Journal of Applied Agricultural Science and Technology
JAAST 8(1): 78-91 (2024)
E-ISSN: 2621-2528
ISSN: 2621-4709

THE STUDY OF RELATIONSHIP OF SOIL PHYSICS HEALTH AND MICRO-CLIMATE CHARACTERISTICS ON PADDY FIELDS

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Abstract. *Global food security and environmental stability will be threatened by population growth, land usage, and land change. Proper soil management in plant production helps reduce temperature and humidity-induced plant deterioration. This study aims to identify soil physics health (SPH), microclimate characteristics, and the relationship between the two in managing organic and inorganic paddy fields. The research location is in Purwantoro District, Wonogiri Regency, using descriptive explorative research, with purposive soil sampling at work map, made by overlay thematic maps, resulting in 9 LMU. The observation and sampling were carried out in the maximum vegetative phase of plants, while the micro-climate is in the generation phase. The determination of the soil physics health status used the scoring method. Using the T-test, Pearson's correlation test finds the relationship between SPH and micro-climate characteristics and the differences between the two. The results showed the distribution of SPH in organic farming is healthy (74.7) and very healthy (83.3), while inorganic farming is healthy (79.72). The temperature is optimal, ranging from 23.5°C to 30.1°C, but the humidity is minimum in the range of 35.3% to 76.1%. The SPH and micro-climate have a significant relationship, with a positive correlation between air and soil temperature with SPH and a negative correlation between air humidity and soil moisture.*
Keywords: *chemical fertilizers; humidity; organic materials; temperature*

1. Introduction

Increasing human population, land use, and land change (LULC) will raise concerns about the stability of food security and the environment globally (Molotoks *et al.*, 2021). The dynamic conditions of the environment could affect the climate and soil health. In supporting plant growth and production, soil health and micro-climate aspects must be considered as they affect soil function. The micro-climate is important in plant growth and development fluctuations (Julia & Dingkuhn, 2013). Micro-climate conditions are related to plant growth, the rate of photosynthesis, and respiration (Marrou *et al.*, 2013). Proper soil management in plant production can minimize the consequences of plant decay caused by non-optimal temperature and humidity (Ayu *et al.*, 2021).

The level of soil health can vary due to various factors such as poor drainage, soil erosion, and chemical fertilizers. Healthy soil has the content of the elements of nutrients and minerals that plants need so that they can support the growth of plants (Nugroho *et al.*, 2019). Healthy soil has many microorganisms, so plants' metabolic processes can run well and adapt to erratic micro-climates (Khatoon *et al.*, 2020). Unhealthy soil conditions will result in plants not growing

Received July 23, 2023; Accepted January 7, 2024; Published February 24, 2024
https://doi.org/10.55043/jaast.v8i1.194

optimally and unable to adjust to environmental pressures. Adaptation to the stresses of climate change and frequency is critical for crops regarding crop production. Healthy soil functions lead to sustainable agriculture with high soil organism populations, symbiosis with plant roots, recycling plant nutrients, and improving soil structure to optimize soil output (Kurniawan *et al*., 2023).

Nowadays, the extent of agricultural land, such as paddy fields, is shrinking due to soil degradation caused by chemical fertilizers, which impedes rice production to fulfill national rice needs (Listyowati *et al*., 2022). The research area is in Purwantoro District, Wonogiri District, and intensively implements inorganic farming with chemical fertilizers. The continuous supply of chemical fertilizers leads to imbalances in soil and organic substances, soil saturation, and decreased soil health (Sholihah *et al*., 2018). Long-term addition of chemical fertilizers can reduce the abundance of soil organisms and the emergence of more resilient pests, leading to unhealthy soil (Lian *et al*., 2022). The amount of grain production may increase when the fertilizer is added under the recommended dosage (Chittapun *et al*., 2018). Organic material will be able to control the growth of plant parts such as roots by providing ideal soil moisture conditions and preserving soil moisture during the plant growth period (Syaranamual *et al*., 2022). Land management efforts that are useful for increasing soil productivity while maintaining land health and sustainability can be done by adding organic material through fertilization (Moe *et al*., 2019). According to Adviany and Maulana (2019), using organic fertilizers can improve soil biota biodiversity and stimulate the growth of plant-burning systems. Organic fertilizers can maintain soil balance and improve soil health (Han-wen *et al*., 2022).

Different management systems will result in diverse soil physics health and micro-climate. Plant growth can be increased, erosion can be reduced, pests and diseases can be prevented, and the soil can function as a carbon sink under healthy soil conditions and an appropriate micro-climate (Stevens, 2018). Purwantoro District has no research on soil health and micro-climate managed by organic and inorganic paddy fields. The purpose of this research was to know the status of soil health, the micro-climate characteristics, and the relationship between the two. The research results are expected to be used by farmers and stakeholders as a figure in determining land management planning targets to increase productivity and provide optimal land use. The description that we have provided refers to the hypothesis that land management will affect the soil's physical health and the soil's micro-climate conditions around the planting.

2. Methods

2.1. Study Area

The research was carried out in the inorganic and organic paddy fields of Purwantoro District, Wonogiri Regency. The research location is geographically between 7°54’0”-7°46’30” S and 111°13’30”-111°18'0” E at an altitude of approximately 296 meters above sea level (m asl). Based on the data from the Central Bureau of Statistics in 2019, the area of Purwantoro District is about 1,426 ha, where there is a different farming system, namely organic and inorganic farming, with a planting period of 3 times a year. The type of soil in Purwantoro District is included in Alfisol, with a high level of fertility.

2.2. Soil and Micro-Climate Sampling

This research is a study with an explorative, descriptive approach in which primary data collection is carried out with surveys, field observations, and soil analysis in the laboratory. The research variables consist of soil physics and micro-climate properties. Purposive sampling on land mapping units (LMU) consists of different farming systems (organic and inorganic). The LMU is obtained from the overlaid rainfall, slope, and farming systems maps. Rainfall in the study area was 1.750 mm/year and 2.250 mm/year. The slope ranges were 0-8%, 8-15%, 15-25%, and 25-45%. Thematic map overlay results obtained 9 LMUs and were repeated at 3 points in each LMU, so the total number of points sampling is 27 (Figure 1).

Soil sampling is carried out in 0-20 cm depth. The harvest is carried out at the time of the maximum vegetative phase of the plant (50-60 days after planting) using ground drilling (Hartati *et al*., 2014)**.** Micro-climate observations occur during the plant generative period (60-80 days after planting) (Rizqi *et al*., 2019)**.** Micro-climate measurements were carried out for 2 weeks with a frequency of 3 times daily in the morning, afternoon, and evening.

2.3. Sample Analysis

Physical and chemical research variables and methods used were soil penetration (penetrometer), porosity (pycnometer), soil texture (pipette), effective soil depth (soil boring), soil water content (gravimetry), and C-organic (walkley & black). Variables of micro-climate research and the method used were air humidity and temperature (thermohygrometer), soil moisture, and soil temperature (soil thermometer). The soil samples dried first and were then analyzed with several variables using various methods. The method of samples was soil drying method by air and not exposed to sunlight. The drying time took 5 to 10 days. After the soil analysis, the determination of the indicator of soil physics health was calculated by the scoring method by giving the weight of each variable (Table 1) and then calculated through (1) (Clune *et al*., 2016).

$$\text{Soil physics health} = \frac{Number\ of\ scores}{30} \times 100 \quad (1)$$

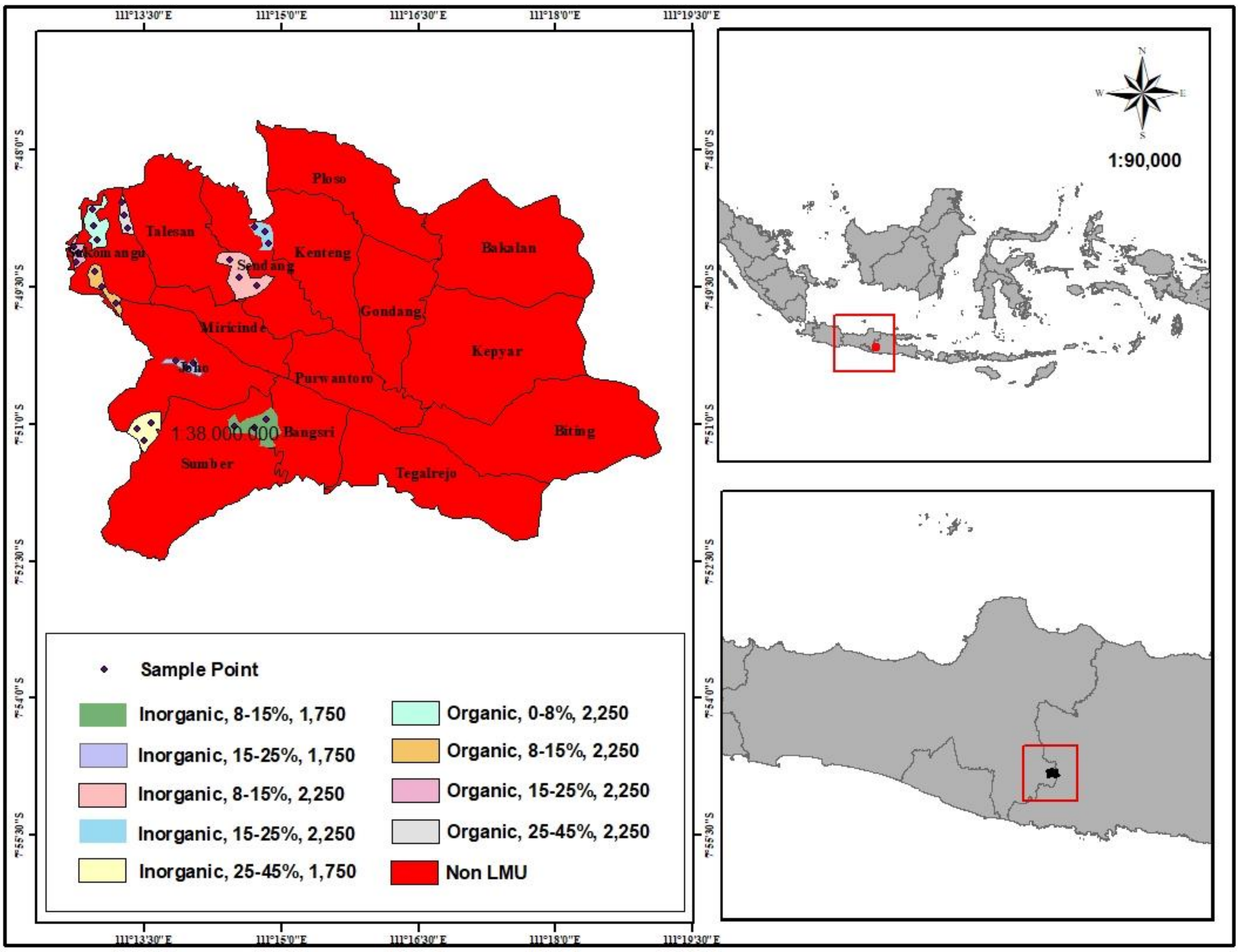

Figure 1. Land Mapping Unit of Study Area

The indicator of soil physics health has a range value of 0-100, in which the value is 0-20 (unhealthy), 20-40 (low healthy), 40-60 (moderate healthy), 60-80 (healthy), 80-100 (very healthy). The higher the value of the soil physics health indicator, the better the soil's health, but the lower the value of soil health indicators, the worse the soil health.

Table 1. The score of the Soil Physics Variable

No	Variable	Very Low	Low	Moderate	High	Very High
		Score 1	Score 2	Score 3	Score 4	Score 5
1	Texture	S, C	SiC, Si	SL, L, SiL	SCL, SC, SiCL	CL
2	Porosity (%)	<30	30-40	40-60	60-80	100
3	Soil Water Content (%)	>75	<25	75	50	25-50
4	Effective Depth of Soil (cm)	<30	30-60	60-90	90-150	>150
5	Soil Penetration (kg/cm^2)	>1.5	1.4-1.5	1.2-1.3	1-1.1	<1
6	C-organic (%)	<1	1-2	2-3	3-5	>5

Source : (Al-Musyafa *et al*., 2016) (Mankotia *et al*., 2019)

2.4. Statistical Analysis

Data analysis is determined by statistical analysis using SPSS ver 25.0. T-tests are used to identify the significant differences between soil physics health indicators and micro-climate plantations in organic farming systems and inorganic. Pearson's correlation was carried out between the soil health indicators and the micro-climate characteristics.

3. Results and Discussion

3.1. Soil Physics Health

Evaluation of the soil physics health of paddy fields is necessary to measure the health status of the land being used to keep it functioning properly. The research's results showed various values. Evaluating soil physics health uses physical research variables such as soil penetration, effective soil depth, soil water content, porosity, texture, and C-organics (additional variable).

Table 2. Variable Values of Soil Physics

Variable	LMU								
	Inorganic					Organic			
	1	2	3	4	5	6	7	8	9
Soil Penetration (kg/cm^2)	1.12	0.88	0.98	0.85	1.10	0.55	0.35	0.68	0.35
Effective Depth of Soil (cm)	46.7	55.3	54.3	57.7	50	68.3	63.3	60.7	61
Soil Water Content (%)	16.1	19.5	15.6	18.4	14.7	29.3	26.6	25.7	25.3
C-organic (%)	1.7	0.9	1.9	2.4	1.1	2.8	2.5	3.1	2.9
Porosity (%)	42.8	38.1	39.8	44.7	50.8	65.3	70.3	55.1	58.7
Texture	C	SCL	C	SC	SL	CL	CL	CL	CL

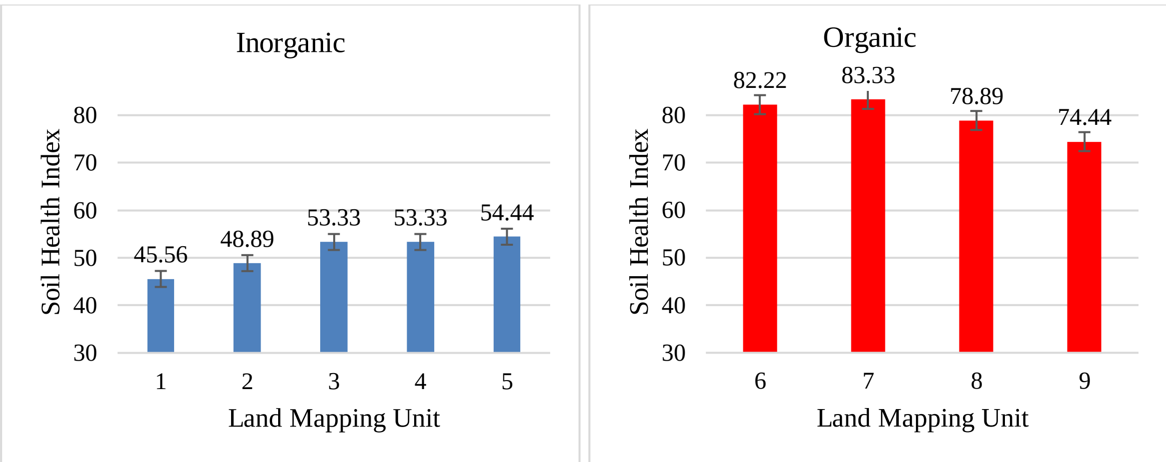

Figure 2. Distribution of Soil Physics in Organic and Inorganic Fields

Table 2 shows the values of each variable condition in the study area. Soil physics health values range from 45.6 to 83.33, as shown in Figure 2. The average soil physics health value on inorganic farming was 51.11, while on organic farming, it was 79.72. Organic farming has a higher soil health than inorganic farming. Evaluating soil physics health is essential to know the conditions of the soil being managed and if it still works well to support plant growth (Juan *et al*., 2013). Based on Table 2, the results of the study showed that soil was in healthy conditions with the range of values of soil penetration (0.35-1.1 kg/cm^2), soil water content (25.3-29.3%), porosity (65.3-70.3%) and texture (silty clay loam-clay loam). The physical properties of the soil affect the growth of the plant's roots to find water and nutrient content (Indoria *et al*., 2017).

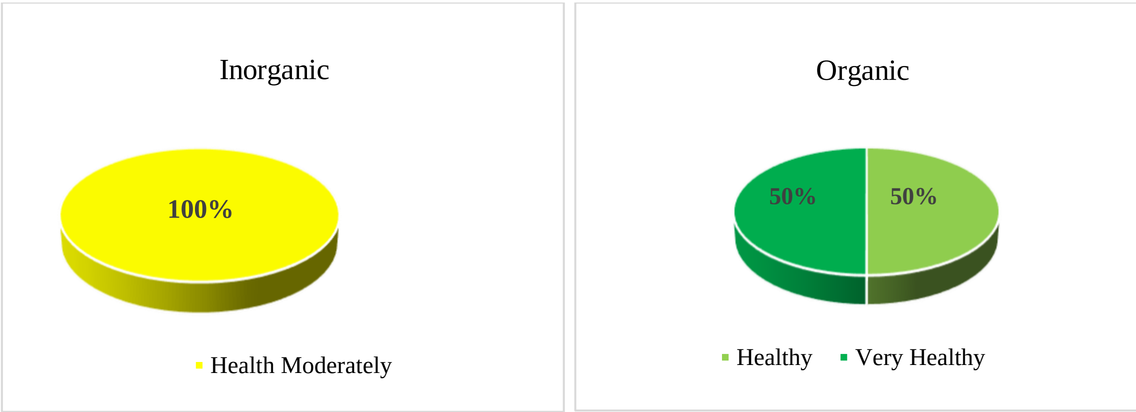

Figure 3. Status of Soil Physical Health in Study Area

Soil physical health evaluation (based on Figure 2) is distributed in three categories: moderate, healthy, and very healthy. The soil physics health class on inorganic farming consists of a moderately healthy class (100%). In comparison, the soil physics health value of organic farming can be categorized into a healthy class (50%) and a very healthy class (50%) (Figure 3). Soil physical health in the study area belongs to 3 classes: moderate, healthy, and very healthy. Differences in soil physics health conditions in inorganic farming can be caused by differences in the dose input and different types of chemical fertilizer in the soil. According to research by Ning *et al.* (2017), using chemical fertilizers in doses exceeding the normal limits affects soil pollution by systolic materials and reduces soil physics health. The concentration of macronutrients in inorganic fertilizers impacts the soil's physical health in supporting crop production needs (Ariyanti *et al.*, 2017).

Soil physics health in organic farming can be categorized into healthy and very healthy. The tendency to differentiate is seen in the amount of soil organic material content. According to Amirinejad *et al.* (2011), incorporating organic components into the soil can improve the characteristics of the soil and provide complete harvest products, hence improving the status of soil physics health. The organic material used in livestock manure can supply the soil with heat nutrients such as nitrogen, phosphorus, and potassium. Thus, a higher dose will also increase the level of NPK (Seguel *et al.*, 2013).

The soil physical health of organic farming is greater than that of inorganic. In line with research by Fadillah *et al.* (2022), the increase in grain production in the inorganic system is short-lived because the decrease in soil physics health and the accumulation of chemical residues over a sufficiently long time can poison the plant. In contrast, in the organic system, soil health improves due to the use of more environmentally friendly organic materials (Romadhon *et al.*, 2024). Introducing organic materials into the soil increases the availability of nutrients for microbial activity, accelerates organic material decomposition, improves soil stability, increases soil recovery capacity, and improves soil health (Shah *et al.*, 2017).

3.2. Micro-climate of Crop

Climate factors that significantly affect plant growth are temperature and humidity. The micro-climate of the crop varies depending on several factors, including different farming systems and rainfall. Inappropriate micro-climate conditions for plant growth will lead to a decrease in grain productivity due to stress experienced by plants during the generative phase.

Table 3. Micro-climate Conditions of Planting

LMU	Farming System	Micro-climate			
		Air Temperature (°C)	Soil Temperature (°C)	Air Humidity (%)	Soil Moisture (%)
1	Inorganic	28.3	26.0	65.9	48.1
2		27.8	25.6	62.8	45.9
3		29.1	27.6	60.5	35.3
4		29.9	26.6	64.9	37.9
5		30.1	26.8	63.4	42.5
6	Organic	26.2	24.6	73.9	63.5
7		27.3	25.4	76.1	60.2
8		25.8	23.5	70.7	54.4
9		25.4	24.0	68.9	55.0

The air temperature in the inorganic farming of paddy fields in the study area ranges between 27.8 °C and 30.1 °C, while in organic farming, it ranges from 25.4 °C to 27.3 °C. (Table 3). Soil temperature values in organic farming range from 23.5 °C to 25.4 °C, whereas in inorganic farming ranges from 25.6 °C to 27.6 °C. (Table 3). The humidity in inorganic farming ranges between 60.5%-65.9%, while in organic farming ranges from 68.9%-76.1% (Table 3). Inorganic farming obtained soil humidity ranges from 35.3-48.1%, while in organic farming ranges from 54.4%-63.5% (Table 3). The highest temperature is inorganic farming, while the highest humidity is in organic farming.

Plant micro-climate refers to the circumstances surrounding plants, which range from the soil surface to crops grown beneath the canopy. The air temperature in the study area is within the normal range (Table 3). This is supported by Laza *et al.* (2015), who state that the optimal air temperature for the growth of paddy crops is at the generative phase, ranging from 20 °C to 33 °C. Based on research conducted by Khamid *et al.* (2019), severe low or high air temperatures can cause seed sterility during the generative phase. The study's soil temperature findings are still optimal. The optimal soil temperature for plants in the reproductive phase is 23 °C to 34 °C (Liu *et al.*, 2018). Low soil temperatures can delay water flow into the soil, resulting in insufficient interaction between plant roots and soil particles, whereas high soil temperatures promote excessive soil water evaporation (Santoso *et al.*, 2020).

Soil and air temperatures are high in inorganic farming, and conditions are low in organic soil (Table 3). Adding organic material to arid soil can increase water retention capacity, improve groundwater content, and lower soil and air temperatures (Naftchali *et al*., 2013). In addition to organic material added to the soil, rainfall creates diverse micro-climate conditions. The average rainfall in areas of organic farming of 2,250 mm/year is higher than the average precipitation in areas of inorganic farming of 1,750 mm/year. Different rains can also affect air and soil temperatures (Poll *et al*., 2013). Higher rainfall in organic agriculture can increase plant water availability, resulting in more plentiful leaf titles covering plants and lower temperatures (Estiningtyas & Syakir, 2017).

Air humidity values (shown in Table 3) in the research area are optimum for the growth of paddy crops, which is 45-80% (Jia *et al*., 2015). Extremely low or high humidity will inhibit growth and flowering because it affects the rate of photosynthesis (Janu & Mutiara, 2021). The soil moisture in organic farming is already optimal, but in inorganic farming, it is not. It can be experienced due to differences in soil water content, radiation on the soil surface, and organic material added to the soil. According to Siswanti *et al*. (2018), the optimal humidity plants required in the flowering phase is 60 to 80%. Low soil moisture prevents paddy crop flowering during the reproductive season, but high soil moisture results in plant wilt.

Organic farming's soil moisture and air humidity are valued higher than inorganic farming's (Table 3). The binding of water by the organic material added to organic farming can reduce water loss through percolation and evaporation so that the water stored in the soil becomes abundant and causes soil moisture to be higher (Dass *et al*., 2017). Inputting organic matter into the soil will increase plant productivity and wider leaf growth. Besides that, the plants will become more fertile because the necessary nutrient content will be available. Because of dense crop leaves, the decrease in sunlight that penetrates the plant's side might generate more outstanding water vapor content in the air due to slower evaporation, raising the humidity of the air and soil (Hendra *et al*., 2014).

Table 4. The Impact of Farming System on Soil Health and Micro-climate

Impact of	Variable	F-Count	P-Value
Farming System	Soil Physics Health	1.365	0.000
	Air Temperature	0.782	0.000
	Soil Temperature	0.070	0.000
	Air Humidity	6.137	0.000
	Soil Moisture	0.842	0.000

3.3. Effects of Farming Systems on Soil Physical Health & Micro-climate Characteristics of Planting Paddy

The results of the T-test statistical test of farming systems with indicators of soil physics health (shown in Table 4) showed a P-value of 0.000 < 0.05, meaning it is a significant value between organic and inorganic farming systems. The results of the T-test between the soil physical health and the micro-climate of planting under different farming systems (based on Table 4) also showed a significant effect between organic and inorganic farming. The P-value in the micro-climate of planting (air temperature, soil temperature, air humidity, and soil moisture) is 0.000 < 0.05.

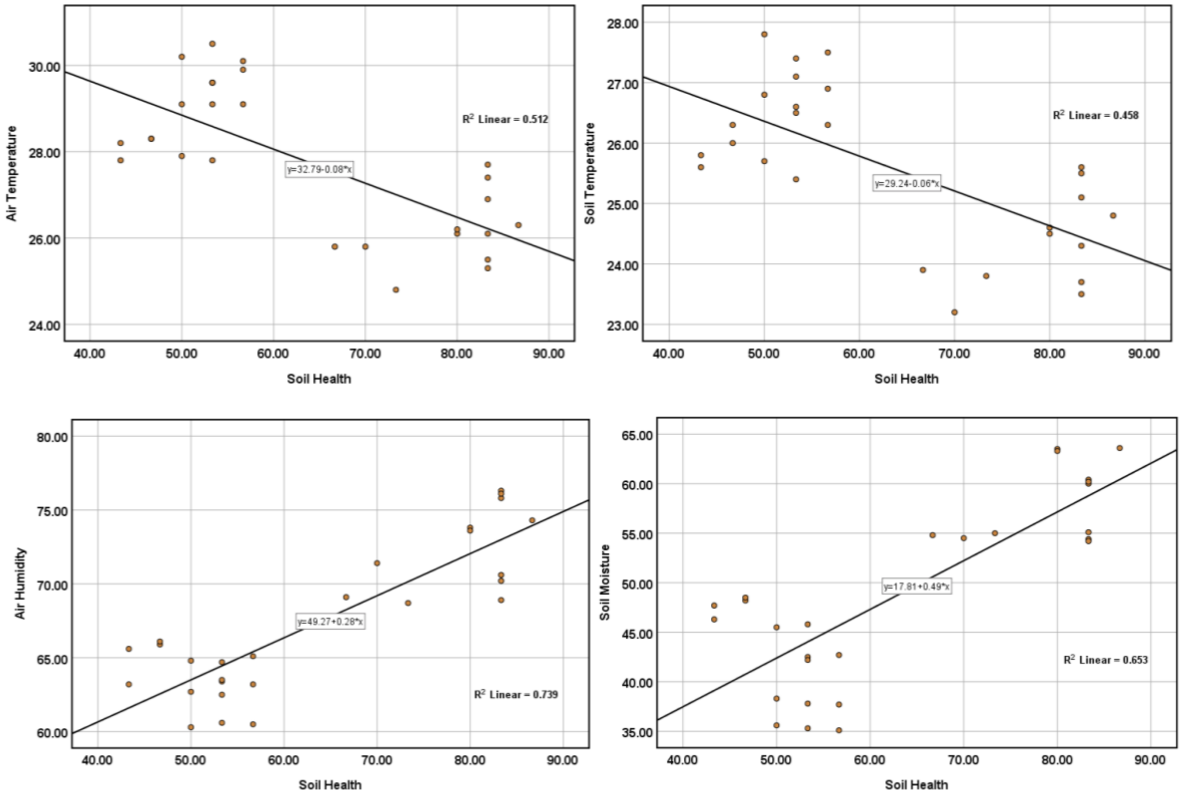

Figure 4. The Relationship Between Soil Physics Health and Micro-climate Conditions of Planting

Different farming systems will affect soil physical health and micro-climate planting conditions. The addition of organic materials in organic farming can improve soil physics health by increasing grain absorption, such as potassium at 0.07-0.28 grams per plant and grain productivity at 5.4-9.0% (Wihardjaka & Harsanti, 2021). For a long time, chemical fertilizers in inorganic farming can impact the soil's physical qualities and decrease organic matter, affecting temperature and humidity fluctuations around canopy plants (Supriyadi *et al.*, 2021). Chemical fertilizers in dry soils cannot be absorbed entirely by the plant's roots and leave chemical residues that, in the long run, risk the soil's health. Based on research conducted by Lelang *et al.* (2022), the chemical elements left in the soil can damage the roots of plants so that the absorption process of the elements is disrupted, plants do not grow optimally, and increasing the total leaves that little sunlight can directly affect the surface of the ground and the temperature of the air and soil around the plant.

3.4. The relationship between soil health and micro-climate agriculture

Study results of the relationship between the soil physics health indicators and the micro-climate of the planting resulted in varying correlations. The soil physics health indicator has the highest correlation value with air humidity (r = 0.859) in a positive correlation. In contrast, the soil health indicator has the lowest relationship with soil temperature (r = 0.676) in a negative correlation. The correlation between soil physics health indicators and both soil and air temperature has a negative value, which means that the higher the health value of the soil, the more the temperature decreases.

Soil physics health relates to optimal soil conditions to support the growth and production of plants. Soil physics health variables have correlations that can be explained through Pearson's correlation test. Based on Figure 4, soil physics health indicators strongly correlate with humidity and temperature. The correlation between the indicators of soil physics health with the temperature of the air and soil temperature is a negative value, which means the higher the value of the soil physics health indicator, the lower the air temperature and the soil temperature will be. Soil moisture and air humidity positively correlate with soil physics health, which means the higher the humidity, the higher the soil physics health of the planting. Abdollahi *et al*. (2015) stated that healthy soil can increase water retention so that the drainage is not excessive. Results in the temperature and humidity that occur will be more stable. A healthy soil has sufficient water content for plant growth. A higher level of groundwater will cause both air and soil temperatures to be lower because the soil needs a lot of solar energy to heat the ground and evaporate the excess groundwater (Shen *et al*., 2018).

4. Conclusions

Plants that grow in unhealthy soil cannot adapt to their environment. Adding chemical fertilizers can enhance crop productivity, but the soil's health suffers in the long term. Based on the research results, the soil's physical health in Purwantoro District, based on the organic farming of paddy fields, is healthy and very healthy. In contrast, the inorganic farming of paddy fields is quite healthy. The micro-climate conditions in Purwantoro District include the optimum that paddy's crop needs, except soil humidity that does not have optimal conditions. Soil physics health with the micro-climate of planting has a high correlation. The correlation between the indicator of soil physics health and the temperature value is negative, while its humidity value is positive. Increasing temperatures and humidity can lead to more stable soil physics health values. A healthy soil helps plant metabolism function well, water and plant demands are met, and plants can adjust to the dynamic plant temperature and humidity. Knowledge of the relationship between soil physics health and the micro-climate of plants helps the farmers and the stakeholders to plan ahead of time for micro-climate circumstances that are unsuitable for planting and can be used as a guide in selecting environmentally friendly management strategies as long as the soil is healthy.

Acknowledgment

The author would like to thank the P2M Research Grant from the Institute for Research and Community Service (LPPM) Universitas Sebelas Maret, which funded this research. The author expressed gratitude to the Wonoagung Wonogiri Organic Farming Association called PPOWW. Also, thank you to Muhammad Rizky Romadhon, Viviana Irmawati, Nanda Mei, Tiara Hardian, Akas Anggita, and Khalyfah Hasanah for the paper elaboration.

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