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Evaluation of Soil Quality and Macrofauna Abundance in Three Agricultural Systems in Subak Abasan, Badung Regency

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ABSTRACT: Soil quality is a key factor in supporting sustainable agricultural productivity. This study aims to evaluate soil quality and macrofauna abundance in three different agricultural systems (organic, semi-organic, and conventional) in Subak Abasan, Badung Regency. The study employed Lal's method (1994) for soil quality evaluation by analyzing 10 Minimum Data Set (MDS) parameters encompassing physical, chemical, and biological soil properties. Soil macrofauna were collected using pitfall trap and monolith (hand sorting) methods. The results showed that the Soil Quality Index (SQI) for the organic system was 18.33 (very good category), semi-organic system 20.00 (good category), and conventional system 20.00 (good category). The highest macrofauna abundance was found in the organic system with 0.693 ind/m^2 and earthworm abundance of 1,696 ind/m^2, which were 5.66 times and 2.94 times higher respectively compared to the conventional system. The Shannon-Wiener diversity index showed the highest H' value in the organic system (1.605) with moderate category, followed by semi-organic system (1.540) and conventional system (1.312). The highest Evenness Index was found in the semi-organic system (E = 0.791 - high category) indicating a stable community, while the lowest dominance index was also in the semi-organic system (C = 0.220 - low category) indicating no species was highly dominant. Organic and semi-organic agricultural systems showed conditions more supportive of macrofauna abundance and diversity compared to the conventional system. The relationship between soil quality and macrofauna abundance indicates that biological parameters (microbial biomass-C) are better predictors of macrofauna abundance than traditional physical-chemical parameters, suggesting the need to integrate biological parameters with greater weight in soil quality assessment systems.

KEYWORDS: Soil Quality Assessment, Soil Macrofauna, Organic Farming Systems, Agricultural Sustainability, Subak Irrigation System

I. INTRODUCTION

Soil is a fundamental component in agricultural systems that serves as a growing medium for plants and habitat for various organisms. Soil quality is defined as the capacity of soil to support plant and animal productivity, maintain or improve water and air quality, and support human health and habitat (Li *et al.*, 2023). Soil quality evaluation is important for assessing conditions and identifying changes that occur due to applied management practices.

In Bali, particularly within the subak system, there is diversity in rice farming systems applied, namely organic, semi-organic, and conventional. The subak system as a Balinese agricultural cultural heritage not only functions as an irrigation system but also plays a role in preserving sustainable agricultural practices (Windia *et al.*, 2022). These differences in agricultural practices have significant effects on soil quality and soil organism abundance.

Soil macrofauna have proven to be effective bioindicators in evaluating soil quality. Macrofauna play vital roles in organic matter decomposition processes, soil structure formation, and nutrient and water cycling (Tauro *et al.*, 2021). High macrofauna abundance and diversity indicate good soil conditions. Macrofauna presence is greatly influenced by environmental conditions and land management practices.

Subak Abasan in Mengwi District, Badung Regency, represents a traditional Balinese irrigation system that remains active in wetland rice cultivation. The uniqueness of this area lies in the presence of three agricultural systems applied simultaneously in the same planting season, providing an ideal opportunity to examine the impact of agricultural practices on soil quality and macrofauna abundance. This study aims to analyze the differences in soil quality and macrofauna abundance in these three agricultural systems and to evaluate the relationship between soil quality and macrofauna abundance.

II. RESEARCH METHODS

The research was conducted in Subak Abasan, Sembung Village, Mengwi District, Badung Regency, Bali with an agricultural area of 12 hectares. Subak Abasan is located at coordinates -8.476991, 115.187356. The research was conducted from January to April 2025, at the end of the planting season and before soil preparation for the next planting season. Laboratory analysis was conducted at the Soil Science and Environment Laboratory, Faculty of Agriculture, Udayana University. Sampling point determination used the *stratified random sampling* method based on agricultural systems. Three Homogeneous Land Units (HLU) were established: HLU I (organic), HLU II (semi-organic), and HLU III (conventional). In each HLU, 3 sampling points were randomly determined with 3 replications, resulting in a total of 27 sampling points. Soil samples were collected at a depth of 0-30 cm using a soil auger. Soil quality parameters analyzed referred to Lal's method (1994) which includes 10 Minimum Data Set (MDS).

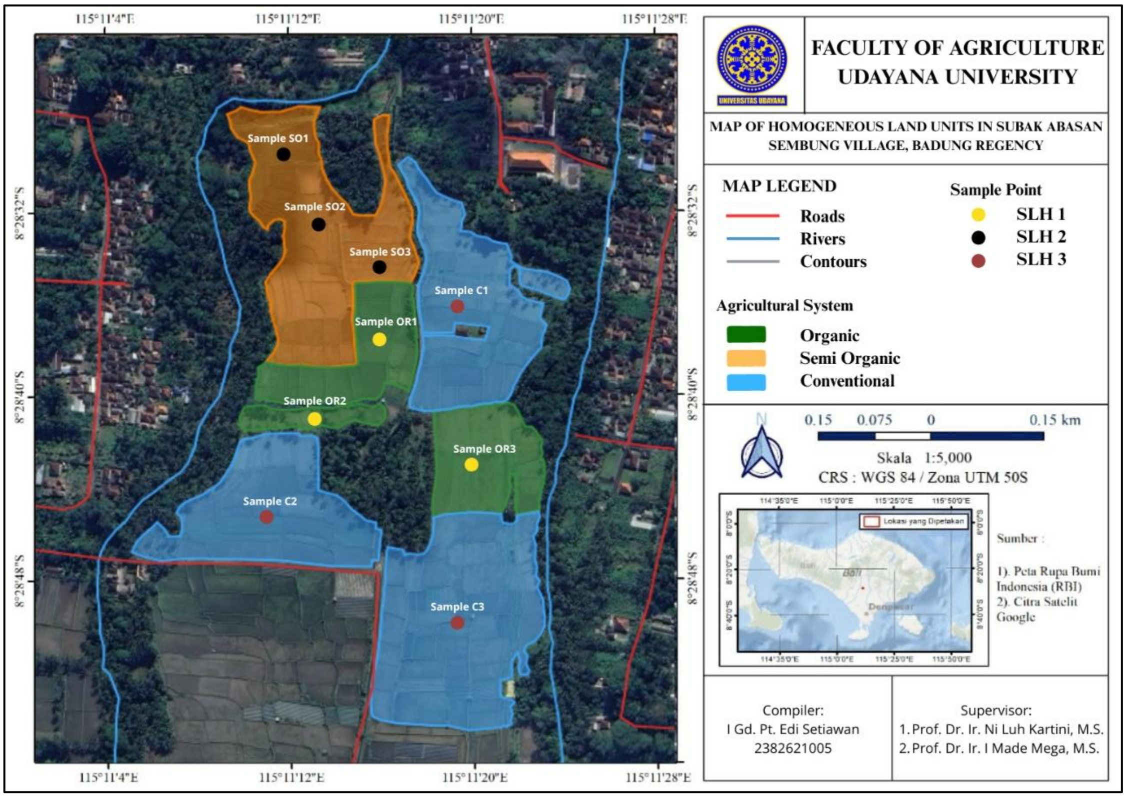

Figure 1. Map of Homogeneous Land Units in Subak Abasan, Badung Regency

A. *Soil Quality Index (SQI)*

Soil quality analysis was conducted by calculating the Soil Quality Index (SQI). First, laboratory analysis results on physical, chemical, and biological soil property parameters were tabulated. Next, the analysis data were categorized as limiting factors based on the relative weighting of soil quality indicators according to Lal (1994). The Soil Quality Index (SQI) was calculated using the formula:

SQI = SP + SC + SB

Where:

SQI : Soil Quality Index

SP : Physical Soil Property Parameters

SC : Chemical Soil Property Parameters

SB : Biological Soil Property Parameters

Where SP is the score of physical property parameters, SC is the score of chemical property parameters, and SB is the score of biological property parameters. Each parameter is given a weight of 1-5 based on the limiting level according to Lal (1994).

Table 1. Limiting Factors and Relative Weighting of Soil Quality Indicators

No.	Indicator	Limiting Factors and Relative Weighting				
		None	Slight	Moderate	Severe	Extreme
		1	2	3	4	5
1	Bulk Density (g cm^{-3})	<1,2	1,3-1,4	1,4-1,5	1,5-1,6	>1,6
2	Soil Texture	L	SiL, Si, SiCL	CL, SL	SiC, LS	S, C
3	Porosity (%)	>20	18-20	15-18	10-15	<10
4	Available Water Capacity (%)	>30	20-30	8-20	2-8	<2
5	Organic carbon (%)	5-10	3-5	1-3	0,5-1	<0,5
6	pH	6,0-7,0	5,8-6,0	5,4-5,8	5,0-5,4	<5,0
7	Cation Exchange Capacity (me/100g)	>40	25-40	17-24	5-16	<5
8	Base saturation (%)	>70	51-70	36-50	20-30	<20
9	Nutrient (N,P, and Po)					
	Total organic nitrogen (%)	>0,75	0,51- 0,75	0,21-0,50	0,10-0,20	<0,10
	Available phosphate (ppm)	>35	26-35	16-25	10-15	<10
	Available potassium (ppm)	>1,0	0,6-1,0	0,3-0,5	0,1-0,2	<0,1
10	C-micobial biomass (mg CO^2 kg^{-1})	>25	20-25	10-20	5-10	<5

Note : L=*Loam*; Si = *Silt*; S= *Sand*); C=*Clay*). Source : Lal (1994)

Table 2. Soil Quality Index Category

No.	**Index Range (SQI)**	**Soil Quality Category**
1	< 20	Very Good
2	20-25	Good
3	25-30	Moderate
4	30-40	Poor
5	> 40	Very Poor

Source : Lal (1994)

B. Analysis of Macrofauna Abundance and Diversity

Macrofauna were collected using the *pitfall trap* method for surface fauna and the *monolith (hand sorting)* method for subsurface fauna.

- ***Abundance Index***

The abundance index is measured to determine the population density of individuals. The formulas for population abundance and relative abundance of soil fauna calculations refer to Suin (2003) as follows:

Population Abundance (K):

$$\mathrm{K} = \frac{\boldsymbol{N}}{\boldsymbol{A}}$$

Where :

K = Population abundance of species-i (individuals/m²)

N = Number of individuals of a species found

A = Number of sample units or area

Relative Abundance(KR) :

$$\mathrm{KR} = \frac{\boldsymbol{K}}{\sum \boldsymbol{KN}} \, \boldsymbol{x}\ \mathbf{100}\%$$

Where:

KR = Relative abundance of species-i (%)

K = Population abundance of species-i

KN = Total abundance of all species

Interpretation:

- If N represents beneficial fauna species for agriculture, higher K or KR values indicate that soil and crop management is moving towards sustainable crop cultivation.
- If N represents harmful fauna species for agriculture, higher K or KR values indicate that soil and crop management is ecologically unfavorable and at certain thresholds threatens sustainable crop cultivation. This is also influenced by the abundance of other soil fauna acting as predators of the harmful fauna species.

- ***Shannon-Wiener Diversity Index (H')***

  Soil macrofauna diversity was analyzed using the Shannon-Wiener method (1949) with the following formula:

$$\mathbf{H}' = \sum_{i=1}^{n} pi \ln pi$$

Where:
H' = Shannon-Wiener diversity index
pi = ni/N (proportion of species i)
ni = Number of individuals of species i
N = Total number of individuals of all species
ln = Natural logarithm

Criteria for Shannon-Wiener diversity index values:
H' < 1.0 = Low diversity
1.0 ≤ H' ≤ 3.0 = Moderate diversity
H' > 3.0 = High diversity

- ***Evenness Index (E)***

The Evenness Index is a measure that shows how evenly the number of individuals is distributed among species in a community. The formula for the Evenness Index is:

$$E = \frac{H'}{\ln S}$$

Where:
E = Evenness Index (Pielou's J)
H' = Shannon-Wiener Index calculated
S = Number of species found
ln = Natural logarithm

Criteria for Evenness Index values:
0 < E ≤ 0.4 = Low evenness
0.4 < E ≤ 0.6 = Moderate evenness
0.6 < E ≤ 1 = High evenness

- ***Dominance Index (C)***

This index focuses on species dominance, which is how much a species dominates the community. The formula for the Dominance Index (Simpson, 1949) is:

$$\mathbf{C} = \sum (pi)^2$$

Where:
C = Dominance Index
pi = Proportion of number of individuals of species i to total individuals
The Simpson Dominance Index value ranges from 0 to 1, with interpretation:

a. Value approaching 0: indicates no species dominates, or in other words high diversity
b. Value approaching 1: indicates there is a highly dominant species, or low diversity

Criteria for dominance index values:
0 < C ≤ 0.5 : Low dominance
0.5 < C ≤ 0.75 : Moderate dominance

0.75 < C ≤ 1 : High dominance

III. RESULTS

A. *Soil Quality Index (SQI)*

Soil quality evaluation in the three agricultural systems was conducted through laboratory analysis of physical property parameters including bulk density, soil texture, porosity, and field capacity water content, chemical property parameters including organic carbon content, soil pH, Cation Exchange Capacity (CEC), Base Saturation (BS), and macro-nutrient content of total N, available P, and available K, and biological property parameters measured through soil microbial biomass-C, where all these parameters were then weighted based on limiting factor levels using Lal's method (1994) to calculate the Soil Quality Index (SQI) consisting of physical parameter score (SP), chemical parameter score (SC), and biological parameter score (SB), with complete analysis results along with weighting and soil quality categories for each agricultural system presented in Table 3.

Table 3. Results of Physical, Chemical, and Biological Property Analysis and Soil Quality Evaluation

Limiting Factors and Relative Weighting								
HLU	**Bulk Density (g cm⁻³)**	**Soil Texture**	**Porosity (%)**	**Field Capacity (%)**	**Organic-C (%)**	**pH**	**CEC (me/100g)**	**BS (%)**
1	2	3	4	5	6	7	8	9
I	1,103(1)	Clay Loam(3)	35,5(1)	35,620(1)	3,030(2)	6,800(1)	35,330(2)	89,320(1)
II	1,232(2)	Clay Loam (3)	33,5(1)	34,540(1)	2,180(3)	6,720(1)	26,180(2)	88,890(1)
III	1,323(2)	Clay Loam (3)	31,0(1)	33,490(1)	2,160(3)	6,730(1)	22,800(3)	70,440(1)

Note: *Relative weight & Limiting Factors: (1) None, (2) Slight, (3) Moderate, (4) Severe, (5) Extreme*

(Continued)

Nutrient			**Average Nutrient Weight**	**Microbial Biomass-C (mg CO_2 kg⁻¹)**	**Soil Quality**			
Total-N (%)	**Available-P (ppm)**	**Available-K (ppm)**			**SP**	**SC**	**SB**	**SQI**
10	11	12	13	14	15	16	17	18
0,160(4)	9,310(5)	186,170(1)	3,33	19,07(3)	6	9,33	3	18,33
0,180(4)	10,090(4)	197,090(1)	3,00	18,55(3)	7	10,00	3	20,00
0,200(4)	12,430(4)	191,670(1)	3,00	7,70(4)	7	11,00	4	22,00

Note: *Relative weight & Limiting Factors: (1) None, (2) Slight, (3) Moderate, (4) Severe, (5) Extreme*

Based on soil quality assessment criteria according to Lal (1994), the organic farming system obtained an SQI value of 18.33 which is in the very good category (SQI < 20), the semi-organic system obtained an SQI value of 20.00 which is in the good category (SQI 20-25), and the conventional system obtained an SQI value of 22.00 which is also in the good category (SQI 20-25).

B. *Macrofauna Abundance and Diversity*

- ***Abundance Index***

Based on observations of macrofauna abundance in Subak Abasan, Badung Regency, significant differences in population distribution were found among the three agricultural systems studied. In general, land with organic farming systems showed the highest levels of individual abundance and species diversity compared to semi-organic and conventional systems, as presented in the graph below.

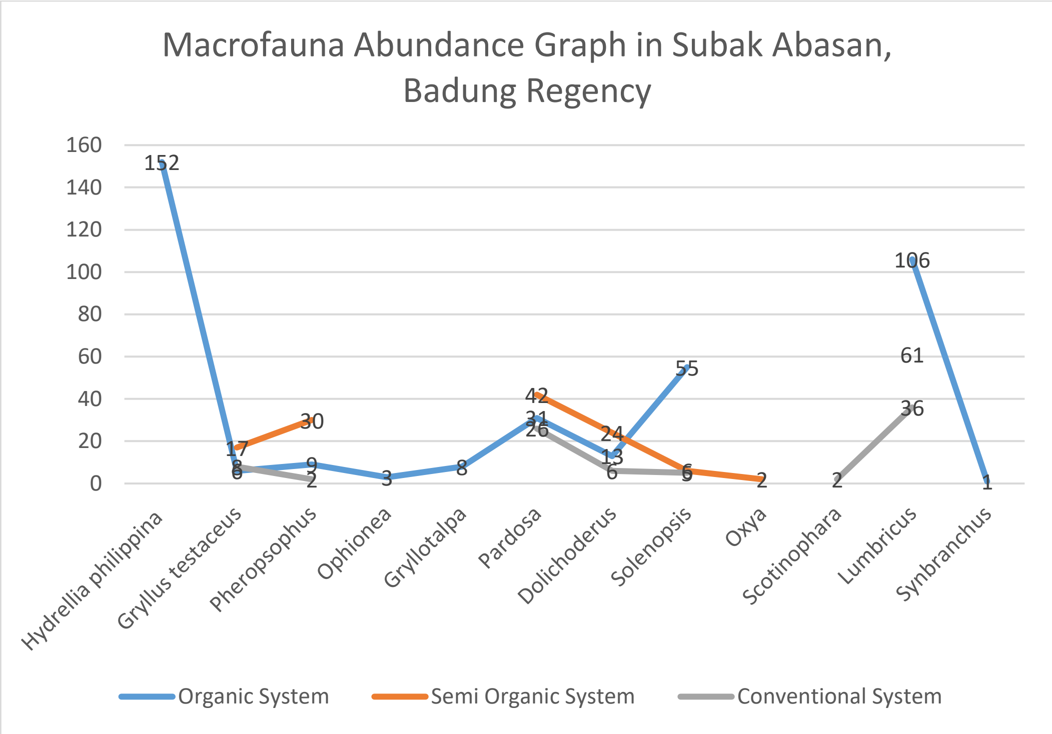

Figure 2: would be inserted here: Graph of Macrofauna Abundance in Subak Abasan, Badung Regency

Observation of surface soil macrofauna was conducted using the pitfall trap method installed in each agricultural system to capture fauna active on the soil surface, where each individual macrofauna caught was identified to genus level and its abundance counted in units of individuals per square meter (ind/m²), then relative abundance (RA) calculations were performed to determine the percentage contribution of each genus to the total macrofauna population in each agricultural system, with population abundance and relative abundance data from various families and genera of macrofauna found in organic (HLU I), semi-organic (HLU II), and conventional (HLU III) systems presented in detail in Table 4.

Table 4. Surface Soil Macrofauna Abundance (Pitfall Trap Method)

Family	Genus	K (ind/m2)			KR (%)		
		HLU I	HLU II	HLU III	HLU I	HLU II	HLU III
Muscidae	Hydrellia philippina	0.380	0.000	0.000	54.87	0.000	0.000
Gryllidae	Gryllus testaceus	0.015	0.043	0.020	2.17	14.05	16.33
Carabidae	Pheropsophus	0.023	0.075	0.005	3.25	24.79	4.08
	Ophionea	0.008	0.000	0.000	1.08	0.000	0.000
Gryllotalpidae	Gryllotalpa	0.020	0.000	0.000	2.89	0.000	0.000
Lycosidae	Pardosa	0.078	0.105	0.065	11.19	34.71	53.06
Formicidae	Dolichoderus	0.033	0.060	0.015	4.69	19.84	12.25
	Solenopsis	0.138	0.015	0.013	19.87	4.96	10.20
Acrididae	Oxya	0.000	0.005	0.000	0.000	1.65	0.000
Pentatomidae	Scotinophara	0.000	0.000	0.005	0.000	0.000	4.08
	∑n	0.693	0.303	0.123	100.00	100.00	100.00

Earthworm (Lumbricidae) sampling was conducted using the monolith or hand sorting method at three different soil depth layers of 0-10 cm, 10-20 cm, and 20-30 cm to determine the vertical distribution of earthworm populations in each agricultural system, where each earthworm individual found at each depth was counted and identified based on family and genus, then abundance calculations were performed in units of individuals per square meter (ind/m²) and relative abundance (RA) in percentage to determine the proportion of earthworm distribution at each depth layer, with complete earthworm abundance data at various depths for the three organic (HLU I), semi-organic (HLU II), and conventional (HLU III) agricultural systems displayed in Table 5.

Table 5. Earthworm Abundance at Various Depths (Monolith Method)

Family	Genus	Depth (cm)	K (ind/m2)			KR (%)		
			HLU I	HLU II	HLU III	HLU I	HLU II	HLU III
Lumbricidae	Lumbricus	0-10	816	304	160	47.66	31.15	27.78
		10-20	576	512	336	33.64	52.46	58.33
		20-30	304	160	80	17.76	16.39	13.89
		∑n	1696	976	576	99.07	100.00	100.00
Synbranchidae	Synbranchus	10-20	16	0	0	0.93	0.00	0.00
		∑n	16	0	0	0.93	0.00	0.00
		∑N	1712	976	576	100.00	100.00	100.00

- ***Shannon-Wiener Diversity Index (H'), Species Evenness (E), Species Dominance (C)***

Ecological analysis of soil macrofauna communities was conducted by calculating several ecological indices based on data on the number of individuals (N) and number of species (S) found in each agricultural system, including the Shannon-Wiener Diversity Index (H') to measure the level of species diversity in the macrofauna community with criteria of low ($H' < 1.0$), moderate ($1.0 \leq H' \leq 3.0$), or high ($H' > 3.0$), Species Evenness Index (E) to determine the distribution of individual numbers among species with criteria of low ($0 < E \leq 0.4$), moderate ($0.4 < E \leq 0.6$), or high ($0.6 < E \leq 1$), and Simpson Dominance Index (C) to measure the level of dominance of a species in the community with criteria of low ($0 < C \leq 0.5$), moderate ($0.5 < C \leq 0.75$), or high ($0.75 < C \leq 1$), with calculation results of the three ecological indices along with the number of individuals and number of species in organic (HLU I), semi-organic (HLU II), and conventional (HLU III) systems presented comprehensively in Table 6.

Table 6. Soil Macrofauna Diversity, Evenness, and Dominance Indices

Family	Genus	Agricultural System		
		Organic (SLH I)	Semi Organic (SLH II)	Conventional (SLH III)
Muscidae	Hydrellia philippina	152	-	-
Gryllidae	Gryllus testaceus	6	17	8
Carabidae	Pheropsophus	9	30	2
	Ophionea	3	-	-
Gryllotalpidae	Gryllotalpa	8	-	-
Lycosidae	Pardosa	31	42	26
Formicidae	Dolichoderus	13	24	6
	Solenopsis	55	6	5
Acrididae	Oxya	-	2	-
Pentatomidae	Scotinophara	-	-	2
Lumbricidae	Lumbricus	106	61	36
Synbranchidae	Synbranchus	1	-	-
	N	384	182	85
	S	10	7	7
	H'	1.605	1.540	1.312
	Categori	Moderate	Moderate	Moderate
	E	0.697	0.791	0.674
	Categori	High	High	High
	C	0.262	0.220	0.291
	Categori	Low	Low	Low

Note: Number of Individuals (N), Number of Species (S), Shannon-Wiener Index (H'), Evenness Index (E),Dominance Index (C)

C. Relationship Between Soil Quality and Macrofauna Abundance Across Three Agricultural Systems

A relationship analysis was conducted to identify the linkages and correlation patterns between soil quality parameters and macrofauna abundance and diversity across the three agricultural systems in Subak Abasan, where the analysis included evaluation of how soil physical parameters (bulk density, texture, porosity) affect macrofauna distribution and abundance, how soil chemical parameters (organic-C, pH, CEC, base saturation, and nutrient content) correlate with macrofauna presence and activity, and how soil biological parameters (microbial biomass-C) relate to macrofauna population abundance, followed by analysis of whether the Soil Quality Index (SQI), which represents the integration of physical, chemical, and biological parameters, can serve as an accurate predictor for macrofauna abundance and diversity, or whether specific parameters have more dominant influence, as well as identification of the main limiting factors that determine macrofauna communities in each of the organic (HLU I), semi-organic (HLU II), and conventional (HLU III) agricultural systems to provide a comprehensive understanding of the interactions between soil conditions and soil fauna biodiversity in the context of sustainable agriculture.

IV. DISCUSSION

A. Soil Quality Index (SQI)

Laboratory analysis results showed differences in soil characteristics across the three agricultural systems (Table 3). Soil physical parameters indicated that soil texture in HLU I and III was classified as Clay Loam (CL), while HLU II was classified as Clay (C). Bulk density ranged from 1.103-1.323 g/cm³, with the lowest value in the conventional system (1.103 g/cm³) and the highest in the organic system (1.323 g/cm³). Soil porosity ranged from 31.0-35.5%, with the highest value in the conventional system (35.5%).

Chemical parameters showed the highest organic-C content in the semi-organic system (3.03%) and the lowest in the conventional system (2.18%). Soil pH values were relatively neutral across all three systems (6.72-6.80). The highest Cation Exchange Capacity (CEC) was found in the semi-organic system (35.33 me/100g), while base saturation ranged from 70.44-89.32%. Total-N content was classified as low in all three systems (0.16-0.20%), with the highest value in the conventional system (0.20%). Available-P was classified as very low in all systems (9.31-12.43 ppm), with the highest value in the conventional system (12.43 ppm). Conversely, available-K was classified as very high in all systems (186.17-197.09 ppm), with the highest value in the semi-organic system (197.09 ppm).

Biological parameters measured through soil microbial biomass-C showed the highest value in the organic system (19.07 mg CO_2 kg^{-1}) and the lowest in the conventional system (7.70 mg CO_2 kg^{-1}). This indicates higher soil microorganism activity in the organic system compared to the conventional system. The semi-organic system showed a microbial biomass-C value of 18.55 mg CO_2 kg^{-1}, which was not significantly different from the organic system.

Based on parameter weighting using the Lal (1994) method, the Soil Quality Index (SQI) showed values of 18.33 for the organic system (very good category), 20.00 for the semi-organic system (good category), and 22.00 for the conventional system (good category) (Table 3). The difference in SQI values among systems was relatively small, with only a 1.67-point difference between the organic and semi-organic systems. This indicates that all three agricultural systems in Subak Abasan still maintain good to very good soil quality.

The organic system had a physical parameter score (PS) of 6, semi-organic of 7, and conventional of 7. The chemical parameter score (CS) showed the organic system at 9.33, semi-organic at 10.00, and conventional at 11.00. Meanwhile, the biological parameter score (BS) showed that both organic and semi-organic systems had a value of 3, while the conventional system had a value of 4. Lower total scores indicate better soil quality because the Lal (1994) scoring system assigns higher weights to more severe limiting conditions.

These results are consistent with research by Kumar and Singh (2023), who stated that organic farming systems tend to have higher organic matter content compared to conventional systems, although some soil physical parameters may be better in conventional systems due to intensive soil cultivation. The higher organic-C content in the organic system (3.03%) indicates that organic matter input provides a positive contribution to soil fertility. According to Sharma and Mandal (2022), optimal organic-C content ranges from 3-5% to support sustainable agricultural productivity.

B. Macrofauna Abundance and Diversity

- ***Macrofauna Abundance***

Soil macrofauna observations using the pitfall trap method showed significant differences in abundance among agricultural systems. The highest macrofauna abundance was found in the organic system (0.693 ind/m²), which is classified as very high, followed by the semi-organic system (0.303 ind/m²), and the lowest in the conventional system (0.123 ind/m²) (Table 4). The organic system had macrofauna abundance 5.66 times higher than the conventional system, and 2.29 times higher than the semi-organic system.

The composition of surface macrofauna showed variation among systems. In the organic system, Muscidae (Hydrellia philippina) dominated with a relative abundance of 54.87%, followed by Formicidae (Solenopsis) with a relative abundance of 19.87% and Lycosidae with a relative abundance of 11.19%. The semi-organic system was dominated by Lycosidae (Pardosa) with a relative abundance of 34.71%, followed by Carabidae (Pheropsophus) with a relative abundance of 24.79% and Formicidae (Dolichoderus) with a relative abundance of 19.84%. Meanwhile, the conventional system was dominated by Lycosidae (Pardosa) with a relative abundance of 53.06%, followed by Formicidae (Dolichoderus) with a relative abundance of 22.45% and Gryllidae (Gryllus testaceus) with a relative abundance of 16.33%. The dominance of Muscidae in the organic system indicates the absence of chemical pesticide use in organic agricultural land, as this fauna is a pest for rice plants.

Earthworm abundance (Lumbricidae) measured using the monolith method also showed a similar pattern (Table 5). The organic system had the highest earthworm abundance (1,696 ind/m²), followed by semi-organic (976 ind/m²), and conventional (576 ind/m²). The organic system had earthworm abundance 2.94 times higher than the conventional system, and 1.74 times higher than the semi-organic system.

The vertical distribution of earthworms showed that the largest population was found in the 0-10 cm layer, indicating maximum activity in the surface soil layer rich in organic matter. In the organic system, 48.11% of earthworms were found in the 0-10 cm layer, 33.96% in the 10-20 cm layer, and 17.92% in the 20-30 cm layer. A similar distribution pattern was found in the semi-organic and conventional systems, although with lower total abundance. In addition to earthworms, Synbranchus (rice field eel) was also found in the organic system with an abundance of 16 ind/m² at a depth of 10-20 cm, which was not found in other systems.

- ***Macrofauna Diversity***

Diversity analysis using the Shannon-Wiener index showed interesting results (Table 6). The highest diversity index was found in the semi-organic system (H' = 1.570) with a moderate category, followed by the organic system (H' = 1.519) and conventional system (H' = 1.390), all three falling within the moderate category. Although the organic system had the highest abundance (N = 384 individuals), its species diversity was slightly lower than the semi-organic system. This indicates that high abundance is not always directly proportional to species diversity.

The organic system had the highest number of species (S) at 10 species, while the semi-organic and conventional systems each had 7 species. However, the higher H' value in the semi-organic system indicates a more even distribution of individuals among species compared to the organic system, which had higher dominance by certain species (Muscidae).

The highest Evenness Index (E) was found in the semi-organic system (0.876), classified as high, showing a very even distribution of individuals among species and indicating a stable community. The conventional system showed an E value of 0.776 (high category), while the organic system had an E value of 0.691 (high category). The high E values across all three systems (>0.6) indicate no extreme dominance by any particular species, although the semi-organic system showed the most optimal evenness.

Simpson's Dominance Index (C) showed low values across all three systems: 0.262 for the organic system, 0.220 for semi-organic, and 0.291 for conventional. All C values fall within the low dominance category ($0 < C \le 0.5$), indicating that no species strongly dominates the community. The semi-organic system had the lowest C value, which is consistent with the highest E value, showing the most balanced macrofauna community.

These differences in macrofauna abundance and diversity are closely related to land management practices and soil conditions. The organic system, which relies on organic matter input without the use of synthetic pesticides, creates a more conducive habitat for soil macrofauna. This aligns with research by Winarto et al. (2022), who found higher macrofauna abundance in organic land compared to conventional in Central Java.

The higher earthworm abundance in the organic system demonstrates the importance of organic matter availability as a food source for earthworms. According to Tauro et al. (2021), earthworms play a vital role in improving soil structure through burrowing activities and the production of nutrient-rich casts. The decrease in earthworm abundance in the conventional system is likely caused by the use of pesticides and chemical fertilizers that can be toxic to earthworms.

The high diversity in the semi-organic system shows that this system is able to balance productivity and soil biodiversity conservation. The semi-organic system, which combines organic practices with limited chemical input use, can be a transitional alternative toward fully organic farming. These results support research by Zhang and Thompson (2024), who stated that semi-organic systems provide positive impacts on soil biota diversity while maintaining productivity.

C. Relationship Between Soil Quality and Macrofauna Abundance Across Three Agricultural Systems

The relationship between soil quality and macrofauna abundance across the three agricultural systems showed a complex and not always linear pattern. Although the conventional system had the lowest SQI (20.00), indicating very good soil quality, its macrofauna abundance was actually the lowest (5.44 ind/trap/day for surface macrofauna and 576 ind/m² for earthworms). Conversely, the organic system with the highest SQI (21.33) had the highest macrofauna abundance (30.78 ind/trap/day and 1,696 ind/m²). This indicates that soil quality evaluation methods based solely on physical-chemical parameters (SQI) do not fully reflect the ecological health of soil.

Microbial biomass-C parameter showed a strong positive correlation with macrofauna abundance. The organic system with the highest microbial biomass-C (19.07 mg CO_2 kg^{-1}) had the highest macrofauna abundance, while the conventional system with the lowest microbial biomass-C (7.70 mg CO_2 kg^{-1}) had the lowest macrofauna abundance. This indicates that soil microorganism activity is a better indicator for predicting macrofauna abundance compared to traditional physical-chemical parameters. According to Martinez et al. (2024), microorganism activity creates micro-environmental conditions that support macrofauna presence, including food availability and habitat quality.

Organic-C content also showed a positive relationship with macrofauna abundance, although not entirely linear. The semi-organic system had the highest organic-C (3.03%) but its macrofauna abundance was in the middle position. The organic system with lower organic-C (2.16%) actually had the highest macrofauna abundance. This indicates that the quality of organic matter and the absence of synthetic pesticide inputs may be more important than the quantity of organic-C alone. Research by Suryani et al. (2023) in Bali's subak systems showed that the composition and decomposition rate of organic matter have more influence on macrofauna communities compared to total soil organic-C.

Soil physical parameters such as bulk density and porosity showed relationships contrary to theoretical expectations. The conventional system with the lowest bulk density (1.103 g/cm³) and highest porosity (35.5%) actually had the lowest macrofauna abundance. This indicates that intensive soil cultivation that produces optimal physical structure in the short term does not necessarily support macrofauna abundance. Repeated mechanical disturbance can actually disrupt the habitat and tunnel systems created by soil macrofauna, particularly earthworms.

The relationship between macrofauna diversity and soil quality showed a different pattern from abundance. The semi-organic system with an SQI of 21.00 had the highest H' value (1.570) and highest E value (0.876), indicating that this system provides the most balanced conditions for various types of macrofauna. This system appears to offer sufficiently diverse habitats with moderate disturbance levels, allowing the coexistence of various macrofauna species without extreme dominance by certain species.

The presence of synthetic pesticides appears to be the main limiting factor for macrofauna abundance, even more important than traditional soil quality parameters. The conventional system, despite having generally good physical-chemical parameters, experienced a drastic decline in macrofauna abundance due to the toxic effects of pesticides. This is consistent with research by Pratama et al. (2024), which showed that long-term pesticide exposure causes significant decreases in soil macrofauna abundance and diversity across various agricultural systems in Bali.

This analysis shows that comprehensive soil quality evaluation must integrate biological parameters, particularly macrofauna abundance and diversity, as soil health indicators. The Lal (1994) method used in this research, although it includes microbial biomass-C parameter, still assigns disproportionate weight to soil biological aspects. Research by Zhou et al. (2022) suggests that modern soil quality indices should give greater weight to biological indicators to reflect the ecological sustainability of agricultural systems.

V. CONCLUSIONS

All three agricultural systems in Subak Abasan have good to very good soil quality based on the Soil Quality Index (SQI), with SQI values of 21.33 for the organic system (good category), 21.00 for the semi-organic system (good category), and 20.00 for the conventional system (very good category). The conventional system showed superiority in soil physical parameters with the lowest bulk density (1.103 g/cm³) and highest porosity (35.5%), while the semi-organic system excelled in chemical parameters with the highest organic-C (3.03%) and highest CEC (35.33 me/100g). Soil biological parameters showed that the organic system had the highest microbial biomass-C (19.07 mg CO_2 kg^{-1}), nearly 2.5 times higher than the conventional system (7.70 mg CO_2 kg^{-1}).

Macrofauna abundance showed highly significant differences among systems, with the highest abundance in the organic system (30.78 ind/trap/day for surface macrofauna - very high category; 1,696 ind/m² for earthworms - moderate category). The organic system had surface macrofauna abundance 5.66 times higher than the conventional system (5.44 ind/trap/day - moderate category) and earthworm abundance 2.94 times higher than the conventional system (576 ind/m² - low category). The semi-organic system showed intermediate abundance with 13.44 ind/trap/day (high category) for surface macrofauna and 976 ind/m² (low category) for earthworms. The vertical distribution of earthworms showed the highest concentration in the 0-10 cm layer (47.66-27.78% of total population), indicating maximum activity in the surface layer rich in organic matter.

The highest Shannon-Wiener diversity index was found in the semi-organic system (H' = 1.570) with a moderate category, followed by the organic system (H' = 1.519) and conventional system (H' = 1.390), all three falling within the moderate category. The semi-organic system showed the highest Evenness Index (E = 0.876 - high category) and lowest Dominance Index (C = 0.229 - low category), indicating the most balanced macrofauna community with even distribution without extreme dominance by certain species. The organic system, despite having the highest abundance and the highest number of species (9 species), showed a lower E value (0.691) and higher C value (0.272) due to Muscidae dominance (54.87% relative abundance). All three systems showed high evenness (E > 0.6) and low dominance (C < 0.5), indicating relatively stable communities.

There were substantial differences in soil quality characteristics and macrofauna communities among the three agricultural systems. The conventional system showed a trade-off between optimal physical parameters (result of intensive cultivation) and low biological parameters (impact of pesticides and synthetic chemical fertilizers). The organic system showed significant advantages in soil biological aspects and macrofauna abundance despite having some limitations in certain physical-chemical parameters. The semi-organic system appears to offer an optimal balance among various parameters, with the highest macrofauna diversity and good chemical parameters, making it a potential transitional alternative toward sustainable agriculture.

The relationship between soil quality and macrofauna abundance showed that biological parameters (microbial biomass-C) are better predictors of macrofauna abundance compared to traditional physical-chemical parameters. The system with the lowest SQI (conventional - 20.00) actually had the lowest macrofauna abundance, indicating that soil quality evaluation methods based solely on physical-chemical parameters do not fully reflect the ecological health of soil. The presence of synthetic pesticides appears to be the main limiting factor that overrides the positive influence of good physical-chemical parameters. These results indicate the need to integrate biological parameters with greater weight in soil quality assessment systems to reflect the long-term ecological sustainability of agricultural systems.

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