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Analysis of Soil Physics Quality Index in Terms of Soybean Crop Productivity

Analisis Indeks Kualitas Fisika Tanah dan Hubungannya dengan Produktivitas Tanaman Kedelai

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Abstract. Soil physics properties determine soil quality and fertility, as well as play a role in plant growth and production. This study aims to determine the soil physics quality index (SPQI) in soybeans and the relationship between soil physics quality index and soybean productivity. The location of this research was the Ciwalen Experimental Garden, Cianjur Regency, West Java Province, Indonesia. The physical properties of the soil used to determine the SPQI were texture, bulk density, porosity, drainage pores, available water, permeability, and aggregate stability. Each soil physic parameter was rated and scored 0 (very bad) to 5 (very good). SPQI indicates the range of soil physics qualities. The SPQI on each land unit planted with soybeans, ranged from 0.74-0.91 with categories rather good on land units P10 as a control, good on land units P1, P2, P3, P4, P5, P6, P7, and P9, and very good on P8 land units. SPQI positively correlates with soybean productivity, with the r of 0.4223. That is because productivity is not only influenced by the physical properties but also by the chemical and biological properties of the soil. However, this study showed that organic matter and arbuscular mycorrhizal fungi affected soil physical quality and soybean productivity.

Abstrak. Sifat fisika tanah menentukan kualitas dan kesuburan tanah, serta berperan dalam pertumbuhan dan produksi tanaman. Penelitian ini bertujuan untuk mengetahui indeks kualitas fisika tanah (IKFT) pada tanaman kedelai dan untuk mengetahui hubungan indeks kualitas fisika tanah dengan produktivitas kedelai. Lokasi penelitian ini berada di Kebun Percobaan Ciwalen, Kabupaten Cianjur, Provinsi Jawa Barat, Indonesia. Sifat fisika tanah yang digunakan untuk menentukan IKFT adalah tekstur, bobot isi, porositas, pori drainase, air tersedia, permeabilitas, dan stabilitas agregat. Setiap parameter fisika tanah menggunakan skor dalam rentang 0 (buruk sekali) sampai 5 (baik sekali). IKFT dalam suatu lahan dapat menunjukkan kualitas fisika tanah yang beragam. IKFT pada masing-masing unit lahan yang ditanami kedelai, yaitu berkisar antara 0,74-0,91 dengan kategori agak baik pada unit lahan P10 sebagai kontrol, baik pada unit lahan P1, P2, P3, P4, P5, P6, P7 dan P9, serta sangat baik pada unit lahan P8. IKFT berkorelasi positif dengan produktivitas kedelai dengan r sebesar 0.4223. Hal ini dikarenakan produktivitas tidak hanya dipengaruhi oleh sifat fisika tanah, tetapi juga dipengaruhi oleh sifat kimia maupun biologi tanah. Namun, penelitian ini menunjukkan bahwa pemberian bahan organik dan fungi mikoriza arbuskular berpengaruh terhadap kualitas fisika tanah dan produktivitas kedelai.

Introduction

Soybean production in Indonesia has not been able to meet national needs. According to FAO (2020), national soybean production from 2014 to 2018 fluctuated, with the total production being 954,997 tons, 963,183 tons, 859,653 tons, 538,729 tons, and 953,572 tons. Therefore, Indonesia still imported 2.67 million tons of soybeans in 2018 (ITC 2020). That is due to the increasingly limited land for agricultural extensification and the decreasing area of agricultural land due to the conversion of agricultural land to suboptimal land.

Suboptimal land in Indonesia is quite extensive, namely 149,489,993 ha or about 78.2% of the total land area of Indonesia, which consists of acid upland, semi-arid upland, tidal swampland, lowlands, and peatland (Mulyani *et al*. 2016). That is because productivity is still low due to various constraints or problems, namely poor soil physics, chemical, and biological properties, such as high soil density and very low capacity of available water for plants (Aprisal *et al*. 2016), thus causing soil degradation. Therefore, technological input and recommendations for appropriate soil management are urgently needed to increase productivity. The input of

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technology and recommendations for soil management in this research is the provision of organic matter in humica and petroganics, and *Arbuscular Mycorrhizal Fungi* (AMF).

Humica and petroganic are included in organic fertilizers that have humic acid. Humic acid is a compound produced from the decomposition process of organic matter (Humika 2010). While AMF is an organism in symbiosis with higher plant roots and helps plant growth (Masria 2013), and the presence of AMF in plant roots can result in increased crop yields (Noertjahyani 2012). The addition of humic acid and AMF can keep plants alive in critical environments because their presence can overhaul the physical and biological properties of the soil (Pradyudyaningsi and Sari 2016).

Soil is one of the natural resources that are the main component in the agricultural sector which acts as a supporter of plant growth and development and a supplier of nutrients, water, and air for plants. According to Regelink *et al*. (2015), soil provides ecosystem services such as crop production, water retention, and soil organic carbon sequestration. In addition, the soil's physical structure has a crucial role in the processes to support soil functions. Therefore, it is crucial to maintain soil quality.

Soil quality is a combination of physical, biological, and chemical properties of the soil, where soil quality assessment can be carried out by assessing these properties or indicators that describe crucial processes in the soil. According to Dexter (2004), the component of soil properties that plays a central role in soil quality is soil physics properties.

Soil physics properties are one of the soil properties that determine soil quality and also one of the determinants of soil fertility, whose primary function is as a place for plant root penetration, nutrient absorption, water absorption, and root respiration (Damanik *et al.* 2011) so that it will affect the value of soil productivity, growth, and crop production. According to Rachman (2019), the contribution of soil physics properties to plant growth and production, namely as a physical medium for the availability or place of the presence of nutrients, water, and air or gases needed by plants as well as a place for plant roots to grow, controlling the availability of water for plants, and control the process of supplying gas needed by plants. However, the physical properties of the soil are difficult to overcome and require a longer time for recovery and improvement. Therefore, it is necessary to assess the quality of soil physics properties by determining the Soil Physics Quality Index (SPQI).

SPQI is determined based on selecting several indicators of soil physics properties to obtain an overall assessment. Doran and Parkin (1994) stated that indicators were selected based on their relevance to soil functionality and sensitivity to changes caused by tillage management. Thus, it is necessary to study SPQI by integrating soil physics properties by artificially making soil physics properties, i.e., conducting experiments on soybean plants with several treatments given to produce a range of soil physics properties that vary from poor to very good and the resulting productivity varies. This study aimed to determine the physics quality index of the soil on soybeans and determine the relationship between the soil physics quality index and the productivity of soybeans.

Materials and Methods

The research was conducted from September 2020 to May 2021 at the Ciwalen Experimental Garden, Cianjur Regency, West Java Province, Indonesia (6°42′51.6″ South and 107°3′44.7″ East). Soil analysis was carried out at the Laboratory of Soil Science and Land Resources, Faculty of Agriculture, IPB University, and the Bogor Soil Research Institute.

The materials used in this study were soybean seeds of Biosoy variety, soil samples, aquadest, petroganic, humica, *Arbuscular Mycorrhizal Fungi* (AMF), NPK 16:16:16, and other materials used in the study. At the same time, the tools used include sample rings, field knives, ovens, digital scales, wet and dry sieves, aluminum cups, pipettes, permeameters, film bottles, measuring flasks, measuring cups, beakers, spatulas, spray bottles, plastics, permanent marker, rubber bands, stationery, and other equipment used in research.

This study used a completely randomized design (CRD) and was carried out with various fertilizer recommendations in each plot of ten experimental units. Each experimental unit with three replications so that there are thirty experimental plots, with each experimental plot measuring 4 m x 4 m (16 m^2). The treatment was given seven days before planting by distributing it to each experimental unit. Each experimental unit was given basic fertilizer in NPK 16:16:16 fertilizer as much as 500 $kg.ha^{-1}$. The treatments used in this study were:

P1 = Humica 1 + Petroganic

P2 = Humica 2 + Petroganic

P3 = AMF 1 + Petroganic

P4 = AMF 2 + Petroganic

P5 = Humica 1

P6 = Humica 2

P7 = AMF 1

P8 = AMF 2

P9 = Petroganic

P10 = Control

Description of the dose given:

Humica 1 = 1.5 $kg.ha^{-1}$

Humica 2 = 3 $kg.ha^{-1}$

AMF 1 = 100 $kg.ha^{-1}$

AMF 2 = 200 $kg.ha^{-1}$

Petroganic = 4,000 $kg.ha^{-1}$

Planting was carried out seven days after the treatment was given to each experimental unit. Before planting, the seeds are selected first from seeds that are not good by choosing seeds that are uniform and not wrinkled. Soybean seeds were planted in a single unit with a planting hole depth of ± 3 cm. Each planting hole is inserted 2-3 soybean seeds. The spacing used is 20 cm x 40 cm. The soybean seed variety used was the Biosoy variety.

Harvesting is done when the soybean plants have shown the characteristics of soybeans that can be harvested, including the leaves (90-95%) have turned brown and then fall, the stems are dry, slightly brownish-yellow, and bare, and the soybean pods are ripe as indicated by the filled soybean pods full, the skin of the pods is yellow-brown and easy to peel.

Soil samples were taken after harvest for each experimental unit. Soil samples taken include intact soil samples and disturbed soil samples. Intact soil samples were taken to analyze bulk density, porosity, moisture content at various pressures (pF 1, pF 2, pF 2.54, and pF 4.2) for drainage pores and available water, permeability, and aggregate stability. Meanwhile, disturbed soil samples were used for texture analysis. The following are the parameters of soil physics properties and analytical methods used in this study (Table 1).

Analysis of the soil physics quality index was carried out based on three conceptual frameworks, i.e., (1) the selection of indicators; (2) indicator interpretation; (3) integration of all indicator scores to assess the quality of soil physics properties (Andrews *et al.* 2004). An assessment of the physical quality of the soil can be obtained by following several expert opinions (Amacher *et al.* 2007). Each soil physics parameter is given a score of 0 to 5 according to its conditions and performance. Soil parameters and SPQI score criteria are listed in Table 2. After that, categorize the final SPQI score into 7 categories (Table 3). Then the individual index values are added up to get the total SPQI using the following equation:

$$\mathbf{SPQI} = \sum \mathbf{S/n * i}$$

Where:

SPQI = Soil Physics Quality Index

S = soil parameter score

n = number of parameters

i = maximum index (in the index range 0 to 5)

Soybean production used is the yield of soybean plants expressed in dry weight per plot from each experimental plot so that the productivity of soybean plants is obtained. Soybean crop productivity was statistically analyzed using the Least Significant Difference (LSD) test at the 5% level. Statistical analysis used simple regression correlation analysis to determine the relationship between soil physics quality index and soybean productivity. The mathematical equations of linear regression correlation are as follows:

$$Y = a + bx$$

Where:

Y = soybean productivity (dependent variable)

x = SPQI (independent variable)

a = intercept parameter

b = regression coefficient parameter

Table 1. Parameters and analytical method

Tabel 1. Parameter dan metode analisis

Parameters	Method Analysis/Reference	Unit
Texture	Hydrometer/Pipette	-
Bulk Density	Gravimetri (ring sample)	$g.cm^{-3}$
Porosity	Gravimetri (ring sample)	%
Drainage Pore	Gravimetri (Pressure plate apparatus)	%
Available Water	Gravimetri (Pressure plate apparatus)	%
Permeability	Water Constant Head (Klute and Dirksen 1986)	$cm.jam^{-1}$
Agregate Stability	Wet and Dry Sieving	%

Table 2. Soil parameters and criteria for the score of Soil Physics Quality Index

Tabel 2. Parameter tanah dan kriteria skor Indeks Kualitas Fisika Tanah

Parameters	Unit	Score					
		0	1	2	3	4	5
Texture	-	Sa	LSa	SiC	SaL, Cl	SCl, Si, SiL, SiCl	L, SiClL, ClL, SaClL
Bulk Density	g/cm^3	> 1,6	1,4 - 1,6	1,2 - 1,4	1,0 - 1,2	0,8 - 1,0	≤ 0,8
Porosity	%	< 20	20 - 30	30 - 40	40 - 50	50 - 60	> 60
Agregate Stability	-	< 40	40 - 50	50 - 66	66 - 80	80 - 200	> 200
Available Water	%	< 2	2 - 4	4 - 6	6 - 8	8 - 16	> 16
Drainage Pore	%	< 2	2 - 4	4 - 6	6 - 8	8 - 16	> 16
Permeability	cm/jam	< 0,025	0,025 - 0,125	0,125 - 0,50	0,5 - 2,0; > 25,0	2,0 - 6,25; 12,5 - 25,0	6,25 - 12,5

Description: Sa = Sand; LSa = Loamy Sand; SaL = Sandy Loam; L = Loam; SiL = Silty Loam, SiClL= Silty Clay Loam; SaClL = Sandy Clay Loam; ClL = Clay Loam; SaCl = Sandy Clay, Si = Silt; SiCl = Silty Clay; Cl = Clay; ClW = Clay Weight (Clay > 80 %).

Table 3. Criteria of Soil Physics Quality Index

Tabel 3. Kriteria Indeks Kualitas Fisika Tanah

Class	Value	Category
1	< 0,20	Very Bad
2	0,20 - 0,39	Bad
3	0,40 - 0,54	Rather Bad
4	0,55 - 0,69	Moderate
5	0,70 - 0,79	Rather Good
6	0,80 - 0,89	Good
7	0,90 - 1,00	Very Good

Results and Discussion

Soil Physics Properties

Soil physics quality assessment in this study used ten land units on a stretch of land with an adequate depth of > 60 cm. Each experimental unit was given a different treatment and a different dose. Table 4 shows that the physical properties of the soil in each land unit are different. Soil physics properties are used as key parameters, i.e., bulk density, porosity, drainage pore, available water, permeability, aggregate stability, and texture.

Bulk Density and Porosity

The results of the analysis of the density and porosity of the soil in each land unit are different. The value of soil density ranged from 0.75 - 1.19 g.cm^{-3}, while soil porosity ranged from 55.05% - 71.73% and was classified as good. That is because porosity is closely related to bulk density. The control land unit has bulk density and porosity suitable for plant growth and production, so the treatment given does not have a significant effect. However, the control had a higher bulk density and lower porosity than the soil treated with organic and biological fertilizers. Organic fertilizers and biological fertilizers have an essential role in maintaining and improving soil physics properties, creating a low density and high porosity.

The bulk density is still relatively good because generally, the bulk density is between 1.1 - 1.6 g.cm^{-3} (Hardjowigeno 2010), and the optimal value for conducive plant growth is 0.9 - 1.2 g.cm^{-3} (Drewry *et al.* 2008). The value of soil density will vary in each field, and this is due to the diversity of soil organic matter content, texture, structure, types of clay minerals, depth of plant roots, and types of soil fauna (Utomo *et al.* 2016)). The soil density is an indication of the density of the soil. The higher the density, the denser the soil, making it more difficult for water to pass or be penetrated by plant roots (Hardjowigeno 2010). Taghavifar and Madani (2014) revealed that soil compaction that continues to increase would cause soil erosion and inhibit plant shoots from growing because plant root penetration is disrupted, it is not easy to take mineral materials from the soil, air circulation will be disrupted.

Soils with high porosity tend to have low bulk density. Porosity is the proportion of total pore space contained in a volume of soil that can be occupied by water and air so that porosity is an indicator of soil drainage and aeration conditions. Porous soil means that the soil has sufficient pore space to freely move water and air into or out of the soil (Hanafiah 2005). Thus, density and porosity are closely related to plant root systems where the growth action can break up dense layers, reduce soil density, and increase total soil porosity (Vogelmann *et al.* 2012, Prevedello *et al*. 2013, Cavalcante *et al.* 2019).

Drainage Pore and Water Available

Based on the analysis results, each land unit has a different drainage pore value and available water. Each land unit has drainage pores >16%, which ranges from 21.62% - 41.03%, and available water has the same value, namely 8% - 16%, which ranges from 8.74% - 15.84%. In general, this study showed that the experimental control unit had good drainage pores and available water, so that it had no significant effect on the treatment given. However, the application of humica can increase the drainage pores and available water because the application of humica can bind water (soil water holding capacity) is greater (Humica 2010). According to this study, the available pore water in the land unit given humica, namely P6, showed a higher value than the land unit without humica. Baskoro (2010) research revealed that soils fed with organic materials containing humic materials could retain water longer than controls.

Drainage pore or macropores are macro-sized soil pores, unable to hold water under the influence of gravity so that water flows downwards. Meanwhile, available water is in the form of meso size soil pores and is defined as the amount of water that can be released by the soil between field capacity and permanent wilting point (Rachman *et al.* 2019)). Drainage pores and available water pores are parameters of Soil Water Holding Capacity (SWHC) which are strongly influenced by several soil properties, including soil organic matter content, density, texture, and stability of soil aggregates (Rachman *et al.* 2013).

Arya *et al.* (2008) stated that SWHC describes the ability of soil to retain water and reflects the influence of soil mineral composition, soil texture, soil structure, soil organic matter content, and soil management. Thus, soils with good drainage pores and available water capacity must be maintained with adequate soil management to function correctly, especially for plant productivity. Good management of groundwater content is crucial for plant growth and production (Lawes *et al.* 2009; Hosseini *et al.* 2016).

Permeability

Permeability is one of the soil properties that influence soil erosion, so it is necessary to assess soil quality. In this study, the permeability has different values in each treatment, which ranges from 7.04-29.69 cm/hour, four land units with very fast permeability (>25.4 cm/hour) at P2, P5, P6, and P9, three land units with rapid permeability (12.7-25.4 cm/hour) at P1, P4, and P10, and three land units with moderate permeability (6.3-12.7 cm/hour). hours) at P3, P7, and P8. This study showed that the soil given organic fertilizer in the form of humica and petroganic and a combination of humica petroganic had very fast permeability compared to the control. This is because organic fertilizers can increase soil permeability, compared to without humica or petroganic. Based on the research of Lawenga *et al*. (2015) that the soil that was given organic fertilizer was significantly different from the control. By the statement to Rahim (2003) that the structure, texture, and other organic elements increase the rate of soil permeability. In addition, soil permeability is also influenced by texture, where the soil textures in this study are clayey loam, sandy clay loam, and sandy clay.

According to Hillel (1971), the factors that affect permeability are soil texture, soil porosity, pore size distribution, aggregate stability, soil structure stability, and soil organic matter content (C-organic). C-organic in this study ranged from 0.64 to 3.01 with a very low to high category (data not presented). This study shows that C-organic and permeability have a negative linear relationship (r = -0.37) which means the relationship between variables is inversely proportional so that the higher the C-organic, the lower the permeability. That is because the permeability is not only influenced by C-organic but is influenced by other variables. Hardjowigeno (2010) stated that the more critical relationship to permeability is pore size distribution, while other factors only determine porosity and pore size distribution. As supported by Utomo *et al*. (2016), the soil permeability level is determined by the size of the pores and the relationship between the soil pores. Soil with macro-pores or coarse texture will quickly drain water into the soil. Meanwhile, soil with micro-pores or fine texture will have low permeability, making it difficult to drain water into the soil, or the water flowing will be slower.

Aggregate Stability

Aggregate stability in each land unit varies, ranging from 47.11-365.30 with a category of less stable to very stable, including two land units with very stable aggregates (> 200), seven land units with very stable aggregates

(>200), and one land unit with moderately stable aggregate (50-66). Aggregate stability in this study is still quite good because there is still treated with a less stable category at P18. That is presumably due to intensive tillage and low organic matter content. Therefore, efforts are needed to improve the stability of the aggregate, i.e., by good soil management and application of soil organic matter.

Several factors influence aggregate stability, including tillage, soil microbial activity, and plant canopy on the soil surface from rain. Intensive tillage tends to break down solid soil aggregates into unstable ones, and the soil will be quickly destroyed due to the rainwater that falls to the soil surface during the rainy season if the soil aggregate is unstable (BBSDLP 2006). This study showed that the soil given AMF had better soil physics quality than other land units. That is supported by the research of Graf *et al.* (2019) that with mycorrhizal inoculation on Betula pendula species, a higher potential for soil aggregation was obtained when compared to soil without mycorrhizal inoculation (control). In addition, it is also because AMF hyphae can increase the formation and stability of soil aggregates under conditions very similar to those that occur in nature (Peng *et al.* 2013). The external hyphae network in AMF produces the secretion of polysaccharide compounds, organic acids, and mucus that can bind primary grains into macro-aggregates (Basri 2018).

Aggregate stability indicator is the content of organic matter in the soil. Organic matter is one of the ingredients for forming soil aggregates which has a role as an adhesive material between soil particles and other soil particles to form soil aggregates. Li *et al.* (2007) stated that soils with low organic matter caused an increase in soil density to reduce soil porosity, soil aggregates, and water content of field capacity. Thus, stable soil aggregates will maintain good soil properties for plant growth and production, such as porosity and water availability for longer than unstable soil aggregates.

Texture

Soil texture is a soil characteristic that is not easily changed and requires a long time to change. According to Grzywna and Ciosmak (2021), soil texture is a physics property of soil that is not easily changed, tends to remain, and is not easily changed by humans. However, this study showed a variety of soil textures, i.e., five land units with clay loam (ClL), three land units with sandy clay loam (SaClL), and two land units with sandy clay (SaCl). However, in general, the texture in this study was dominated by a slightly finer fraction with Sandy Clay Clay texture class as indicated by the average particle size distribution of sand, silt, and clay, respectively 48.31%, 20.58%, and 31.11%. Based on this analysis, the location of this study has a texture that is classified as suitable for land use for soybean plants. The land suitability criteria for soybeans support that; according to Hardjowigeno and Widiatmaka (2017) that soils with ClL, SaClL, and SiClL textures belong to class S1 (very suitable), while SaCl textures belong to class S2 (appropriate).

In addition, texture plays a vital role because it is interrelated with other soil properties and affects the movement of water and solutes, soil density, soil water storage, ease of tillage, aeration, and fertilization. Utomo *et al.* (2016) stated that mineral soils have textures that vary in each type of soil and the depth of the soil layer. Sandy soil is suitable for plant roots. However, sandy soils dry out quickly and lose nutrients, while soils with high clay content have a higher CEC so that there is less nutrient leaching. However, clay has few macro-pores so that water enters the soil slowly and flooding can occur, and plant roots are difficult to penetrate the micro-pores.

Soil Physics Quality Index (SPQI)

The scores for each parameter of soil physics properties and the score of the soil physics quality index based on the treatment given can be seen in Table 5. Based on the analysis results, there are significant differences in each treatment given, resulting in very little variability in soil physics properties in this study in the same land unit. Soil physics quality index in soybean planted area ranged from 0.74 to 0.91 (Figure 1) with moderate to very good (Table 6). Land units with a rather good category on land units P10 as a control, good categories on land units P1, P2, P3, P4, P5, P6, P7, and P9, and very good category on land units P8. The factors influencing the high and low soil quality index are bulk density, porosity, drainage pores, available water, permeability, aggregate stability, and texture. The highest soil quality is at P8, and this is because P8 has no limiting factor and has low bulk density, high porosity, good drainage, and available water pores, very fast permeability, stable soil aggregates, and a suitable texture for soybean plants. In addition, it is also due to the administration of AMF with a high dose of 200 kg/ha. While the lowest soil quality is at P10, this is because P10 has a limiting factor in the form of aggregate stability. The soil will be quickly destroyed during the rainy season if the soil aggregate on land is not stable (BBSDLP 2006).

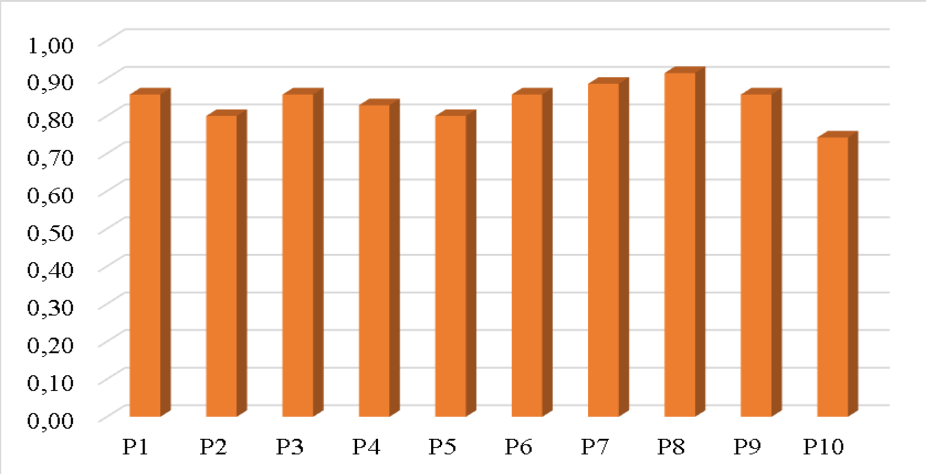

Figure 1. Soil Physics Quality Index on Soybean Planted Land

Gambar 1. Indeks Kualitas Fisika Tanah pada Lahan yang Ditanami Kedelai

Table 4. Characteristics of soil physical properties

Tabel 4. Karakteristik sifat fisika tanah

Land Units	BD ($g.cm^{-3}$)	Poro (%)	DP (%)	AW (%)	Permea ($cm.jam^{-1}$)	AS	Te
P1	1.03	61.30	29.72	15.34	24.03	178.16	SaClL
P2	1.10	58.31	28.06	13.72	28.98	365.30	SaCl
P3	1.19	55.25	24.46	12.06	8.41	102.86	ClL
P4	1.06	59.89	30.64	9.79	20.54	100.49	SaClL
P5	1.11	58.12	27.31	11.96	28.58	84.30	ClL
P6	0.90	66.02	28.15	15.84	27.45	81.58	ClL
P7	1.10	58.67	21.62	11.59	7.04	239.98	ClL
P8	0.82	69.05	32.46	14.51	9.24	109.48	SaClL
P9	0.75	71.73	41.03	15.58	29.69	101.83	SaCl
P10	1.19	55.05	26.71	8.74	21.51	47.11	ClL

Description: BD: Bulk Density, Poro: Porosity, DP: Drainager Pore, AW: Available Water, Permea: Permeability, AS: Agregate Stability, Te: Texture, ClL: Clay Loam, SaClL: Sandy Clay Loam, SaCl: Sandy Clay.

Soil that has a rather good quality becomes very good, land management techniques in the form of organic matter are needed. That is because organic matter affects soil physics properties, such as assisting in forming soil aggregates, improving soil structure, increasing soil porosity, and increasing soil resistance to erosion where this study has very low to high C-organic (data not shown). According to Marzuki *et al.* (2012), organic matter is an energy source for soil microorganism activity that can improve soil bulk density, soil structure, soil aeration, water holding capacity, aggregate stability, and increase soil permeability. In addition, organic matter also supports the role and function of soil physics properties to determine the ability of the soil to retain water, prevent nutrient loss (leaching), provide good aeration, and facilitate plant root penetration (Foth and Turk 1972). Thus, the physics quality of the soil is crucial in soil management actions and increasing crop productivity.

Soybean Crop Productivity

Soybean productivity in Indonesia fluctuates every year. Many factors influence Soybean productivity, one of which is soil as a growing medium. If the soil has poor soil physics properties and is difficult to cultivate, it can cause the root system to be disturbed, roots will be difficult to develop and grow in a limited way, so plant productivity

Table 5. Result of soil physics properties parameter score and Score of Soil Physics Quality Index

Tabel 5. Hasil skor parameter sifat fisika tanah dan Skor Indeks Kualitas Fisika Tanah

Land Units	BD	Poro	DP	AW	Permea	AS	Te	SPQI
P1	3	5	5	4	4	4	5	0.86
P2	3	4	5	4	3	5	4	0.80
P3	3	4	5	4	5	4	5	0.86
P4	3	4	5	4	4	4	5	0.83
P5	3	4	5	4	3	4	5	0.80
P6	4	5	5	4	3	4	5	0.86
P7	3	4	5	4	5	5	5	0.89
P8	4	5	5	4	5	4	5	0.91
P9	5	5	5	4	3	4	4	0.86
P10	3	4	5	4	4	1	5	0.74

Description: BD: Bulk Density, Poro: Porosity, DP: Drainager Pore, AW: Available Water, Permea: Permeability, AS: Agregate Stability, Te: Texture

will also be disrupted.

Soybean productivity in this research location has the highest to lowest productivity values (Table 7). The lowest productivity is found in P10 of 0.96 tons/ha because it has the lowest soil quality value with rather good category. In contrast, the highest productivity is found in P6 of 3.14 tons/ha and a soil quality value of 0.86 with the good category. Table 7 shows that P6 is not significantly different from other experimental units but is significantly different from P10. That shows that the treatment is given by organic fertilizers and AMF is significantly different from the productivity of soybean plants because the application of organic fertilizers and biological fertilizers can affect the properties of the soil, one of which is the physical properties of the soil.

Table 6. Index criteria of Soil Physics Quality Index in each land unit

Tabel 6. Kriteria indeks Kualitas Fisika Tanah pada setiap satuan lahan

Land Units	Category
P1	Good
P2	Good
P3	Good
P4	Good
P5	Good
P6	Good
P7	Good
P8	Very Good
P9	Good
P10	Slightly Good

Table 7. Soybean plant productivity in each land unit

Tabel 7. Produktivitas tanaman kedelai pada setiap satuan lahan

Land Units	Productivity (ton/ha)
P1	2.59 ab
P2	2.28 ab
P3	2.78 ab
P4	2.92 ab
P5	2.49 ab
P6	3.14 ab
P7	2.54 ab
P8	1.96 abc
P9	1.72 bc
P10	0.96 c

Description: Numbers followed by the same lowercase letter in the same column are not significantly different based on the Least Significant Difference (LSD) test at the 5% level

Land units P1, P2, P3, P4, P5, P7, P8, and P9 also have good and excellent soil quality, but their productivity is lower than P6, which has the highest productivity. That is because soil productivity determinants are influenced not only by soil physics properties but also by other soil properties such as soil chemical and biological properties. However, the limiting factor that affects the physical quality of the soil at this research location is the value of aggregate stability (unstable or less stable). Soil aggregate is one of the soil properties in determining soil quality.

Soil with less stable aggregate causes the soil to be easily destroyed when hit by rainwater. BBSDLP (2006) states that aggregate stability is the ability of the soil to withstand the repair of forces that will damage it. The force consists of wind shear, rainwater blow, irrigation water degradability, and soil tillage load.

The Relationship between Soil Physical Quality Index and Soybean Crop Productivity

Figure 2 shows that SPQI has a reasonably close relationship with soybean productivity. Each level of increase in the SPQI variable will affect 0.751 on the value of soybean plant productivity based on its regression coefficient. The correlation coefficient value between SPQI and soybean productivity is relatively low, namely r of 0.4223 (or R^2 = 0.1784). The correlation between soil physics quality index and soybean productivity is positive. That shows a moderate positive linear relationship between SPQI and soybean productivity, every increase in soil quality will be followed by an increase in soybean productivity. The relationship between the two variables is unidirectional and quite close because the value is close to one. The higher the SPQI value, the higher the productivity of soybeans produced because the physical properties of the soil affect soybean productivity, although the confidence level of the correlation between the two variables is relatively low, i.e., 17.84%, because productivity is not only influenced by the physical properties of the soil but is also influenced by other variables, namely the chemical and biological properties of the soil. According to the statement of Armenise et al. (2013), physics indicators are less responsive to management than chemical parameters. However, soil physics properties have an important role in soybean crop productivity.

According to Cherubin (2016) that soil has a critical soil physical function, namely, supporting root growth, being able to supply water for edaphic plants and fauna, allowing gas exchange between the soil and the atmosphere (soil aeration), and having the ability to resist erosion and soil degradation. So these functions are essential to maintain plant productivity and maintain ecosystem services. In addition, to support soybean productivity and soil quality, it is necessary to add organic matter. According to Winarso (2005), most soil experts agree that organic matter is the key to soil productivity, quality, and health. Therefore, it is necessary to add organic matter. According to Cherubin (2016), soil processing techniques are needed to add organic matter to support plant productivity. Organic materials and biological fertilizers in the form of humica, petroganic, and AMF also help the availability of nutrients, one of which is P which is thought to be a factor that is closely correlated with soybean production. Soil applied by AMF and organic matter can increase P uptake in soybean plants, where P nutrients play an essential role in filling seeds, ripening fruit or grain, and increasing grain production (Mulyani 2002).

Conclusions

The studied soil physical properties' variability, i.e., the aggregate stability, was very little, and unlikely to be a limiting factor for crop growth. Soil physical quality index in soybean planted area ranged from 0.74 to 0.91 which belongs to rather good to very good category. Land units

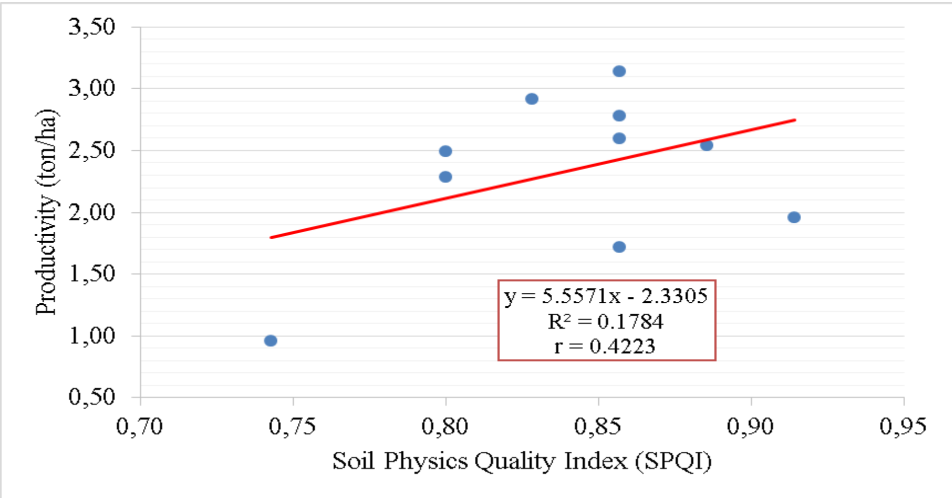

Figure 2. Graph of Soil Physics Quality Index relationship with soybean crop productivity

Gambar 2. Grafik hubungan Indeks Kualitas Fisika Tanah dengan produktivitas tanaman kedelai with a rather good category was found on land units P10 as a control, good categories were found on land units P1, P2, P3, P4, P5, P6, P7, and P9, and very good category on land unit P8. Soil physical quality index has a positive linear relationship with soybean productivity, and the correlation coefficient between the two variables, the r was 0.4223 (R^2 = 0.1784). The low r is understandable as the productivity is not only influenced by the physical properties, but also by the soil chemical and biological properties. This study also showed that the application of organic matter and *arbuscular mycorrhizal fungi* (AMF) affected the physical quality of the soil and the productivity of soybean crops.

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