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ORIGINAL PAPER

# The genesis of rainfed agricultural soils in Indonesian lowlands with two different climate types

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**Abstract**

This study analyzes the genesis of rainfed agricultural soil derived from carbonate rocks in two climates types of the South Sulawesi Indonesian lowlands. Soil analysis included the physical and chemical characteristics of soil, clay minerals, and oxide minerals. Rock samples were analyzed using petrography analysis. There are ten soil profiles, 51 soil samples, and ten rock samples. Correlation statistics were used to determine the correlation between climate and soil characteristics. The Bantimurung District has a C-2 climate type, and Bangkala District has a D-3 climate type. The Bantimurung District as a wet area has a positive correlation between rainfall and cation exchange capacity but negative correlation with soil pH and base saturation. The dry Bangkala District shows a positive correlation between c-organic with base saturation and a negative correlation between water content and soil bulk density. Finding shows that the process of mineral transformation is strongly influenced by hydropedology activity. Kaolinite minerals are more commonly found in Bantimurung District, while nontronite-montmorillonite minerals are more common in Bangkala District. The pan-oxide plow was only found in Bantimurung District with a thickness of up to 3–8cm, indicating intensive land cultivation. Soil derived from carbonate rocks with high hydropedological activity demonstrates a faster soil formation process. To maintain soil fertility, C-organic levels of the soil need to be increased by returning harvest waste to the soil. Increasing the soil water content can be done with water harvesting and the use of perennial rivers for irrigation.

**Keywords** Soil · Rainfed · Kaolinite · Montmorillonite · Oxide · Indonesia

## Introduction

Rainfed lowlands are characterized by a lack of water control, and their soil can only be flooded with water to a depth of 50 cm for no more than ten consecutive days during the cropping season (Dobermann and Fairhust 2000). Rainfed agriculture includes a unique type of land use because the land undergoes an inundation process that affects the soil characteristics. According to some experts, water is essential for soil genesis in wetlands and drylands (Kipkemoi et al. 2021; de Vicente 2021). Inundated of the rainfed soil for paddy field increased in the reduction process, while at the end of the planting process, the oxidation process replaced the reduction process, and results in mineral weathering alterations and changes in soil physical, chemical, and biological properties for developing different soils in drylands (Hardjowigeno et al. 2005). Hydropedological characteristics influence the water in rainfed agricultural soils and present a complete view of a soil unit from the microscopic to the macroscopic levels, which is extremely useful for research on soil classification and genesis (Mello and Curi 2012). The soil genesis, parent rock characteristics, and different climates contribute to the hydropedological characteristics, which can differ with location and particularly morphology (such as lowland, hilly, and mountainous areas) (Van Tol et al. 2017).

The rainfed lowlands have high agricultural potential in South Sulawesi, Indonesia, with an area of up to 255,516 ha (Central Bureau of South Sulawesi 2015). However, rainfed lowlands in this area have been cultivated 70 years on average which has reduced their ability to support rice production. The capacity of rainfed lowland to support food production has decreased over

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the last decade, particularly with the onset of global climate change, because they are highly dependent on rainfall (Tanure et al. 2020). Soil plays an important role in increasing the value of ecosystems, especially in crop production (Abd El-hamid et al. 2020). However, soil nutrient loss is an increasing problem in the tropics due to global climate change (Kumar and Das 2014). Climate change factors, such as rainfall and temperature, considerably impact soil nutrients (Pareek 2017). Rainfall increases the downward movement of water in the soil, causing the loss of soil nutrients. Moreno et al. (2012) studied the relationship between rainfed lowland soil and the fertilization response in Castilla-La Mancha (Central Spain) and concluded that is more strongly influenced by climate than fertilization treatment. However, the impact of climate change has considerably increased the use of chemical fertilizers, decreased soil quality, and induced widespread poverty (Erbas and Solakoglu 2017). Negative implications owing to changes in land use lead to land degradation through landslides, floods, and flash floods (Ahmad et al. 2018; Olsson et al. 2019). In Indonesia, the government is continuously pursuing efforts to expand productive paddy fields in South Sulawesi to contribute to food security (Rusono et al. 2010). Nevertheless, additional information is needed on the genesis of rainfed lowland soil to guide its successful management, particularly in areas with high and low rainfall. The present study analyzes the genesis of rainfed agricultural soil from carbonate rocks for two climates in the lowlands of South Sulawesi.

## Material and methods

### Study site

In the tropics, climatic factors and land use strongly influence soil formation originating from Tonasa Formation (Eocene to Miocene) (Sukamto 1982). South Sulawesi is a tropical region in Indonesia that shows a varied morphology (Desaunettes 1977), resulting in different rainfall distribution among districts, with a range of wet to dry climates (BMKG 2016). This study evaluated the genesis of soil development in the rainfed lowlands of South Sulawesi and the impact of different climatic factors on soil formation. Two study sites were considered (Fig. 1). The first study site was located in the Bangkala District of Jeneponto Regency. This site exhibits a dry climate and is located 119° 34′ 0″ E and 5° 38′ 0″ S with slope 2–8% (RePPProT 1988). The second study site was located in Bantimurung District of Maros Regency. This site has a slightly wet climate and is located at 119° 39′ 0″ E and 5° 0′ 0″ S, with slope of 2–8%.

### The geological site

During the Early Cretaceous period, plate tectonic attributed to the Australian, Indian, and Asian plates formed the Indonesian plate, which actively produced the Sulawesi Islands in the Early Paleocene epoch (Hall 2012). According to Sukamto (1982), the Eocene Malawa Formation (Tem) comprised sedimentary rock mainly characterized by land and coal deposits. This formation showed a thickness of at least 400 m. From the Lower Eocene to the Lower Middle Miocene, the Tonasa Formation (Temt) was above the Malawa Formation and comprised partially stretched solid coral limestones in white and light gray as well as bioclastic and calcarenite limestones in white, light brown, and light gray. Some of these deposits were well layered and alternated with marl. The Tonasa Formation is approximately 3000 m thick and forms a karts landscape called the Maros-Pangkep karst area. It subsequently formed sedimentary rocks interspersed with volcanic rocks from the Middle Miocene to Lower Pliocene (Tmc and Tmcv). The rock unit members included tuffaceous sandstones interspersed with tuffs, sandstones, siltstone, claystone, marl, limestone, conglomerates, and volcanic breccia. This formation contained limestones from the Tonasa Formation and rocks from the Malawa Formation. According to Sukamto and Supriatna (1982), volcanic activities continued during the Pliocene to produce Baturape-Cindako volcanic rocks (Tpbv and Tpbl). The igneous rocks occurring in this area were all linked to volcanic activities. These breakthroughs comprised stocks, sills, and dykes in basalt and diorite aged 8.3–19, 2 million years. No significant deposition or volcanic activity occurred in this area after the Upper Pliocene. The Maros-Pangkep karts area contains large Holocene deposits in the form of alluvium.

The Middle Miocene geological structure showed a major fault trending north-northwest that grew after the Pliocene (Sukamto and Supriatna,1982; Maulana et al. 2010). In Tertiary and Quaternary (Pleistocene) rocks, the rock layers exhibited a slope characterized by a folding structure, implying that the fold occurred after the Pleistocene. The fault structure was linked to magmatic activities in the Upper Pleistocene, followed by tectonic movements that caused faults in this area. The fault runs in three directions: north-south, southwest-northeast, and northwest-southeast.

During the Holocene period, soil formation was affected by a combination of rock factors, climate, topography, organisms, and time (Weil and Brady 2016). The characteristics of the rock and the structures acting on the rock had a significant impact on the soil formation. Rock provides a substantial subsidy for soil fertility. In particular, soil formed from carbonate rock show neutral reaction and high nutrient contents, making them suitable for crop production (Ferreira et al. 2016).

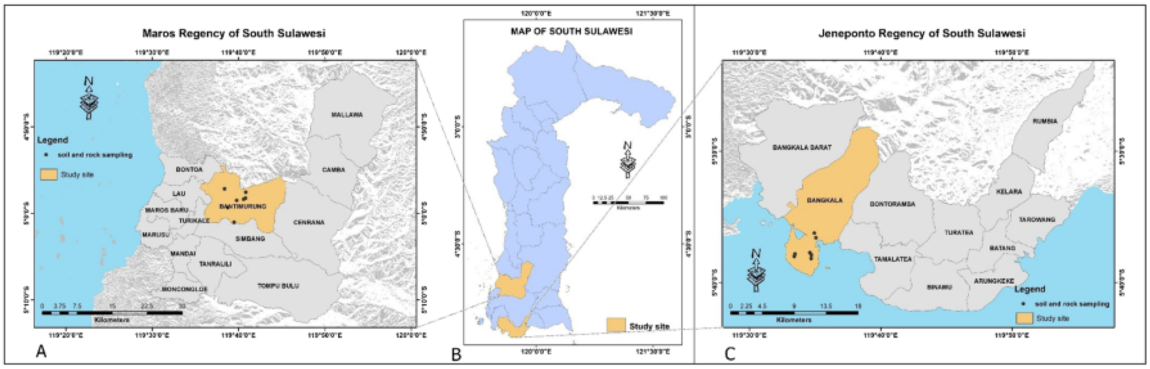

**Fig. 1** Location of study site; the light brown color is the study site in Bantimurung District in Maros Regency (**A**) and Bangkala District in Jeneponto Regency (**C**). Map index of South Sulawesi (**B**) and the black points are the soil and rock sampling site

Carbonated rocks have immense agricultural potential in several regencies of South Sulawesi, with the largest found in the Tonasa Formation (Temt). Fig. 2 shows geological maps of Bantimurung District and Bangkala District.

## Soil and parent rock sampling

Soil samples were collected from several locations used/not used for rainfed lowland agriculture as the control for both of the study sites (Fig. 1). We created 10 soil profiles, collected 51 soil samples for analyzing the physical and chemical characteristics, and collected 10 parent rock samples in R horizon for petrography analysis.

## Soil analysis

Soil pH was measured with a pH meter (van Reeuwijk 2002). The C-organic level was determined using the Walkley and Black method. The particle size distribution was determined using the hydrometer method. The cation exchange capacity (CEC) and exchangeable cations ($Ca^{2+}$, $Na^{+}$, $K^{+}$, and $Mg^{2+}$) were measured using the $NH_4OAc$ process (Ngewoh et al. 1989). The base saturation (BS) of exchangeable cations was estimated using the following equation:

$$BS = \frac{Ca + Mg + K + Na}{CEC} \times 100\% \tag{1}$$

where CEC refers to the cation exchange capacity of the soil. The bulk density was obtained using the gravimetric method (BPT 2005):

$$BD = \frac{drysoilweight(g)}{soilvolume(cm3)} \tag{2}$$

The soil water content was calculated using the following equation (BPT 2005):

$$\%soilwater = \frac{weightofwater(g) - weightofdrysoil(g)}{weightofdrysoil(g)} \times 100 \tag{3}$$

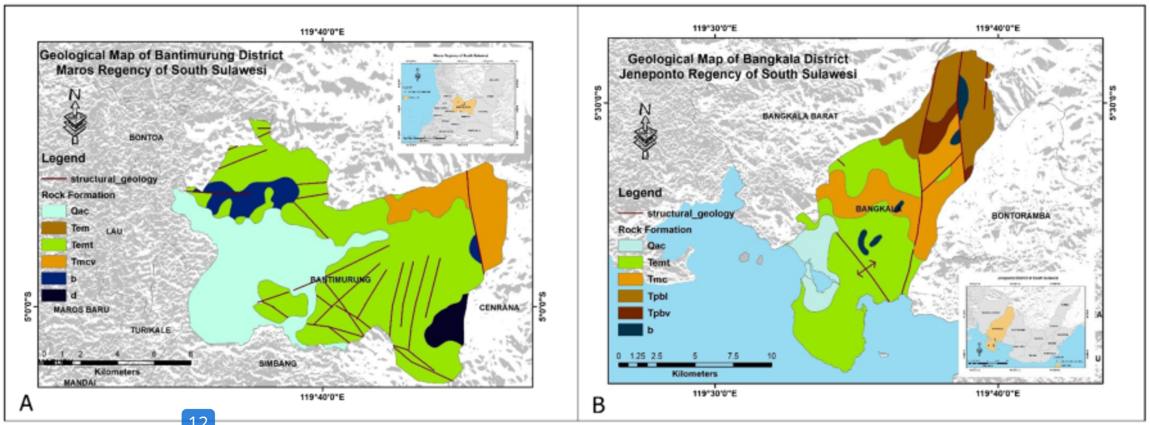

**Fig. 2** Geological map of the study site; **A** geological map of Bantimurung District and **B** geological map of Bangkala District

### Minerals analysis

Mineral oxides were analyzed using X-ray fluorescence based on the method provided by IAEA (IAEA 1997). Powdered samples of clay and nonclay minerals were analyzed using an X-ray diffractometer.

### Statistical analysis

The correlation between the climate and soil characteristics was statistically determined as follows:

$$r=\frac{\sum\left(xi-\overline{x}\right)\left(yi-\overline{y}\right)}{\sqrt{\sum\left(xi-\overline{x}\right)2\sqrt{\sum\left(yi-\overline{y}\right)2}}} \qquad (4)$$

where $r$ is correlation coefficient, xi is values of the x-variable in a sample, $\overline{x}$ is mean of the values of the x-variable, yi is values of the y-variable in a sample, and $\overline{y}$ is mean of the values of the y-variable.

### Petrography analysis

For analysis, the Buehler procedure (Buehler 2015) was used to convert rock samples into thin section using a polarizing microscope and mineral identification based on the Kerr guidelines (Kerr 1959).

### Precipitation

Precipitation data were collected from 2000 to 2019. Monthly rainfall data were obtained from the satellite image analysis of the data from Climate Hazard Group Infrared Precipitation with Station (https://www.chc.ucsb.edu/data/chirps) and the meteorological, climatological, and geophysical agency of Indonesia (https://www.bmkg.go.id/?lang=EN).

### Soil type

The US Department of Agriculture (USDA) method (Soil Survey Staff 2014) was used to classify soil type from orders/suborders and groups/subgroups.

## Result

### Precipitation

As shown in Fig. 3, Bantimurung District has an average rainfall (2000–2019) of 3374 mm/year (Fig. 3), with six wet months and three dry months, corresponding to the C-2 climate based on the Oldeman climate type (Munandar and Sumiati 2017). Bangkala District has an average rainfall (2000–2019) of 1989 mm/year with four wet months and four dry months, corresponding to the D-3 climate (Munandar and Sumiati 2017). The effects of global climate change were observed in 2010, with changing rainfall patterns that occasionally flooded the study site at Bangkala District.

### Parent rock

The parent rock obtained from the two study site comprised sedimentary carbonate rock from the Tonasa Formation (Temt), which was Eocene to Miocene (Sukamto 1982). Because of high rainfall activities, the sedimentary carbonate rocks in Bantimurung District were characterized by calcite recrystallizing in rock cavities (Fig. 4), although they originated from the same rock formation. In contrast, the parent rock in Bangkala District exhibited a lack of climatic influence on mineral recrystallization. As shown in Fig. 5, the pores of the rock body were only partially filled by the recrystallization of calcite.

### Soil characteristic

The soil color in Bantimurung District showed a higher value and chroma (Table 1) than in the dry area of Bangkala District (Table 2). The depth of the soil solum at the two study sites was affected by climatic activities and lowland morphologies. At both study sites, the depth of the soil solum reached ±70cm. The alkaline and clastic nature of the parent rock made it prone to weathering and influenced the soil depth, which is also strongly influenced by the hydropedological and topographic processes of the area (Schoeneberger and Wysocki 2005; Yu et al. 2017). Because of the accumulation of sedimentary materials in the lowland morphology, the study sites were amply supplied by weathering material from the surrounding areas, which were predominantly hilly and mountainous landform.

Because of the low hydropedological activity in Bangkala District, the soil exhibited a neutral pH. The soil samples showed a high CEC, attributed to high content of $Ca^{2+}$ and $Mg^{2+}$ in the soil (Table 2). When clay minerals and organic content captured a cation, CEC can directly influence the soil pH (Aprile and Lorandi 2012). As an evidence of high nutrient content in the soil, BS was in the medium-high category. However, opposite trend was for Bantimurung District, which exhibited a relatively high hydropedological activity. The study site also showed a low soil pH, and the CEC value was from 10.74 to 20.27cmol (+)/kg (Table 1), indicating a low-moderate alkaline cation content.

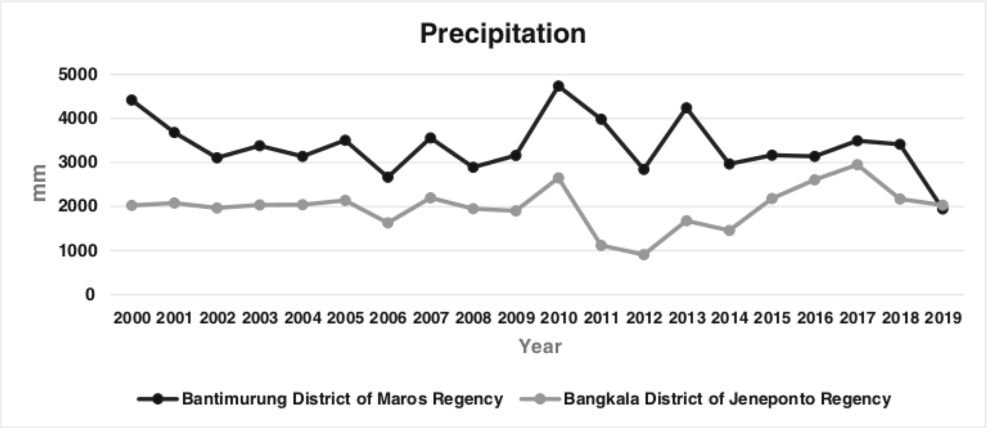

**Fig. 3** Precipitation in Bantimurung District of Maros Regency and Bangkala District of Jeneponto Regency (2000–2019)

## Statistical correlation

A statistical correlation test was performed to identify the relationship between soil parameters. In Bantimurung District, the rainfall has a positive correlation with soil water content and CEC but a negative correlation with soil pH and BS (Table 3). This shows that the parent rock in areas with sufficient rainfall contributes to soil fertility to small extent. In Bangkala District, the C-organic level exhibited positive correlations with BS, $Ca^{2+}$, and $Mg^{2+}$; however, the water content and soil bulk density showed a negative correlation (Table 4). Bantimurung District has two cropping seasons a year, resulting in a greater soil bulk density than in Bangkala District, which has one cropping season a year.

## Clay minerals

Clay minerals formed from carbonate rock showed approximately the same composition at the two study sites. However, dry areas exhibited a 2:1 clay mineral content (55.33%) which is higher than in the slightly wet areas (38.67%).

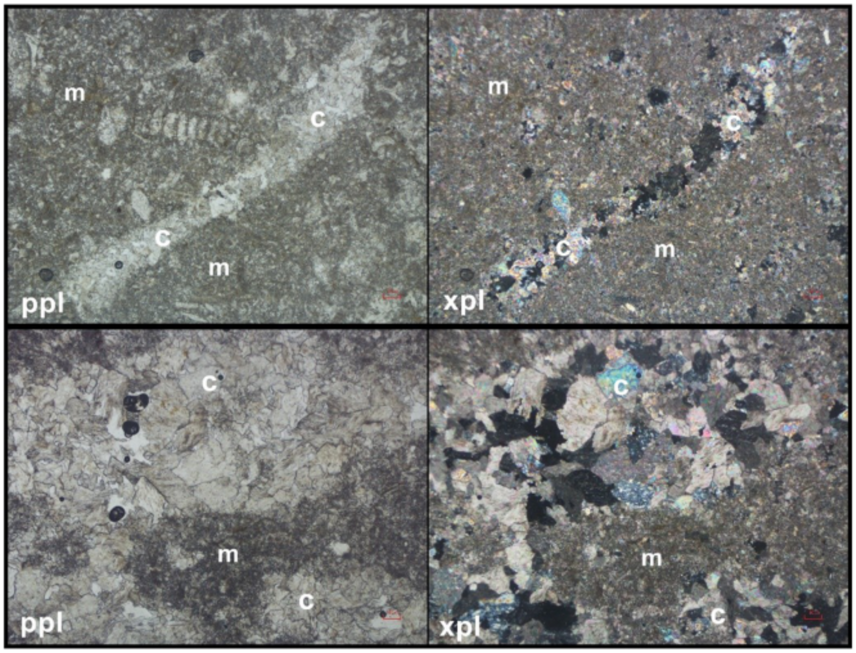

**Fig. 4** The appearance of parent rock in the Bantimurung District showed recrystallization of calcite minerals (C) in vein and cracked with a mass of calcite called micrite (m). Size 100μm

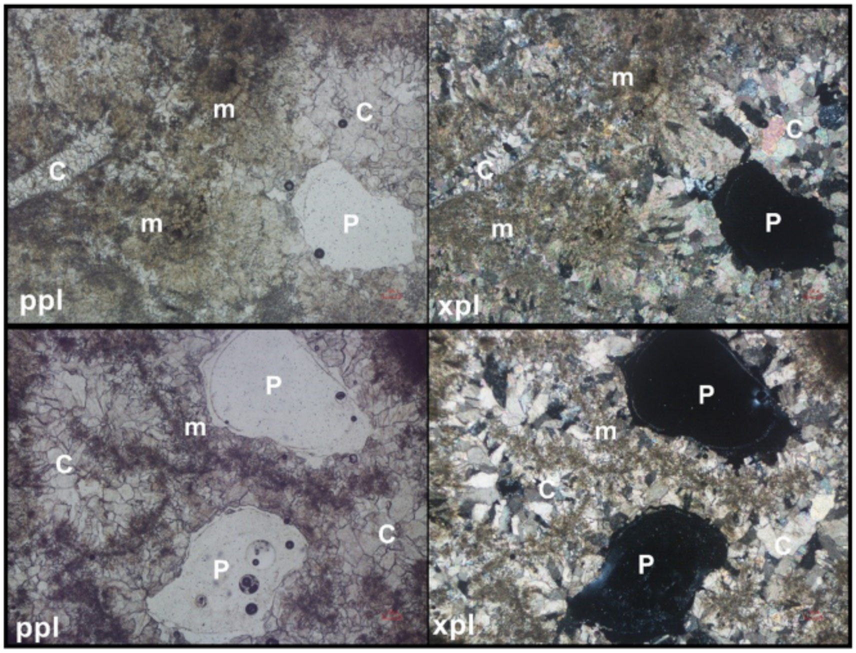

**Fig. 5** The appearance of parent rock in the Bangkala sub-district showed calcite minerals (C), a mass of calcite called micrite (m), and pore (p). Size 100μm

Montmorillonite, nontronite, and vermiculite are examples of the 2:1 clay mineral content, whereas kaolinite and halloysite are examples of the 1:1 clay mineral content (Figs. 6 and 7). Halloysite was found only in Bantimurung District because of its high rainfall activities (Fig. 6). Moreover, the presence of vermiculite and nontronite in the soil was strongly influenced by $Ca^{2+}$ and $Mg^{2+}$ contents in the carbonate parent rock (Hazen et al. 2013).

## Oxide minerals in soils

At the study sites, the rainfed lowland undergoes the inundation process twice a year, which increased the formation of oxide minerals in the soil. The oxides formed pan-oxides plows with thicknesses of 3–8 cm (Fig. 8). The mineral oxides with the highest contents were $Fe_2O_3$ and $Al_2O_3$ (Table 5) in the form of ferrihydrite, hematite, and goethite. Ferrihydrite and goethite are commonly found in paddy fields (Maisch et al. 2020). Goethite gives the soil a yellowish color (Mehmood et al. 2014) (Table 1). The rainfed land in Bangkala District was plowed only once a year; hence, no pan-oxide plow was observed. However, mineral oxides in the form of ferrihydrite and lepidocrocite were found in the soil because of the inundation process. These minerals were still easily transformed into mineral oxides (Maisch et al. 2020) and show the rainfed age of <50 years, which does not indicate intensive land cultivation (Ahmad et al. 2019).

## Soil type

In Bantimurung District (Fig. 8), the soil showed a cambic horizon: a fine silt texture, no aquatic conditions within 50 cm of the soil surface, high of hue, value, and chroma, and the evidence of carbonate compound displacement. The soil was categorized in the Inceptisol order and Udepts suborder with an udic soil moisture regime. Further, the soil exhibited a cemented pan-oxide horizon within 100 cm of the soil surface and was categorized in the Durudepts group. It was also categorized in the Aquic Durudepts subgroup because it showed redox activities owing to inundation process.

In Bangkala District (Fig. 9), all horizons exhibited a clay content >30%, slickensides, and cracks that opened and closed periodically. Thus, the soil was categorized in the Vertisols order. The cracks were >5cm wide and 50cm thick; hence, the soil was further categorized in the Usterts suborder. Moreover, the soil was categorized in the Haplusterts groups because it lacked salic, gypsic, calcic, or petrocalcic horizon. If the soil is not irrigated for at least 150 cumulative days/year, it generates cracks with a width of ≥5 mm and a thickness of ≥25 cm within 50 cm of the soil surface; hence, it was categorized in the Udic Haplusterts subgroups.

## Discussion

In Bantimurung District (Fig. 3), the wet climate encouraged the recrystallization of calcite, which increased the content of

**Table 1** Soils physical and chemical characteristic in Bantimurung District, Maros Regency

| Profile | Depth | Sand | Silt | Clay | Texture | Water content | BD | Color | pH | C-organic | Ca | Mg | K | Na | CEC | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | % | | | | % | g/cm$^3$ | | $H_2O$ | % | (cmol (+)kg-1) | | | | | % |
| 1M | 0–10 | 8 | 69 | 23 | Silt loam | 20.55 | 1.32 | 10YR 5/8 (yellowish brown) | 6.13 | 2.61 | 6.42 | 2.74 | 0.36 | 0.41 | 20.27 | 49 |
| | 10–33 | 16 | 61 | 23 | Silt loam | 17.43 | 1.36 | 10YR 5/4 (yellowish brown) | 6.07 | 2.42 | 5.09 | 0.76 | 0.22 | 0.36 | 19.22 | 33 |
| | 33–70 | 9 | 61 | 30 | Silty clay loam | 15.59 | | 10YR 5/6 (yellowish brown) | 6.12 | 1.78 | 5.92 | 1.33 | 0.41 | 0.25 | 20.20 | 39 |
| 2M | 0–5 | 4 | 86 | 10 | Silt | 13.39 | 1.29 | 2,5Y 7/4 (pale yellow) | 6.18 | 3.02 | 4.01 | 2.80 | 0.19 | 0.41 | 15.53 | 48 |
| | 5–15 | 3 | 87 | 10 | Silt | 16.15 | 1.36 | 2,5Y 7/4 (pale yellow) | 6.09 | 2.38 | 4.38 | 2.80 | 0.22 | 0.32 | 13.38 | 58 |
| | 20–50 | 8 | 70 | 22 | Silt loam | 17.98 | | 2,5Y 6/4 (light yellow brown) | 6.18 | 2.31 | 3.81 | 2.71 | 0.19 | 0.25 | 18.53 | 38 |
| | 50–70 | 8 | 69 | 23 | Silt loam | 15.41 | | 2,5Y 7/3 (pale yellow) | 6.19 | 1.78 | 3.52 | 2.90 | 0.22 | 0.19 | 17.97 | 38 |
| 3M | 0–10 | 12 | 77 | 11 | Silt loam | 21.84 | 1.29 | 2,5Y 5/4 (light olive brown) | 6.67 | 3.15 | 6.43 | 0.99 | 0.39 | 0.25 | 16.40 | 49 |
| | 20–40 | 13 | 63 | 24 | Silt loam | 15.41 | 1.39 | 2,5 5/6 (light olive brown) | 6.65 | 1.89 | 5.76 | 1.36 | 0.24 | 0.34 | 18.11 | 43 |
| | 40–60 | 19 | 57 | 24 | Silt loam | 17.62 | | 2,5 4/4 (olive brown) | 6.62 | 1.56 | 4.92 | 2.12 | 0.19 | 0.19 | 17.16 | 43 |
| 4M | 0–20 | 9 | 81 | 10 | Silt | 16.33 | 1.19 | 2,5Y 5/4 (light olive brown) | 6.60 | 3.87 | 6.54 | 2.84 | 0.32 | 0.45 | 22.34 | 45 |
| | 20–30 | 6 | 84 | 10 | Silt | 15.41 | 1.43 | 2,5Y 5/4 (light olive brown) | 6.33 | 1.78 | 6.53 | 2.75 | 0.25 | 0.39 | 18.33 | 54 |
| | 30–50 | 5 | 67 | 28 | Silty clay loam | 17.43 | | 10YR 5/6 (yellowish brown) | 6.29 | 2.04 | 6.78 | 3.54 | 0.14 | 0.41 | 21.93 | 50 |
| 5M | 0–20 | 16 | 73 | 10 | Silt loam | 15.78 | 1.28 | 2,5 5/6 (light olive brown) | 6.71 | 3.43 | 5.82 | 2.94 | 0.32 | 0.25 | 16.09 | 58 |
| | 20–40 | 13 | 70 | 17 | Silt loam | 16.33 | 1.40 | 2,5 5/4 (light olive brown) | 6.78 | 2.04 | 5.59 | 2.27 | 0.25 | 0.32 | 15.42 | 55 |
| 6M | 0–10 | 15 | 82 | 3 | Silt | 13.39 | 1.41 | 2,5 5/6 (light olive brown) | 6.81 | 2.36 | 8.57 | 1.39 | 0.14 | 0.41 | 24.28 | 48 |
| | 10–30 | 15 | 76 | 9 | Silt loam | 11.38 | 1.43 | 2,5 5/6 (light olive brown) | 6.49 | 2.14 | 5.53 | 2.51 | 0.32 | 0.25 | 20.29 | 42 |
| | 30–60 | 25 | 66 | 9 | Silt loam | 15.78 | | 2,5 5/6 (light olive brown) | 6.38 | 1.56 | 3.71 | 1.96 | 0.28 | 0.21 | 10.74 | 57 |

*M* Maros District, *BD* bulk density, *CEC* cation exchange capacity, *BS* base saturation

carbonate minerals in the formed soil. Even for lowland morphologies, an intensive washing process in areas with sufficient rainfall can free calcite minerals from the soil. The free carbonate in the soil did not show an even distribution; however, it was observed only in isolated spots, indicating a high hydropedological activity. This led to the formation of the 2:1 type of clay mineral content and accelerated the formation of the 1:1 clay mineral content. According to Hazen et al. (2013), the intensive hydropedology activity accelerates the transformation of the 2:1 clay mineral content into the 1:1, forming polymorphs of kaolinite with excessive $H_2O$ in the crystal layer as halloysite ($Al_2Si_2O_5(OH)_4 \cdot nH_2O$) (Fig. 6). Zhang et al. (2016) found that a soil environment with a low C-organic level causes the 2:1 type clay mineral content to transform into kaolinite mineral more quickly than in an environment with a high C-organic level (Table 1). However, Kowalska et al. (2021) showed that carbonate minerals in the soil do not affect the formation and transformation of clay minerals in temperate climates. Carbonate minerals were found in all soil layers; thus, their contribution to the formation of clay minerals was insignificant.

In Bangkala District with the D-3 climate (Fig. 3), the parent rock was less affected by the relatively dry climate on mineral recrystallization; hence, less mineral recrystallization was observed. Calcite made a minor contribution to the soil quality; however, the environment caused the accumulation of free carbonate in the soil, aiding the formation of secondary 2:1 type clay mineral content, which was more dominant than the 1:1 clay mineral content. The condition of this study site is suitable for rainfed rice paddies because it can store water for long duration and reducing water consumption.

The result showed that the process of mineral transformation in the soil is strongly influenced by hydropedological activity, which accelerates the soil genesis process. Owing to different climates, iron oxide undergoes both reduction and oxidation (Vepraskas and Lindbo 2012). The hydropedology

**Table 2** Soils physical and chemical characteristic in Bangkala District, Jeneponto Regency

| Profile | Depth | Sand | Silt | Clay | Texture | Water content | BD | Color | pH | C-organic | Ca | Mg | K | Na | CEC | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | % | | | | % | g/cm$^3$ | | $H_2O$ | % | (cmol (+)kg-1) | | | | | % |
| 1J | 0–5 | 11 | 28 | 61 | Clay | 15.41 | 1.17 | 10YR 2/1 (black) | 7.04 | 4.33 | 13.68 | 2.42 | 0.41 | 0.51 | 28.56 | 60 |
| | 5–25 | 3 | 34 | 63 | Clay | 15.05 | 1.16 | 10YR 3/1 (very dark grey) | 7.03 | 4.12 | 9.56 | 2.77 | 0.36 | 0.35 | 22.00 | 59 |
| | 30–50 | 11 | 47 | 42 | Clay | 14.68 | | 10YR 3/1 (very dark grey) | 7.06 | 3.52 | 8.82 | 1.17 | 0.22 | 0.41 | 20.20 | 53 |
| | >60 | 14 | 34 | 52 | Clay | 14.31 | | 10YR 4/1 (dark grey) | 7.00 | 2.88 | 6.27 | 1.08 | 0.15 | 0.28 | 17.16 | 45 |
| 2J | 0–20 | 8 | 32 | 60 | Clay | 13.95 | 1.20 | 10YR 2/1 (black) | 6.15 | 3.92 | 14.55 | 3.28 | 0.39 | 0.41 | 35.54 | 52 |
| | 20–40 | 2 | 26 | 72 | Clay | 13.58 | 1.16 | 10YR 4/2 (dark grayish brown) | 6.13 | 3.71 | 10.24 | 3.15 | 0.32 | 0.32 | 27.58 | 51 |
| | 40–60 | 9 | 44 | 47 | Clay | 13.21 | | 10YR 3/3 (dark brown) | 6.27 | 3.82 | 8.50 | 2.56 | 0.25 | 0.29 | 21.72 | 53 |
| 3J | 0–10 | 2 | 52 | 46 | Clay | 12.84 | 1.16 | 10YR 2/1 (black) | 7.10 | 3.96 | 14.46 | 3.36 | 0.42 | 0.36 | 29.69 | 63 |
| | 10–30 | 19 | 30 | 50 | Clay | 12.48 | 1.23 | 10YR 2/1 (black) | 7.08 | 4.38 | 12.37 | 2.31 | 0.19 | 0.21 | 25.65 | 59 |
| | 30–70 | 19 | 33 | 48 | Clay | 12.11 | | 10YR 2/1 (black) | 7.08 | 3.53 | 10.95 | 1.17 | 0.32 | 0.19 | 22.42 | 56 |
| | >70 | 22 | 30 | 46 | Clay | 12.01 | | 10YR 2/1 (black) | 7.20 | 3.33 | 12.95 | 1.21 | 0.22 | 0.19 | 23.40 | 62 |
| 4J | 0–15 | 18 | 51 | 32 | Silty clay loam | 11.01 | 1.26 | 2,5Y 2,5/1 (black) | 7.30 | 3.71 | 14.75 | 1.69 | 0.38 | 0.39 | 31.02 | 55 |
| | 15–30 | 13 | 55 | 32 | Silty clay loam | 10.64 | 1.23 | 2,5Y 4/1 (dark gray) | 7.22 | 3.91 | 11.72 | 3.27 | 0.26 | 0.24 | 28.95 | 54 |
| | 30–60 | 10 | 32 | 59 | Clay | 10.28 | | 2,5Y 4/1 (dark gray) | 7.22 | 3.22 | 10.45 | 2.15 | 0.24 | 0.22 | 25.11 | 52 |

*J* Jeneponto District, *BD* bulk density, *CEC* cation exchange capacity, *BS* base saturation

activity attributed to the inundation process enhances the transformation of primary and secondary minerals into mineral oxides (Rabenhorst and Parikh 2000). The transformation of mineral oxides in the soil affects the availability of nutrients and toxicity in rice paddies (Pezeshki and Delaune 2012). The rainfed lowlands of Bantimurung District showed a medium category BS with values of 33 to 58%, which is in line with pan-oxide plow formation. This indicates that the soil's ability to provide nutrients for plants decreased (Table 1). The rainfall significantly influences the pH, BS, CEC, and water content

**Table 3** Pearson correlation for soil parameters in Bantimurung District, Maros Regency

| | Precipitation | Sand | Silt | Clay | Water content | Bulk density | pH | C-organic | Ca | Mg | K | Na | CEC | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation | 1 | | | | | | | | | | | | | |
| Sand | −0.359 | 1 | | | | | | | | | | | | |
| Silt | −0.096 | −0.634$^{**}$ | 1 | | | | | | | | | | | |
| Clay | 0.384 | 0.114 | −0.840$^{**}$ | 1 | | | | | | | | | | |
| Water content | 0.523$^{*}$ | −0.066 | −0.301 | 0.439 | 1 | | | | | | | | | |
| Bulk density | −0.236 | 0.181 | −0.137 | 0.053 | −0.396 | 1 | | | | | | | | |
| pH | −0.660$^{*}$ | 0.553$^{*}$ | −0.054 | −0.326 | −0.126 | 0.014 | 1 | | | | | | | |
| C-organic | 0.103 | −0.022 | 0.225 | −0.277 | 0.268 | −0.952$^{**}$ | 0.113 | 1 | | | | | | |
| Ca | −0.077 | 0.388 | 0.021 | −0.288 | 0.095 | 0.111 | 0.579$^{*}$ | 0.002 | 1 | | | | | |
| Mg | 0.070 | −0.552$^{*}$ | 0.504$^{*}$ | −0.280 | −0.277 | −0.234 | −0.186 | 0.228 | −0.260 | 1 | | | | |
| K | 0.089 | 0.112 | −0.216 | 0.197 | 0.585$^{*}$ | −0.425 | 0.094 | 0.408 | 0.039 | 0.151 | 1 | | | |
| Na | 0.308 | −0.434 | 0.204 | 0.052 | −0.053 | −0.210 | −0.275 | 0.085 | 0.228 | 0.150 | −0.406 | 1 | | |
| CEC | 0.502$^{*}$ | −0.129 | −0.299 | 0.478 | 0.543$^{*}$ | −0.542$^{*}$ | −0.141 | 0.353 | 0.183 | −0.045 | 0.232 | 0.598$^{*}$ | 1 | |
| BS | −0.483$^{*}$ | 0.191 | 0.401 | −0.651$^{**}$ | −0.577$^{*}$ | 0.448 | 0.345 | −0.214 | 0.312 | 0.263 | −0.059 | −0.331 | −0.780$^{**}$ | 1 |

$^{*}$ Correlation is significant at the 0.05 level (2-tailed)

$^{**}$ Correlation is significant at the 0.01 level (2-tailed)

**Table 4** Pearson correlation for soil parameters in Bangkala District, Jeneponto Regency

| | Precipitation | Sand | Silt | clay | Water content | BD | pH | C-organic | Ca | Mg | K | Na | CEC | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation | 1 | | | | | | | | | | | | | |
| Sand | −0.060 | 1 | | | | | | | | | | | | |
| Silt | 0.076 | −0.030 | 1 | | | | | | | | | | | |
| Clay | −0.029 | −0.548 | −0.819$^{**}$ | 1 | | | | | | | | | | |
| Water content | −0.331 | −0.471 | −0.392 | 0.594$^{*}$ | 1 | | | | | | | | | |
| BD | 0.016 | 0.757$^{**}$ | 0.063 | −0.481 | −0.770$^{**}$ | 1 | | | | | | | | |
| pH | −0.052 | 0.482 | 0.346 | −0.566$^{*}$ | −0.178 | 0.337 | 1 | | | | | | | |
| C-organic | 0.312 | −0.134 | −0.176 | 0.226 | 0.067 | 0.132 | 0.008 | 1 | | | | | | |
| Ca | 0.371 | 0.039 | 0.147 | −0.141 | −0.368 | 0.516 | 0.122 | 0.609$^{*}$ | 1 | | | | | |
| Mg | 0.369 | −0.725$^{**}$ | −0.123 | 0.521 | 0.126 | −0.280 | −0.543 | 0.612$^{*}$ | 0.464 | 1 | | | | |
| K | 0.292 | −0.400 | 0.115 | 0.139 | −0.041 | 0.100 | −0.022 | 0.479 | 0.762$^{**}$ | 0.571$^{*}$ | 1 | | | |
| Na | −0.062 | −0.374 | 0.155 | 0.088 | 0.496 | −0.275 | −0.008 | 0.262 | 0.391 | 0.267 | 0.559$^{*}$ | 1 | | |
| CEC | 0.286 | −0.168 | 0.017 | 0.088 | −0.263 | 0.371 | −0.249 | 0.510 | 0.913$^{**}$ | 0.638$^{*}$ | 0.744$^{**}$ | 0.446 | 1 | |
| BS | 0.405 | −0.095 | 0.185 | −0.100 | −0.125 | 0.166 | 0.416 | 0.800$^{**}$ | 0.625$^{*}$ | 0.401 | 0.593$^{*}$ | 0.154 | 0.358 | 1 |

$^{*}$Correlation is significant at the 0.05 level (2-tailed)

$^{**}$Correlation is significant at the 0.01 level (2-tailed)

both negatively and positively (Table 3). If left unchecked, this can decrease the productivity of rainfed agricultural soil and have repercussions on the local community income.

The presence of oxide minerals influenced the soil color in Bantimurung District. Alternatively, the soil color in Bangkala District was considerably affected by the

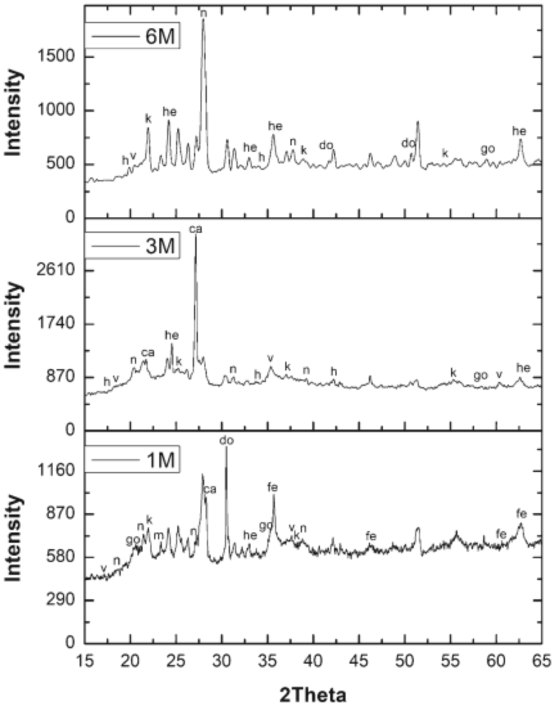

**Fig. 6** X-ray diffractometer data in Bantimurung District with clay mineral: kaolinite (k), halloysite (h), vermiculite (v), montmorillonite (m), nontronite (n). Carbonate minerals: calcite (ca), and dolomite (do). Oxide mineral: hematite (he), goethite, and ferrihydrite (fe)

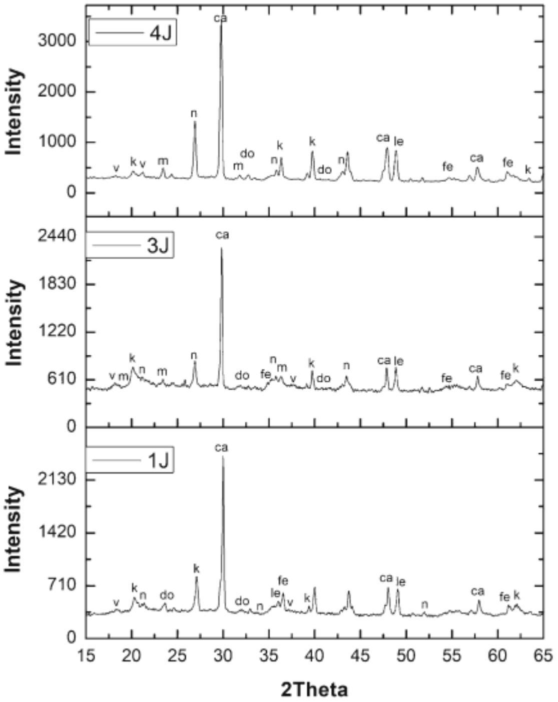

**Fig. 7** X-ray diffractometer data in Bangkala District with clay mineral: kaolinite (k), vermiculite (v), montmorillonite (m), nontronite (n). Carbonate minerals: calcite (ca) and dolomite (do). Oxide mineral: ferrihydrite (fe) and lepidocrocite (le)

**Table 5** Oxide component in a layer of oxide-pan in Bantimurung District

| Profile | $Fe_2O_3$ m/m% | $Al_2O_3$ | $K_2O$ | MnO | $TiO_2$ | CaO | $ZrO_2$ | BaO | ZnO | $MoO_3$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1M | 43.56 | 31.97 | 14.39 | 4.07 | 3.81 | 1.62 | 0.32 | 0.2 | 0.05 | x | x |
| 3M | 25.87 | 31.24 | 32.88 | 3.39 | 2.93 | 4.02 | 0.41 | 0.16 | 0.07 | 0.04 | x |
| 6M | 33.42 | 43.91 | 13.24 | 2.22 | 3.33 | 2.6 | 0.47 | x | 0.07 | 0.04 | 0.71 |

The data has been recalculated in 100%

*x* no data

accumulation of organic matter, resulting in a low chroma value (Table 2). High organic matter and 2:1 clay mineral contents increased the water-holding capacity of the soil (Diatta et al. 2020) but caused the soil cracks under dry conditions (Fig. 9c). Soil cracks reduce crop productivity, and the crop productivity increases when the soil is well irrigated (Pal et al. 2012). In the D-3 climate, the implementation of drip or sprinkle irrigation can improve soil productivity in Vertisols order soils (Crescimanno et al. 2007).

In Bantimurung District, intensive land cultivation decreased organic matter content, as demonstrated by the increase in soil bulk density (Table 1). It will decrease the productivity of rainfed cultivation. This was exacerbated by farmers who sell leftover crops to breeders as animal feed rather than returning them to the soil as a source of organic matter. Instead, farmers prefer to use chemical fertilizers as a nutrient source for rice paddies. Excessive use of chemicals fertilizer can endanger the soil quality and sustainability (Chuan-chuan

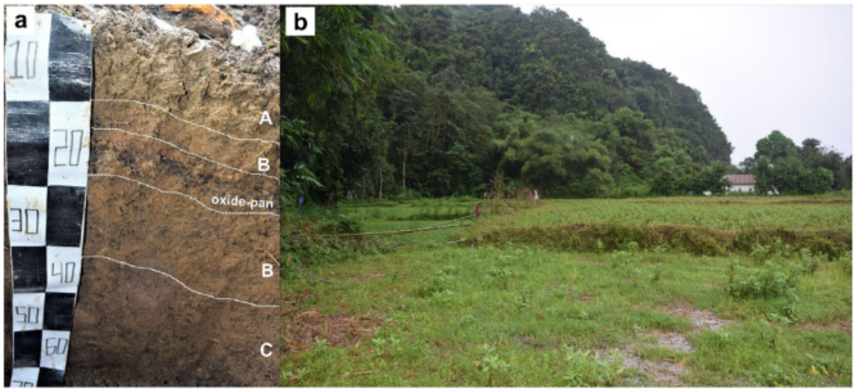

**Fig. 8** Soil profile (1M) in Bantimurung District showed an oxide-pan layer between the B horizon (**a**) and the land use for rainfed (**b**)

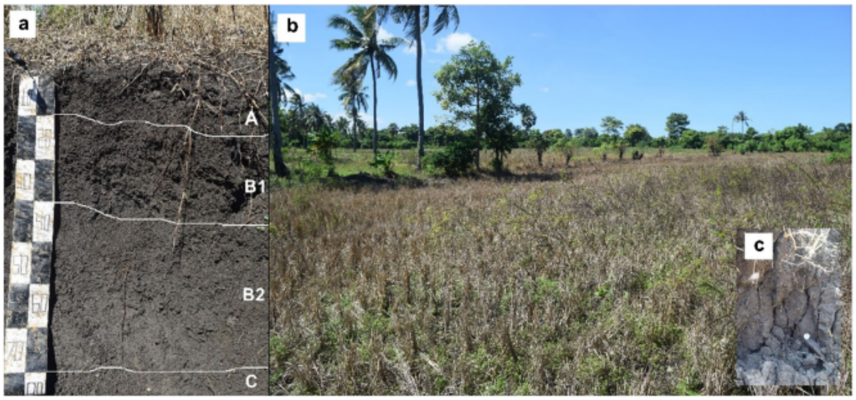

**Fig. 9** Soil profile (3J) in Bangkala District showed a soil profile with A, B1, B2, and C horizons (**a**), the land use for rainfed (**b**), and fracture in soil when it dried (**c**)

et al. 2017). Soil fertility must be maintained by increasing the C-organic level so that nutrients are not quickly lost because of high levels of eluviation (Aprile and Lorandi 2012). In Bangkala District, increasing the water content in dry areas can increase the soil bulk density. This can be performed by collecting and storing water in pools (Kiros et al. 2016), during the rainy season (Li 2003). The use of perennial rivers for irrigation increases the soil water content and lengthens the planting period, thus increasing the crop production in this district.

## Conclusions

Soil genesis from carbonate rocks in rainfed agriculture lowlands is affected by climatic factors, which must be understood to successfully develop arid land use for increased crop production. Based on the result of this study, the soil formation in the study site with the C-2 climate was sufficiently quick because of the intense hydropedological activity and twice-yearly inundation process. This was evidenced by the formation of the pan-oxide plow, kaolinite, and a low C-organic level. Soil fertility can be maintained at this study site by increasing the C-organic level so that nutrients are not quickly lost because of high levels of eluviation. Alternatively, the study site with D-3 climate showed high levels of soil fertility but also tended to undergo soil cracking under dry conditions. This study site requires management in terms of increased water content through rainfall harvesting during the rainy season and the use of perennial rivers for irrigation to improve crop productivity.

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## Declarations

**Conflict of interest** The authors declare no competing interests.

## References

Abd El-hamid HT, Caiyong W, Hafiz MA, Mustafa EK (2020) Effects of land use/land cover and climatic change on the ecosystem. Arab J Geosci 13(1099):1–13. https://doi.org/10.1007/s12517-020-06047-6

Ahmad A, Lopulisa C, Imran AM, Baja S (2018) Soil physicochemical properties to evaluate soil degradation under different land use types in a high rainfall tropical region: A case study from South Sulawesi, Indonesia. Earth and Environmental Science. IOP Publishing, pp. 1–7. https://doi.org/10.1088/1755-1315/157/1/012005

Ahmad A, Alamudi ZF, Lopulisa C (2019) Karakteristik tanah sawah dari batuan lava-vulkanik di lereng Gunung Lompobattang, Sulawesi Selatan. Median 11(3):24–33 http://doi.org/md.v11i3.191

Aprile F, Lorandi R (2012) Evaluation of cation exchange capacity (CEC) in tropical soils using four different analytical methods. J Agric Sci 4(6):278–289. https://doi.org/10.5539/jas.v4n6p278

BMKG (2016) Standardized precipitation index. Buletin Agroklimat (Agroclimate Buletin). Jakarta, Indonesia 5(5):5–10

BPT (2005) Analisis kimia tanah, tanaman, air dan pupuk, Badan penelitian dan Pengembangan. Available at: http://balittanah.litbang.pertanian.go.id

Buehler (2015) Preparation of petrographic thin sections. Solution For Material Preparation, Testing and Analysis. Sumnotes, Buehler 1(3):1–2

Central Bureau of South Sulawesi (2015) Luas padi ladang Sulsel 2015. Makassar, Sulawesi Selatan, Indonesia: BPS. Available at: https://sulsel.bps.go.id/

Chuan-chuan N, Peng-dong G, Bing-qing W, Wei-peng L, Ni-hao J, Kun-zheng C (2017) Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. J Integr Agric. CAAS. Publishing services by Elsevier B. V 16(8):1819–1831. https://doi.org/10.1016/S2095-3119(16)61476-4

Crescimanno G, De Santis A, Provenzano G (2007) Soil structure and bypass flow processes in a Vertisol under sprinkler and drip irrigation. Geoderma 138:110–118. https://doi.org/10.1016/j.geoderma.2006.10.020

de Vicente I (2021) Biogeochemistry of Mediterranean wetlands: a review about the effects of water-level fluctuations on phosphorus cycling. Water 13(1510):1–20. https://doi.org/10.3390/w13111510

Desaunettes J (1977) Catalogue of landforms for Indonesia. FAO-Soil Research Institute, Bogor

Diatta AA, Fike JH, Battaglia ML, Galbraith JM, Baig MB (2020) Effects of biochar on soil fertility and crop productivity in arid regions : a review. Arab J Geosci 13(595):2–17. https://doi.org/10.1007/s12517-020-05586-2

Dobermann A, Fairhust T (2000) Rice: nutrient disorders & nutrient management. First ed. Edited by Tham Sin Chee. Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute (IRRI)

Erbas BC, Solakoglu EG (2017) In the Presence of climate change, the use of fertilizers and the effect of income on agricultural emissions. Sustainability 9(1989):1–17. https://doi.org/10.3390/su9111989

Ferreira EP, Helena L, Pereira MG (2016) Genesis and classification of soils containing carbonate on the apodi. Rev Bras Cienc Solo 40:1–20. https://doi.org/10.1590/18069657rbcs20150036

Hall R (2012) Late Jurassic-Cenozoic reconstructions of the Indonesian region and the Indian Ocean. Tectonophys Robert Hall 570–571:1–41. https://doi.org/10.1016/j.tecto.2012.04.021

Hardjowigeno S, Subagyo H, Rayes ML (2005) Morfologi dan Klasifikasi Tanah Sawah. pp 1–28. http://balittanah.litbang.pertanian.go.id

Hazen RM, Sverjensky DA, Azzolini D, Bish DL, Elmore SC, Hinnov L, Milliken RE (2013) Clay mineral evolution. Am Mineral 98(11–12):2007–2029. https://doi.org/10.2138/am.2013.4425

IAEA (1997) Sampling, storage and sample preparation procedures for X ray fluorescence analysis of environmental materials. International Atomic Energy Agency, Vienna, p 55

Kerr P (1959) Optical mineralogy. 3rd edn. McGraw-Hill Book Company, Inc. https://doi.org/10.1180/minmag.1986.050.355.30

Kipkemoi I, Michaelides K, Rosolem R, Singer MB (2021) Climatic expression of rainfall on soil moisture dynamics in drylands. Hydrol. Earth Syst. Sci. (February), pp. 1–24. https://doi.org/10.5194/hess-2021-48

Kiros G, Shetty A, Nandagiri L (2016) Analysis of variability and trends in rainfall over northern Ethiopia. Arab J Geosci 9(451):1–12. https://doi.org/10.1007/s12517-016-2471-1

Kowalska JB, Skiba M, Maj-Szliga K, Mazurek R, Zaleski T (2021) Does calcium carbonate influence clay mineral transformation in soils developed from slope deposits in Southern Poland ? J Soils Sediments 21:257–280. https://doi.org/10.1007/s11368-020-02764-

Kumar R, Das AJ (2014) Climate change and its impact on land degradation: imperative need to focus climatology & weather Fforecasting. J Climatol Weather Forecast 2(1):1–3. https://doi.org/10.4172/2332-2594.1000108

Li X (2003) Rain water harvesting for agriculture production in the semi-arid loess region of China. Food, Agric Environ 1(3&4):282–285

Maisch M, Lueder U, Kappler A, Schmidt C (2020) From plant to paddy-how rice root iron plaque can affect the paddy field iron cycling. Soil Syst 4(28):1–19. https://doi.org/10.3390/soilsystems4020028

Maulana A, Ellis DJ, Christy AG (2010) Petrology, geochemistry and tectonic evolution of the South Sulawesi basement rocks, Indonesia. Proceeding, Indonesian Petroleum Association, 34(IPA10-G-192). https://doi.org/10.29118/IPA.707.10.G.192

Mehmood A, Akhtar MS, Deng Y, Dixon JB, Imran M, Rukh S (2014) Iron oxides minerals in soils derived from different parent materials iron oxides minerals in soils derived from different parent materials. Int J Plant Soil Sci 5(2):110–116. https://doi.org/10.9734/IJPSS/2015/14384

Mello CR, Curi N (2012) Hydropedology. Ciênc. agrotec. Lavras 36(2): 137–146

Moreno MM, Moreno C, Lacasta C (2012) Evolution of soil biochemical parameters in rainfed crops : effect of organic and mineral fertilization. Applied and Environmental Soil Science, 2012(ID 826236), pp. 1–10. 2012:1–9. https://doi.org/10.1155/2012/826236

Munandar TA, Sumiati (2017) The classification of cropping patterns based on regional climate classification using decision tree approach. J Comput Sci 13(9):408–415. https://doi.org/10.3844/jcssp.2017.408.415

Ngewoh ZS, Taylor RW, Shuford JW (1989) Exchangeable cations and CEC determinations of some highly weathered soils. commum. In Soil Sci Plant Anal 20(17718):1833–1855. https://doi.org/10.1080/00103628909368187

Olsson L, Barbosa H, Bhadwal S, Cowie A, Delusca K, Flores-Renteria D, Hermans K, Jobbagy E, Kurz W, Li D, Sonwa DJ, Stringer L (2019) Land degradation. IPCC Special Report on Climate Change, pp. 345–436

Pal DK, Bhattacharyya T, Wani SP (2012) Formation management of cracking clay soils (Vertisols) to enhance crop productivity Indian Experience. World Soil Resources and Food Security, pp. 317–343

Pareek N (2017) Climate change impact on soils: adaptation and mitigation. MOJ Ecol Environ Sci 2(3):136–139. https://doi.org/10.15406/mojes.2017.02.00026

Pezeshki SR, Delaune RD (2012) Soil oxidation-reduction in wetlands and its impact on plant functioning. Biology 1:196–221. https://doi.org/10.3390/biology1020196

Rabenhorst M, Parikh SJ (2000) Propensity of soils to develop redoximorphic color changes. *Soil Sci Soc Am J* 64(September-October):1904–1910. https://doi.org/10.2136/sssaj2000.6451904x

RePPProT (1988) Regional physical planning programme fo transmigration. Tinjauan Hasil-Hasil Tahap I Sulawesi. Jakarta, Indonesia: Direktorat Bina Program dan Direktorat Jenderal Penyiapan Pemukiman Departemen Transmigrasi

Rusono N, Maghfirra D, Indarto J (2010) In: Darajati W (ed) Rencana Kebjakan Strategis Perluasan Areal Pertanian Baru dalam Rangka Mendukung Prioritas Nasioanal Ketahanan Pangan. Direktorat Pangan dan Pertanian BAPPENAS, Jakarta, Indonesia

Schoeneberger PJ, Wysocki DA (2005) Hydrology of soils and deep regolith: A nexus between soil geography, ecosystems and land management. Geoderma 126:117–128. https://doi.org/10.1016/j.geoderma.2004.11.010

Soil Survey Staff (2014) Keys to Soil Taxonomy, Twelfth edn. United States Deapertment of Agriculture, Natural Resources Conservation Service, p 663

Sukamto R (1982) Geologic map of the Pangkajene and western part of Watampone Quadrangles, Sulawesi. Geological Research and Development Centre, Bandung

Sukamto R, Supriatna S (1982) Geologic map of the Ujungpandang, Bnteng and Sinjai Quadrangles, Sulawesi. Geological Research and Development Centre, Bandung

Tanure TMP, Miyajima DN, Magalhaes AS, Domingues EP, Carvalho TS (2020) The impacts of climate change on agricultural production, land use and economy of the legal Amazon Region between 2030 and 2049. EconomiA Nat Assoc Postgrad Centers Econ ANPEC 21(1):73–90. https://doi.org/10.1016/j.econ.2020.04.001

van Reeuwijk L (2002) Technical Paper 9. Exchange organizational behavior teaching journal. sixth edit. Wageningen, Netherlands: International Soil Reference and Information Centre. Available at: www.isric.org

Van Tol JJ, Roux PL, Lorentz S (2017) Hydropedology; the science of hydropedology – linking soil morphology with. The Water Wheel, (May) pp. 20–22

Vepraskas MJ, Lindbo DL (2012) Redoximorphic features as related to soil hydrology and hydric soils. Hydropedology. Elsevier B.V., pp. 143–172. https://doi.org/10.1016/B978-0-12-386941-8.00005-8

Weil RR, Brady NC (2016) The nature and properties of soils, Fifhteenth edn. Pearson Education inc, New York, p 1071

Yu F, Faybishenko B, Hunt A, Ghanbarian B (2017) A simple model of the variability of soil depths. Water 9(460):1–13. https://doi.org/10.3390/w9070460

Zhang ZY, Huang L, Liu F, Wang MK, Fu QL, Zhu J (2016) Applied clay science characteristics of clay minerals in soil particles of two Alfisols in China. Appl Clay Sci. Elsevier B.V. 120:51–60. https://doi.org/10.1016/j.clay.2015.11.018

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