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Assessing Soil Degradation Status under Different Types of Agricultural Land (Case Study: Jatisrono Sub-district, Wonogiri District, Indonesia)

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ABSTRACT/ABSTRAK

Penilaian Status Kerusakan Tanah pada Berbagai Jenis Lahan Pertanian (Studi Kasus: Kecamatan Jatisrono, Kabupaten Wonogiri, Indonesia)

Jatisrono Sub-district is located in a hilly area which makes the land vulnerable to erosion and land activities. This condition affect biomass production and cause soil degradation. This study aims to analyze the status of soil degradation, assess the determinants of soil degradation, and provide recommendations for soil management at Jatisrono Sub-district. The research was conducted in December 2022 at 36 points representing each land mapping units (LMU) in Jatisrono, Wonogiri, Indonesia. The observation parameters for dryland and wetland were adopted from the Government Regulation of the Republic of Indonesia No. 150/2000. Dryland parameters include solum depths, surface rocks, soil texture, bulk density, total porosity, soil permeability, pH (H_2O), electrical conductivity, redox, and microbes total. Wetland parameters include pyrite content, shallow groundwater depth, pH (H_2O), electrical conductivity, and the microbes total. The methods used were exploratory surveys and descriptive methods. Sampling was done by the purposive sampling method. The 12 land mapping units comprised 6 drylands (plantations and moors) and 6 wetlands (rice fields). The results showed that dryland agriculture have a slightly and moderately status of soil degradation. Wetlands, on the other hand, have soil degradation levels that are undegraded or slightly degraded. Dryland soil deterioration is largely influenced by slope, but wetland soil degradation is influenced by soil type. Dryland soil degradation is determined by bulk density, total porosity, and soil permeability, whereas wetland soil degradation is determined by soil pH (H_2O). The dryland management strategy advice is to increase soil organic matter, whereas the wetland management strategy recommendation is to improve irrigation.

Kata Kunci:
Faktor lingkungan, Jenis tanah, Kemiringan lereng, Kerusakan lahan, Sawah

Kecamatan Jatisrono berada di wilayah perbukitan yang menjadikan lahannya rentan terhadap erosi serta aktivitas lahan. Kondisi ini dapat mempengaruhi produksi biomassa dan menyebabkan kerusakan tanah. Penelitian ini bertujuan untuk menganalisis status kerusakan tanah, mengkaji faktor penentu kerusakan tanah, serta memberikan rekomendasi pengelolaan tanah di Kecamatan Jatisrono. Penelitian dilakukan pada bulan Desember 2022 pada 36 titik yang mewakili setiap satuan peta lahan (SPL) di Kecamatan Jatisrono, Kabupaten Wonogiri, Provinsi Jawa Tengah, Indonesia. Parameter pengamatan lahan kering dan lahan basah mengadopsi dari Peraturan Pemerintah Republik Indonesia No. 150 Tahun 2000. Lahan kering meliputi parameter ketebaan solum, kebatuan permukaan, tekstur, bobot volume, porositas, permeabilitas, pH (H_2O), daya hantar listrik, potensial redoks, dan jumlah mikroba. Lahan basah meliputi parameter kandungan pirit, kedalaman air tanah dangkal, pH (H_2O), daya hantar listrik, dan jumlah mikroba. Metode yang digunakan adalah survei dan *deskriptif eksploratif.* Pengambilan sampel dilakukan dengan metode *purposive sampling.* Sebanyak 12 satuan peta lahan (SPL) terdiri dari 6 SPL lahan kering (kebun dan tegalan) serta 6 SPL lahan basah (sawah). Hasil penelitian menunjukkan pertanian lahan kering memiliki tingkat kerusakan tanah rusak ringan serta rusak sedang sedangkan lahan basah memiliki tingkat kerusakan tanah tidak rusak serta rusak ringan. Kerusakan tanah lahan kering sangat dipengaruhi oleh kemiringan lereng sedangkan kerusakan tanah lahan basah sangat dipengaruhi oleh jenis tanah. Faktor penentu kerusakan tanah lahan kering adalah bobot volume, porositas, dan permeabilitas tanah. Faktor penentu kerusakan tanah lahan basah adalah pH H_2O tanah. Strategi pengelolaan kerusakan tanah lahan kering dengan meningkatkan bahan organik tanah. Strategi pengelolaan kerusakan tanah lahan basah dengan perbaikan irigasi.

INTRODUCTION

Land degradation is frequently induced by land use considerations, which reduces the area of land use. The statement by Sofyan *et al.* (2014) is that human intervention in managing land and land conversion activities increases the area of degraded land. In Government Regulation Number 150 of 2000, agricultural land areas managed using dry or wet farming can experience degradation at different levels and factors. Globally, wetlands are defined as land that is inundated and saturated with water during certain periods (seasonally) or permanently and is intended to support plant growth (Hu *et al.,* 2017). Dryland refers to agricultural land that is not irrigated and relies solely on natural precipitation for water supply, resulting in limited water availability for plant growth and agriculture (Faria & Morales, 2020). Wetland agriculture in this research is rice fields, and dry agriculture is forests, gardens, moors and shrubs. Rice fields are managed with a special irrigation system and drainage channels to control soil flooding. Wetlands such as rice fields have soil conditions that are saturated with water, and this is inversely proportional to dry lands where the soil is low in water content because irrigation is provided regularly and periodically (Hatta *et al.,* 2018). Wetland degradation factors that are often encountered include salination, acidic soil reactions (low pH), the presence of pyrite (Rama *et al.,* 2016), and excessive waterlogging, while on dry land soil erosion often occurs (Krisnayanti *et al.,* 2023). Soil degradation is the loss or decline of soil function, both as a source of plant nutrients and as a matrix where plant roots are anchored and water is stored (Tolaka *et al.,* 2013). The most important factor influencing soil deterioration is human participation in ecosystems (Curebal *et al.,* 2015). Soil degradation occurs in several aspects, namely physical, chemical, and biological.

Wonogiri District experienced an increase in population from 2020 to 2022 of 13,910 people (Central Bureau of Statistics of Wonogiri District, 2022). As the population growth, the food and water demand continues to increase (Lathifah *et al.,* 2018). The increasing demand for rice causes stakeholders to emphasize production to the maximum level and land is used continuously (intensively). This demand is due to a continuous increase in agricultural production. The need to increase production encourages farmers and agricultural stakeholders to carry out land management with high intensity (Jambak *et al.,* 2017). Using land for agricultural purposes without paying attention to soil and water conservation in farm management will result in soil degradation (Christanto *et al.,* 2010).

The research area, Jatisrono Sub-district is located at the foot of Mount Lawu, it has a hilly terrain with flat to steep slopes. If not addressed appropriately, a steep slope condition can cause substantial soil degradation. Such topography restricts land utilization, particularly land area for plant biomass production. Wonogiri District, in which Jatisrono Sub-district located, has a larger percentage of land for biomass production than residential land, at 57.73%, so proper tillage is necessary to keep the land productive for biomass production. Based on Central Bureau of Statistics of Wonogiri District, rice production in Jatisrono Sub-district in 2013 (Central Bureau of Statistics, 2013), 2014 (Central Bureau of Statistics, 2014), and 2018 (Central Bureau of Statistics, 2018) was recorded reaching 19,441 tons, 18,231 tons, and 17,889 tons which gradually decreased. The decline can be caused by damaged soil conditions that are less supportive of plant growth.

Research results by Mujiyo *et al.* (2022) showed agricultural land with diverse topography, having different levels of degradation. The soil deterioration score for land with a very steep slope, namely 16-25%, was higher than the degradation score for sloping (8-15%) and flat (0-8%) slopes. Suryanto & Wawan (2017) stated that higher land slopes significantly influence erosion because rainwater has a large kinetic energy to degrade soil aggregates. Land with a 16-25% slope and rainfall of 2,250 mm/year will quickly lose topsoil. This condition causes a decrease in solum depths, effective rooting depth, and porosity (Nugroho, 2016).

Based on the preceding description, it is required to map the soil degradation state, particularly in terms of slope. Spatial data on soil degradation status is also still scarce, particularly in Jatisrono Sub-district, Wonogiri District, necessitating studies on the degradation status in the area. This research will examine the status of land degradation by differentiating between dry land and wet land according to the characteristics of each type of land. The analysis of soil degradation status refers to Government Regulation of the Republic of Indonesia Number150/2000. It is conducted to find factors that affect soil degradation and formulate appropriate and targeted soil management strategies for agriculture in dryland and wetland in Jatisrono Sub-district, Wonogiri District.

MATERIAL AND METHODS

Study Area

The Jatisrono Sub-district is located at 7°32'-8°15' South Latitude and 110°41'-111°18' East Longitude. The district has a total area of 50.03 km^2, which consists of rice fields, moor, plantations, land for buildings and yards, and land used for other purposes such as roads and others (Figure 1). It is a highland area with an average altitude of 411 meters above sea level (Central Bureau of Statistics of Wonogiri District, 2022). Wonogiri has a tropical climate with two seasons, rainy and dry seasons (Central Bureau of Statistics of Wonogiri District, 2018). The average rainfall in Jatisrono Sub-district is 2,250 mm per year. The slopes in the Jatisrono Sub-district range from 0-8% to >40%, but are characterised by slopes of 8-15% and 15-25%.The dominant soil types in Jatisrono Sub-district are Alfisols and Inceptisols.

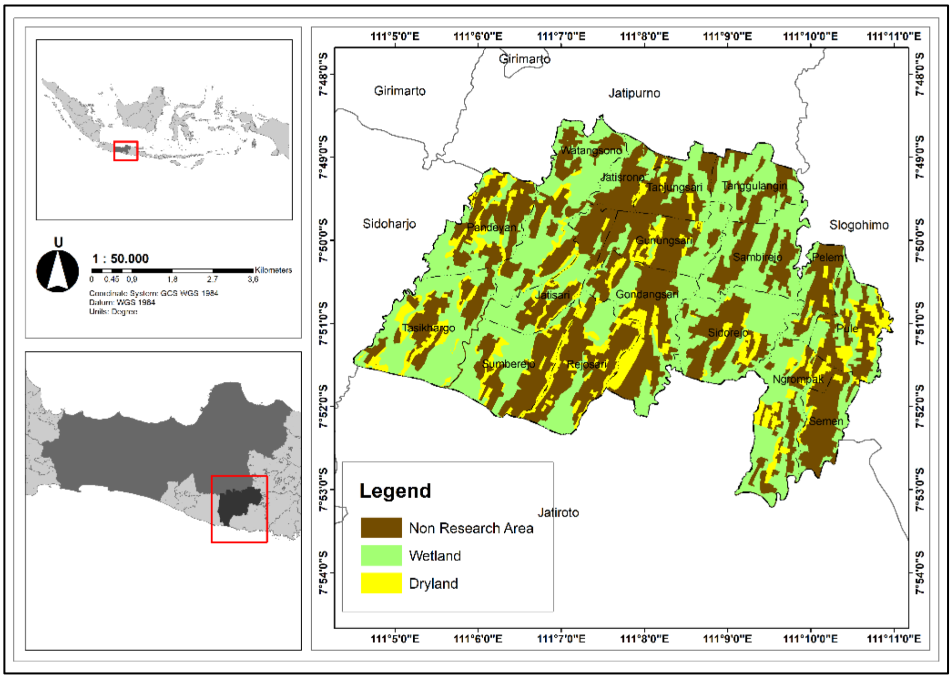

Figure 1. Location of sampling site

The land used in the soil degradation status research is dryland and wetland agricultural land (Figure 1),consisting of rice fields, plantations, and moorlands. Rice fields are planted with *Oryza sativa* (rice), *Zea mays* (corn) and *Manihot esculenta* (cassava) predominate in the Moorland. On the plantations, teak (*Tectona grandis*), Saigon (*Albizia chinensis*), and mahagoni (*Swietenia mahagoni*) are found. Each research land unit illustrates the uniformity of its land characteristics. These characteristics include soil type, climate (rainfall), form of agricultural land use and slope.

Soil Sampling Analysis

The methods used in this research were survey and explorative descriptive methods, namely making direct observations in the field, followed by laboratory analysis. Sampling in the area was done by the purposive sampling method, referring to the LMU map made earlier. Land Mapping Unit (LMU) was created to show the diversity of an area by overlaying shapefiles of land use, soil type, rainfall, and slope class percentages in Jatisrono Sub-district using the ArcGIS 10.3 application. The overlay and elimination processes in the ArcGIS application (Sengupta & Thangavel, 2023), resulted in 12 land mapping units consisting of 6 drylands and and 6 wetlands (Figure 2). Three repetitions were conducted, so the total sample was 36 observation points.

The research parameters observed was referring to the Government of Indonesia's Government Regulation of the Republic of Indonesia Number 150 in 2000 concerning the Control of Soil Degradation for Biomass Production to Prevent and Control Soil Degradation. Surveys were conducted for soil sampling, measurement of solum depths, shallow groundwater thickness, and surface rock analysis. Laboratory analysis was conducted to test the parameters of soil physical properties (porosity, bulk density, soil permeability, and soil texture), soil chemical properties (pH H_2O, pH pyrite, electroconductivity, and redox), and soil biological properties (microbes total). Field observations and laboratory analysis results were then plotted on a working map and re-analysed spatially using the ArcGIS programme to produce a soil degradation map.

Soil analysis was conducted at the Soil Physics and Conservation Laboratory, the Soil Biology and Biotechnology Laboratory, and the Soil Chemistry and Fertility Laboratory of the Soil Science Study Programme, Faculty of Agriculture, Sebelas Maret University. Solum depths, surface rocks, and shallow groundwater depth were observed directly in the field. Some soil parameters are analysed in the laboratory using some specific methods as mentioned: texture (pipette method, Balittanah 2006), bulk density (gravimetrically, Balittanah 2006), porosity(gravimetrically, Balittanah 2006), soil permeability (permeameter method, Balittanah 2006), pyrite pH and actual pH (electrometric method, Balittan 2009), electro conductivity (EC meter, Balittanah 2009), redox (EH meter, Balittanah 2009), and microbes total (plate count method, Balittanah 2007).

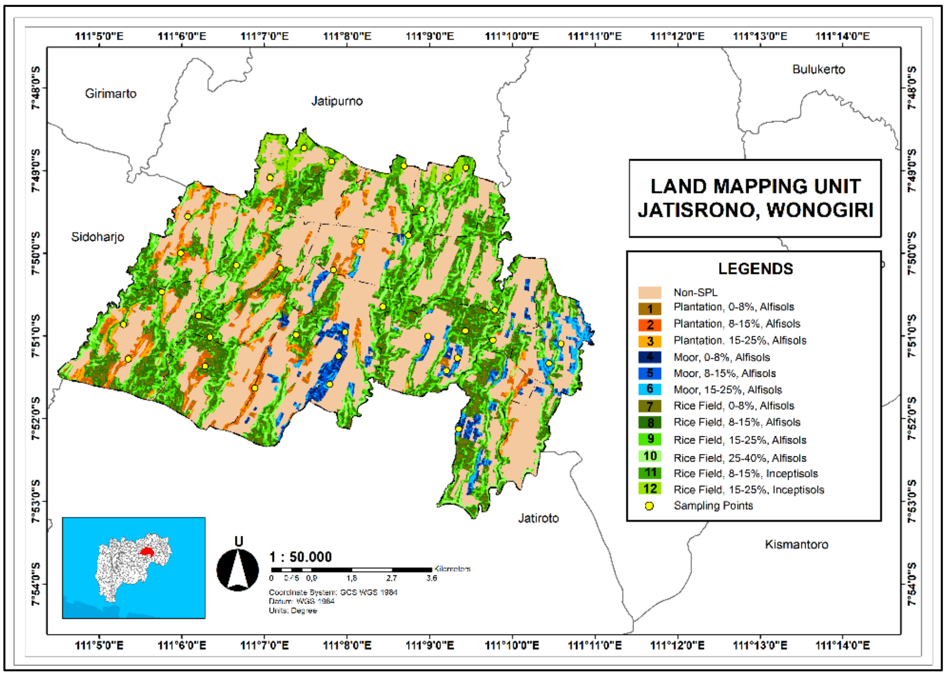

Figure 2. Land mapping unit of Jatisrono Sub-district

Data Analysis

Data analysis was conducted by compiling soil degradation status using the relative frequency scoring (SFR) method. Data analysis begins with matching the observation data with the critical threshold value of soil degradation as regulated in Government Regulation of the Republic of Indonesia No. 150/2000 (Table 1). Each parameter's relative frequency (%) was calculated by comparing the number of sampling points classified as degraded (exceeding national quality standards) with the number of sampling points in one land unit multiplied by 100%. Then, relative frequency scoring was conducted by calculating the data score that considered the relative frequency of soil degradation (Table 2). The total SFR obtained from the sum of the results at each land mapping unit will determine the class of soil degradation status of the land (Table 3). If there is a real effect of slope, land use, rainfall, and soil type on soil degradation, statistical analysis with ANOVA and T-test was performed, followed by DMRT (Duncan's New Multiple Range Test) to find the type of source of diversity that most effects soil deterioration. Correlation test was conducted to assess the relation between the standard soil degradation criteria parameters and soil degradation factors, in which was then used as a basis for determining soil degradation determinants.

Table 1. Soil degradation standard criteria for dryland and wetland

Land Type	Parameters	Critical Limit Value
Dryland	Solum depts	<20 cm
	Surface Rocks	>40%
	Soil Texture	<18% colloid; >80% sand
	Bulk Density	>1.4 g/cm^3
	Porosity	<30%; > 70%
	Soil Permeability	<0.7 cm/hour; >8 cm/hour
	pH (H_2O)	<4.5; >8.5
	Electrical Conductivity	>4.0 mS/cm
	Redox	<200 mV
	Microbes total	<10^2 cfu/g soil
Wetland	pH Pyrite	<2.5
	Shallow groundwater depth	>25 cm
	pH (H_2O)	<4.0; >7.0
	Electrical Conductivity	>4.0 mS/cm
	Microbes total	<10^2 cfu/g soil

Source: Government Regulation of the Republic of Indonesia No. 150/2000

Table 2. Soil degradation score based on the relative frequency

Relative Frequency of Degradation Soil (%)	Score	Soil Degradation Status
0-10	0	Undegraded
11-25	1	Slightly Degraded
26-50	2	Moderately Degraded
51-75	3	HeavilyDegraded
76-100	4	Very Heavily Degraded

Source: Ministry of Environment, Technical Guidelines for the Compilation of Soil Condition and Degradation Status Maps for Biomass Production (2009)

Table 3. Soil degradation status based on accumulated soil degradation score value

Symbol	Soil Degradation Status	Score	
		Dryland	Wetland
N	Undegraded	0	0
R. I	Slightly Degraded	1-14	1-8
R. II	Moderately Degraded	15-24	9-14
R. III	Heavily Degraded	25-34	15-20
R. IV	Very Heavily Degraded	35-40	21-24

Source: Ministry of Environment, Technical Guidelines for the Compilation of Soil Condition and Degradation Status Maps for Biomass Production (2009)

RESULTS AND DISCUSSION

Soil Degradation

Dryland agriculture in the area of Jatisrono Sub-district is classified as slightly degraded (487 ha) and moderately degraded (158 ha) (Table 4; Table 5; Figure 3). Soil degradation is found lowest at LMU 1 and highest at LMU 3. LMU 1 has limiting factors of surface rocks and permeability, while LMU 3 has to limiting factors surface rocks, bulk density, porosity, and soil permeability factors. Wetland agriculture is classed as slightly degraded (2,413 ha) and undegraded (46.18 ha) (Table 6; Table 7; Figure 4). LMU 11 has the least soil degradation, while LMUs 9 and 10 have the most. The limiting parameters for LMUs 9 and 10 are pH H_2O and shallow groundwater depth. Soil degradation measures such as pH, electrical conductivity, and microbial count are similar in drier and wetland fields. Wetlands have a pH of 6.05-6.93 and drylands have a pH of 6.19-7.35, which is slightly acidic to neutral. The electrical conductivity of the dryland was 0.021-0.044 mS/cm, while that of the wetland was quite low, 0.03-0.139 mS/cm. The dryland had $18.3 x 10^5$-$54.5 x 10^5$ cfu/g soil, while the wetland had $0.5 x 10^5$-$55.2 x 10^5$ cfu/g soil.

Table 4. Parameters value of soil degradation in dryland

Land Unit	Parameter										
	Solum Depts (cm)	Surface Rocks (%)	Soil Texture Colloid (%)	Soil Texture Sand (%)	Bulk Density (g/cm^3)	Porosity (%)	Soil Permeability (cm/hour)	pH (H_2O)	Electrical Conductivity (mS/cm)	Redox (mV)	Microbes Total (cfu/g)
1A	90	25	68.18	31.82	1.15	36.08	0.67*	6.67	0.041	300	$51.6 x 10^5$
1B	83	20	61.84	38.16	1.38	43.50	0.64*	6.93	0.044	255	$41.6 x 10^5$
1C	80	50*	56.58	43.42	1.26	41.61	0.73	6.80	0.044	260	$49.8 x 10^5$
2A	70	7	65.79	34.21	1.42*	29.04*	0.40*	6.74	0.042	275	$54.5 x 10^5$
2B	75	5	60.14	39.86	1.08	40.33	0.63*	6.60	0.037	266	$23.1 x 10^5$
2C	85	10	68.08	31.92	1.31	35.65	0.43*	6.87	0.044	258	$19.8 x 10^5$
3A	85	50*	66.47	33.53	1.57*	21.25*	0.31*	6.64	0.039	268	$36.9 x 10^5$
3B	65	50*	63.11	36.89	1.48*	24.14*	0.38*	6.64	0.038	270	$30.9 x 10^5$
3C	75	50*	63.40	36.60	1.51*	28.15*	0.39*	6.60	0.037	275	$31.6 x 10^5$
4A	92	7	60.14	39.86	1.44*	28.64*	0.65*	6.17	0.024	285	$39.5 x 10^5$
4B	110	10	62.23	37.77	1.28	38.86	0.63*	6.17	0.022	265	$39.3 x 10^5$
4C	85	5	58.04	41.96	1.33	34.20	0.60*	6.47	0.026	285	$38.4 x 10^5$
5A	89	30	62.77	37.23	1.37	32.54	0.55*	6.51	0.036	321	$33.1 x 10^5$
5B	80	10	58.04	41.96	1.46*	27.65*	0.81	6.47	0.021	280	$23.3 x 10^5$
5C	85	15	65.45	34.55	1.47*	26.15*	0.51*	6.43	0.034	304	$32.1 x 10^5$
6A	95	7	65.59	34.41	1.55*	23.30*	0.44*	6.22	0.032	324	$18.3 x 10^5$
6B	70	10	59.89	40.11	1.56*	26.40*	0.30*	6.05	0.035	305	$33.1 x 10^5$
6C	80	15	68.52	31.48	1.60*	20.01*	0.48*	6.50	0.027	275	$37.8 x 10^5$

Remarks: the symbol (*) means that the data is categorized as degraded.

Table 5. Scoring of soil degradation in dryland

Land Unit	Parameters											Score	Soil Degradation Status	Score	Limiting Factor
	SD	SR	TC	TS	BD	TP	SP	PH	EC	R	MT				
1A	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
1B	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
1C	0	4	0	0	0	0	0	0	0	0	0	4	Slightly Degraded	R. I	Surface Rocks
2A	0	0	0	0	4	4	4	0	0	0	0	12	Slightly Degraded	R. I	Bulk Density, Porosity, Permeability
2B	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
2C	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
3A	0	4	0	0	4	4	4	0	0	0	0	16	Moderately Degraded	R. II	Surface Rocks, Bulk Density, Porosity, Permeability
3B	0	4	0	0	4	4	4	0	0	0	0	16	Moderately Degraded	R. II	Surface Rocks, Bulk Density, Porosity, Permeability
3C	0	4	0	0	4	4	4	0	0	0	0	16	Moderately Degraded	R. II	Surface Rocks, Bulk Density, Porosity, Permeability
4A	0	0	0	0	4	4	4	0	0	0	0	12	Slightly Degraded	R. I	Bulk Density, Porosity, Permeability
4B	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
4C	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
5A	0	0	0	0	0	0	4	0	0	0	0	4	Slightly Degraded	R. I	Permeability
5B	0	0	0	0	4	4	0	0	0	0	0	8	Slightly Degraded	R. I	Bulk Density, Porosity
5C	0	0	0	0	4	4	4	0	0	0	0	12	Slightly Degraded	R. I	Bulk Density, Porosity, Permeability
6A	0	0	0	0	4	4	4	0	0	0	0	12	Slightly Degraded	R. I	Bulk Density, Porosity, Permeability
6B	0	0	0	0	4	4	4	0	0	0	0	12	Slightly Degraded	R. I	Bulk Density, Porosity, Permeability
6C	0	0	0	0	4	4	4	0	0	0	0	12	Slightly Degraded	R. I	Bulk Density, Porosity, Permeability

Description: SD: Solum Depts; SR: Surface rocks; TC: Colloid Composition; TS: Sand Composition; BD: Bulk Density; TP: Total Porosity; SP: Soil Permeability; PH: pH (H_2O); EC: Electrical Conductivity; R: Redox; MT: Microbes Total.

Table 6. Matching observation data to soil degradation default values on wetland

Land Unit	Parameters				
	pH (Pyrite)	Groundwater Depth (cm)	pH (H_2O)	Electrical Conductivity (mS/cm)	Microbes Total (cfu/g)
7A	4.64	10	7.26*	0.088	17.3 x 10^5
7B	4.52	15	7.30*	0.089	13.9 x 10^5
7C	4.77	10	7.22*	0.043	21.2 x 10^5
8A	4.36	15	7.16*	0.122	25.7 x 10^5
8B	4.35	17	7.11*	0.093	42.0 x 10^5
8C	4.32	18	7.21*	0.139	24.8 x 10^5
9A	4.05	22	7.28*	0.134	33.2 x 10^5
9B	4.24	20	7.05*	0.084	30.4 x 10^5
9C	4.36	26*	7.35*	0.088	55.2 x 10^5
10A	4.55	27*	7.31*	0.059	16.3 x 10^5
10B	4.92	24	7.06*	0.051	30.2 x 10^5
10C	4.88	23	7.04*	0.051	41.5 x 10^5
11A	4.08	21	6.19	0.045	24.1 x 10^5
11B	4.26	18	6.54	0.043	49.2 x 10^5
11C	4.27	16	6.43	0.051	37.3 x 10^5
12A	4.48	20	7.01*	0.044	32.3 x 10^5
12B	4.24	26	6.70	0.061	0.5 x 10^5
12C	4.33	26*	6.51	0.030	18.5 x 10^5

Remarks: the symbol (*) means that the data is categorized as degraded.

Table 7. Scoring of wetland soil degradation

Land Unit	Parameters					Score	Soil Degradation Status	Symbol	Limiting Factor
	pH (Pyrite)	Groundwater Depth (cm)	pH (H_2O)	EC (mS/cm)	Microbes total (cfu/g)				
7A	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
7B	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
7C	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
8A	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
8B	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
8C	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
9A	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
9B	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
9C	0	4	4	0	0	8	Slightly Degraded	R. I	pH H_2O, Shallow Groundwater Depth
10A	0	4	4	0	0	8	Slightly Degraded	R. I	pH H_2O, Shallow Groundwater Depth
10B	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
10C	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
11A	0	0	0	0	0	0	Undegraded	N	
11B	0	0	0	0	0	0	Undegraded	N	
11C	0	0	0	0	0	0	Undegraded	N	
12A	0	0	4	0	0	4	Slightly Degraded	R. I	pH H_2O
12B	0	4	0	0	0	4	Slightly Degraded	R. I	Shallow Groundwater Depth
12C	0	4	0	0	0	4	Slightly Degraded	R. I	Shallow Groundwater Depth

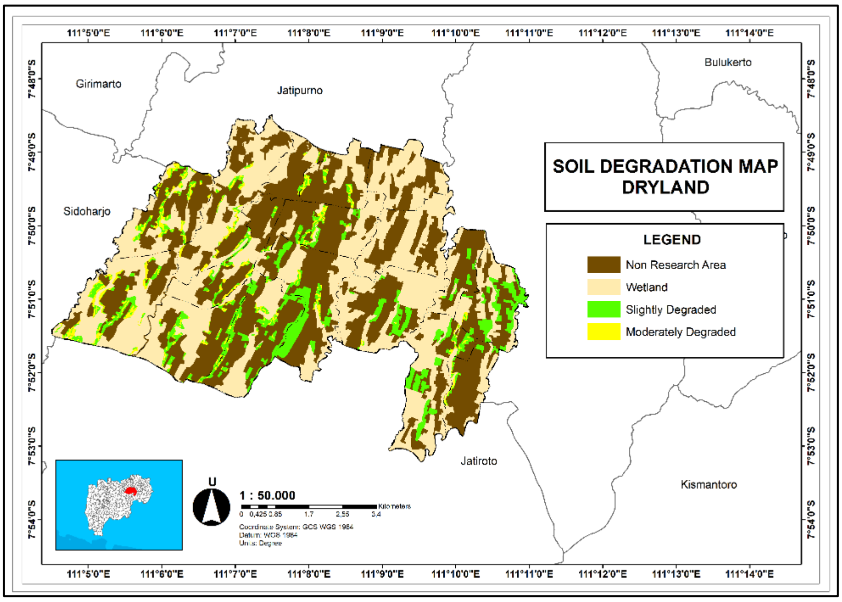

Figure 3. Dryland soil degradation map

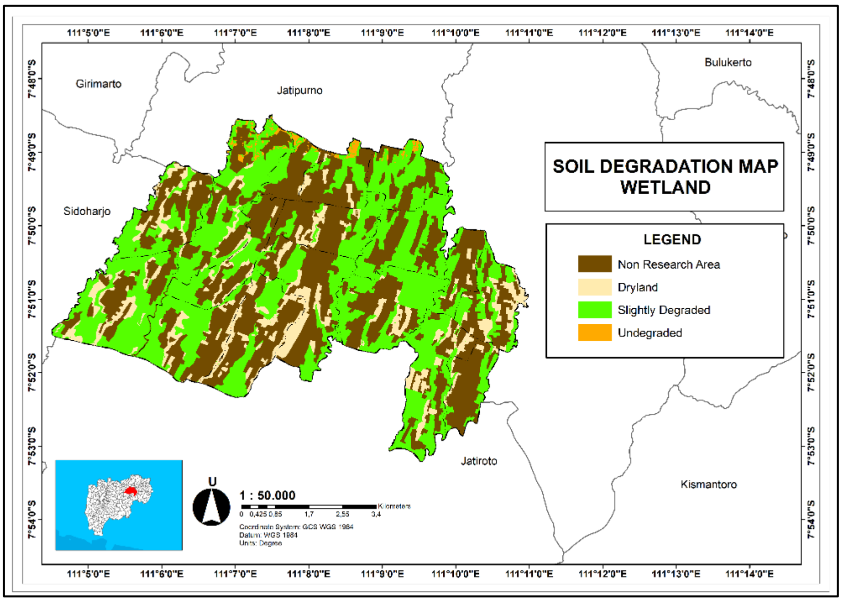

Figure 4. Wetland soil degradation map

Environmental Factors on Soil Degradation Status

The diversity of land characteristics can affect soil degradation. The sources of diversity analyzed are land use, soil type, and slope. Rainfall at each point in the study area has the same condition (2.250 mm/years), so no analysis was conducted on soil degradation status.

Slope

Slope significantly affects dryland soil degradation status in the Jatisrono Sub-district (F-count = 11.983; P-value = 0.001; N = 18). Table 8 show that slopes of 0-8%, 8-15%, and 15-25% have a mean level of soil degradation of 5.33, 7.33, and 14.00, respectively, with a significance value of less than 0.05 which indicates that the greater the slope,the higher soil degradation. Land that has a slope of >15%, according to Andrian *et al.*(2014), is more easily degraded. A large slope will affect the amount of runoff and flow volume Widiatiningsih *et al.*(2018a), making soil erosionmore significant. This condition causes land with large slopes to risk soil degradation due to erosion (Hartati *et al.,* 2018). Agricultural cultivation on land with steep slopes can hinder land management, but it also has the potential for landslides (Supriyono *et al.,* 2009). Landslides on steep slopes, according to Prancevic *et al.*(2020), are triggered by rainwater.

Table 8. Effect of slope on dryland soil degradation status at Jatisrono Sub-district

Slope	Soil Degradation Status
0-8%	5.33a
8-15%	7.33a
15-25%	14.00b
Sig.	P = 0.001**

Remarks:** = highly significant

Table 9 shows that the slopes of 0-8%, 8-15%, 15-25%, and 25-40% in wetlands have a mean level of soil degradation of 2.00, 4.00, 4.66, and 5.33, respectively, with a significance p-value > 0.05. This indicates that the slope does not significantly affect soil degradation in wetlands. This condition is due to the rice fields on steep slopes have been terraced. Terracing is a form of soil and water conservation in mountainous areas to increase soil productivity (Wang *et al.,* 2023). Steep slopes are prone to soil erosion, where rainwater can erode fertile soil layers. By using terraces, rainwater flow is controlled and waterways slowly flow through the terraces, reducing water velocity and preventing erosion. The terrace walls also help keep the soil in place, reducing the chance of landslides. Terraces are also part of a distinctive cultural landscape by Fukamachi (2017) as they involve human interaction with the natural environment to create an efficient agricultural system.

Table 9. Effect of slope on wetland soil degradation status

Slope	Soil Degradation Status
0-8%	2.00a
8-15%	4.00ab
15-25%	4.66ab
25-40%	5.33b
Sig.	P = 0,065^{ns}

Remarks:^{ns} = not significant

Soil Type

In wetlands, soil type significantly affected soil degradation status (F-count = 8.982; P-value = 0.009; N = 18). Table 10 shows that Alfisols and Inceptisols soil types in wetlands have a mean level of soil degradation of 4.66 and 2.00, respectively, with a significance p-value < 0.05 which indicates that the level of soil degradation on land with Alfisols is higher than that with Inceptisols. In this research, degradation to Alfisols is caused by the value of pH H_2O, which exceeds the critical threshold of soil degradation, which is > 7. pH H_2O in the study area ranges from 6.19-7.01 for Inceptisols and 7.04-7.35 for Alfisols. Inceptisols, according to Kaya (2014), have some unfavorable chemical properties such as acidic pH, low organic matter, and low nutrients N, P, and K. This can be caused by the way it is formed as according to Setiawan *et al.*(2020), Inceptisols are formed as a result of active leaching and erosion where the process results in the washing away of basic anions and cations that play an essential role in meeting plant nutrient needs. Inceptisols is a newly formed young soil, while Alfisolsis classified as a fully developed soil with karst or limestone parent material, according to Syamsiyah et al. (2023). This soil is rich in Ca and Mg, so it contains higher base cations than Inceptisols(Munir & Herman, 2019). This condition causes the pH of Alfisols to be higher than Inceptisols. Drylands do not have different soil types, so no soil degradation status was assessed.

Table 10. Effectof soil type on wetland soil degradation status

Soil Type	Soil Degradation Status
Alfisols	4.66b
Inceptisols	2.00a
Sig.	P = 0.009**

Remarks:** = highly significant

Land Use

Table 11 shows that plantation and moor land use on dry land havea mean level of soil degradation of 8.88 each with a significance value of more than 0.05 which indicates that on dry land, the difference in land use has no significant effect on soil degradation status. The processing of moorland is generally more intensive than plantation. Moor typically has a smaller area than plantations. Due to the limited area, moorland management often uses intensive methods to maximize the use of available land. In addition, moorlands are often planted with vegetable or food crops with shorter growing cycles, requiring more frequent tillage, including land preparation, soil structure improvement, planting, maintenance, and repeated harvesting in a short period of time. Intensive tillage can affect the environment by increasing soil topsoil erosion due to heavy machinery use (Adesina *et al.,* 2021). Despite certain variances in tillage, good soil management also plays a role in decreasing the impact of soil deterioration. Because there are no changes in land use in wetlands, no soil degradation status was determined.

Table 11. Effect of land use on dryland soil degradation status

Lang Use	Soil Degradation Status
Plantation	8.88a
Moor	8.88a
Sig.	P = 1.000[ns]

Remarks:[ns] = not significant

Determinant Factors of Soil Degradation Status

The determinants of soil degradation show the cause-and-effect relationship between soil degradation parameters and soil degradation in Jatisrono Sub-district. Based on Table 12, it is known that dryland soil degradation is positively correlated with bulk density (r = 0.798; P-Value = 0.000; N = 18), negatively correlated with porosity (r = -0.851; P-Value = 0.000; N = 18), and negatively correlated with permeability (r = -0.676; P-Value = 0.002; N = 18). It means there is a strong relationship between soil bulk density, porosity, and permeability with soil degradation status, where an increase in bulk density values will be followed by an increase in soil degradation status value (Figure 5a). An increase in porosity and permeability, on the other hand, will be followed by a decrease in soil degradation status scores (Figures 5b and 5c).

Table 12. Determinants of dryland degradation parameters

Parameters	r
Solum depths	-0,401
Surface Rocks	0,342
Colloid Composition	0,279
Sand Composition	-0,279
Bulk Density	**0,798****
Porosity	**-0,851****
Soil Permeability	**-0,676****
pH (H_2O)	-0,245
Electrical Conductivity	-0,066
Redox	0,132
Number of Microba	-0,111

Remarks: (r) value is coefficient of correlation. Numbers followed by (*) are correlated at the 5% level, and (**) are correlated at the 1% level.

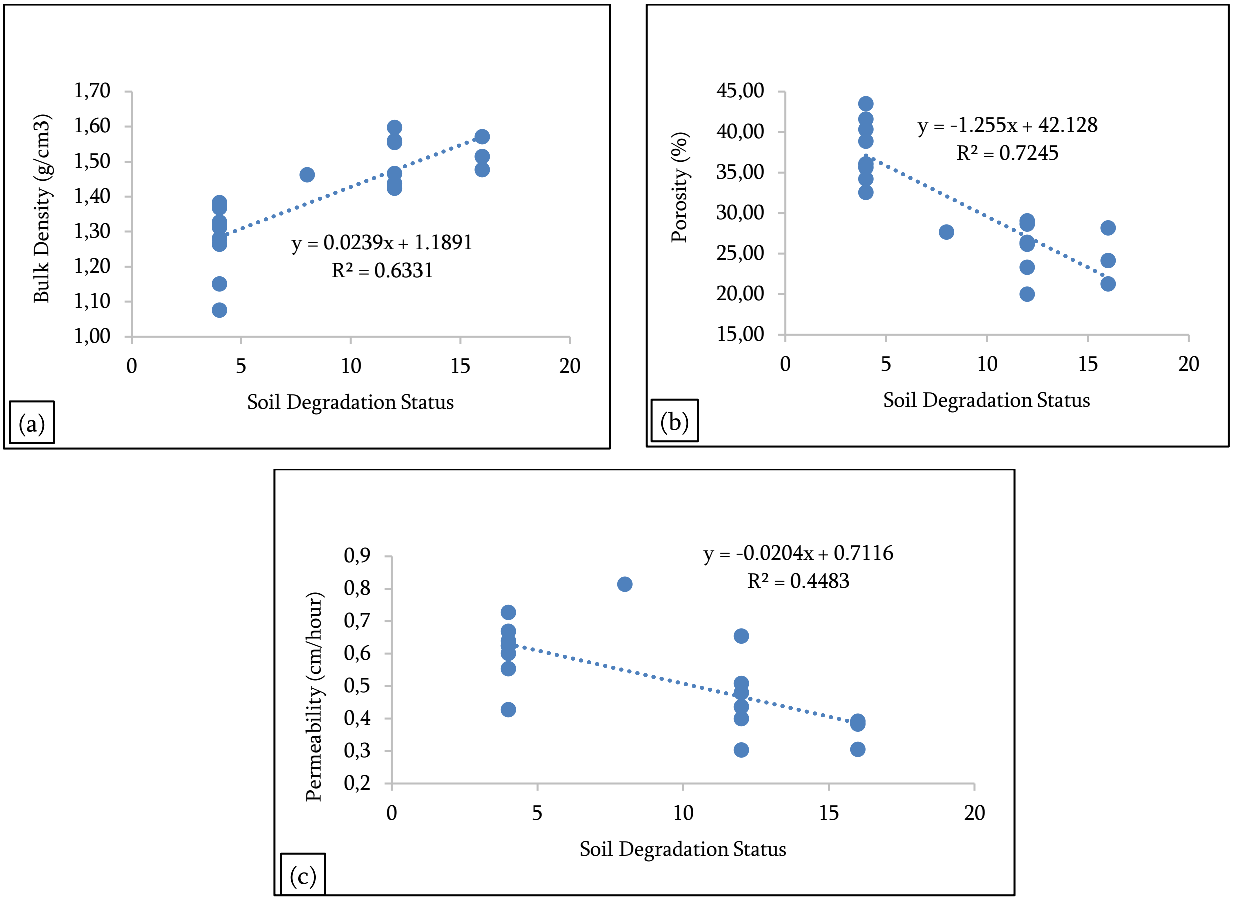

Figure 5. Correlation between dryland soil degradation status with determinants parameters of bulk density (a), porosity (b), and permeability (c).

Soil that has a bulk density value >1.4 g/cm^3 and then undergoes soil compaction will make it difficult for the soil to become loose, hindering the movement of plant roots (Widiatiningsih *et al.,* 2018b). Bulk density is not an inherent attribute of soil; rather, it is modified by a variety of external events that occur naturally and anthropogenically (Casanova *et al.,* 2016). Bulk density was negatively correlated with soil porosity (r = -0.842; P-value = 0.000; N = 18). Soil compaction causes a decrease in porosity value, which will interfere with water distribution into the soil (Ledermüller *et al.,* 2021). Bachtiar (2019) found that the lower the bulk density, the more the total pore volume of the soil increases, and Sudaryono (2001) revealed the same thing. Namely, in his research, there was a decrease in porosity in line with the increase in bulk density. This condition occurs due to soil compaction caused by pore space filled by soil particles dissolved in water through deposition.

Jatisrono Sub-district area has a low porosity value. According to Nuraida et al. (2021), the low value of soil porosity affected by the capability of the land that cannot block rainwater droplets. Rainwater will hit directly with the soil aggregate, breaking them down into smaller particles that will fill the spaces between the soil aggregate. Because of this condition, the soil compacts and roots find it difficult to break down soil aggregates, resulting in high bulk density values. The soil in the research area is also dominated by a clay texture. According to Dewi et al. (2021), clay texture has a total porosity dominated by micropores, so the soil infiltration rate is slow. This results in the soil being less able to bind water. The higher the porosity value, the easier it is for water to pass through the soil (Shao *et al.,* 2020).

Bulk density, porosity, and permeability are correlated with each other. Low porosity values and high bulk density values influence low permeability values. Soil permeability negatively correlates with bulk density (r = -0.584; P-Value = 0.011; N = 18) and positively with soil porosity (r = 0.596; P-Value = 0.009; N = 18). In Sudaryono's (2001)research, The decrease in soil permeability value was explained as a result of soil compaction, as shown by an increase in bulk density and a decrease in soil porosity. The higher the porosity, the higher the rate of soil permeability(Bintoro *et al.,* 2017). Slow permeability causes only a small portion of rainwater to enter the soil (infiltration), while the rest flows as surface flow that causes erosion (Mujiyo *et al.,* 2007).

In addition, the slope had a highly significant effect on bulk density (F-count = 8.653; P-Value = 0.003; N = 18), soil porosity (F-count = 11.928; P-Value = 0.001; N = 18), and soil permeability (F-count = 11.431; P-Value = 0.001; N = 18). Higher bulk density values and lower soil porosity and permeability values will follow higherslope values. This conditionaligns with Saribun (2007),who stated that the decline onsoil physical properties would be more significant in relatively steep slopes. This condition is due to continuous erosion, so the soil will have a shallow solum depts, high soil density, and low porosity. The soil in areas with steep slopes will have a large surface flow velocity due to erosion causing low soil permeability because more water will escape and little will beabsorbed (Yulina *et al.,* 2015). Based on the analysis results, the slope affects several determinants of dryland soil degradation in the Jatisrono Sub-district.

Based on Table 13, wetland soil degradation is positively correlated with pH H_2O (r = 0.769; P-Value = 0.000; N = 18). This condition indicates a strong relationship between pH H_2O and soil degradation status, where an increase in the value of pH H_2O will be followed by a rise in the value of soil degradation status (Figure 6). The correlation test results indicate that pH H_2O determines wetland soil degradation in the Jatisrono Sub-district.

Table 13. Determinants of wetland soil degradation parameters

Parameters	r
pH Pyrite	0,316
Shallow Groundwater Depth	0,367
pH (H_2O)	**0,769****
Electrical Conductivity	0,266
Microbes total	-0,090

Remarks: (r) value is coefficient of correlation. Numbers followed by (*) are correlated at the 5% level, and (**) are correlated at the 1% level.

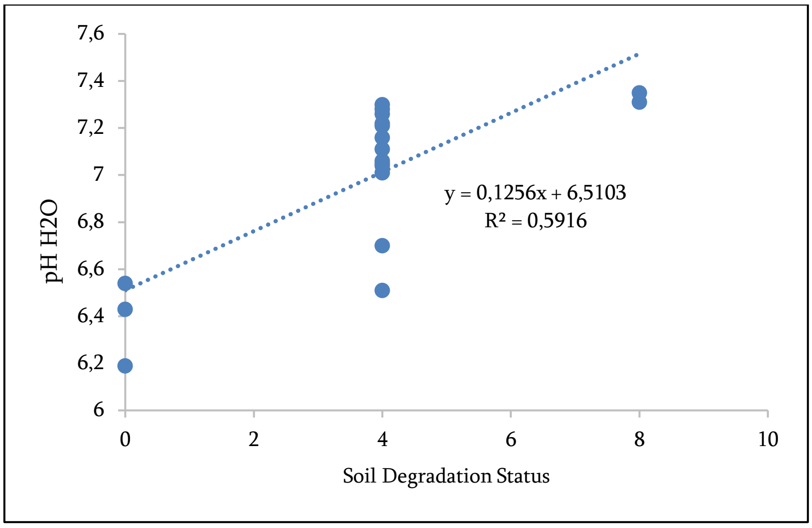

Figure 6. Correlation between pH H_2O and wetland soil degradation status

The soil pH on wetland area of Jatisrono Sub-district is too high. Acidity level can interfere with plant growth. Al saturation will be increased in soils that are too acidic, limiting root penetration to obtain nutrients and causing plants to experience nutrient deficiencies (Bian *et al.,* 2013). If the soil pH is too alkaline, the solubility of Al, Fe, Mn, Cu, and Zn ions will be very low, so plants become deficient in the intake of these ions Aulia *et al.* (2021). With neutral soil pH, the availability of nutrients will increase (Ekawati *et al.,* 2021).

In addition, soil type had a highly significant effect on pH H_2O (F-count = 50.102; P-Value = 0.000; N = 18). Alfisols have a higher pH H_2O value than pH H_2O in Inceptisols. The results showed that Inceptisols were dominated by slightly acidic pH while Alfisols were dominated by neutral pH. This condition is explained by Munir & Herman (2019), that Inceptisols is a newly formed young soil while Alfisolsis is classified as a fully developed soil and contains higher base cations than Inceptisols. This condition causes Alfisols to to have a higher pH than Inceptisols. Hasibuan *et al.* (2014)stated that Inceptisols have chemical properties in the form of pH classified as acidic to slightly acidic. Inceptisolsare young soils beginning to develop, have low chemical properties, and react somewhat acidic, making almost all Inceptisols have low fertility levels (Perdana *et al.,* 2021).

CONCLUSION

Dryland farming in Jatisrono Sub-district has soil degradation levels ranging from weakly to moderately damaged. Wetland agriculture uses soil that is both undamaged and slightly deteriorated. In dryland, slope has a substantial impact on soil degradation state, and the determinants of soil degradation are bulk density, porosity, and soil permeability. In contrast, soil type has a substantial impact in wetlands, with actual pH being the determinant of soil degradation. Dryland soil degradation can be improved by incorporating organic matter. Organic fertilizers can reduce porosity in sandy soil and help aeration in clay soil. Providing organic matter can stabilize soil aggregates so that the soil becomes looser and easier to process,increasingsoil permeability. Soil management on steep slopes involves soil conservation with minimum tillage by leaving crop residues as mulch that can improve soil structure and suppress erosion. Because the shallow groundwater component is too deep, the soil above it struggles to get adequate water, resulting in drought. This condition can be overcome by improving the irrigation system. Land management recommendations strive for long-term biomass production while minimising vital agriculture land.

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