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Research Article

Short-Term Response of Soil Organic Carbon Indices to Different Farming Strategies and Crop Rotation Systems in a Semiarid Warm Region

Aram Gorooei,[1] Amir Aynehband,[2] Dominik Behrend,[1] Sabine J. Seidel,[1] Amit Kumar Srivastava,[1,3] Afrasyab Rahnama,[2] and Thomas Gaiser[1]

[1]*The Institute of Crop Science and Resource Conservation (INRES), University of Bonn, Bonn 53115, Germany*
[2]*Faculty of Agriculture, Plant Production and Genetics Department, Shahid Chamran University of Ahvaz, Ahvaz 6135783151, Iran*
[3]*Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany*

Correspondence should be addressed to Aram Gorooei; gorooei@uni-bonn.de

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Several indices can be used to assess the impact of short-term conservation agriculture strategies on improving soil organic carbon (SOC). To find out how the SOC pools and the carbon lability influence the carbon management index (CMI) in response to different agricultural practices in a warm semiarid region, the carbon lability index (LI) and the carbon pool index (CPI) were measured under the interactive effect of different fertilizer applications and crop residue management (hereafter referred to as "farming strategies") in combination with four crop rotation systems in Ahvaz, Khuzestan, Iran, over four growing seasons from 2018 to 2020. The farming strategies were as follows: (1) using the standard rate of inorganic fertilizer used in the region and removing crop residues from the soil (SIF_no-CR); (2) applying the standard rate of organic fertilizers used in the region and returning 30% of crop residues to the soil (SOF_30% CR); and (3) integrating the use of inorganic and organic fertilizers and returning 15% of crop residues to the soil (IOF_15% CR). The crop rotation systems were fallow-wheat (F-W), corn-wheat (C-W), sesame-wheat (S-W), and mung bean-wheat (B-W). No statistically significant difference was observed between the different farming strategies and rotation systems with respect to LI after two years of the experiment. The highest (1.26) and lowest (1.06) CPIs were observed for SOF_30% CR and SIF_no-CR, respectively. The magnitude of the CMI values followed the order SOF_30% CR (121) > IOF_15% CR (107) ≥ SIF_no-CR (106). B-W and F-W had the highest and lowest CPI with values of 1.29 and 1.01, respectively. No statistically significant difference was found for the different crop rotation systems. Given the low impact of the common farming practices in the region, e.g., SIF_no-CR and F-W, on CPI and CMI at 24 months, our results showed that farming strategies with manure application and crop residue management and summer wheat-based rotation systems appear to be more appropriate farming strategies to improve CMI in arable land.

1. Introduction

The dynamics of organic carbon (C) in agricultural soils affect the C cycle, the global C budget, and the global climate change [1, 2]. C sequestration in agricultural soils has been known to be one of the major agents in reducing atmospheric C [3], increasing soil organic carbon (SOC), and improving crop productivity [4]. SOC plays a vital role in assessing soil quality as it has compound effects on the geochemical and biological properties of the soil [5]. Agronomic management practices, e.g., tillage, fertilizer application, crop residue management, and cover crop types, strongly influence the potential for C sequestration in arable soils [6, 7]. However, short-term changes in total SOC are difficult to measure because a large fraction of SOC consists of stable C (hereafter referred to as nonlabile SOC) with a slow turnover in the soil (from 10 to 1000 years) [8]. On the other hand, many researchers have used labile soil organic carbon (labile-SOC) fractions such as microbial biomass C, particulate organic C, and $KMnO_4$ oxidised organic C ($KMnO_4$-C) as a sensitive indicator of management practices [9–11]. These fractions refer to small pools of SOC that are susceptible to short-term turnover [12]. Labile-SOC is essential to provide energy for microbial metabolism and plant growth due to its rapid decomposition [13]. It has been proposed as an important criterion for measuring soil productivity. This is due to its shorter turnover and the rapid transition between fresh crop residues and stabilized organic matter [9, 14, 15].

Blair et al. [16] introduced the C management index (CMI) which was derived by combining labile and nonlabile SOC. Subsequently, many researchers have used the CMI as a sensitive indicator for the investigation of the variation rate of SOC in response to agricultural management practices [2, 17–20]. The CMI is calculated by multiplying the C pool index (the ratio of SOC pools at the end of an experiment to the reference SOC) and the C lability index (the lability of C at the end of the experiment relative to the lability of C in the reference) [16]. According to [21], improvements in CMI due to agricultural practices occur when one or both of the SOC pools and the labile-C fractions increase in relation to the reference. For example, organic nutrient management and integrated fertilization (i.e., the application of both organic and inorganic fertilizers) improved CMI compared to the use of inorganic fertilizers alone by improving soil C pools and the labile C fraction of the soil [22]. In addition, incorporating crop residues with manure has been shown to be more beneficial in improving the SOC pool and therefore promoting CMI [23, 24]. These fertilization practices are more effective when combined with an appropriate crop rotation system. For instance, higher CMI values were obtained in a rye-potato rotation system than in the monoculture of each crop [25]. Crop rotation systems that including spring-sown legumes such as chickpea can significantly increase CMI compared to summer fallow [26].

It is assumed that agricultural management practices affecting different C inputs, e.g., organic fertilizer application, shoot and root residues, and root exudates would influence SOC fractions and CMI [26, 27]. A contribution to this body of knowledge can be made by understanding how SOC pools and their labile fractions contribute to changes in carbon management, especially in semi-arid regions with intensive irrigation water use. However, current studies have extensively investigated the effects of agricultural practices and different crop rotation systems on C lability and CMI [26]. Based on this, the main objective of this study is to determine the effect of short-term fertilizer application (organic and inorganic), combined with different types of crop residue management (henceforth referred to as farming strategies) as well as various wheat-based rotation systems with summer crops on the changes of SOC indices, namely, lability C index, C pool index (CPI), and CMI in irrigated systems under a semiarid warm climate in Iran.

2. Materials and Methods

2.1. Study Area. An experiment was conducted at the experimental farm of the Sahid Chamran University in Ahvaz, Khuzestan Province (48°39′35.2″E and 31°18′06.2″N, altitude: 22.5 m). The climate of Khuzestan is mainly semiarid and warm [28]. Favourable weather conditions during the winter season in Khuzestan have resulted in a large proportion of agricultural land being devoted to irrigated and rainfed wheat cultivation, making the province the country's leading wheat producer. The average temperature in the region is 25°C. The absolute maximum and minimum temperatures in summer and winter are 48°C and 4°C, respectively. The average annual rainfall is 213 mm yr^{-1}, with the highest intensity in January. The experimental soil is classified as sandy-loamy, consisting of 67% sand, 21% silt, and 12% clay. Soil analysis revealed a nitrogen content of 0.039%, a carbon content of 0.45%, a phosphorus concentration of 26 $kg{\cdot}ha^{-1}$, an available potassium concentration of 318 $kg{\cdot}ha^{-1}$, an electrical conductivity of 3.4 $dS{\cdot}m^{-1}$, and a pH of 7.8 [11].

2.2. Field Experimental Design. Twelve treatments were arranged in a randomized complete block design with three replications. Each treatment consisted of three main plots divided into four subplots. The size of the main plot and the subplot was 12 m × 4 m and 3 m × 4 m, respectively. The main plots consisted of three farming strategies as follows: (1) using the regional standard rate of the inorganic fertilizer and removing crop residues from the soil (SIF_no-CR), (2) applying the standard rate of organic fertilizer without any mineral fertilizer and returning 30% of crop residues to the soil (SOF_30% CR); and (3) integrating the use of inorganic and organic fertilizers and returning 15% of crop residues to the soil (IOF_15% CR) [29]. Four wheat double-cropping systems were grown in the subplots: wheat-fallow (W-F), wheat-corn (W-C), wheat-sesame (W-S), and wheat-mung bean (W-B).

The inorganic fertilizers used in this study included nitrogen (urea), solid phosphorus ($H_2PO_4^-$), and potassium (K_2SO_4). The total amount of mineral fertilizers used in the research is given in Table 1 for each farming strategy and cultivated crop. For the inorganic-based management strategies (SIF_no-CR and IOF_15% CR), all phosphorus, potassium, and two-thirds of the nitrogen were applied to the soil at the time of tillage. One-third of the nitrogen was applied at the time of crop tillering. In organic-based management (SOF_30% CR and IOF_15% CR), the manure used consisted of compost and vermicompost (Table 1). Compost and vermicompost were produced from cattle manure. The duration of composting and vermicomposting was five months. The air-dried manure fertilizers was spread on the surface of the experimental plots. It was completely mixed with the topsoil (20 cm) before planting the crops. Crop residues were returned to the soil after the harvest of each summer and winter crop. The residues were first chopped and then mixed with the top layer of the soil in the experimental plots. More details on the quantity and

Table 1: Type and amount of organic/inorganic fertilizers and crop residues applied for three farming strategies: SIF_no-CR (standard rates of inorganic fertilizer, no return of crop residues to the soil), SOF_30% CR (standard rates of organic fertilizer, returning 30% of crop residues to the soil), and IOF_15% CR (integrated use of organic/inorganic fertilizers, returning 15% of crop residues to the soil) and four crops: mung bean (B), corn (C), sesame (S), and wheat (W) at the experimental plots implemented in Ahvaz, Khuzestan.

Farming strategy	Crop	Organic inputs		Inorganic fertilizer (kg ha^{-1})
		Vermicompost + compost (t ha^{-1})	Crop residues retention (g m^{-2})	N-P-K
SIF_no-CR	B	—	Removed	30-50-50
	C	—	Removed	200-100-100
	S	—	Removed	75-50-50
	W	—	Removed	110-100-100
SOF_30% CR	B	3.3 + 10	228	—
	C	3.3 + 13.3	393	—
	S	3.3 + 10	129	—
	W	3.3 + 10	90	—
IOF_15% CR	B	1.7 + 5	114	15-25-25
	C	1.7 + 6.7	196.5	100-50-50
	S	1.7 + 5	64.5	32.5-25-25
	W	1.7 + 5	45	55-50-50

Physio-chemical properties	Compost	Vermi-compost	Crop residue			
			B	C	S	W
Carbon (%)	58	65	48.5	49.5	47.5	48.5
Nitrogen (%)	1.84	2.18	3.3	6.63×10^{-1}	2.8	6.84×10^{-1}
C/N ratio	31.5	29.8	14.7	74.6	16.96	70.9
pH	7.35	5.38	—	—	—	—
EC (dS/m)	3.1	5.38	—	—	—	—
Moisture (%)	15	10	5	2	5	0

physiochemical properties of the crop residues as well as manures applied to the soil are given in Table 1.

In the strategies under organic matter management strategies: SOF_30% CR and IOF_15% CR, humic acid ($5\,mL\cdot L^{-1}\cdot m^{-2}$), and biological phosphate fertilizer (3R-BioPhosphate with 35% of P, *Pseudomonas putida*, and *Pantoea agglomerans*: 10^7 bacteria gr^{-1}) were used. Humic acid was sprayed on the plant at the flowering stage of wheat growth. Biological phosphate was applied in powder form. One hour before planting, wheat seeds were soaked in a mixture of water and biological phosphate fertilizer. In addition, the dominant weed that was observed during the trail was *Cynodon dactylon* L. which was controlled with the herbicide Roundup (41% active substance glyphosate). The herbicide was applied once a year before the wheat was sown when weeds were still in active growth. Weed control was chemical for SIF + no-CR, manual for SOF + 30% CR, and chemical and manual for the IOF + 15% CR strategy [11].

The predominant crop management in the experimental field was conventional monocropping wheat with foliar spraying, except for one year before the start of this research, when wheat was grown with a combination of mineral and biological fertilizers.

The experiment started with the planting of summer crops on 5 July 2018. Figure 1 shows the different types of crop rotation systems during the experimental years. Detailed information, e.g., planting and harvesting dates, cultivation method, irrigation, and tillage for summer, and winter crops are highlighted in our published research [11]. All crops were irrigated. Water requirements for each crop were calculated using CROPWAT version 8.0 based on the crop coefficient and evapotranspiration [30]. Accordingly, the irrigation requirements **for the growing season** were 369, 347, 337, and 315 mm for wheat, corn, mung bean, and sesame, respectively.

2.3. Soil Sampling and Measurement of Carbon Fractions. Soil samples were taken at 20 cm (ploughing depth) below the surface before the start and at the end of the experiment. Each soil sample was obtained by collecting the soil from three locations on each experimental plot using a soil auger and mixing them as one sample. Soil samples were air-dried and sieved through a 2 mm mesh size before measuring total SOC and labile SOC. Total SOC was analysed according to the method proposed by [31]. The labile-SOC was determined using 333 mM $KMNO_4$, and then the nonlabile-SOC pools were estimated by deducting the labile-SOC from the total SOC [16, 32]. Detailed information on the measurement of SOC fractions is documented in [11]. The information and the range of the initial and final values for total SOC, labile-SOC, and nonlabile SOC are given in Table 2.

2.4. Determination of Soil Carbon Management Indices. The lability of C (LC), the lability index (LI), the C pool index (CPI), and the C management index (CMI) were calculated using the equations provided by [16] as follows:

$$\begin{aligned}
LC &= \frac{\text{Labile} - \text{SOC}}{\text{Non} - \text{labile} - \text{SOC}},\\
LI &= \frac{LC_{\text{sample}}}{LC_{\text{reference}}},\\
CPI &= \frac{SOC_{\text{sample}}}{SOC_{\text{reference}}},\\
CMI &= CPI \times LI \times 100,
\end{aligned} \tag{1}$$

where the *sample* refers to the value of the *C* in the soil samples taken from each experimental plot at the end of the study (after 24 months of the experiment), and the *reference* refers to the amount of the *C* in the soil samples taken before the study.

2.5. Statistical Analysis. All data were subjected to analysis of variance (ANOVA) for a split-plot randomized complete block design using the general linear model. The ANOVA was performed using the mixed method of SAS, version 9.4 [33]. Means were separated using Duncan's multiple range test at a 5% significance level ($p < 0.05$) and plotted using the "ggplot2" package in the R programming environment [34]. Pearson's correlation coefficients were used to examine the relationship between different *C* indicators and *C* fractions using SAS 9.4 [35]; *p* values <0.05 were considered to be statistically significant. In addition, a Pearson's correlation was carried out using the "ggplot2" package in R to show a matrix correlation between the LI and the CPI with the CMI under different farming strategies and rotation systems as different *C* sources.

3. Results

3.1. The Effect of Farming Strategy on Carbon Indices. The ANOVA results indicate that although the farming strategy did not affect the lability of C and LI ($p > 0.05$) after 24 months of the experiment, it did significantly affect the magnitude of CPI ($p \le 0.01$) and CMI ($p \le 0.05$). In addition, no significant interaction effects were found between the experimental treatments on the measured indices (Table 3). There was no notable difference in terms of the lability of C and LI between farming strategies. However, the variability of labile C and LI was greater in SOF_30% CR and IOF_15% CR than in the strategy SIF_no-CR (Figure 2). Furthermore, the highest and lowest values of CPI were obtained in SOF_30% CR and SIF_no-CR with values of 1.25 and 1.06, respectively. No significant statistical difference was found between SOF_30% CR and IOF_15% CR in terms of CPI (Figure 2). The CPI was significantly higher in the SOF_30% CR treatment than in the SIF_no-CR treatment. The results revealed that the SOF_30% CR farming strategy had the highest CMI with an average of 121, which was significantly higher than SIF_0%-no-CR. The same holds true for the comparison between SOF_0%-no CR and IOF_15% CR (Figure 2). Although the interaction effects of the treatments were not statistically significant, the mean comparison

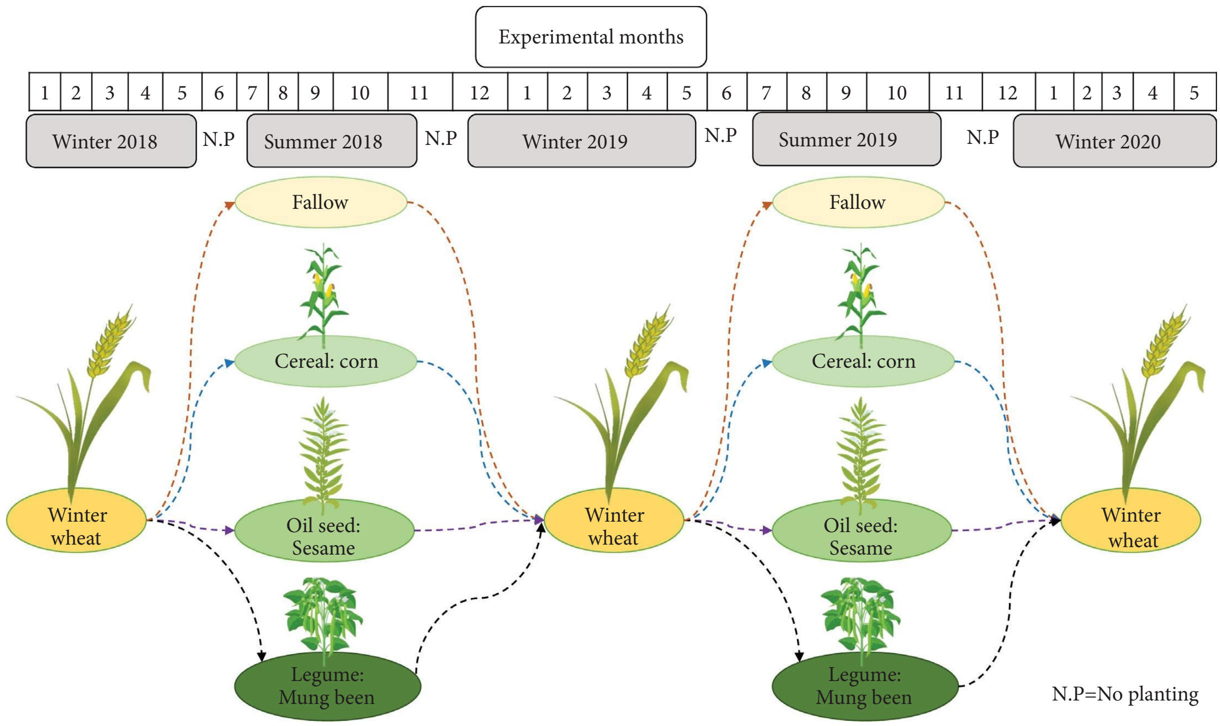

FIGURE 1: Diagram of different wheat-based cropping systems. N.P refers to the intervals between summer and winter cultivations when the field was bare.

TABLE 2: Initial and final values of total SOC, labile-SOC, and non-labile-SOC (mean ± standard deviation) under three farming strategies and four crop rotation systems.

Treatment	Time after the implementation of the experimental treatments	TSOC (g·kg^{-1})	Labile-SOC (g·kg^{-1})	Non-labile-SOC (g·kg^{-1})
Before starting experiment	0	4.5	1.74	2.77
Farming strategy				
SIF no-CR	24 months	4.79 ± 0.02	1.8 ± 0.007	2.95 ± 0.02
SOF_30% CR	24 months	5.64 ± 0.07	2 ± 0.02	3.5 ± 0.07
SOF_15% CR	24 months	5.1 ± 0.07	1.87 ± 0.01	3.29 ± 0.07
Crop rotation system				
Mung bean-wheat	24 months	5.8 ± 0.06	2.11 ± 0.01	3.69 ± 0.05
Corn-wheat	24 months	5.18 ± 0.06	1.92 ± 0.01	3.2 ± 0.07
Sesame-wheat	24 months	5.23 ± 0.06	1.9 ± 0.01	3.27 ± 0.05
Fallow-wheat	24 months	4.69 ± 0.03	1.77 ± 0.009	2.91 ± 0.05

Each value is the average of three values from three replicates.

showed that the highest values of CPI and CMI were obtained in SOF_30% CR and IOF_15% CR under the B-W cropping system (Table S1).

3.2. The Effect of Crop Rotation Systems on Carbon Indices. The ANOVA results indicate that there was no significant effect of the crop rotation system on the lability of C and LI during the 24 months of the experiment. However, crop rotation systems did have a significant effect on CPI at $p \leq 0.05$ and CMI at $p \leq 0.076$. The mean comparison of the different crop rotation systems illustrates that, despite the nonsignificant difference, the lability of C and LI was higher for C-W and F-W compared to B-W and S-W. Furthermore, the magnitude of CPI followed the order of B-W (1.29) > S-W (1.16) ≥ C-W (1.15) ≥ F-W (1.01). Among the wheat-based summer crop rotation systems, B-W had the highest CMI with a value of 119. On the other hand, the lowest CMI with a value of 102 was observed for wheat monocropping (F-W, Figure 3).

3.3. Correlations between Carbon Fractions and Carbon Indices. There were significant and positive correlations between labile C ($r = 0.77$) and lability index ($r = 0.59$) with CMI. In contrast, a negative and nonsignificant correlation was found between nonlabile C and CMI. CPI also had a nonsignificant correlation with CMI ($r = 0.22$) (Figure 4(a)). In addition, interesting information on how different farming strategies and rotation systems contribute to

Table 3: Results of analysis of variance (ANOVA) presented using *F*-values and Pr > *F* (indicated by n.s, * and **) for the effect of farming strategy (FS), crop rotation system (CR), and their interactions on the lability of C, lability index (LI), carbon pool index (CPI), and carbon management index (CMI).

Source	df	Lability of C	LI	CPI	CMI
Block	2	$1.57^{n.s}$	$1.5^{n.s}$	$1.79^{n.s}$	$1.39^{n.s}$
Farming strategy (FS)	2	$0.2^{n.s}$	$0.19^{n.s}$	7.9^{**}	5.3^{*}
Error FS (FS × block)	4	0.3	0.32	0.007	0.62
Crop rotation system (CRs)	3	$0.38^{n.s}$	$0.38^{n.s}$	8.29^{**}	3.07^{ns}
FS × CRs	6	$0.3^{n.s}$	$0.33^{n.s}$	$1.14^{n.s}$	$0.86^{n.s}$
Error	18	0.4	0.46	3	1.7
C.V		18	18	10	11

* and ** indicate the significant level at $p \le 0.05$ and $p \le 0.01$, respectively, and ns indicates to no statistically significant difference by the Duncan test based on the statistical design of the split-plot.

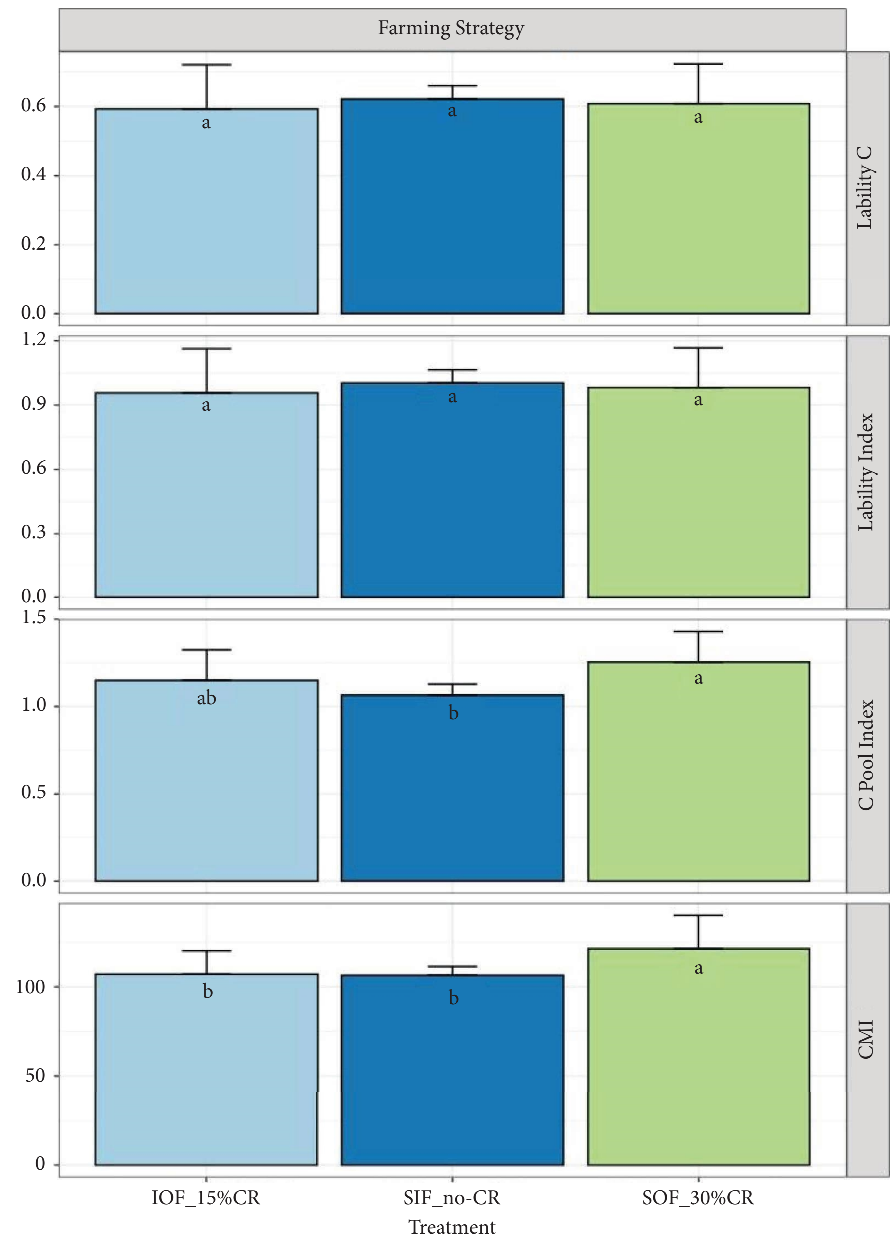

Figure 2: Effect of three farming strategies [SIF_no-CR (inorganic fertilizer, no crop residues added to the soil), SOF_30% CR (organic fertilizer, returning 30% of crop residues), and IOF_15% CR (integrated use of organic and inorganic fertilizers, returning 15% of crop residues)] on lability of C (carbon), lability index, C pool index (CPI), and C management index (CMI). Letters indicating a significant (different letters) and no significant (Identical letters) difference at $p \le 0.05$ according to Duncan's multiple range test.

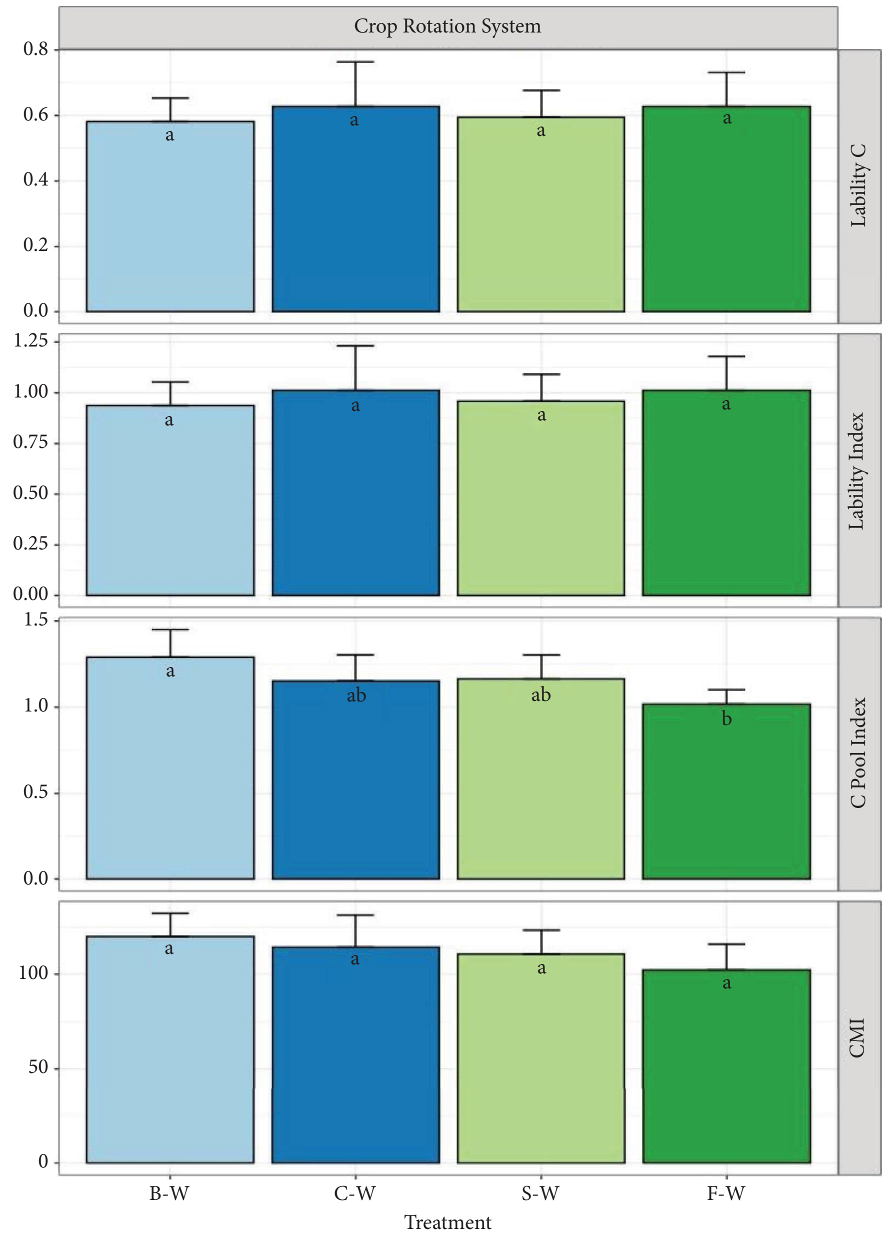

Figure 3: Effect of four crop rotation systems: mung bean-wheat (B-W), corn-wheat (C-W), sesame-wheat (S-W), and fallow-wheat (F-W) on lability of C (carbon), lability index, C pool index, and C management index (CMI). Letters indicate a significant (different letters) and no significant (Identical letters) difference at $p \leq 0.05$ according to Duncan's multiple range test.

the improvement of CMI can be found in the results of the partial correlation analysis (Figure 4(b)). Based on Figure 4(b), LI is strongly correlated with CMI for the most of farming strategies and crop rotation systems, except for IOF_15% CR (0.22) and SIF_no-CR (−0.18) for mono-cropping of wheat.

4. Discussion

To show how agricultural practices can improve or reduce SOC, it is desirable to use C indices. It has been widely documented that the lability index of C (LI) and total SOC (CPI) is altered by the return of crop residues to the soil and the application of manures [36–38]. These two indices are a measure of the changes in lability and quantity of SOC due to changes in crop management. The combination of LI and CPI reflects changes in CMI values, which indicate the potential for labile C accumulation in the soil [12]. The higher is the value of the CMI, the more fertile and higher the soil quality [39]. The results of our study typically revealed an increase in CPI with increasing manure and crop residue application rates in short-term experiments. Research conducted by [40] showed that increased incorporation of crop residues into the soil registered higher values of CMI through improvement of CPI and LI compared to no incorporation of crop residues into the soil. Furthermore, for all management strategies, the lability of C increased after 24 months of the experiment. In addition,

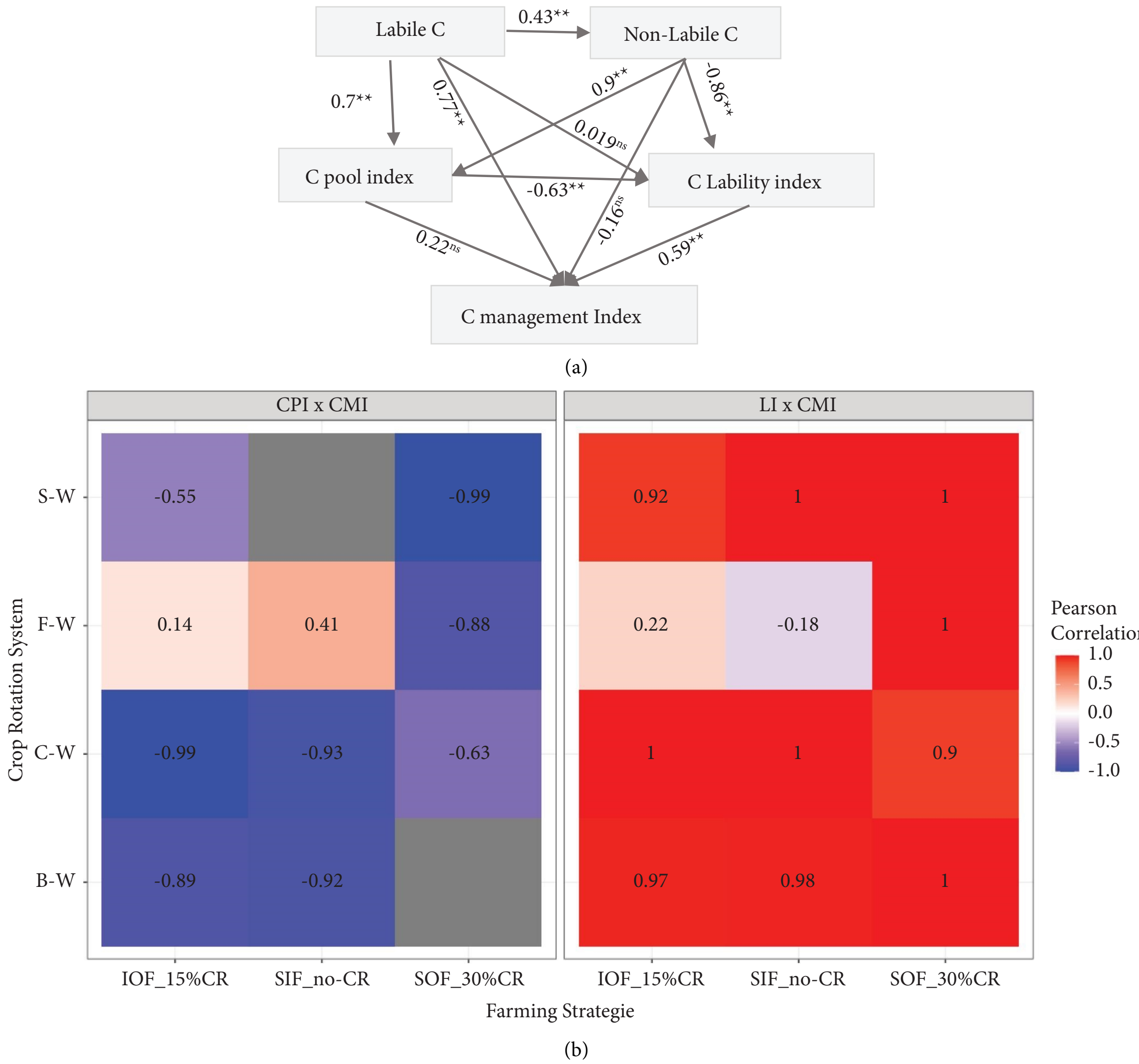

Figure 4: (a) represents the Pearson correlations between carbon (C) fractions consisting of: labile C and non-labile-C, lability index and C pool index with the C management index. ** and ns indicate significant and non-significant correlations between the parameters. (b) represents the matrix of partial correlation analysis between LI (lability index), CPI (C pool index) with CMI (C management index) under different C inputs as: three farming strategies: SIF_no-CR (inorganic fertilizer, no return of crop residues to the soil), SOF_30% CR (organic fertilizer, returning 30% of crop residues), and IOF_15% CR (integrated use of organic/inorganic fertilizers, returning 15% of crop residues) and four crop rotation systems: mung bean-wheat (B-W), corn-wheat (C-W), sesame-wheat (S-W), and fallow-wheat (F-W).

changes in labile SOC (LI) were not significantly different between the management strategies. All management strategies resulted in an increase in the amount of total SOC i.e. CPI >1, but the increase was significantly higher in the SOF_30% CR treatment. Although the labile *C* values were higher for the organic-based farming strategy, LI was lower for SOF_30% CR and IOF_15% CR than for SIF_no-CR. This was due to the fact that the nonlabile C values, which act as the denominator in the LI equation, were higher for SOF_30% CR and IOF_15% CR compared to the mineral-based farming strategy. Our results were consistent with the findings of Leno et al. [41] and Wang et al. [42]. Furthermore, our results showed a strong positive correlation between LI and CMI. In addition, it is noteworthy that in the semiarid region, the addition of more C inputs to soils with low initial C resulted in large variability in the lability of C, CPI, and CMI compared to the mineral-based farming strategy with crop residue removal. The variability in the lability of C, CPI, and CMI in SOF_30% CR and IOF_15% CR might be caused by the quantity and quality of crop residues and manure applied to the soil as well as nutrient availability, which led to an increase in the decomposition rate of organic matter [11, 43]. In addition, the incorporation of crop residues into the soil by improving both total and labile SOC [44] resulted in higher CPI and CMI.

Although the lability of *C* and LI were not significantly affected by different crop rotation systems, CPI was positively affected by crop rotation systems including summer crops; however, these differences were only significant for legume-based wheat rotation compared to monocropping of wheat. Yet, the greater amount of CPI in the B-W cropping system resulted in higher CMI. Probably the biological nitrogen fixation associated with legumes promoted C sequestration and CPI improvement [45]. In addition, a major reason for this improvement could be the return of 54.6 kg·ha^{-1} of wheat and mung bean crop residues to the soil in SOF_30% CR and 27.3 kg·ha^{-1} in IOF_15% CR during the experimental years, compared to 9 kg·ha^{-1} and 4.5 kg·ha^{-1} of only wheat crop residues for F-W under the aforementioned farming strategies, respectively. Previous studies stated that increased nitrogen input through biological nitrogen fixation in legume-based cropping systems was not the main prerequisite for SOC improvement, but that the improvement in SOC and CMI was mainly attributed to increased crop biomass and roots with low C/N ratio in these cropping systems [46–48]. Apart from the positive effect of mung bean as a nitrogen-fixing legume and as a source of C input, our results indicated that the rotation of corn (cereal) and sesame (oilseed) with wheat by producing more root and adding leaf-shoot biomass to the soil at a rate of 87.6 and 34.8 kg·ha^{-1} in SOF_30% CR and 34.8 and 17.4 kg·ha^{-1} in IOF_15% CR, respectively, led to a significant improvement in CPI and, consequently, an increase in CMI compared to monocropping of wheat [49]. Rotation of summer crops with winter wheat provided extended ground cover, increased root biomass, enhanced rhizosphere exudation, and improved soil microbial activities, which acted as a diverse source of labile C and led to an improvement in CPI [50].

5. Conclusion

The potential of agricultural soils to sequester *C* and improve CMI is influenced by the type and diversity of cover crops and management strategies. The results of a two-year study approved that changes in CMI were more influenced by the C pool index than by *C* lability. Moreover, residues returned to the soil and manure application had a significant effect on CPI and CMI compared to the CON farming strategy in the semi-arid region. Although the inclusion of legumes in the wheat-based rotation system had the highest CMI value, the C-W and S-W rotation systems also resulted in higher CPI and CMI than the F-W rotation, although the differences were not statistically significant. However, the study revealed that diversification of wheat-based rotation systems by including summer crops in the rotation, particularly legumes, in combination with organic-based farming strategies has a wide scope for adoption in the region to improve SOC accumulation, where conventional cultivation of cereals with summer fallow is a major threat to soil health.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships with individuals involved in the publication process that might appear to have influenced the work that is reported in this article.

Authors' Contributions

The content of the manuscript and the order of authorship are agreed by all coauthors.

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Supplementary Materials

Table S1: The main effect of three farming strategies: (SIF_no-CR (inorganic fertilizer, no crop residues added to the soil), SOF_30% CR (organic fertilizer, returning 30% of crop residues), and IOF_15% CR (integrated use of organic and inorganic fertilizers, returning 15% of crop residues)) and four crop rotation systems: mung bean-wheat (B-W), corn-wheat (C-W), sesame-wheat (S-W), and fallow-wheat (F-W) on the lability of C (carbon), lability index, C pool index, and C management index (CMI). Letters indicate a significant (different letters) and no significant (Identical letters) difference at $p \leq 0.05$ according to Duncan's multiple range test. (*Supplementary Materials*)

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