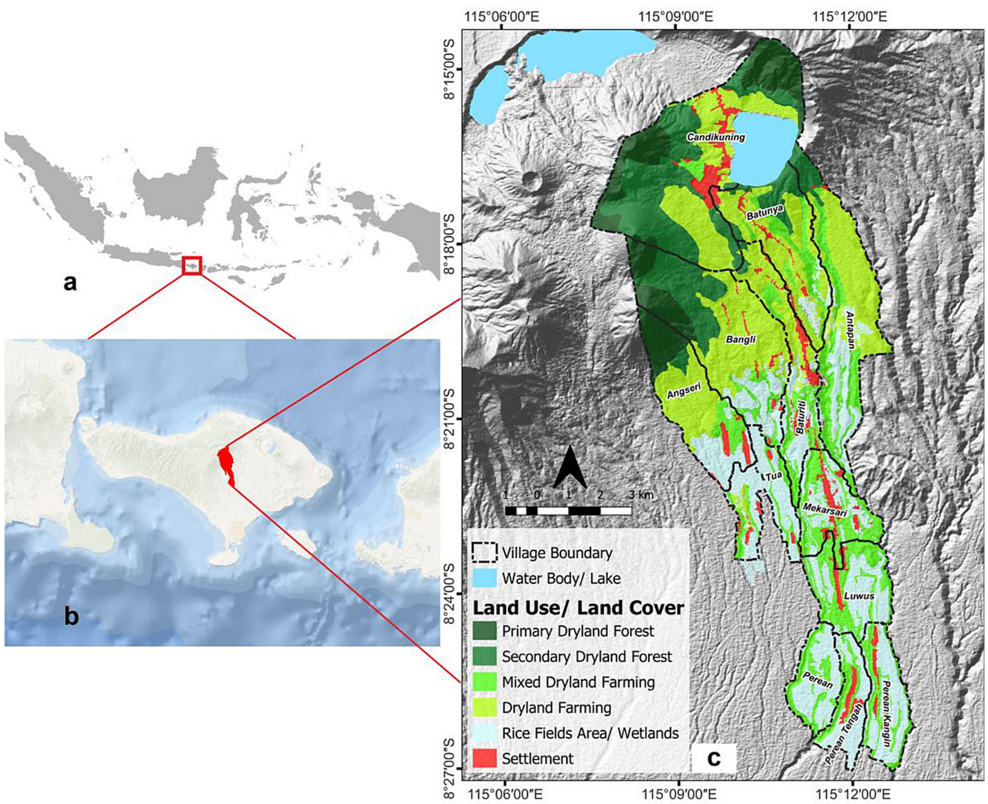

Figure 1. The research location is viewed from a global scale in Indonesia (a) and the island of Bali (b), land use land cover typology of a case study

and specifically in the Baturiti District, Tabanan Regency (Fig. 1c). Geographically it is located between 8°15'00"- 8°27'00" S to 115°06'00"-115°12'00" E with elevations ranging from 350 m asl to 2200 m asl. The research area has a varied land cover, which is dominated by vegetated land. Types of vegetated land cover include primary dryland forest, secondary dryland forest, mixed dryland farming, and dryland farming with areas of 9.88 km^2, 15.59 km^2, 21.10 km^2, 25.68 km^2, and 29.68 km^2, respectively. Other types of land use are settlements and a body of water called Lake Beratan, with 5.78 km^2 and 4.06 km^2, respectively (Fig. 1c). Only dry land farming was examined, namely mixed dryland farming and dryland farming. The dry land agricultural area is relatively large, with annual crop commodities such as cocoa, coffee, cloves, durian and horticultural commodities such as vegetables, tomatoes, strawberries, carrots and other horticultural commodities. The research area is a relatively high producer of horticultural agricultural commodities. Land management carried out by farmers in the field is quite intensive, with high doses of chemical fertilizer. Such conditions can impact land degradation, which will be tested in this study.

DATA AND METHODS

Tools and materials

The materials used in this study include maps of the Baturiti District regarding soil type maps at a review scale of 1:250,000, land use maps at a scale of 1:25,000, Topographical Map of Indonesia in 2021, slope maps, rainfall data, soil as samples analysis, and chemicals for laboratory sample analysis. The tools used include laptops, QGIS 3.22 LTR applications, Global Positioning System (GPS), field tools such as an Abney level, tape measure, sample ring, pH meter, soil drill, dagger, plastic bag (container), petri dish, sieve, scales, oven, and stationery.

Data analysis

Land unit mapping

The conditions of soil degradation in dry land agriculture were examined based on the mapping unit. The mapping units in this study were analyzed based on the biophysical conditions of land cover, slope, and soil type. On the basis of spatial analysis with QGIS software, nine mapping units were obtained (Table 1). The basis of the mapping unit uses these thematic maps to represent the biophysical similarity of the soil on a stretch of land. Previous researchers have used the basis of mapping units to examine soil fertility (Sardiana et al., 2017; Rawal et al., 2018), soil erosion rates (Trigunasih & Saifulloh, 2023), evaluate the suitability of agricultural land (Trigunasih & Wiguna, 2020) and soil degradation (Nujiyo et al., 2021; Hadian et al., 2022).

Each unit represents the same biophysical condition, which is then used as a reference for observing and taking soil samples in the field. The spatial distribution of mapping units and soil sample locations is presented in Figure 2. The sampling technique for each mapping unit was carried out in a composite manner with a depth of 0-30 cm, which represents the condition of the nutrients in the agricultural land being examined. Other samples were obtained using sample rings, visual observations, and using a Belgian drill to collect data on the thickness of the soil solum. The physical properties of the soil tested in the laboratory include fractional composition (soil texture), bulk density, porosity, and degree

Table 1. Land unit mapping [Research analysis in 2021]

Unit	Desa	Landuse	Slope (%)	Soil types	Coordinate location	Area (km^2)
1	Baturiti	Mixed dryland farming	8-15	Latosol	8°21'57.83"S - 115°10'58.30"E	2.55
2	Perean Tengah	Mixed dryland farming	0-8	Latosol	8°25'22.55"S - 115°11'53.94"E	9.71
3	Antapan	Mixed dryland farming	15-25	Andosol	8°20'33.27"S - 115°12'2.75"E	2.43
4	Luwus	Mixed dryland farming	15-25	Latosol	8°23'19.91"S - 115°12'17.50"E	3.58
5	Antapan	Mixed dryland farming	8-15	Andosol	8°18'58.15"S - 115°10'40.62"E	2.8
6	Bangli	Dryland farming	15-25	Latosol	8°19'51.05"S - 115°10'0.85"E	22.08
7	Antapan	Dryland farming	25-40	Andosol	8°19'4.11"S - 115°12'19.51"E	3.08
8	Angseri	Dryland farming	8-15	Latosol	8°21'12.48"S - 115° 9'31.35"E	0.95
9	Candikuning	Dryland farming	8-15	Regosol	8°16'4.30"S - 115° 9'37.80"E	3.56

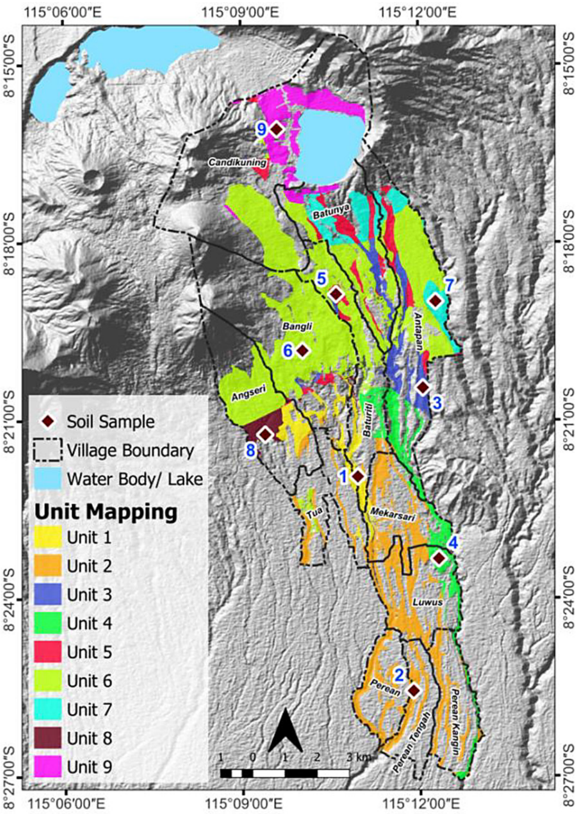

Figure 2. Spatial distributin of land unit mapping and soil sampling

of water permeability. The chemical properties of the soil tested were pH, and electrical conductivity, while the biological properties of the soil were the number of microbes. Other data were observed in the field for each mapping unit, such as the thickness of the solum and surface rocks.

Soil degradation potential analysis

To obtain the value of the potential for soil degradation, it is necessary to score the potential for soil degradation in each parameter. This value is obtained by multiplying the rating value (the potential value of land use, slope, soil type, and rainfall) with the weight value. This assessment is carried out with an overlay to obtain a map of the potential distribution of soil degradation. Classes of potential soil degradation are presented in Table 2.

Table 2. Soil degradation classes on score [State Ministry of Environment of the Republic of Indonesia, 2009]

Symbol	Soil degradation potential	Score
PR.I	Very slight	<15
PR.II	Slight	15-24
PR.III	Moderate	25-34
PR.IV	High	35-44
PR.V	Very high	45-50

Table 3. Soil degradation evaluation [Government Regulation Number 150 of 2000]

No.	Parameters	Critical threshold
1.	Solum thickness	< 20 cm
2.	Surface rock	> 40%
3.	Fraction composition	< 18 % colloid; > 80 % quartzite sand
4.	Bulk density	> 1.4 g/cm^3
5.	Total porosity	< 30 %; > 70 %
6.	Degree of water pass	< 0.7 cm/hour; > 8.0 cm/hour
7.	Ph (H_2O) 1 : 2.5	< 4.5; > 8.5
8.	Electrical conductivity	> 4.0 mS/cm
9.	Microbial count	< 10^2 cfu/g soil

Soil degradation analysis

Analysis was carried out in the field and in the laboratory to determine and consider the basic properties of the soil based on the parameters of soil degradation based on the standard criteria of the Indonesian Government Regulation No. 150 of 2000 concerning Control of Soil Degradation for Biomass Production. The parameters analyzed are presented in Table 3.

Determination of the status of soil degradation

Soil degradation status is determined by scoring based on the percentage of relative frequency for each parameter based on the guidelines from the Ministry of Environment of the Republic of Indonesia of 2009 concerning Technical Guidelines for Compiling a Map of Soil Degradation Status for Biomass Production. Relative frequency is the percentage ratio of the number of degraded samples to the total number of samples analyzed for each parameter. The soil degradation score based on the relative frequency of each soil degradation parameter is presented in Table 4.

Table 4. Soil degradation score based on frequency relative [State Ministry of Environment of the Republic of Indonesia, 2009]

Relative frequency of degraded soil	Score
0 – 9	0
10 – 21	1
22 – 44	2
45 – 67	3
68 – 90	4

Table 5. Soil degradation status based on accumulated degradation score [State Ministry of Environment of the Republic of Indonesia, 2009]

Symbol	Soil degradation status	Accumulated degradation score
N	Not degraded	0
R.I	Slight	1-12
R.II	Moderate	13-21
R.III	Heavy	22-30
R.IV	Very heavy	31-36

On the basis of the sum the total scores obtained, the status of soil degradation is categorized. Soil degradation status categories are divided into five, including not degraded, slightly, moderately, heavily, and very heavily. Soil degradation status based on the sum of the soil degradation scores is presented in Table 5.

RESULTS AND DISCUSSIONS

Soil degradation potential

The analysis of the potential for soil degradation in the study area based on the scoring method obtained three classes of potential for soil degradation. The potential for soil degradation includes light, medium, and high damage potential classes. Dry land in Baturiti District has a light soil degradation potential class spread over Unit 2, moderate soil degradation potential is spread over Unit 1, 3, 4, 5, 6, 8, and 9, and a high soil degradation potential class at Unit 7 (Table 6).

The distribution of potential soil degradation in dry land in Baturiti District includes the potential for light soil damage spread across Perean Tengah Village and the potential for moderate damage spread across several villages, namely Baturiti, Antapan, Bangli, Angseri , and Candikuning, while the high ground damage potential is in the village of Luwus (Fig. 3).

On the basis of characteristics the land in the study area, slope and soil type are parameters that significantly influence the class of potential degradation. Steep slopes have a high potential for erosion, so the potential for soil degradation will also be more critical. This is in line with the results of the research conducted by Pasaribu et al. (2018), that the steeper the slope, the greater the erosion rate. Land with steep slopes triggers a high erosion rate due to rainwater flowing on the ground.

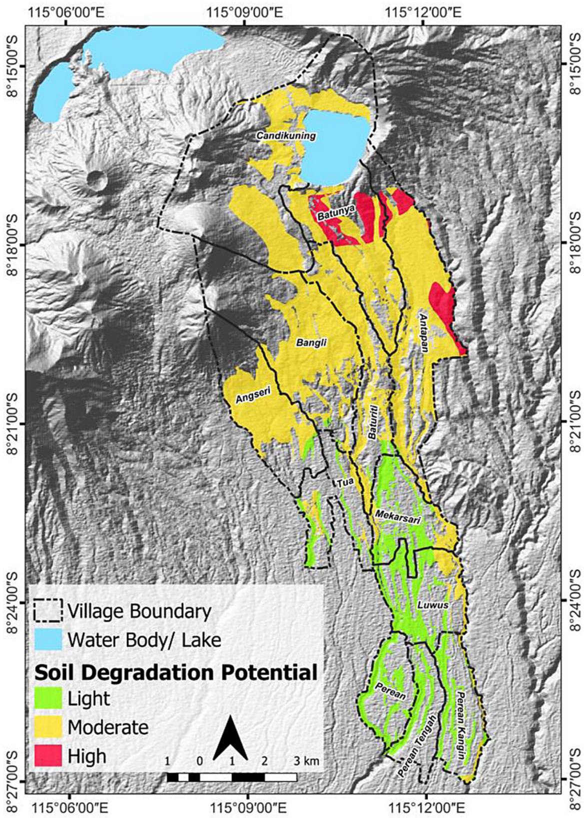

Figure 3. Spatial distribution of soil degradation potential

In addition, rainfall influences soil degradation. Rainfall is related to water availability for biomass production and is one of the factors causing erosion. Rainfall constitutes one of the factors causing soil degradation (Pasaribu et al., 2018). This is caused by the kinetic impact of rainwater on the ground, triggering soil erosion. The condition of the land with little land cover or vegetation that is not possible to hold the soil from the crashing of rainwater will undoubtedly support the high level of erosion on the land. The rainwater that falls to the ground will damage soil aggregates and increase erosion (Trigunasih, 2018).

Table 6. Soil degradation potential [Research analysis in 2021]

No.	Score	Categories	Symbol	Area (km^2)
1	19-22	Slight	PR.II	9.71
2	25-32	Moderate	PR.III	37.97
3	39	High	PR.IV	08.11

Soil degradation status

The analysis of physical, chemical, and biological parameters carried out through field and laboratory observations showed that there was degradation in the parameters of fractional composition or texture, permeability, and total porosity in several units. A parameter that is said to be degraded is determined from the analysis of each parameter compared to the critical threshold limit of standard criteria for soil degradation status.

The fractional composition and total porosity parameters obtained a relative frequency of 11.11%, while permeability has a relative frequency of 77.77% degraded soil. The total score obtained from the relative frequency of degraded soil is 6, indicating that the study area has a status of lightly degraded soil degradation. Determination of the relative frequency of degraded land and the status of soil degradation is presented in Table 7.

The distribution of actual degradation status in the field has land that is still neutral or not classified as degraded, namely dry agricultural land in Luwus Village and partly in Antapan Village. The rest, including the status of light soil degradation with permeability limiting factors in Baturiti Village, partly in Antapan, Bangli, and Angseri Villages, texture, and permeability limiting factors spread across Candikuning Village and partly in Antapan Village, as well as total porosity and permeability limiting factors spread over the Village Middle Perean (Figure 4).

On the basis of the data from the analysis of the status of soil degradation, the porosity and permeability of several units are classified as degraded. A high degree of water escape will result in a reduced ability of the soil to hold water and nutrients. Soil permeability level is influenced by texture and porosity factors. The coarser the texture of the soil, the higher the water permeability. The low content of clay fraction in the soil will reduce the ability of the soil to absorb water. Clay colloids form soil aggregates that can maintain soil pore stability so that they are not easily transported by surface runoff. This is supported by the statement of Nurhartanto et al. (2022) in their research on soil degradation with low clay content in soils that are usually sensitive to erosion.

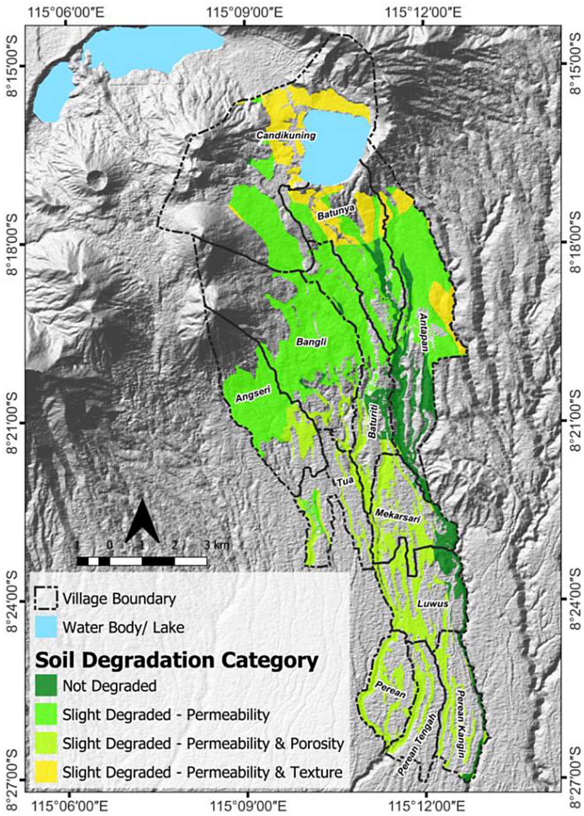

Figure 4. Spatial distribution of soil degradation in dryland farming

Table 7. Result of accumulated value of soil degradation [Data analysis and laboratory in 2021]

No.	Parameters	Relative frequency of degraded soil	Score	Status
1.	Solum thickness	0	0	Not degraded
2.	Surface rock	0	0	Not degraded
3.	Fraction composition	Clay 22.22 + sand 0 = 22.22 22.22 : 2 = 11.11	1	Slight
4.	Bulk density	0	0	Not degraded
5.	Total porosity	11.11	1	Slight
6.	Degree of water pass	77.77	4	Very heavy
7.	pH (H2O) 1 : 2.5	0	0	Not degraded
8.	Electrical conductivity /DHL	0	0	Not degraded
9.	Microbial count	0	0	Not degraded
		Total score	*6*	*Slight*

Organic matter content that does not meet soil needs can be one of the factors causing soil degradation. On the basis of soil C-Organic analysis in the study area, Unit 2, 7, and 9 had low to moderate C-Organic content. These data prove that it is true that the content of organic matter affects the results of soil degradation status. To increase the water holding capacity of the soil, organic matter can be added. Research by Mulyono et al. (2019) showed a positive correlation between soil organic matter content and the level of permeability. Aggregate stability is influenced by organic matter in the soil. The organic matter content added will improve and strengthen the soil aggregate. Besides stabilizing the aggregate, adding organic matter can increase the holding capacity of groundwater. The condition of land management in the field still depends on the use of chemicals that can disrupt the ecosystem of soil organisms which is one of the factors in soil degradation. The stability of soil aggregates affects the degree of porosity, aeration, and soil water holding capacity, which will create a good physical environment for the growth of plant roots.

CONCLUSIONS

Integration between laboratory and spatial analysis effectively examines the potential and status of land degradation in dryland farming. Spatial analysis with GIS is more effective in taking soil samples through mapping units, which are applied at the sub-district level mapping scale and even at a wider scale. This study found that there were three successive classes of soil degradation, namely slight, moderate, and high. The degradation potential was analyzed only using secondary data from thematic maps. Furthermore, with the integration of soil testing in the laboratory, the criteria for land degradation status are obtained, representing the actual conditions of agricultural land in the field. There are two statuses of soil degradation, including non-degraded and light soil degradation status. The soils with a mild degree of degradation are due to the limiting factors of permeability, fractional composition, and total porosity. Some actions that can be taken include planning soil degradation prevention measures by utilizing soil degradation potential maps that have been made for areas with high soil degradation potential. For areas with a status of soil degradation, efforts are made to start carrying out soil improvement actions in accordance with conservation principles to reduce the soil degradation that occurs. Moreover, organic matter is added to degraded and potentially degraded soils to increase the stability of soil aggregates and water-carrying capacity.

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