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Pot experiment to assess soil quality index and rice harvest index in sandy soil using *Azolla microphylla* and chicken manure

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Abstract

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Sandy soil in Indonesia have the potential to develop as cultivated land, but it has low soil organic carbon, nutrients, and less water holding capacity. This less quality of sandy soil needs to be improved. One of the ways to improve the quality of sandy soil is the application of organic matter. This study aims to measure the soil quality index (SQI) and rice harvest index (HI) on the sandy soil with the application of *Azolla microphylla* (azolla) and chicken manure and to determine the correlation between the soil quality index and the rice harvest index. The previous pot research in the greenhouse used a Completely Randomized Design (CRD) with two factors and three replications. Factor I is fresh azolla (0, 50, 100, 150) tons ha^{-1}. Factor II is chicken manure (0, 20, 40) tons ha^{-1}. Pots with a height of 37 cm and a diameter of 24 cm are filled with sandy soil weighing 9.6 kg. Incubation of the soil with fresh azolla and chicken manure was proceed in two weeks before transplantation. The results showed that there was an increase in the soil quality index and rice harvest index in the sandy soil with the application of azolla and chicken manure. The use of azolla 100 tons ha^{-1} and chicken manure 20 tons ha^{-1} gives the rice harvest index is the highest of 25.57% and increased 47.97 % of the control. The soil quality index was the highest at 0.36 (moderate class) and it increased 24.14 % of the control obtained on the use of azolla 100-150 tons ha^{-1} and chicken manure 40 tons ha^{-1}, with the determining factor of soil quality index being soil organic carbon. The soil quality index was positively correlated with the harvest index of rice (r = 0.645**).

Keywords: soil organic carbon; organic matter; completely randomized design

Introduction

Indonesia is an archipelago country that has coastlines of 108,000 km (Badan Pusat Statistik, 2020) and with a stretch of about 1-3 km of coastlines. These large sandy soil areas are considerable potential to develop as agricultural lands. That is an alternative to replace the reduction of agricultural land due to land conversion. However, sandy soil has a variety of obstacles, such as low soil organic carbon, water content, total N, available P, available K, and the cation exchange capacity (CEC) are classified as very low (Herawati et al., 2021; Yuwono, 2009). These conditions lead to its low productivity.

Various studies have been conducted to improve the productivity of sandy soils, including the addition of clay and manure (Partoyo, 2005), the use of organic matters both compost and manure (Wigati et al., 2006; Hijria et al., 2020), the use of soil ameliorant (cow manure and rock phosphate) and mycorrhizal (Herawati et al., 2021), that all the results conclude the existence of the improvement of soil fertility, such as soil organic carbon, cation exchange capacity (CEC), and plant growth. However, the use of organic matter such as azolla on the sandy soil is still very limited.

Azolla is an aquatic plant that is often used as green manure. It grows at twice the initial biomass in 3-5 days and is capable of fixing nitrogen. Elmizan et al., (2014), stated that the application of 45 tons ha^{-1} of fresh azolla on paddy fields was able to increase soil organic carbon, total N, available P, exchangeable K, cation exchange capacity (CEC), number of tillers, number of panicles, panicle weight, and grain yield of rice plants (Razavipour et al., 2018). However, giving azolla alone has not been able to replace the use of manure (Syamsiyah et al., 2018).

The assessment of soil quality index was initially only based on one element (Phom et al., 2012), but now various soil quality index evaluation systems have been developed. One of the assessment methods developed, based on the heterogeneity and variability of soil properties due to differences in location and management is the soil quality index (Nabiollahi et al., 2018). This method has been widely developed because it is very flexible in integrating various soil properties (Biswas et al., 2017)particularly of wet land rice. The present investigation was undertaken to identify sensitive soil quality indicators and to develop soil quality indices and establishment of their critical limits in Inceptisols, Entisols and Alfisols collected from farmers' fields with long-term rice-rice cropping system in sub-tropical India. The soil samples were analysed for 37 physical, chemical and biological properties. Principal component analysis (PCA. Measurement of the soil quality index is carried out through the stages of selecting indicators, scoring indicators, and scoring comprehensively into one index (Nabiollahi et al., 2018).

Lin et al., (2019), reported that setting the Minimum Data Set (MDS) with the selection of indicators is the most appropriate way to evaluate soil quality index, is easy to do, and has been widely used. The selection of MDS indicators can be done using the Principal Component Analysis (PCA) method, to reduce redundancy of soil data. In addition, the weight of the selected indicator can be calculated, when compiling the MDS, thereby reducing the influence of subjectivity (Rezaei et al., 2006). The preparation of MDS can be done using scoring. Research on soil quality index assessment using MDS has been carried out by various types of land use for agricultural activities.

Arifin et al., (2018), stated that there was an increase in the sandy soil quality index from low to moderate by applying 5 tons ha^{-1} of cow manure + 50% inorganic fertilizer (NPK) and with mycorrhizal inoculation. So far, there has been no research on the combination of azolla and chicken manure to evaluate soil quality index and rice harvest index in sandy soil, so this research needs to be done to support previous research on soil quality index in sandy soil.

The study aims to evaluate the soil quality index and rice harvest index in sandy soils, which are given azolla and chicken manure and to determine the correlation between the soil quality index and the rice harvest index.

Materials and Methods

Preparation of growing media and rice planting

The pot research was carried out at the Greenhouse, Faculty of Agriculture, Sebelas Maret University, Surakarta, from November 2020-July 2021. The sandy soil used in this study was taken from the coast of Samas, Bantul Regency of Yogyakarta Province, Indonesia (7°59′39.0″S 110°15′41.4″E).

Table 1. Characteristics of sandy soil, azolla, and chicken manure

Variable	Sandy soil	*Azolla microphylla*	Chicken manure
Water content (%)	0.27	92.84	27.62
pH	6.61	–	8.85
SOC (%)	0.11	35.78	51.82
Total N (%)	0.05	2.31	2.59
C/N ratio	–	15.49	19.93
Av-P (ppm)	1.3	–	–
Av-K (me 100g^{-1})	0.29	–	–
CEC (me 100g^{-1})	3.21	–	–

Remark: SOC = Soil Organic Carbon, Av-P = Available P, Av-K = Available K, CEC = Cation Exchange Capacity

The sandy soil was sieved through a 2 mm sieve, weighed 9.6 kg, and put into a pot with a diameter of 24 cm, a height of 37 cm. Chicken manure and fresh azolla were mixed with sandy soil, according to the treatment, two weeks before transplanting. Characteristics of sandy soil, azolla, and chicken manure used in the study are presented in Table 1. Planting of Inpari 32 rice varieties is done in 15 days after sowing. Treatment of rice plants is done by weeding weeds every 2 weeks and installing nets to protect rice plants from pests. Inundation is carried out by maintaining stagnant water conditions, namely as high as 5 cm from the soil surface to the maximum vegetative phase adding water every 2 days, and shrinking water during the maturation phase (Sauki et al., 2014). Harvesting is done when the rice plants are 120 days old, by pulling them slowly one by one from the research pot.

Research Design

This study uses a factorial Completely Randomized Design (CRD) with two factors. The first factor is the fresh azolla which consists of 0 tons ha^{-1} (A0), 50 tons ha^{-1} (A1), 100 tons ha^{-1} (A2), and 150 tons ha^{-1} (A3). The second factor is chicken manure with a dose of 0 tons ha^{-1} (M0), 20 tons ha^{-1} (M1), and 40 tons ha^{-1} (M2). The total is 12 treatments with three replications, so there are 36 units of the experiments.

Soil sample and plant analysis

Soil samples were taken from each experimental pot when the plants were harvested, air-dried, and then cleaned from roots and sieved through a 2 mm sieve. As for soil biological analysis (C microbial biomass), fresh soil samples for each treatment were brought to the laboratory and stored in a refrigerator.

The analysis of soil samples that include water content (gravimetric method) (Sukma et al., 2019), bulk density (ring samples) porosity (ring samples) (Rahmat et al., 2020), pH H_2O (1:2.5) (potentiometric method) (Herawati et al., 2021), soil organic carbon (Walkey and Black) (Syamsiyah et al., 2019)which also promotes global warming. It can be formed from the decomposition of organic matter like rice straw in the soil. The laboratory study was conducted to determine CO2 production and carbon (C, total N (Kjeldahl method) (Lin et al., 2020), Available P (Olsen method) (Wang et al., 2018) few studies have focused on the response of soil microbes to decreases in P input in a rice-wheat rotation. To determine the feasibility of a P reduction regime and its impacts on soil microbes, we modified P fertilizer inputs in a four-year pot experiment. Our treatments contained P fertilization during both rice and wheat seasons (PR + W, Available K (ammonium acetate extraction) (Bilias and Barbayiannis, 2019)based on free energy of exchange and potential available illite K. This method aimed to overcome limitations arising from the complexity of K release and fixation dynamics which makes conventional extraction methods often inadequate. Winter wheat was grown in a greenhouse pot experiment until K-depletion and soil K was assessed with ammonium acetate (NH4OAc, cation exchange capacity (CEC) (ammonium acetate extraction) (Gumbara et al., 2019), base saturation (ammonium acetate extraction) (Zgorelec et al., 2019) and C microbial biomass (fumigation and extraction) (Syamsiyah et al., 2019)which also promotes global warming. It can be formed from the decomposition of organic matter like rice straw in the soil. The laboratory study was conducted to determine CO2 production and carbon (C. Plant parameters observed include the straw yield is determined by weighing the weight of the plant parts over after the grain is knocked out. Grain is determined by weighing the weight of the grain after it is knocked out at the time of harvest.

Soil quality index calculation

There are four steps to calculate the soil quality index (Figure 1). The first is correlation analysis to determine the level of closeness between parameters and is used as a reference for determining the selected indicator. The second is PC analysis to select the MDS (Minimum Data Set) indicator and obtain its weight index. Third, do a scoring or assessment on each of the selected indicators as MDS. Finally, the soil quality index is calculated based on the weight index and the score of the selected indicator.

1. Determination of MDS (Minimum Data Set)

Soil quality index assessment is based on the selection of representative soil indicators (Jiang et al., 2020). This can be done by correlation analysis and PCA to obtain MDS. The concept of the Minimum Data Set (MDS) is the selection of a few indicators as possible, but can represent all the values of the soil quality indicators used (Lal, 1994). The indicator chosen to set the MDS is the indicator on the PC that has an eigenvalue >1, is positively correlated, and has the highest value from each PC.

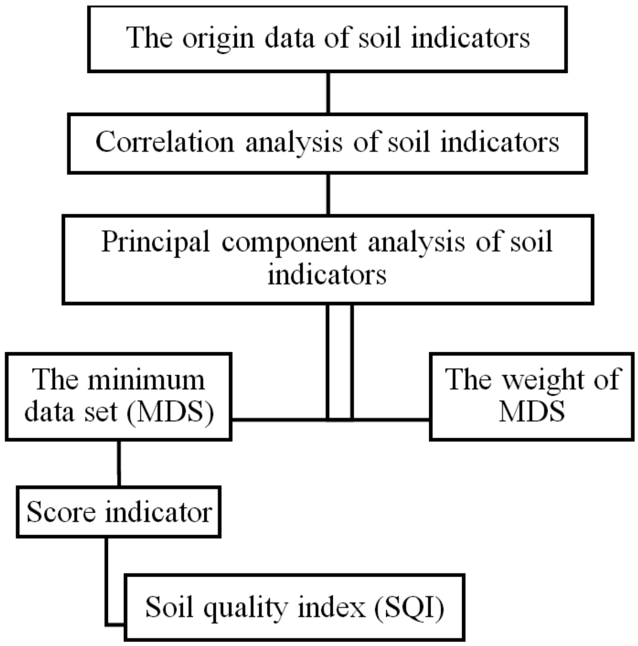

Fig. 1. Flowchart of soil quality index measurement procedure (Jiang et al., 2020)

2. Weight Index of MDS (Wi)

The weighted index is calculated from the proportion of each indicator divided by the highest cumulative value. The proportion of each indicator is the proportion value of the PCA divided by the number of selected indicators. Mean-

Table 2. Soil indicator assessment score

Indicator	VL (1)	L (2)	M (3)	H (4)	VH (5)
WC	<2	2-8	8-20	20-30	>30
BD	>1.6	1.5-1.6	1.4-1.5	1.3-1.4	<1.3
Porosity	<10	10-15	15-18	18-20	>20
pH	<5 and >8.2	5-5.4 and 7.8-8.2	5.4-5.8 and 7.4-7.8	5.8-6 and 7-7.4	6-7
SOC	<0.5	0.5-1	1-3	3-5	5-10
Total N	<0.1	0.1-0.2	0.21-0.5	0.51-0.75	>0.75
Av-P	<10	10-15	16-25	26-35	>35
Av-K	<0.1	0.1-0.2	0.3-0.5	0.6-1	>1
CEC	<5	5-16	17-24	25-40	>40
BS	<20	20-30	31-50	51-70	>70
C-Mic	<5	5-10	10-20	20-25	>25

Remark: WC = Water Content, BD = Bulk Density, SOC = Soil Organic Carbon, Av-P = Available P, Av-K = Available K, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass, VL = Very Low, L = Low, M = Moderate, H = High, VH = Very High

while, the highest cumulative value is the highest cumulative value on PCA which has an eigenvalue >1.

3. Score Indicator of MDS (Si)

The scoring of the indicators used is based on (Lal, 1994) and is presented in Table 2.

4. SQI calculation method

Soil Quality Index (SQI) is calculated based on (Lal, 1994):

$$SQI = \sum_{i=1}^{n} Wi \times Si, \quad (1)$$

where: SQI was soil quality index, *Wi* was weight index, *Si* was score Indicator, and n was number of selected indicators (MDS). The soil quality index is classified based (Cantú et al., 2007) in Table 3.

Table 3. Soil quality index (SQI) Classification (Cantú et al., 2007)

Class of SQI	Score f SQI
Very High	0.80-1.00
High	0.60-0.79
Moderate	0.35-0.59
Low	0.20-0.34
Very Low	0.00-0.19

Rice harvest index calculation

Harvest index was calculated by dividing plant biomass (fresh and dry weight). The Harvest Index based on (Bharati et al., 2000):

$$\text{Harvest Index (HI)} = \frac{\text{grain yield}}{\text{grain + straw yield}} \times 100\% \quad (2)$$

where: straw yield was straw yield is determined by weighing the weight of the plant parts over after the grain is knocked out. Grain yield was grain is determined by weighing the weight of the grain after it is knocked out at the time of harvest

Analysis data

The data obtained were tested with ANOVA (Analysis of Variance) at the 95% confidence level, to determine the effect of treatment on the observed variables and continued with DMRT (95%) further test to determine the comparison between treatments. Furthermore, Pearson correlation test was conducted to determine the relationship between SQI and HI.

Results

1. Soil properties are given azolla and chicken manure

Properties of sandy soil are given azolla and chicken manure is presented in Table 4. The value of the water content of sandy soil ranged from 0.27% – 1.41%. Bulk density shows the value ranged from 1.1 g cm^{-3} – 1.84 g cm^{-3}. The value of the porosity ranges between 40.49% – 43.60%. pH H_2O (1:2.5) are classified as a neutral range between 7.40 – 7.53. Soil organic carbon varied between 0.05% – 0.52%. The levels of total-N sandy soils ranged from 0.07% – 0.35%. Available P ranges between 3.46 ppm- 8.77 ppm. Available K ranged between 0.35% – 0.77%. The value of the CEC ranged from 3.74 me 100g^{-1} – 9.27 me 100g^{-1}. Base saturation Ranged from 25.75% – 41.23%. The value of C microbial biomass ranged from 0.18 µg g^{-1} – 0.72 µg

2. Determination of MDS and calculation of SQI

a. Determination of MDS

The correlation analysis between soil indicators is listed in Table 5. Bulk density has a significant negative correla-

Table 4. Result of analysis of physical, chemical and biological soil properties

Treatment	WC (%)	BD (g cm^{-3})	Por (%)	pH	SOC (%)	Total N (%)	Av-P (ppm)	Av-K (%)	CEC (me 100g^{-1})	BS (%)	C-Mic (μg g^{-1})
A0M0	0.27	1.84	40.49	7.47	0.05	0.07	3.46	0.35	3.74	38.38	0.18
A0M1	0.48	1.72	43.17	7.43	0.25	0.17	6.79	0.68	5.68	37.20	0.48
A0M2	1.12	1.70	43.41	7.53	0.31	0.23	6.99	0.51	5.88	37.40	0.55
A1M0	0.33	1.81	41.25	7.47	0.17	0.25	6.00	0.66	7.20	28.05	0.21
A1M1	0.65	1.72	41.42	7.40	0.27	0.24	7.46	0.68	8.08	28.17	0.54
A1M2	1.41	1.67	42.23	7.47	0.36	0.28	7.30	0.61	8.60	25.75	0.52
A2M0	0.50	1.76	41.85	7.50	0.27	0.30	7.00	0.67	7.37	26.19	0.40
A2M1	0.71	1.73	42.16	7.47	0.32	0.35	8.77	0.79	9.19	40.85	0.33
A2M2	2.08	1.61	43.25	7.47	0.52	0.24	8.73	0.75	9.02	41.23	0.72
A3M0	0.86	1.74	40.99	7.43	0.31	0.31	7.55	0.65	6.70	32.78	0.44
A3M1	1.22	1.72	42.17	7.50	0.39	0.32	7.36	0.70	6.21	36.99	0.70
A3M2	2.20	1.61	43.60	7.43	0.52	0.34	8.71	0.77	9.27	41.15	0.71

Remark: A0 = Azolla 0 tons ha^{-1}, A1 = Azolla 50 tons ha^{-1}, A2 = Azolla 100 tons ha^{-1}, A3 = Azolla 150 tons ha^{-1}, M0 = Chicken Manure 0 tons ha^{-1}, M1 = Chicken Manure 20 tons ha^{-1}, M2 = Chicken Manure 40 tons ha^{-1}, WC = Water Content, BD = Bulk Density, Por = Porosity, SOC = Soil Organic Carbon, Av-P = Available P, Av-K = Available K, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass

tion with porosity (r = -0.753), SOC (r = -0.567), Available P (r = -0.520), CEC (r = – 0.384) and C microbial biomass (r = -0.491). Soil porosity was only significantly correlated with bulk density and not significantly correlated with other soil indicators. pH did not show a significant correlation with other soil indicators. Soil organic carbon showed a significant positive correlation with total N (r = 0.608), Available P (r = 0.780), Available K (r = 0.590), CEC (r = 0.648) and C microbial biomass (r = 0.638). Total N soil was positively and significantly correlated with Available P (r = 0.745), Available K (r = 0.673) and CEC (r = 0.573). Available P showed a significant positive correlation with Available K (r = 0.732), CEC (r = 0.696) and C microbial biomass (r = 0.465). Available K has a positive and significant correlation with CEC (r = 0.570) and C microbial biomass (r = 0.345). Meanwhile, base saturation does not show a significant correlation with other soil indicators.

The results of PC analysis (Table 6) showed that three PCs had eigenvalues > 1. PCs 1, 2, and 3 represented 75.4% of the

Table 6. Result of principal component analysis (PCA)

Eigenvalue	4.4234	1.6169	1.4966
Proportion	0.442	0.162	0.150
Cumulative	0.442	0.604	0.754
Variable	PC1	PC2	PC3
Bulk Density	-0.334	-0.471	0.144
Porosity	0.179	**0.634**	-0.134
pH	-0.088	-0.114	0.637
SOC	**0.419**	-0.033	0.120
Total N	**0.359**	-0.291	0.068
Available P	0.433	-0.129	0.087
Available K	**0.367**	-0.231	0.092
CEC	**0.355**	-0.303	-0.294
BS	0.066	0.248	**0.643**
C-Mic	**0.302**	0.231	0.142

Remark: SOC = Soil Organic Carbon, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass

Table 5. Result of correlation analysis between physical, chemical and biological indicator

Variabel	Bulk Density	Porosity	pH	SOC	Total N	Available P	Available K	CEC	BS
Porosity	-.753**								
pH	0.279	-0.196							
SOC	-.567**	0.195	-0.035						
Total N	-0.309	0.104	0.053	.608**					
Available P	-.520**	0.209	-0.084	.780**	.745**				
Available K	-0.312	0.072	-0.148	.590**	.673**	.732**			
CEC	-.384*	0.019	-0.281	.648**	.573**	.696**	.570*		
BS	-0.136	0.113	0.297	0.195	-0.022	0.196	0.206	-0.280	
C-Mic	-.491**	0.315	-0.017	.638**	0.288	.465**	.345*	0.291	0.172

Remark: SOC = Soil Organic Carbon, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass

Table 7. Calculation of the weight index for each MDS indicator

MDS	Proportion (a)	*Cumulative* (b)	Wi (a / b)
Porosity	0.162	0.754	0.215
SOC	0.074	0.754	0.098
Total N	0.074	0.754	0.098
Available P	0.074	0.754	0.098
Available K	0.074	0.754	0.098
CEC	0.074	0.754	0.098
BS	0.150	0.754	0.199
C-Mic	0.074	0.754	0.098

Remark: Wi = Weight index, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass

data for determining MDS. From PC1 representing 44.2% of data, PC2 representing 16.2%, while PC3 representing 15% to determine MDS indicators. From the three PCs, 8 MDS indicators were selected, namely available P, soil organic carbon, total N, available K, cation exchange capacity, C microbial biomass, porosity, and base saturation (Table 6).

On PC1, the proportion is 0.442 divided by 6 selected indicators, so each indicator has a proportion value of 0.074. Then on PC2, the proportion is 0.162 divided by 1 indicator, namely porosity. In PC3 the proportion is 0.150 divided by 1 indicator, namely BS. After getting the proportion value for each indicator, then calculate the weight index of the MDS indicator (Table 7).

Table 8. MDS indicator score

Treatment	Available P	Organic carbon	Total N	Available K	CEC	C-Mic	Porosity	BS
A0M0	1	1	1	2	1	1	5	2
A0M1	2	1	2	4	2	1	5	2
A0M2	2	1	3	3	2	1	5	2
A1M0	2	1	3	4	2	1	5	2
A1M1	2	1	3	4	2	1	5	2
A1M2	2	1	3	4	2	1	5	2
A2M0	2	1	3	4	2	1	5	2
A2M1	2	1	3	4	2	1	5	2
A2M2	2	1	3	4	2	1	5	3
A3M0	2	1	3	4	2	1	5	2
A3M1	2	1	3	4	2	1	5	2
A3M2	2	1	3	4	2	1	5	3

Remark: A0 = Azolla 0 tons ha^{-1}, A1 = Azolla 50 tons ha^{-1}, A2 = Azolla 100 tons ha^{-1}, A3 = Azolla 150 tons ha^{-1}, M0 = Chicken Manure 0 tons ha^{-1}, M1 = Chicken Manure 20 tons ha^{-1}, M2 = Chicken Manure 40 tons ha^{-1}, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass

Table 9. Result of soil quality index assessment

Treatment	Wi × Si								SQI	Class
	Por	SOC	Total N	Av-P	Av-K	CEC	BS	C-Mic		
A0M0	1.075	0.098	0.098	0.098	0.196	0.098	0.398	0.098	0.29 c	Low
A0M1	1.075	0.098	0.196	0.196	0.392	0.196	0.398	0.098	0.33 bc	Low
A0M2	1.075	0.098	0.294	0.196	0.294	0.196	0.398	0.098	0.34 ab	Low
A1M0	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.33 b	Low
A1M1	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.34 ab	Low
A1M2	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.34 ab	Low
A2M0	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.34 ab	Low
A2M1	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.35 ab	Moderate
A2M2	1.075	0.098	0.294	0.196	0.392	0.196	0.597	0.098	0.36 a	Moderate
A3M0	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.34 ab	Low
A3M1	1.075	0.098	0.294	0.196	0.392	0.196	0.398	0.098	0.35 ab	Moderate
A3M2	1.075	0.098	0.294	0.196	0.392	0.196	0.597	0.098	0.36 a	Moderate
Azolla (A)									0.007*	
Chicken Manure (M)									0.000**	
A × M									0.000**	

Remark: A0 = Azolla 0 tons ha^{-1}, A1 = Azolla 50 tons ha^{-1}, A2 = Azolla 100 tons ha^{-1}, A3 = Azolla 150 tons ha^{-1}, M0 = Chicken Manure 0 tons ha^{-1}, M1 = Chicken Manure 20 tons ha^{-1}, M2 = Chicken Manure 40 tons ha^{-1}, Por = Porosity, SOC = Soil Organic Carbon, Av-P = Available P, Av-K = Available K, CEC = Cation Exchange Capacity, BS = Base Saturation, C-Mic = C Microbial Biomass, Wi = Weight index, Si = Score indicator, SQI = Soil Quality Index, * = significant; ** = very significant; ns = not significant

Table 8 shows the indicator scores based on Table 2. The score of the available P and cation exchange capacity (CEC) indicator in all treatments is 2, except for the control treatment (A0M0) which has a score of 1. Soil organic carbon and C microbial biomass in all treatments have a score of 1. Total N has a score of 3, except for the control treatment (A0M0) the score is 1 and the A0M1 treatment has a score of 2. The available K indicator score in all treatments is 4, except for the A0M0 treatment which has a score of 2 and the A0M2 treatment has a score of 3. The porosity indicator score on all treatments was 5. While the base saturation (BS) indicator score in all treatments was 2, except for the A2M2 and A3M2 treatments which had a score of 3.

b. Calculation of SQI

The calculation of the soil quality index for each treatment is listed in Table 9 and based on formula 1. SQI values ranged from 0.29 to 0.36 with a low to moderate category. The results of variance showed that SQI was influenced by the application of azolla and chicken manure (p = 0.000).

3. Calculation of harvest index (HI)

The rice harvest index is calculated by dividing the weight of grain harvested by the total plant biomass (formula 2). Table 10 shows that azolla and chicken manure significantly increased the straw yield (p = 0.000), grain yield (p = 0.000), and harvest index (p = 0.014). The value of straw yield ranged from 3.40-109.93, grain yield ranged from 0.71-36.91 and the harvest index value ranged from 17.28-25.57.

Table 10. Result of rice harvest index calculation.

Treatment	Straw yield	Grain yield	HI
A0M0	3.40 e	0.71 e	17.28 c
A0M1	48.54 bc	14.42 cd	22.62 ab
A0M2	19.61 cd	5.87 de	23.13 ab
A1M0	23.48 cd	6.13 de	20.88 b
A1M1	84.67 ab	26.03 abc	23.59 ab
A1M2	19.63 cd	6.02 de	24.29 a
A2M0	45.47 bcd	13.52 cde	22.87 ab
A2M1	109.93 a	36.91 a	25.57 a
A2M2	18.11 cd	5.89 de	24.66 a
A3M0	59.43 bc	17.53 bcd	22.73 ab
A3M1	86.08 ab	29.62 ab	25.50 a
A3M2	52.56 bc	17.11 bcd	24.52 a
Azolla (A)	0.109_{ns}	0.062_{ns}	0.102_{ns}
Chicken Manure (M)	0.001**	0.000**	0.000**
A × M	0.000**	0.000**	0.014*

Remark: A0 = Azolla 0 tons ha^{-1}, A1 = Azolla 50 tons ha^{-1}, A2 = Azolla 100 tons ha^{-1}, A3 = Azolla 150 tons ha^{-1}, M0 = Chicken Manure 0 tons ha^{-1}, M1 = Chicken Manure 20 tons ha^{-1}, M2 = Chicken Manure 40 tons ha^{-1}, HI = Harvest Index, * = significant; ** = very significant; ns = not significant

Discussion

1. Sandy soil quality index

Azolla and chicken manure significantly interacted with the soil quality index (Table 9). This is because azolla is a green manure (Bordoloi et al., 2007) which has a high N fixing ability, reaching 1,2 kg N ha-1 per day (Talley et al., 1977), and can increase the soil organic carbon content (Bhuvaneshwari and Kumar, 2013). On the other hand, chicken manure is an organic mateter that can improve soil properties, including sandy soil in supplying soil nutrients such as N, P, K and cation exchange capacity (CEC) (Dikinya and Mufwanzala, 2010).

The application of azolla 100-150 tons ha^{-1} accompanied by 40 tons ha^{-1} chicken manure gave the highest soil quality index (SQI) of 0.36 (Table 9) and increased by 24.14% from the control. Increasing the SQI value has been able to improve soil quality index from low to moderate. This was caused by an increase in some soil properties due to the application of azolla and chicken manure.

There is a positive correlation between SQI and soil organic carbon (r = 0.744). Soil organic carbon is the most important parameter and the most influential on soil quality index (Ghaemi et al., 2014). The application of azolla and chicken manure was able to increase the organic matter content and availability of nutrients in the soil, such as soil organic carbon (Blanco-Canqui et al., 2013; Singh and Singh, 1987), N, P, K, cation exchange capacity (CEC) content (Muddarisna and Priyono, 2009) and C microbial biomass (Kusumawati and Prayogo, 2019). This is supported by the positive correlation between SQI and total N (r = 0.717), available P (r = 0.845), available K (r = 0.784), CEC (r = 0.586) and C microbial biomass (r = 0.490).

Improving the quality of sandy soil can be done by applying organic matter in the form of azolla at a dose of 100-150 tons ha^{-1} and chicken manure 40 tons ha^{-1}. This is in line with the results of Partoyo's (2005) research which states that the addition of manure and clay on the sandy soil of Samas beach, Bantul can improve the soil quality index to a moderate class. Arifin et al., (2018) also stated that improving soil quality index from low to moderate requires an input of 5 tons ha^{-1} of organic fertilizer (farmyard manure, green manure, or both) and 50% recommended fertilizer.

2. Rice harvest index on sandy soil

The harvest index describes the ratio between crop yields and total plant biomass (Haque et al., 2015), which is influenced by the amount of photosynthate translocation. The higher the crop yield index indicates that the photosynthate yield in the canopy is translocated to the rice grains, which will increase the grain yield (Safriyani et al., 2019).

The application of azolla and chicken manure significantly increased the rice harvest index (Table 10). These results are in line with research by Bharati et al., (2000) that azolla combined with other fertilizers will provide a significant increase in grain yield. The nutrient content of azolla and chicken manure fulfills the elements needed by plants, including NPK elements, especially P elements which play an important role in filling rice grains (Afif et al., 2014). This can be shown by the positive correlation between harvest index and total N (r = 0.613), Available P (r = 0.760) and Available K (r = 0.414). N is an important element in increasing plant biomass because of its main role in plant vegetative growth (Leghari et al., 2016)so, it is compulsory supplied to plants. It is top most 100% deficient in Pakistani soils due to low organic matter content, additionally, various factors are associated with the insufficiency such as improper application, methods, timings and harvesting causes losses through volatilization, leaching, denitrification and crop removals etc. An estimate 78-79% N is available in the atmosphere in inert structure (N2, P and K elements play a role in stimulating seed filling so that it affects increasing grain yield (Datta, 1981).

Increasing the dose of azolla and chicken manure did not give a significant difference in harvest index in all treatments except control (Table 10). According to Yang and Zhang (2010)if defined as the biomass accumulation over water consumed, may be fairly constant for a given species in given climate. WUE can be enhanced by less irrigation. However, such enhancement is largely a trade-off against lower biomass production. If WUE is defined as the grain production per unit amount of water irrigated, it would be possible to increase WUE without compromising grain yield through the manipulation of harvest index. Harvest index has been shown to be a variable factor in crop production, and in many situations, it is closely associated with WUE and grain yield in cereals. Taking rice as an example, this paper discussed crop management techniques that can enhance harvest index. Several practices such as post-anthesis controlled soil drying, alternate wetting and moderate soil drying regimes during the whole growing season, and non-flooded straw mulching cultivation, could substantially enhance WUE and maintain or even increase grain yield of rice, mainly via improved canopy structure, source activity, sink strength, and enhanced remobilization of pre-stored carbon reserves from vegetative tissues to grains. All the work has proved that a proper crop management holds great promise to enhance harvest index and, consequently, achieve the dual goal of increasing grain production and saving water. © 2010 The Author(s the optimal rice harvest index varies between 17%-56%. Hambali and Lubis (2015) reported that the average rice harvest index for high-yielding varieties is 50%. Meanwhile, the highest harvest index was found in the application of azolla 100 tons ha^{-1} and chicken manure 40 tons ha^{-1} (A2M1) at 25.57% or less than 50%, so other efforts still need to be made to achieve the ideal rice harvest index. The rice harvest index is very closely correlated with the soil quality index (r = 0.645) which is presented in Figure 2. This shows that every increase in the soil quality index is followed by an increase in the rice harvest index.

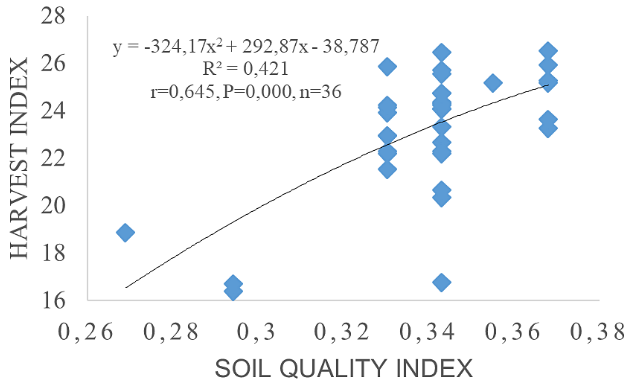

Fig. 2. Correlation between soil quality index (SQI) and harvest index (HI)

Conclusion

Soil quality index and rice harvest index in sandy soil increased with the application of azolla and chicken manure. The highest SQI was obtained at azolla 100-150 tons ha^{-1} with chicken manure 40 tons ha^{-1} giving an index of 0.36 (moderate class) and an increase of 24.14% from control. Meanwhile, the use of azolla 100 tons ha^{-1} with chicken manure 20 tons ha^{-1} (A2M1) gave the highest rice yield index of 25.57% and an increase of 47.97% from the control. Soil quality index is positively correlated with rice harvest index (r = 0.645**). The use of azolla and chicken manure has not provided maximum soil quality index but has been able to improve the quality of sandy soil from low to moderate class.

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