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MORALITY BEFORE KNOWLEDGE

Agricultural land development strategies based on regional potential for sorghum cultivation

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ABSTRACT

Background: Sorghum has been known in Indonesia for a long time, but its development is not as good as rice and corn. This is because there are still few areas that utilize sorghum plants as food. Land evaluation is a process of assessing the potential of a land used as the basis for sector development in an area that is useful for reorganizing existing land use to assist in making land use planning decisions. This study aims to identify the characteristics of soil physical and chemical properties in Sitimulyo Village and develop agricultural land development directions for sorghum. **Method**: The research used a stepwise diagram interpretation method, integrating soil laboratory analysis, field observations based on Land Map Units, and interviews using the key-person informant approach. Spatial analysis with ArcMap was also applied to evaluate land characteristics, including land use, slope classes, and cultivation suitability. **Finding**: The findings indicate that land suitability in Sitimulyo Village generally falls within moderately suitable (S2) to suitable (S1) categories, with limiting factors including rainfall, slope, and cation exchange capacity. Furthermore, this analysis confirms that existing seasonal agricultural areas—particularly rice fields, swampland, and mixed gardens—are in line with the 2021-2026 Piyungan Subdistrict Strategic Plan, which indicates high potential for sorghum development. **Conclusion**: Policy implications include the need for targeted management of limiting factors and the development of extension programs to promote sorghum as an alternative crop, thereby supporting food diversification and improving the socio-economic resilience of local farmers. **Novelty/Originality of this article:** The originality of this study lies in integrating soil laboratory analysis with spatial evaluation to provide site-specific recommendations for sorghum cultivation.

KEYWORDS: land suitability; sorghum cultivation; spatial planning; soil characteristics; agricultural development.

1. Introduction

Indonesia's reliance on rice, its staple food, poses a risk to national food security, particularly under climate variability and global shocks. El Niño events, for instance, delay monsoon onset and negatively affect rice yields in Java and Bali, potentially creating seasonal food shortages and price instability (Naylor et al., 2007). At the same time, the global upheaval caused by the Russia–Ukraine conflict has renewed attention on food diversification, prompting the Indonesian government to forward sorghum as an alternative carbohydrate source (Widodo et al., 2023). Moreover, agencies like Bapanas (the National Food Agency) and regulatory directives from national leadership have prioritized the development of sorghum agribusinesses, from upstream cultivation to downstream

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processing, as part of a broader food resilience strategy (Antara New Yogyakarta, 2023; Office of Assistant to Deputy Cabinet Secretary for State Documents & Translation, 2022a).

Yogyakarta Regency, Indonesia is one of the areas currently experiencing land use change problems because most of the land that was originally used for agriculture has been converted into industrial land. This has an impact on the decline in land quality so that the community makes efforts so that the land does not experience damage, one of which is by replanting it with food crops such as rice, corn and cassava. Based on these conditions, it is necessary to make a handling effort to increase productivity, both the quality and quantity of farming results and land regeneration. so that an evaluation of land suitability is needed, especially for the cultivation of food crops, one of which is sorghum (Juniati et al., 2025).

Sorghum plants in Indonesia have long been known, but their development is not as good as rice and corn. This is because there are still few areas that utilize sorghum plants as food. In addition, the absence of a market for sorghum, one of which is sorghum flour, has resulted in farmers still being reluctant to plant sorghum. Widodo et al. (2023) highlight that despite its nutritional and economic potential in Central Java and Yogyakarta, sorghum is underdeveloped largely due to market underdevelopment and lack of farmer adoption. Every year the government always allocates budgets and activities for its development, but the progress is not significant. The Agriculture and Forestry Service of Yogyakarta Regency also has a commitment to develop a substitute crop for sugarcane as a raw material for sugar through sorghum (Office of Assistant to Deputy Cabinet Secretary for State Documents & Translation, 2022b).

Sorghum stands at the intersection of global challenges in food security, climate resilience, and sustainable agriculture. Despite its status as the fifth most cultivated cereal crop worldwide and its remarkable tolerance to drought and heat, sorghum has long suffered from limited investment and an image as a “poor man’s crop”. However, research trends over the past two decades highlight its growing recognition as a vital crop for addressing future food and environmental needs. Advances in genomics, biotechnology, and food science have uncovered sorghum’s unique potential, not only as a resilient staple in semi-arid regions, but also as a source of health-promoting compounds, renewable energy, and soil remediation solutions (Hossain et al., 2022).

Yet, challenges remain. Sorghum continues to face competition from crops like maize and rice, particularly in industrial and feed markets, while difficulties in processing its endosperm limit broader adoption in high-value food industries. Overcoming these barriers requires sustained, market-driven research that enhances sorghum’s food functionality, nutritional profile, and consumer acceptance. Looking ahead, positioning sorghum as a mainstream food crop, support by its climate resilience, bioactive diversity, and adaptability, could significantly strengthen global food systems. By aligning research and policy efforts with long-term consumer and environmental needs, sorghum can transition from a marginalized grain to a cornerstone of sustainable food security in the face of climate change (George et al., 2022).

Sorghum processing, both for flour and rice substitutes, has many benefits. In terms of quality, sorghum flour is considered better because it does not contain gluten. This is very good for consumption, especially for people with autism (Aguiar et al., 2023; Hosseini et al., 2018). In addition, the mixture of sorghum flour in processed food will not change the original taste of the food. Meanwhile, if consumed as a substitute for rice, sorghum has a higher protein content than rice (Winarti et al., 2023). Apart from seeds, the leaves and stems of the sorghum plant can also be utilized. Sorghum leaves can be used for animal feed and sorghum stems can be used as raw material for wood substitute furniture (Morales et al., 2024; Zarei et al., 2022).

Land use in an area cannot be separated from the intervention of humans both in terms of their activities and population growth in the region, because the increasing number of people in a place will have an impact on increasing changes in land use. This is the basis for the need for land use in accordance with the designation of the area. For instance, (Seto et al., 2011) meta-analysis of 326 studies revealed that urban land expansion rates consistently match or exceed urban population growth, particularly in India, China, and

Africa, highlighting population as a leading driver of land-use change. Bantul Regency is one of the regencies in the Special Region of Yogyakarta Province, which is currently experiencing land use change problems. Data on the extent of land use change in Bantul Regency fluctuated from 2019 to 2022.

One of the causes of these problems is land use that is not aligned with appropriate land-use planning, causing land suitability to significantly influence the environmental quality of an area, including in Yogyakarta Regency. Land evaluation is carried out to determine the level of land suitability for various purposes based on the natural potential of the land. In agricultural contexts, land evaluation is essential to assess the suitability of land for specific crops. Soil characteristics are one of the most important indicators for determining the suitability of land for agricultural development. For example, the study by (Sadiq et al., 2025) demonstrates how soil texture, effective depth, drainage, fertility status, salinity, and erosion hazard are systematically analyzed to classify land and determine its suitability for tomato cultivation. This illustrates how detailed soil characterization supports accurate crop-specific land suitability assessment.

Thus, it is important to know how soil characteristics are in village in Yogyakarta Regency. In this research, the approach used is spatial analysis to examine soil characteristics that are related to land use. Furthermore, by knowing soil characteristics based on the direction of land use functions in Yogyakarta Regency, the suitability of the land as a land use for the cultivation of annual crops for the development of sorghum in several land uses such as rice fields, moorlands, shrubs, and mixed gardens can also be known. This research provides information about the potential of a land based on land use direction and land suitability evaluation. so that it can be used as a consideration or reference for cultivating sorghum plants. In addition, it can make consideration for evaluating the spatial plan that has been made so that it can later be refined to be more in accordance with the conditions that have developed.

Regional planning and development is basically an effort to apply the concepts of economic development to the spatial dimension, so that regional planning and development is an accumulation that cannot be ignored. It is disconnected from the concept of economic development that looks at the opportunity and supply side. Spatial planning functions not merely as economic planning translated into maps, but as a more strategic, policy-integrative framework, a "spatial logic," or planning doctrine, that guides land use regulation, investments, infrastructure deployment, and resource protection (Balz, 2018). One of the efforts to develop the region is agricultural development, where Indonesia has a large proportion of its population working in the agricultural sector. Planning and development of agricultural areas is very important because the role of the agricultural sector in the economy has a significant influence due to the fact that most people in developing countries depend on the agricultural sector. The principles of planning and development of agricultural areas are basically carried out by considering various aspects such as physical suitability (land suitability), not conflicting socioculturally, not damaging the environment, economically feasible, and sustainable (Food and Agriculture Organization of the United Nations, 2001; Trentinaglia et al., 2023).

The principles of planning and developing agricultural areas physically consider aspects of land suitability, pest and disease risk, and availability of accessibility or infrastructure. Successful planning and development of agricultural areas must go beyond soil characteristics by also accounting for pest and disease risks and the availability of infrastructure and accessibility. A recent multi-criteria GIS-based land suitability study in; ranking factors for sustainable agriculture found that in addition to slope and soil properties, proximity to roads and rivers (as components of accessibility) significantly influenced suitability outcomes (Choudhary et al., 2023). According to the East Java Food Crops and Horticulture Area Development Master Plan 2015-2019 in the Methods of Planning and Development of Agricultural Areas, the superior commodities developed can at least be divided into two groups, namely economic base superior commodities and non-economic base superior commodities. Economic-based superior commodities are superior commodities developed within the framework of economic development and oriented to local, regional, national, and international markets (Zukhrifa et al., 2025).

According to Law of the Republic of Indonesia Number 26 of 2007 concerning Spatial Planning, it is explained that spatial planning is a system of spatial planning processes, space utilization, and control of space utilization, where activities include regulatory activities, guidance, implementation and supervision of spatial planning. Spatial Planning is a process to determine the spatial structure and spatial pattern which includes the preparation and determination of spatial plans, starting from the preparation, implementation of programs, and financing.

To realize sustainable development, spatial planning efforts are needed. Spatial planning involves all aspects of life so that the community needs to have access to t h e planning process. Spatial planning is a system of spatial planning processes, space utilization, and control of space utilization. Based on the Regulation of the Minister of Agrarian Affairs and Spatial Planning. Number 1 of 2018, spatial planning is a system of spatial planning processes, space utilization, and control of space utilization. Spatial planning is classified according to functions to accommodate all community interests while still considering environmental sustainability for ecological sustainability for future generations.

In Indonesia, prior sorghum studies have typically focused either on GIS-based habitat/suitability modelling at broad scales (such as climate-driven MaxEnt) or on socio-economic strategy design without spatially explicit soil evaluation. Only a few works link land suitability to development strategies, and those are context-specific or not grounded in detailed soil laboratory characterization at the village scale. Consequently, there remains a methodological gap in integrating soil physical–chemical properties with GIS-based land evaluation to produce sorghum-specific, regionally actionable development strategies (Ramdhani et al., 2023; Utomo et al., 2025; Widodo et al., 2023).

The originality of this study lies in integrating soil laboratory analysis, field observations, and GIS-based spatial analysis with a spatial planning perspective to formulate sorghum development strategies at the village level. While previous studies in Indonesia have focused on either broad-scale climatic suitability modeling or socio-economic evaluations of sorghum, few have combined detailed soil characterization with spatial analysis to assess land suitability in relation to existing spatial plans. By situating the analysis within the context of Sitimulyo Village, Piyungan Sub-district, Bantul Regency, this research provides a site-specific, scientifically grounded, and policy-relevant framework for sorghum cultivation. This approach not only strengthens the technical basis of land evaluation but also bridges the gap between biophysical assessments and regional development strategies, offering practical recommendations for local governments and farmers in supporting food diversification and sustainable land use.

2. Methods

2.1 Location and time of research

The research was conducted from October 2023 to December 2023. The research included field surveys, qualitative field observations, soil sampling, and quantitative laboratory analysis. Field observations were conducted in the Sitimulyo Village area, Piyungan District, Bantul Regency, Yogyakarta, while laboratory analysis was carried out at the General Soil Laboratory and Soil Physics Laboratory, Department of Soil, Faculty of Agriculture, Gadjah Mada University, Yogyakarta.

2.2 Selection of research location

Sitimulyo Village is located in Piyungan District, Bantul Regency, which is included in Development Sub-Region VI, designated as an agricultural area. In general, Sitimulyo Village is developed as an agricultural and industrial area. As explained in the Bantul Regency

Spatial Plan/*Rencana Tata Ruang Wilayah* (RTRW), Sitimulyo Village itself is designated for industrial development, tourism, and agricultural cultivation. Sitimulyo Village has an orientation towards agricultural development, which is the most prominent sector among mining, building and construction, and others. Furthermore, according to the Bantul Regency Spatial Plan, the agricultural utilization area includes wet agricultural areas and dry agricultural areas, some of which are designated as Sustainable Food Agricultural Land and are regulated separately by local regulations.

One form of substitution and diversification in strengthening food security in agricultural areas, especially sustainable food agriculture areas, is the development of sorghum (*Sorghum bicolor L. Moench*). The development of sorghum in Sitimulyo Village is currently only carried out by the Banyakan Installation of Testing and Implementation of Agricultural Instrument Standards/*Instalasi Pengujian Dan Penerapan Standar Instrumen Pertanian* (IP2SIP), Center for the Application of Agricultural Modernization in Yogyakarta/*Balai Penerapan Modernisasi Pertanian* (BPSIP Yogyakarta). Therefore, the development of sorghum crops in Sitimulyo Village needs to be assessed in terms of several land uses, such as rice fields, dry fields, and mixed gardens, based on the guidelines for the utilization of seasonal crop cultivation land at the research site.

2.3 Data collection methods

The data collection method used in this study was the stepwise method based on land use guidelines. The stepwise estimation method was carried out by entering independent variables that had the greatest contribution to the dependent variable. This was done continuously until all independent variables had a significant contribution (Kokaly & Clark, 1999). The land use guidelines were obtained from spatial analysis of slope, soil type, and rainfall parameters. The results of the overlay of the three maps produced land units, which were then used to determine the sampling points based on the land map units.

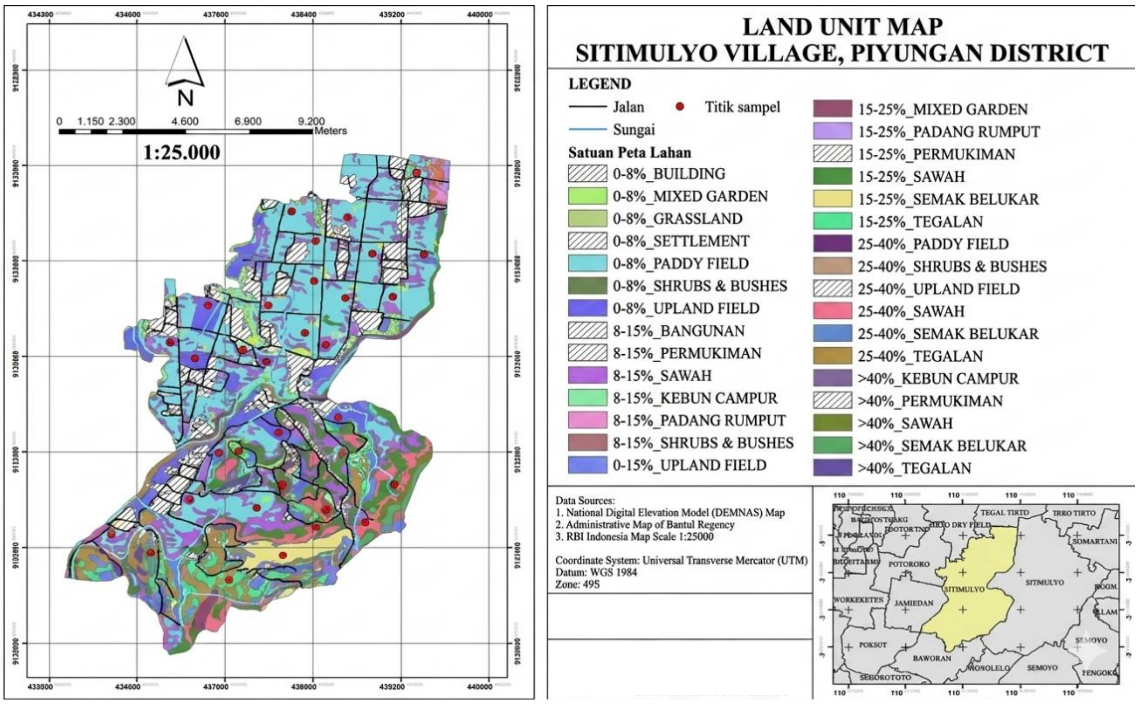


Fig. 1. Land unit map of Sitimulyo Village

Representativeness for variations in land form units. Observations were then made based on several considerations, namely land use, slope, and land use guidelines. The slope factor consists of five classes, namely: flat (0-8%), gentle (8-15%), moderately steep (15-25%), steep (25-40%), and very steep (>40%). Land use guidelines consist of four types, namely protected areas, buffer zones, annual crop cultivation areas, and seasonal crop cultivation and settlement areas. Meanwhile, land use consists of mixed gardens, grasslands, rice fields, dry fields, and shrubs.

3. Results and Discussion

3.1 Description of the area

Sitimulyo Village is located in the northeastern part of Bantul Regency, 5 km from the subdistrict capital and 18 km from the regency capital. Administratively, Sitimulyo Village is part of Piyungan Subdistrict, Bantul Regency, Special Region of Yogyakarta. Geographically, Sitimulyo Village is bordered by Tegaltirto Village to the north, Srimulyo Village to the east, Bawuran and Wonolelo Villages to the south, and Potorono Village to the west. Sitimulyo Village has a flat area of 130 ha, a hilly area of 572 ha, and a total area of 940,962 ha. According to the 2006-2025 Bantul Regency Long-Term Development Plan/ *Rencana Pembangunan Jangka Panjang Daeah* (RPJPD), Sitimulyo Village generally has a development direction that is an agricultural and industrial area covering: protected forest areas around settlements, with the development of community forests and agroforestry; tourism areas including nature, culture, and industry; small industry development areas (home industry); and large industry development areas.

The geological conditions of Sitimulyo Village developed from the Semilir Formation (*Tmse*) and the Young Merapi Volcano Deposits (*Qmi*). The Semilir Formation is well exposed on Mount Semilir around Baturagung, consisting of alternating layers of tuff, lapilli tuff, tuffaceous sandstone, claystone, shale, and siltstone with breccia intercalations, as gravity flow deposits in a deep marine environment. This formation dates back to the Early Oligocene (N1-N2). Furthermore, the Young Merapi Volcanic Deposits are volcanic rocks in the form of young volcanic deposits from Mount Merapi, formed during the Quaternary period.

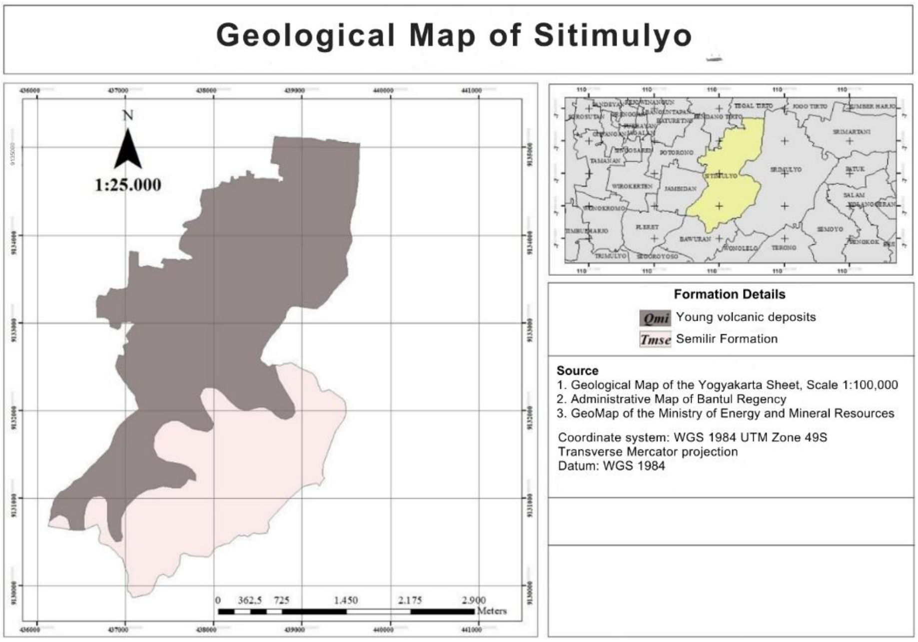
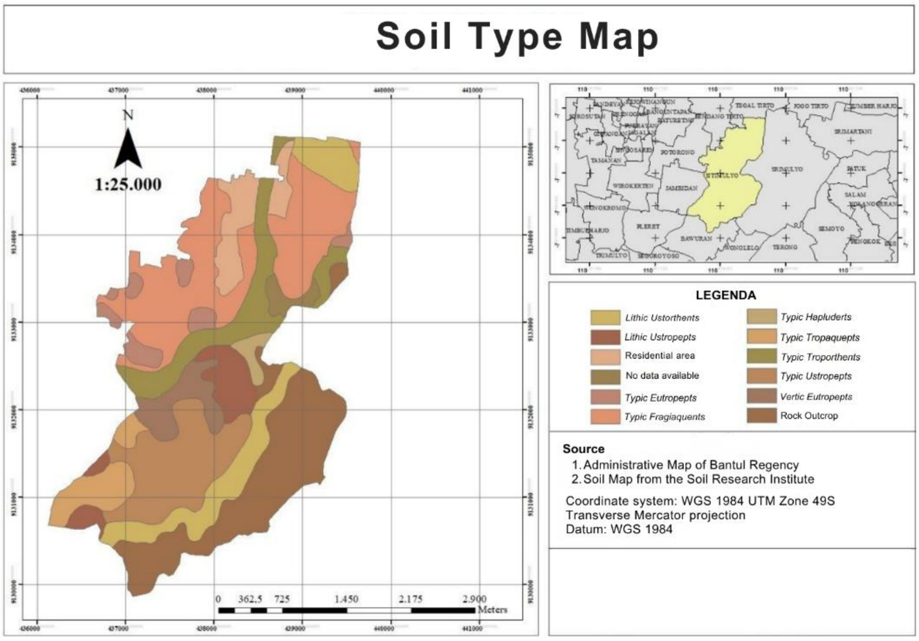
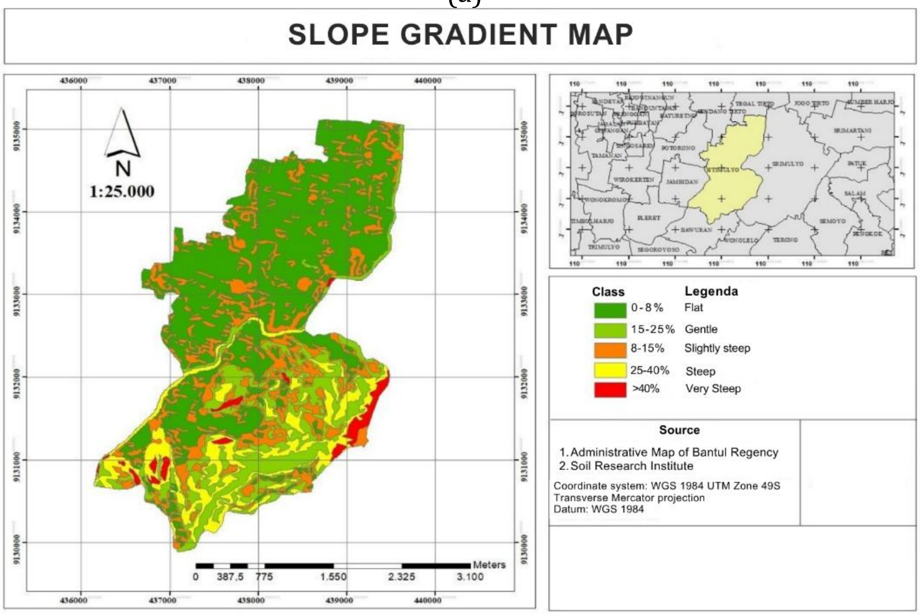


Fig. 2. Geological map of Sitimulyo Village

Based on spatial analysis, the soil types in Sitimulyo Village include Entisols and Inceptisols. The soil in Sitimulyo Village developed from the Semilir Formation with a lithology of pumice breccia, tuffaceous sand, and tuff. This soil has a thin layer, contains many rocks, is not very fertile, and has the potential for white stone mining, especially in the areas of Banyakan Hamlet, Ngablak Hamlet, and Pagergunung Hamlet (Azis et al., 2021). In general, the inceptisol soil in Sitimulyo Village has characteristics of soil that is still new and in the development stage, so there are no signs of development in the soil horizon. Inceptisol soil has a thin solum, is dark brown in color, has a dusty texture, dusty clay, clay, angular soil structure, and a pH content of 5.0–6.0. Inceptisol soil is commonly found in areas with steep to very steep slopes. Entisol soil in Sitimulyo Village has various textures, ranging from sandy to clayey and dusty, and has a brighter and younger color. The color can range from white, gray, to light brown.



(a)



(b)

Fig. 3. (a) Soil type and (b) Slone map of Sitimulyo Village

Land use in Sitimulyo Village is generally for agricultural and non-agricultural purposes. According to Bantul Regency Regulation No. 04 of 2011 concerning the 2010-2030 Bantul Regency Spatial Plan, areas designated for agriculture include wet agricultural areas, dry agricultural areas, and livestock areas. Wetland areas in Sitimulyo Village include rain-fed rice fields and irrigated rice fields, while dryland agricultural areas include moorland, mixed gardens, shrubbery, and grasslands. Non-agricultural land use includes residential areas, public buildings, factories, roads, and so on.

3.2 Physical aspects affecting agricultural land development

Rainfall is one of the climate characteristics used as a requirement for plant growth, because rainfall is one of the factors that determines the availability of water in the soil for plant growth. The monthly rainfall data for 2014-2023 at the Piyungan SDA Rainfall Station, Bantul Regency, above shows that the highest rainfall was 588 mm in January 2018. The lowest rainfall occurred from July to October at 0 mm. The data (-) indicates no rainfall in that month. Meanwhile, the data 0 indicates that there was rainfall in that month, but the intensity was below 0.5 mm. The highest average annual rainfall in the Sitimulyo Village area was 227.9 mm/year in 2018, and the lowest average annual rainfall was 78.2 mm/year in 2023. The average rainfall in Piyungan District in 2014-2023 was 1634.52 mm/year. Based on the Schmidt-Ferguson climate classification, Sitimulyo Village is classified as climate type D, which is a temperate climate (Q = 0.6-1.00), as indicated by a Q value of 0.77.

Table 1. Rainfall data 2014-2023

Month	Year									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Jan	258	360	105	249	588	370	180	209	193	216.4
Feb	258	174	244	208	311	145	146	256	196	489.5
Mar	134	397	118	137	460	465	302	150	337	108.3
Apr	109	212	155	149	74	96	200	249	122	38.5
May	58	36	157	74	31	-	172	8	148	32
June	32	4	185	29	-	-	3	115	98	0
Jul	42	0	85	2	-	-	-	4	3	13
Aug	0	0	52	0	-	0	2	16	20	0
Sep	0	0	211	62	7	-	0	71	22	0
Oct	0	0	163	65	-	-	79	99	295	0
Nov	297	136	306	447	111	20	284	464	467	16
Dec	350	214	288	124	241	263	305	130	194	24.5
Total	1538	1533	2069	1546	1823	1359	1673	1771	2095	938.2
	128.2	127.8	172.4	128.8	227.9	194.1	152.1	147.6	174.6	78.2
Average										
	1634.52 mm/year									
BB	6	6	10	6	5	4	7	7	8	3
BL	0	0	1	3	1	1	1	2	1	0
BK	6	6	1	3	6	7	4	3	3	9
Q	0.77									

Note. BB: Wet Month; BL: Humid Month; BK: Dry Month

Based on the above analysis, the average rainfall in Sitimulyo Village is low, at 1634.52 mm/year. However, this condition is excessive for sorghum plants because in the land suitability assessment sorghum can grow optimally with rainfall of 500-1200 mm/year. Excessive rainfall makes plants must be able to adapt to environmental conditions. Sorghum plants require 375-425 mm of rainfall. Sorghum generally requires 450–650 mm of water across its growing season for optimal productivity. This range stems from FAO's crop water requirement data and reflects typical conditions for rainfed sorghum development (Critchley & Siegert, 1991). Beyond just quantity, sorghum demonstrates robust tolerance to drought due to morphological traits like deep roots and osmotic adjustment. While resilient, excessively wet conditions, particularly those causing waterlogging, can still stress the crop (Khalifa & Eltahir, 2023; Sharma et al., 2019).

Air temperature is an element that is highly susceptible to climate change. It also affects plant metabolism, thereby determining plant productivity. Based on the data above, during the 2014-2023 period, the highest annual average air temperature measured at the Geophysical Station, Bantul Regency, occurred in 2016 with an average air temperature of 26.7°C, while the lowest annual average air temperature occurred in 2014 with an average air temperature of 24.1°C. Fluctuations in monthly average temperatures are generally influenced by the apparent movement of the sun. The closer the sun is to a location, the higher the solar energy received by that location, so that if there are no other factors (such as cloud cover), the temperature in that area will also be relatively higher.

Table 2. Air temperature data 2014-2023

Month	Year									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Jan	25.8	26.2	27.5	26.0	25.9	26.4	26.9	26.5	26.5	26.4
Feb	26.1	26.2	26.6	26.1	26.0	26.6	26.8	26.1	26.3	25.9
Mar	26.8	26.3	26.8	26.4	26.4	26.2	26.6	26.3	26.3	26.5
Apr	26.7	26.4	27.3	26.5	27.0	27.2	27.0	26.8	26.6	26.8
May	27.1	26.2	27.2	26.4	26.2	26.7	26.9	27.0	26.9	26.5
June	×	25.2	26.4	26.3	25.6	25.0	26.2	26.4	25.8	26.2
Jul	25.3	24.6	26.5	25.0	24.2	24.2	25.5	25.6	25.5	24.9
Aug	25.3	24.8	26.2	25.2	24.4	24.5	25.8	25.9	25.7	24.8
Sep	25.5	25.6	26.8	25.8	25.8	25.4	26.7	26.6	26.5	25.5
Oct	27.5	26.8	26.7	26.9	27.1	26.8	26.6	26.7	25.5	27.3
Nov	26.7	27.8	26.3	25.8	27.0	27.5	27.2	26.1	25.8	28.1
Dec	26.0	26.9	26.5	26.3	26.5	27.5	26.9	26.5	26.2	27.3
Average	24.1	26.1	26.7	26.1	26.0	26.2	26.6	26.4	26.1	26.4

Air temperature strongly influences the development of the soil profile so that it determines the chemical and physical properties in the soil. High average temperatures tend to increase the speed of weathering and clay formation (Gu et al., 2014). Temperature is an environmental factor that has an influence on plant growth and development, because every plant needs an appropriate temperature because plants can only grow and develop properly at the optimum temperature. Another climatic factor that affects plant growth and development is air humidity. Air humidity affects the water content in the air and air in the soil. If the humidity is too high, it will reduce the evapotranspiration process and the absorption of plant roots to obtain nutrients, while if it is too low, evapotranspiration will run so fast that it is not balanced by the provision of water by the roots and causes the plant to wilt (Kuwagata et al., 2012; Rawson et al., 1977). Previous research has shown that sorghum is highly sensitive to high temperature stress, which negatively affects its physiological processes such as photosynthesis, transpiration, and overall growth, indicating the importance of maintaining optimum temperature for proper plant development (Rajendra Prasad et al., 2021)

Table 3. Air Humidity data 2014-2023

Month	Year									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Jan	89	85	86	88	87	88	86	86	86	89
Feb	87	86	89	88	87	87	87	88	87	91
Mar	84	87	89	87	86	88	88	88	88	89
Apr	87	88	88	88	86	85	87	83	92	90
May	85	84	88	83	83	82	86	83	87	86
June	×	83	88	84	83	83	84	86	88	87
Jul	85	82	87	84	82	82	75	82	85	85
Aug	78	79	84	81	82	80	81	82	85	84
Sep	78	77	85	82	83	77	78	80	84	81
Oct	76	75	87	84	80	78	83	83	90	81
Nov	85	81	89	90	84	79	84	91	91	85
Dec	88	88	87	86	87	83	86	88	90	70
Average	76.8	82.9	87.3	85.4	84.2	82.7	83.8	85.0	87.8	84.8

Based on the data above during the period 2014-2023, the highest annual average air humidity measured at Geophysical Station, Bantul Regency occurred in 2020 with an average air humidity of 87.8%, while the lowest annual average air humidity was in 2014 with an average air humidity of 76.8%. Relative or relative air humidity is the ratio of the amount of water vapor in the air (absolute humidity) compared to the maximum amount of water vapor that can be contained in the air. The average monthly air humidity is generally lower in June. This is possible because the month is at the end of the dry season where the air temperature is relatively high but the water vapor in the air is relatively low.

According to the Center for Research and Development of Agricultural Land Resources, land suitable for optimum growth for sorghum cultivation is land that has a relative air humidity of >42%. Land suitable for optimum growth of sorghum cultivation is land that has a relative air humidity of > 42%. Relative humidity significantly influences stomatal opening — when RH is low, stomata tend to close, reducing CO_2 uptake and thereby reducing dry matter production. Environmental conditions that allow moderate to high humidity help maintain stomatal aperture, leaf gas exchange, and support plant metabolism. For example, in a study in Togo, sorghum yield during emergence and milk stages correlated positively with relative humidity, and variations in RH affected leaf area and dry matter accumulation (Affoh et al., 2023). A further study under controlled RH regimes (30-90%) showed that sorghum dry matter yield increased with higher RH and that low RH or high temperature stressful conditions caused stomatal limitations (Dewi et al., 2023). Also, differences in stomatal closure rates among sorghum lines under varying environmental conditions correlate with intrinsic water use efficiency and CO_2 assimilation (Al-Salman et al., 2023). The review by Influence of Environmental Factors provides mechanistic insights into how RH interacts with other variables (light, CO_2, temperature) to govern stomata opening and closure (Driesen et al., 2020).

Based on the Final Report of the Water Balance Study of Bantul Natural Resources Agency in 2011, Bantul Regency has several formations, namely Sentolo Formation, Yogyakarta Formation, Semilir Formation, Nglanggran Formation, Wonosari Formation, Sambipitu Formation, and Gumuk Pasir Formation. According to the Geological Map of Yogyakarta Sheet, Sitimulyo Village has Semilir Formation and Young Merapi Volcano Deposits. The Semilir Formation is well exposed on Mount Semilir around Baturagung, consisting of a mixture of tuff, lapillary tuff, tuffaceous sandstone, claystone, shale and siltstone with breccia inserts, as gravity flow deposits in a deep marine environment. This formation is of Early Oligocene age (N1-N2). Furthermore, the Young Merapi Volcanic Deposits are volcanic rocks in the form of volcanic deposits of Mount Merapi which are relatively young. formed in the Quaternary period.

Fig. 4. Rock outcrops formed from Geological Formations

The lower part of the Semilir Formation, one of which is the Opak River Watershed in Sitimulyo Village, where there is basalt andesite as a pillow lava flow. The sandstone is generally graded to form layers, parallel laminations or wavy and erosional, and forms a loop with fine tuff. The Semilir Formation overlies the Kebobutak Formation, but is locally unaligned. The Younger Merapi Volcanic Deposits (Qmi) consist of tuff, ash, breccia, agglomerate and inseparable lava flows. These geological factors can affect soil and rock structure and texture, soil and rock types, river flow patterns, topography, geological structures (folds and faults), tectonics and volcanoes, surface rocks, and rock outcrops (Figure 4).

Table 4. Surface rocks and rock outcrops in various land uses

No	Slope (%)	Land Use	Surface Rocks (%)	Rate	Slope (%)
1	0-8	rice field	10-50	**2**	<5
2		mixed garden	10-50	**2**	<5
3		rice field	2-10	**2**	<5
4		rice fields	2-10	**2**	<5
5		rice paddy	10-50	**2**	<5
6		moor	10-50	**2**	<5
7		rice field	10-50	**2**	<5
8		rice paddy	2-10	1	<5
9		rice paddy	2-10	**1**	<5
10		moor	10-50	**2**	5-15
11		moor	2-10	1	<5
12		moor	10-50	2	<5
13		rice field	10-50	2	<5
14		rice fields	10-50	2	<5
15		rice paddy	2-10	1	<5
16		rice paddy	10-50	2	<5
17		moor	10-50	2	5-15
18		moor	10-50	2	<5
19	8-15	rice field	10-50	**2**	<5
20		moor	10-50	**2**	5-15
21		rice paddy	10-50	**2**	<5
22		rice paddy	2-10	**1**	<5
23		mixed garden	10-50	**2**	<5
24	15-25	moor	10-50	**2**	5-15
25		shrubs	10-50	**2**	5-15
26		rice field	10-50	**2**	5-15
27		mixed garden	10-50	**2**	5-15
28		mixed garden	10-50	**2**	<5
29		moor	10-50	**2**	<5
30		rice field	10-50	**2**	5-15
31	25-40	rice paddy	10-50	**2**	5-15
32	>40	shrubs	10-50	**2**	5-15

Based on field observations, the surface rocks found in Sitimulyo Village range from 2%-50% (Table 4). The surface rocks in the research location are generally included in the limiting class with mild to moderate grades. Surface rocks in some land uses are inhibiting because the percentage is quite high at >10%. The high percentage of surface rock outcrops will complicate land management and inhibit plant root growth. Rock outcrops indicate the amount of rock present in the soil solum. The amount of rock in the research location in several land uses is classified as little to moderate with a range of <5% and 5-15%. "Studies of land suitability for sorghum in dry-hot valleys (e.g., Luquan County, China) show that bare rock ratio is one of the key factors rendering land unsuitable for sorghum cultivation (Yang & Zhong, 2022). This aligns with findings in karst soils that when rock outcrops cover a large portion of surface, infiltration is altered, root volume is reduced, and plant growth is restricted (Zhao et al., 2020)

3.3 Soil morphological characteristics

Based on observations at the research site, it is suspected that inceptisol soil is located on upper slopes with steep to very steep slopes and is used for land use such as moorland and mixed gardens planted with mahogany, sweet potatoes, and so on. Most of the inceptisol soil in Sitimulyo Village developed on steep slopes, where soil erosion has continuously transported part of the topsoil. This soil is newly developed and has a texture that varies from coarse to fine depending on the degree of weathering of the parent material. According to Ririska et al. (2023), the fertility of inceptisol soil is low, with effective depths ranging from shallow to deep. In addition, the soil type in Sitimulyo Village, which is located on flat to gentle slopes, is thought to be entisol soil that developed from young Mount Merapi deposits (*Qmi*).

Fig. 5. Soil depth at the outcrop of rice fields and dry fields

Soil consistency on the two outcrops also has differences. The consistency at the outcrop with a rather steep to steep slope is rather sticky, while the consistency at the outcrop with a flat to gentle slope is soft. This can be influenced by the type of clay in the adhesion of the soil both in dry, moist, and wet conditions because when pressed, the pulling force is strong because it still contains clay. Soil consistency can also affect rooting in outcrops. Outcrops with moderately steep to steep slopes have a large number of meso sizes in each layer, while outcrops with gentle to flat slopes have a small number of micro sizes and are only found in the first layer. Inceptisol soils that develop based on field observations are still classified as young soils with better soil profile development when compared to entisols. Inceptisol soils have epipedons characterized by umbric and ochric horizons with subsurface horizons or cambic endopedons characterized by changes in soil color or structure. Other horizons commonly found are duripan, fragipan, calcic, gypsy and sulfidic. Inceptisol soils in Sitimulyo Village have diagnostic features in the form of cambic endopedon characterized by the presence of the Bw horizon.

Observations at the research site indicate that soil consistency differs markedly between outcrops on steep slopes and those on gentle to flat slopes, soils on steeper terrain tend to be sticky (especially when moist or wet), likely due to higher clay content and microstructure that retains moisture, while soils on gentler slopes are softer. These consistency differences can influence root penetration and growth. In several studies of Inceptisol soils in Indonesia (e.g., Mount Manglayang toposequence; North Kalimantan from acidic sedimentary parent material), soils have been observed to develop ochric or umbric epipedons and cambic endopedons across slope classes, with clay distribution, structure, and consistency varying with slope and parent material (Herdiansyah et al., 2022).

Enterisol soils tend not to experience deep solum development due to climatic factors, in this case low rainfall where the process of water infiltration and water leaching into the soil solum is less so that the formation of s o i l horizons is inhibited (Wahyuni & Rachma, 2014). This is also supported by the low level of rainfall in Sitimulyo Village with an average value of 1634.52 mm/year in the last ten years. According to Raditya & Retno (2018), entisol is a type of soil commonly found around active volcanoes and is classified as young with a dominant texture of sand so that the water storage capacity is also low because of the high level of soil porosity. The characteristic epipedon is only ochric while the lower horizon is absent.

Table 5. Land use change in Piyungan Sub-district

Year	Year		
	Paddy field land	Non-field land	Non-farm land
2013	1206	968	1080
2014	1209	968	1077
2015	1209	968	1077
2016	1209	968	1077
2017	1209	968	1077

According to the Monograph Data of the Bantul Regency Central Statistics Agency in 2018, Piyungan District experienced changes in land use from 2013 to 2017. These changes were insignificant. This was because there was only an increase in the change in the use of rice fields and non-agricultural land in 2014. Furthermore, the area of land use in Piyungan District did not change or tended to be stagnant. According to data from the Piyungan Subdistrict monograph in 2021, land use in Sitimulyo Village is divided into rice fields, non-rice fields, and non-agricultural land. The area of rice fields in Sitimulyo Village is 423 ha or 35.3%, followed by non-rice fields covering an area of 484.4 ha or 40.49% and non-agricultural land covering an area of 288.9 ha or 24.24%. The rice fields in Sitimulyo Village, which are semi-technical irrigation rice fields, can generally be planted with two crops of rice and one crop of secondary crops, especially corn, per year. Meanwhile, rain-fed rice fields can be planted with one crop of rice and two crops of secondary crops per year. Dry fields are generally planted with secondary crops such as corn, cassava, and peanuts. Gardens are planted with fruits such as rambutan, mango, and papaya.

Table 6. Land use area (Ha) by village in 2020

No	Land Use	Area (Ha)	Percentage (%)
1	Rice Fields	423	45%
2	Non-cropped land	284.4	30.25%
3	Non-Agricultural Land	288.9	30.7%

The land use plan for sorghum development is based on spatial planning in accordance with land use guidelines, land capacity, and land suitability, taking into account limiting factors. Sitimulyo Village still has the potential to develop sorghum crops based on the extent of land use, especially rice fields and non-rice fields. This is because sorghum crops will be developed in areas of seasonal crop cultivation such as rice fields, dry fields, and mixed gardens, which are reviewed based on land use and soil characteristics.

3.4 Social and economic aspects affecting agricultural land development

3.4.1 Age. livelihood. and local wisdom

According to the 2006-2025 Bantul Regency Long-Term Development Plan/*Rencana Pembangunan Jangka Panjang Daerah* (RPJPD), Sitimulyo Village is planned to be an agricultural and industrial area. The existence of this policy certainly has an impact both directly and indirectly on the economic empowerment of farmers in Sitimulyo Village, Piyungan Sub-district. Age, livelihoods, and local wisdom are social and economic aspects that can influence the development of agricultural land because agriculture has an important role, one of which is as a provider of food needs that are needed by the community to ensure food security. The higher the growth of the human population, the higher the need for food.

The majority of the population of Sitimulyo Village is of productive age, namely 15-40 years old. In Sitimulyo Village, there are several factories or companies as well as agricultural land that is still quite extensive and can accommodate residents of productive age, but in reality, many are not accommodated. This is due to varying levels of education, especially in the field of agriculture, which continues to be dominated by people over the age of 40 who work as farmers.

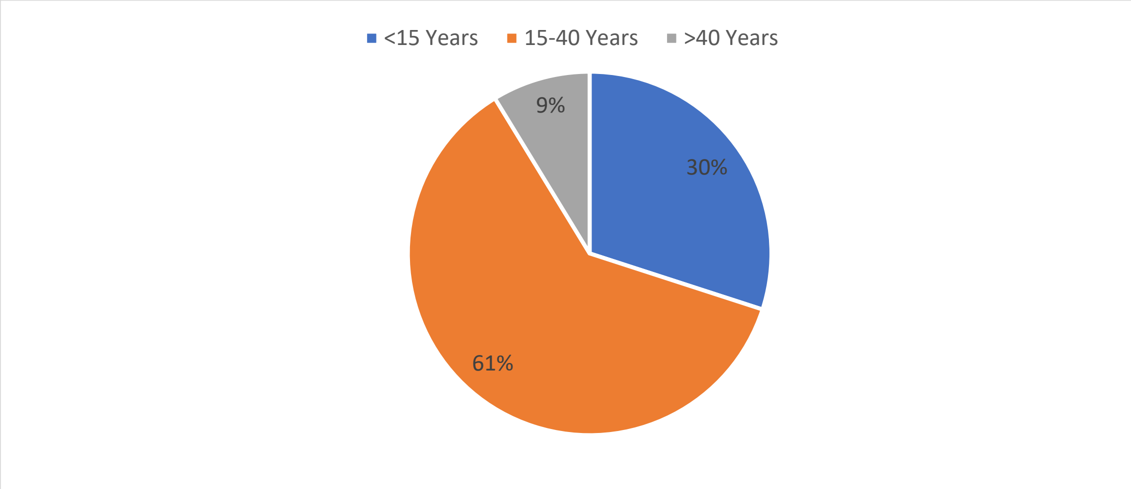


Fig. 6. Agechart of Stimulyo Village population

The productive age of farmers is an important asset for accelerating agricultural production and innovation adoption. Younger, productive farmers tend to be more open to new practices and more able to adopt technological innovations, especially when they possess higher levels of formal education, factors that improve understanding, risk-taking and the implementation of new methods. Empirical and review studies consistently identify age and education/extension contact as major determinants of technology uptake in smallholder agriculture (education increases capacity to learn and implement innovations), and younger educated farmers show higher readiness to adopt digital and climate-smart practices in Indonesian contexts. Hence, increasing the share of productive-aged and well-educated farmers in a region can help speed the diffusion of improved sorghum cultivation practices and related innovations (Rizzo et al., 2024).

Based on the data presented (Figure 6), the largest number of livelihoods is laborers or artisans with special skills, even though the livelihoods of the community in Sitimulyo Village are mostly farm laborers. This is because most people who work as farmers also work as brick and block makers. The areas where bricks and blocks are made are in the vicinity of the rice fields and moorlands owned by the community, especially those who live in the area around the watershed. In fact, most of the land use that should be used for agriculture is converted into a brick and brick industry. This has become the local wisdom of the Sitimulyo Village community for the reason of increasing income, thus utilizing the land as a brick-making industry.

Currently, the agricultural land in Sitimulyo Village is adjacent to companies located in this area. On the other hand, farmers in Sitimulyo Village have also been introduced to the latest technology and farming methods. Problems that are always faced by farmers, such as the lack of agricultural land, the use of modern agricultural equipment, and the bargaining position (price determination) after harvest. This condition makes farmers not yet empowered in determining post-harvest prices in the midst of industrialization.

The land processing technique used by Sitimulyo Village farmers is ploughing, which is carried out in two stages: luku, which is used to uncover and turn the soil in the land preparation process, and harrow, which is used to level the surface of the soil as the final process (finishing) of working on the land every time a cultivation commodity is changed. Fertilizers used for rice cultivation are phonska and urea. In the use of moorland and mixed gardens in Sitimulyo Village, in addition to planting annual crops such as teak, mahogany, lamtoro, and rosewood, peanuts or secondary crops are also planted with no-tillage techniques, only clearing weeds in the area to be planted. The source of irrigation for both paddy fields, moorlands and mixed gardens is rainfed and comes from primary drainage channels originating from the Opak watershed that are made with pumps.

Fig. 7. Terraces in Sitimulyo village

In Sitimulyo Village, agricultural land use is located in lowland or sloping areas, hilly areas, and highlands that fall into the steep or very steep categories. very steep. Therefore, during the rainy season, erosion occurs on some lands that have a certain slope. Terracing in some land uses is suspected to be not optimal because it is not in accordance with its designation. For example, in the use of moorland on steep to very steep slopes, terrace making is only a flat terrace which should be on a slope with this class should use a type of bench terrace or terrace mounds (Figure 7).

In addition, the community of Sitimulyo Village also implements vegetative conservation by planting various types of crops such as mixed gardens, dry fields, and shrubs with plants such as teak, mahogany, sonokeling, and lamtoro. This can reduce the level of moderate to severe erosion (Figure 7). Sitimulyo Village has also implemented a crop rotation system that aims to prevent the loss of nutrients and reduce erosion on the soil surface. For example, after rice or corn is harvested, the land is rotated with legume cover crops such as peanuts, which serve to preserve nutrients and prevent erosion.

Fig. 8. Teak, mahogany, and sonokeling trees as erosion prevention measures

Related to age, livelihoods, and local wisdom, the conversion of agricultural land and its consequences are very evident in Sitimulyo Village. There are several hamlets that are in a rather alarming condition in terms of agricultural land conversion. This can be seen from the environmental impact of converting agricultural land into a brick industry (Figure 8), such as abandoned excavation sites that have become ravines. The conversion of agricultural land into a brick industry can cause problems that must be addressed, such as environmental damage, air pollution, and changes in the physical and chemical characteristics of the soil, which can lead to a decline in the quality of agricultural commodities. This also affects socio-economic changes in the community.

Fig. 9. Brick and concrete block manufacturing industry in Sitimulyo Village

3.4.2 Social and economic analysis of sorghum development

In Indonesia, sorghum is a food cereal crop after rice and corn. Sorghum has great potential to be developed as an alternative crop to meet food, feed, and industrial needs. The main problems in developing sorghum are its relatively low comparative and competitive advantages and the fact that sorghum farming at the farmer level is not yet intensive. According to some information provided, sorghum is an unfamiliar crop and not widely known by the people of Sitimulyo Village, especially those who own land and work as farmers. This is because sorghum is considered a new food crop, and the seeds provided by the Experimental Garden owned by BPSIP Yogyakarta have not been distributed widely in Sitimulyo Village. Therefore, the community tends to choose to cultivate rice and corn as their main commodities. However, if further cultivation is carried out, the results obtained can be developed outside Yogyakarta through CSR programs such as PT. Bukit Asam and PT. Sang Hyang Seri and cultivated outside the region such as East Java or NTT.

Based on CSR news from PT. Bukit Asam in 2014, amid the government's seriousness in developing food diversification, PT.BA, through the Integrated Agricultural Management System/*Sistem Pertanian Terintegras* (SIMANTRI), provided guidance to develop sorghum, especially on former mining land. After successfully harvesting multiple times with continuously increasing sorghum production thanks to management that utilizes the existing soil structure, sorghum has great potential to thrive in Tanjung Enim as an alternative commodity for food, feed, energy, and industry, as well as an economical alternative for reclaiming the extensive post-mining land in the area. The sorghum management technique used is intercropping with vegetables such as spinach and mustard greens, chili peppers, eggplants, and ginger, as well as various types of fruit plants such as custard apples, guavas, papayas, bananas, and mangoes..

In relation to this, similar to the rice and corn crops in Sitimulyo Village, which are developed using intercropping and relay cropping methods, sorghum has the potential to be cultivated in Sitimulyo Village. According to the information obtained, sorghum is suitable for cultivation in dry land such as the fields in the experimental garden owned by BPSIP Yogyakarta. However, the obstacles in developing sorghum are the arid, sandy soil conditions, which are not very fertile, and the suboptimal sorghum ratun technique, which causes a decline in the quality of the sorghum. Basically, sorghum is a plant that is capable of forming tillers. According to Efendi et al. (2013), sorghum tillers have many advantages, including a shorter plant life, lower water requirements, lower production costs because they can save on soil cultivation and seed use, better genetic purity, and yields that are not much different from the main crop.

In addition, PT. Sang Hyang Seri will recently establish a partnership with the National Research and Innovation Agency/*Badan Riset dan Inovasi Nasional* (BRIN) to develop sorghum crops. As well as being a form of food ingredient diversification, sorghum as a food commodity has great potential because it has various advantages, such as its tolerance to extreme weather and water requirements, especially the threat of El Nino, which triggers drought conditions.

Sorghum is a food crop with significant potential as a source of carbohydrates, food, animal feed, and export commodity. In addition, sorghum is more resistant to environmental stress than other cereal crops, for example, on dry land. An important advantage of sorghum from a cultivation perspective is its wide adaptability to drought conditions, giving it a competitive edge over other commodities for development on Indonesia's dry land.

Although sorghum is a versatile crop with high nutritional content, it is currently not being optimally utilized as a commodity. This is because the market value of sorghum is not yet considered as promising as other cereal products such as rice, corn, wheat, and legumes. The utilization of sorghum by farmers themselves is still constrained by the lack of necessary facilities such as seed crushers and other post-harvest processing equipment. This is reinforced by the results of interviews with several people working in the agricultural sector in Sitimulyo Village, who tend to use agricultural land for cultivating crops, especially rice, corn, and secondary crops.

The rice harvest is not only used for personal consumption but also sold at a price of IDR 10,000/kg, with the highest price reaching IDR 12,000/kg. When rice prices are high, farmers can sell it at prices ranging from IDR 13,500/kg to IDR 15,000/kg. When compared to the price of sorghum, which only reaches IDR 3,000/kg to IDR 6,000/kg, this is why farmers who plant sorghum only do so as a side crop. It has not become a main crop. This is one of the obstacles faced when developing sorghum as a food diversification program that supports social and economic conditions in land development initiatives.

3.5 Current regional spatial analysis

The Regional Spatial Plan/*Rencana Tata Ruang Wilayah* (RTRW) of Bantul Regency is stipulated through Bantul Regency Regional Regulation Number 4 of 2011 concerning the Regional Spatial Plan of Bantul Regency 2010-2030. The objective of spatial planning in Bantul Regency is to realize an advanced and independent Bantul Regency by relying on the agricultural sector as an economic base. The area of the spatial pattern plan for wet and dry land agricultural areas in the 2016-2023 The Regional Spatial Plan based on data from the Land and Spatial Planning Office of Bantul Regency in 2024, has not changed. The cultivation area in general has a spatial pattern plan area of 42,102.08 Ha. It can be seen that the largest planning set for cultivation areas is the designation of wetland agriculture with an area of 13,324 Ha. The suitability of space utilization against the spatial pattern of Bantul Regency is divided into three levels, namely not suitable, not suitable, and suitable. At the level of unsuitable suitability, the area of space utilization for wetland agricultural allotments continues to increase by 997.42 Ha (2.37%) from 2021-2023, while the dryland allotment area has decreased by 959.59 Ha (2.27%).

The suitability of spatial utilization of the Bantul Regency spatial pattern at the level of suitability is not suitable for wet and dry land agricultural designation areas has increased. The area of space utilization for wetland agricultural designation increased by 216.99 Ha (0.5%), while dryland agricultural designation increased significantly by 364.82 Ha (0.8%). Furthermore, the suitability of spatial utilization against the spatial pattern of Bantul Regency at the appropriate level of suitability for wetland agricultural designation areas has increased by 957.89 Ha (2.27%), on the other hand for dryland agricultural designation a r e a s has decreased by 833.88 Ha (1.98%).

Based on the analysis of spatial patterns and conformity to the Regional Spatial Planning, the causes of the discrepancy between space utilization and spatial patterns in the Bantul Regency Spatial Plan include population growth which requires land area for various development purposes such as settlements. The land use data used is from 2016-2023, while the spatial pattern in the Regional Spatial Planning is planned for 2010-2030, which means that it is very reasonable if there is a mismatch because the research was not conducted at the end of the validity period of the spatial pattern. In addition, the extent and pattern of land use mismatches indicate that a lack of superior and visionary planning by the local government has resulted in the mismatch of land use against the spatial pattern of the Regional Spatial Planning. The extent of land use that is not in accordance with the Regional Spatial Planning land use that is not in accordance with the Regional Spatial Planning has the potential to cause environmental problems such as drought. erosion. and flooding (Hailu et al., 2023; Ku, 2024; Pizzorni et al., 2024).

Based on the results of interviews with Sitimulyo Village people, Sitimulyo Village has an agricultural and industrial development direction. This makes Sitimulyo Village officials still try to maintain the existing spatial pattern plan, especially as an agricultural development area. Sitimulyo Village tends to follow the rules of the Bantul Regency Government regarding its own spatial pattern, especially areas used as farming roads. However, the community unconsciously changed the spatial pattern plan into roads, settlements, companies, which currently reaches 5% annually reduction of agricultural land. This has resulted in both the zoning of agricultural cultivation land, climate, and drainage created by the government being unable to restore the fertile soil characteristics of Sitimulyo Village.

The spatial utilization pattern plan in land use shows the form of relationships between various aspects such as human resources. natural resources. socio-economic. protection functions. and cultivation. Geological aspects are one of the natural resource aspects that need to be considered in the spatial utilization pattern plan. Geological aspects that are taken into consideration in the planning process are physical or environmental aspects that include morphology (shape of the earth's surface), lithology (soil and rocks), topography (relief of the earth's face), climatology (climate), stratigraphy (soil layers), hydrogeology (water, rock, and soil relationships), and geological hazards. This is the basis for the direction of land development, especially agricultural cultivation areas. In the Madrid region, studies have shown that features such as geological substrate (various rock types), texture, relief/morphology, and soil depth are central criteria for agricultural land suitability evaluation and thus are key geological aspects for spatial land-use planning (Morán-Alonso et al., 2025)

An Indonesian case in the Cianjur watershed demonstrates that topography (slope), soil properties, climatic data, and erosion hazard analyses are integrated via GIS and remote sensing to develop land resource information systems for agricultural landscape planning, emphasizing geological/physical aspects in land development direction (Saroinsong et al., 2007). Topography is one of the important physical aspects considered for regional development planning. Parameters that can be reviewed from the topographic aspect in the spatial utilization pattern plan (Gnann et al., 2025) for cultivated land are morphology and slope because the spatial arrangement and allocation are largely determined by the morphological conditions and slope of an area (Lisso et al., 2024). In addition, hydrological conditions are also one of the physical aspects that need to be considered because planning for the development of an area does not only consider physical aspects that are above the surface but must also pay attention to conditions below the s u r f a c e (Siddik et al., 2022; Sugianto et al., 2022). This is the case with groundwater, which is the source of supply for water needs. Drought and flooding are one of the consequences of changes in land use conditions and climatic factors, especially rainfall (Alharbi, 2023).

Changes in land use such as logging of trees or vegetation, construction of housing as a residential area, construction of buildings for public facilities such as factories in the study area such as Sitimulyo Village, drilling deep wells with large capacity, construction of drainage, making brick industry can affect the hydrological system. This is because there can be transpiration, increased sedimentation of river flows, decreased infiltration areas, decreased groundwater levels, accelerated land erosion, increased flood flows, loss of small rivers, road networks and sewers into flood channels. Studies have shown that conversion of forests and agricultural land into impervious surfaces or built environments significantly increases surface runoff and peak flows, while concurrently reducing infiltration, evapotranspiration, and baseflow; for example, Influence of land use and land cover change on hydrological processes in urban watersheds demonstrates that urban development leads to higher flood risk due to increased impermeable area (Banjara et al., 2024).

Deep well extraction for industrial or domestic usage causes significant decline in groundwater levels, especially in areas densely pumping water; the study 'Modeling of Groundwater Level Changes Due to Deep Well Extraction Using MODFLOW in the North of Bandar Lampung' reports drawdowns of up to more than 8 m around high-capacity deep wells (Purwadi et al., 2023). Land cover change, such as deforestation, logging or removal of vegetation, has been documented to increase sediment yield and reduce soil infiltration; in the Xunwu River watershed study, land-use changes over 30 years led to increased sediment yield and altered runoff components (Liu et al., 2022)

Soil characteristics are also one of the physical aspects considered in the spatial planning process as a form of land analysis. Soil characteristics become a parameter that will determine the classification of land capability which is then used in analyzing land capability in the form of land suitability evaluation using the reference of the Minister of Environment Regulation Number 17 of 2009 concerning Guidelines for Determining Environmental Support Capacity in Spatial Planning (Rizalie et al., 2022). Therefore, soil characteristics are important for any Regional Spatial planning in this case the spatial pattern plan in conducting a land capability assessment (AbdelRahman et al., 2018; El Behairy et al., 2022; Kuchanwar et al., 2025).

4. Conclusions

In land uses such as rice fields, moorland, and mixed gardens with gentle to slightly steep slope classes have land suitability values that are quite sui to suitable so that they have the potential to develop sorghum crops. Land use for the utilization of seasonal crop cultivation areas in Sitimulyo Village is in accordance with its designation as stated in the Piyungan Sub-district Strategic Plan/*Rencana Strategis* (Renstra) 2021-2026. To develop sorghum cultivation in Sitimulyo Village, more information and details are needed for farmers so that agricultural development counseling on sorghum crops needs to be conducted together with IPSI. sorghum plants together with IPSIP under the auspices of BPSIP Yogyakarta and the Yogyakarta-Magelang Agricultural Development Polytechnic as well as the Yogyakarta Agricultural Seed Quality Monitoring and Development Center/*Balai Pengembanagan Perbenihan dan Pengawasan Mutu Benih Tanaman Pertanian* (BP3MBTP). The existence of land use changes that are not in accordance with the land allocation plan should be confirmed by the local government and efforts to provide socialization of the Regional Spatial Plan/*Rencana Tata Ruang Wilayah* (RTRW) to the community so that the community has the awareness to realize land use in accordance with its designation. Brick-making activities should be monitored because they affect the physical and chemical characteristics of the soil in the surrounding land that has the potential for sorghum crop development.

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References
AbdelRahman, M. A. E., Shalaby, A., & Essa, E. F. (2018). Quantitative land evaluation based on fuzzy-multi-criteria spatial model for sustainable land-use planning. *Modeling Earth Systems and Environment*, *4*(4), 1341–1353. https://doi.org/10.1007/s40808-018-0478-1

Affoh, R., Zheng, H., Zhang, X., Yu, W., & Qu, C. (2023). Influences of Meteorological Factors on Maize and Sorghum Yield in Togo, West Africa. *Land*, *12*(1). https://doi.org/10.3390/land12010123

Aguiar, E. V., Santos, F. G., Queiroz, V. A. V., & Capriles, V. D. (2023). A Decade of Evidence of Sorghum Potential in the Development of Novel Food Products: Insights from a Bibliometric Analysis. *Foods*, *12*(20). https://doi.org/10.3390/foods12203790

Alharbi, T. (2023). Mapping of Groundwater, Flood, and Drought Potential Zones in Neom, Saudi Arabia, Using GIS and Remote Sensing Techniques. *Water (Switzerland)*, *15*(5). https://doi.org/10.3390/w15050966

Al-Salman, Y., Ghannoum, O., & Cano, F. J. (2023). Midday water use efficiency in sorghum is linked to faster stomatal closure rate, lower stomatal aperture and higher stomatal density. *Plant Journal*, *115*(6), 1661–1676. https://doi.org/10.1111/tpj.16346

Antara New Yogyakarta. (2013). Bantul akan mengembangkan tanaman sorgum 400 hektare. Antara New Yogyakarta. https://jogja.antaranews.com/berita/308697/bantul-akan-mengembangkan-tanaman-sorgum-400-hektare

Azis, B. N. L., Wikranta, K. A., Anifah, N. S., & Wahyuzar, D. (2021). Integration of Geospatial-Based Resistivity, Seismic Refraction and Geology Methods for Identification of Potential Landslide in Srimartani, Yogyakarta. *Indonesian Journal of Earth Sciences*, *1*(2), 109-122. https://doi.org/10.52562/injoes.v1i2.251

Balz, V. E. (2018). Regional design: Discretionary approaches to regional planning in The Netherlands. *Planning Theory*, *17*(3), 332–354. https://doi.org/10.1177/1473095217721280

Banjara, M., Bhusal, A., Ghimire, A. B., & Kalra, A. (2024). Impact of Land Use and Land Cover Change on Hydrological Processes in Urban Watersheds: Analysis and Forecasting for Flood Risk Management. *Geosciences (Switzerland)*, *14*(2). https://doi.org/10.3390/geosciences14020040

Choudhary, K., Boori, M. S., Shi, W., Valiev, A., & Kupriyanov, A. (2023). Agricultural land suitability assessment for sustainable development using remote sensing techniques with analytic hierarchy process. *Remote Sensing Applications: Society and Environment*, *32*. https://doi.org/10.1016/j.rsase.2023.101051

Critchley, W., & Siegert, K. (1991). *A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production*. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/u3160e/u3160e04.htm

Driesen, E., Van den Ende, W., De Proft, M., & Saeys, W. (2020). Influence of environmental factors light, co2, temperature, and relative humidity on stomatal opening and development: A review. *Agronomy*, *10*(2). MDPI AG. https://doi.org/10.3390/agronomy10121975

Dewi, E. S., Abdulai, I., Bracho-Mujica, G., Appiah, M., & Rötter, R. P. (2023). Agronomic and Physiological Traits Response of Three Tropical Sorghum (Sorghum bicolor L.) Cultivars to Drought and Salinity. *Agronomy*, *13*(11). https://doi.org/10.3390/agronomy13112788

Efendi, R., Aqil, M., & Pabendon, M. B. (2013). Evaluasi genotipe sorgum manis (Sorghum bicolor (L.) Moench) produksi biomas dan daya ratun tinggi. *Jurnal Penelitian Pertanian Tanaman Pangan*, *32*(2), 126242. https://doi.org/10.21082/jpptp.v32n2.2013.p116-125

El Behairy, R. A., El Baroudy, A. A., Ibrahim, M. M., Mohamed, E. S., Kucher, D. E., & Shokr, M. S. (2022). Assessment of Soil Capability and Crop Suitability Using Integrated Multivariate and GIS Approaches toward Agricultural Sustainability. *Land*, *11*(7). https://doi.org/10.3390/land11071027

Food and Agriculture Organization of the United Nations. (2001). *The Role of Agriculture in the Development of LDCs and their Integration into the World Economy*. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/y0491e/y0491e00.htm#TopOfPage

George, T. T., Obilana, A. O., Oyenihi, A. B., Obilana, A. B., Akamo, D. O., & Awika, J. M. (2022). Trends and progress in sorghum research over two decades, and implications to global food security. *South African Journal of Botany*, *151*, 960–969. https://doi.org/10.1016/j.sajb.2022.11.025

Gnann, S., Baldwin, J. W., Cuthbert, M. O., Gleeson, T., Schwanghart, W., & Wagener, T. (2025). The Influence of Topography on the Global Terrestrial Water Cycle. *Reviews of Geophysics*, *63*(1). John Wiley and Sons Inc. https://doi.org/10.1029/2023RG000810

Gu, K., Tang, C., Shi, B., Hong, J., & Jin, F. (2014). A study of the effect of temperature on the structural strength of a clayey soil using a micropenetrometer. *Bulletin of Engineering Geology and the Environment*, *73*(3), 747–758. https://doi.org/10.1007/s10064-013-0543-y

Hailu, T., Assefa, E., & Zeleke, T. (2023). Land use planning implementation and its effect on the ecosystem in Addis Ababa, Ethiopia. *Environmental Challenges*, *13*. https://doi.org/10.1016/j.envc.2023.100798

Herdiansyah, G., Arifin, M., & Suriadikusumah, A. (2022). The Pedogenesis of Inceptisols on Southeast Toposequence of Mount Manglayang in West Java, Indonesia. *Indonesian Journal on Geoscience*, *9*(2), 195–208. https://doi.org/10.17014/ijog.9.2.195-208

Hossain, M. S., Islam, M. N., Rahman, M. M., Mostofa, M. G., & Khan, M. A. R. (2022). Sorghum: A prospective crop for climatic vulnerability, food and nutritional security. *Journal of Agriculture and Food Research, 8*. https://doi.org/10.1016/j.jafr.2022.100300

Hosseini, S., Soltanizadeh, N., Mirmoghtadaee, P., Banavand, P., Mirmoghtadaie, L., & Shojaee-Aliabadi, S. (2018). Gluten-free products in celiac disease: Nutritional and technological challenges and solutions. *Journal of Research in Medical Sciences*, *23*(1). https://doi.org/10.4103/jrms.JRMS_666_18

Juniati, N., S., A., A., & D.P., S. (2025). ND evaluation and suitability of land for development of sorghum (Sorghum bicholor L.) on peat land in west sumatera, Indonesia. *Jurnal Agrium, 22*(2). https://doi.org/10.29103/agrium.v22i2.22811

Khalifa, M., & Eltahir, E. A. B. (2023). Assessment of global sorghum production, tolerance, and climate risk. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1184373

Kokaly, R. F., & Clark, R. N. (1999). Spectroscopic determination of leaf biochemistry using band-depth analysis of absorption features and stepwise multiple linear regression. *Remote sensing of environment*, *67*(3), 267-287. https://doi.org/10.1016/S0034-4257(98)00084-4

Ku, C. A. (2024). Evaluating the effects of land-use strategies on future flood risk reduction in urban areas. *Cities*, *150*. https://doi.org/10.1016/j.cities.2024.104989

Kuchanwar, O. D., Ingle, S. N., Gabhane, V. V., Mondal, B. P., & Moursy, A. R. (2025). Integrated Evaluation of Soil Properties, Land Capability, Productivity, and Crop Suitability in the Deccan Plateau, Central India. *Egyptian Journal of Soil Science*, *65*(3), 0–0. https://doi.org/10.21608/ejss.2025.393732.2207

Kuwagata, T., Ishikawa-Sakurai, J., Hayashi, H., Nagasuga, K., Fukushi, K., Ahamed, A., Takasugi, K., Katsuhara, M., & Murai-Hatano, M. (2012). Influence of low air humidity and low root temperature on water uptake, growth and aquaporin expression in rice plants. *Plant and Cell Physiology*, *53*(8), 1418–1431. https://doi.org/10.1093/pcp/pcs087

Lisso, L., Lindsay, J. B., & Berg, A. (2024). Evaluating the Topographic Factors for Land Suitability Mapping of Specialty Crops in Southern Ontario. *Agronomy*, *14*(2). https://doi.org/10.3390/agronomy14020319

Liu, G., Schmalz, B., Zhang, Q., Qi, S., Zhang, L., & Liu, S. (2022). Assessing effects of land use and land cover changes on hydrological processes and sediment yield in the Xunwu River watershed, Jiangxi Province, China. *Frontiers of Earth Science*, *16*(3), 819–833. https://doi.org/10.1007/s11707-021-0959-9

Morales, M. M., Hoshide, A. K., Carvalho, L. M. P., & Tardin, F. D. (2024). Sorghum Biomass as an Alternative Source for Bioenergy. *Biomass (Switzerland)*, *4*(3), 1017–1030. https://doi.org/10.3390/biomass4030057

Morán-Alonso, N., Viedma-Guiard, A., Simón-Rojo, M., & Córdoba-Hernández, R. (2025). Agricultural Land Suitability Analysis for Land Use Planning: The Case of the Madrid Region. *Land*, *14*(1). https://doi.org/10.3390/land14010134

Naylor, R. L., Battisti, D. S., Vimont, D. J., Falcon, W. P., & Burke, M. B. (2007). Assessing risks of climate variability and climate change for Indonesian rice agriculture. *PNAS May, 8*(19), 7752–7757. https://doi.org/10.1073/pnas.0701825104

Office of Assistant to Deputy Cabinet Secretary for State Documents & Translation. (2022a). *President Jokowi: Sorghum Can Be Alternative Food*. Office of Assistant to Deputy Cabinet Secretary. https://setkab.go.id/en/president-jokowi-sorghum-can-be-alternative-food-source/

Office of Assistant to Deputy Cabinet Secretary for State Documents & Translation. (2022b). *President Jokowi Orders Cabinet to Prepare Sorghum Production and Downstreaming Roadmap*. Office of Assistant to Deputy Cabinet Secretary https://setkab.go.id/en/president-jokowi-orders-cabinet-to-prepare-sorghum-production-and-downstreaming-roadmap/

Pizzorni, M., Innocenti, A., & Tollin, N. (2024). Droughts and floods in a changing climate and implications for multi-hazard urban planning: A review. *City and Environment Interactions,* 41. Elsevier B.V. https://doi.org/10.1016/j.cacint.2024.100169

Purwadi, O. T., Darmawan, I. G. B., Yuwono, S. B., Triyono, S., & Kusumastuti, D. I. (2023). Modeling of groundwater level changes due to deep well extraction using modflow in the north of bandar lampung. *ASEAN Engineering Journal*, *13*(2), 9–17. https://doi.org/10.11113/aej.V13.18310

Raditya, L., & Suntari, R. (2018). Efektifitas kompos tanaman Crotalaria juncea pada ketersediaan dan serapan N, P, K serta pertumbuhan tanaman jagung manis (Zea mays saccharata Sturt) pada Entisol Wajak, Malang. *Jurnal Tanah dan Sumberdaya Lahan*, *5*(2), 969-977. https://jtsl.ub.ac.id/index.php/jtsl/article/view/222

Rajendra Prasad, V. B., Govindaraj, M., Djanaguiraman, M., Djalovic, I., Shailani, A., Rawat, N., Singla-Pareek, S. L., Pareek, A., & Vara Prasad, P. V. (2021). Drought and high temperature stress in sorghum: Physiological, genetic, and molecular insights and breeding approaches. *International Journal of Molecular Sciences, 22*(18). MDPI. https://doi.org/10.3390/ijms22189826

Ramdhani, Widiatmaka, & Trisasongko, B. H. (2023). Food Crop Land Allocation: Integrating Land Suitability Analysis and Spatial Forestry, Study Case Katingan, Indonesia. *Jurnal Manajemen Hutan Tropika*, *29*(3), 187–199. https://doi.org/10.7226/jtfm.29.3.187

Rawson, H. M., Begg, J. E., & Woodward, R. G. (1977). The Effect of Atmospheric Humidity on Photosynthesis, Transpiration and Water Use Efficiency of Leaves of Several Plant Species. *Planta,* 134. https://doi.org/10.1007/BF00390086

Ririska, R., Juniarti, J., & Darfis, I. (2023). Kajian Beberapa Sifat Fisika dan Kimia Tanah pada Lahan Tanaman Aren (Arenga Pinnata Merr) Berdasarkan Kelerengan di Nagari Gadut Kecamatan Tilatang Kamang Kabupaten Agam. *Journal Of Top Agriculture (Top Journal)*, *1*(1), 1-15.

Rizalie, A., Yunita, R., Kadir, S., & Saidy, A. R. (2022). Environmental Carrying Capacity for Spatial Planning of Lemo Sub-Watershed, North Barito Regency, Central Kalimantan, Indonesia. *Journal of Hunan University Natural Sciences*, *49*(4), 68–76. https://doi.org/10.55463/issn.1674-2974.49.4.8

Rizzo, G., Migliore, G., Schifani, G., & Vecchio, R. (2024). Key factors influencing farmers' adoption of sustainable innovations: a systematic literature review and research agenda. *Organic Agriculture, 14*(1), 57–84). Springer Science and Business Media B.V. https://doi.org/10.1007/s13165-023-00440-7

Sadiq, F. K., Yaqub, M. T., Maniyunda, L. M., Alalwany, A. K. A. M., Abubakar, F., & Anyebe, O. (2025). Soil classification and land suitability evaluation for tomato cultivation using analytic hierarchy process under different land uses. *Heliyon*, *11*(1). https://doi.org/10.1016/j.heliyon.2025.e41681

Saroinsong, F., Harashina, K., Arifin, H., Gandasasmita, K., & Sakamoto, K. (2007). Practical application of a land resources information system for agricultural landscape planning. *Landscape and Urban Planning*, *79*(1), 38–52. https://doi.org/10.1016/j.landurbplan.2006.03.002

Sharma, O. P., Kannan, N., Cook, S., Pokhrel, B. K., & McKenzie, C. (2019). Analysis of the effects of high precipitation in Texas on rainfed sorghum yields. *Water (Switzerland)*, *11*(9). https://doi.org/10.3390/w11091920

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE*, *6*(8). https://doi.org/10.1371/journal.pone.0023777

Siddik, M. S., Tulip, S. S., Rahman, A., Islam, M. N., Haghighi, A. T., & Mustafa, S. M. T. (2022). The impact of land use and land cover change on groundwater recharge in northwestern Bangladesh. *Journal of Environmental Management*, *315*. https://doi.org/10.1016/j.jenvman.2022.115130

Sugianto, S., Deli, A., Miswar, E., Rusdi, M., & Irham, M. (2022). The Effect of Land Use and Land Cover Changes on Flood Occurrence in Teunom Watershed, Aceh Jaya. *Land*, *11*(8). https://doi.org/10.3390/land11081271

Trentinaglia, M. T., Baldi, L., & Peri, M. (2023). Supporting agriculture in developing countries: new insights on the impact of official development assistance using a climate perspective. *Agricultural and Food Economics*, *11*(1). https://doi.org/10.1186/s40100-023-00282-7

Utomo, S. W., Lestari, F., Adiwibowo, A., & Fisher, M. R. (2025). Prediction of Sorghum bicolor (L.) distribution ranges provides insights on potential sorghum cultivation across tropical ecoregions of Indonesia. *BMC Plant Biology*, *25*(1). https://doi.org/10.1186/s12870-025-06454-5

Wahyuni, S. Rehabilitasi Lahan Marginal Tipe Entisols Melalui Pembongkaran Bahan Induk Dan Penambahan Bahan Organik. In *Proceeding Biology Education Conference: Biology, Science, Enviromental, and Learning*, *11(*1), 622-628. https://jurnal.uns.ac.id/prosbi/article/view/7848

Widodo, S., Triastono, J., Sahara, D., Pustika, A. B., Kristamtini, Purwaningsih, H., Arianti, F. D., Praptana, R. H., Romdon, A. S., Sutardi, Widyayanti, S., Fadwiwati, A. Y., & Muslimin. (2023a). Economic Value, Farmers Perception, and Strategic Development of Sorghum in Central Java and Yogyakarta, Indonesia. *Agriculture (Switzerland), 13*(3). https://doi.org/10.3390/agriculture13030516

Winarti, C., Widaningrum, Widayanti, S. M., Setyawan, N., Qanytah, Juniawati, Suryana, E. A., & Widowati, S. (2023). Nutrient Composition of Indonesian Specialty Cereals: Rice, Corn, and Sorghum as Alternatives to Combat Malnutrition. *Preventive Nutrition and Food Science*, *28*(4), 471–482. https://doi.org/10.3746/pnf.2023.28.4.471

Yang, R., & Zhong, C. (2022). Land Suitability Evaluation of Sorghum Planting in Luquan County of Jinsha River Dry and Hot Valley Based on the Perspective of Sustainable Development of Characteristic Poverty Alleviation Industry. *Agriculture (Switzerland)*, *12*(11). https://doi.org/10.3390/agriculture12111852

Zarei, M., Amirkolaei, A. K., Trushenski, J. T., Sealey, W. M., Schwarz, M. H., & Ovissipour, R. (2022). Sorghum as a Potential Valuable Aquafeed Ingredient: Nutritional Quality and Digestibility. *Agriculture (Switzerland)*, *12*(5). https://doi.org/10.3390/agriculture12050669

Zukhrifa, A., Irsyad, F., & Yanti, D. (2025). Determination of Superior Agricultural Commodity Areas Based on Historical Data and Land Suitability. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, *14*(2), 701. https://doi.org/10.23960/jtep-l.v14i2.701-713

Zhao, Z., Shen, Y., Jiang, R., & Wang, Q. (2020). Rock outcrops change infiltrability and water flow behavior in a karst soil. *Vadose Zone Journal*, *19*(1). https://doi.org/10.1002/vzj2.20002

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