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The Role of Cover Crop Types and Residue Incorporation in Improving Soil Chemical Properties

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Abstract: Soil chemical properties can be improved by incorporating crop residues in soil and letting it decompose. This study explored the use of incorporating residues of cover crops for improvements in soil chemical properties including soil organic matter (SOM), soil pH, and the selected soil macro- and micronutrients in greenhouse and field trials. Factors of interest included (i) cover crops and their combinations and (ii) methods of crop termination and incorporation in soil (disc, mow + disc, glyphosate, roller crimper). The greenhouse trial showed up to a 20% higher amount of SOM accumulated in soils incorporated with crop residues. Buckwheat (3.12%) and phacelia (3.12%) produced significantly different and larger SOM than that of the control treatment that received no crop residues ($p \leq 0.05$). The soil pH of the brown mustard treatment was also significantly affected by the experimental treatments ($p \leq 0.05$). The incorporation of crop residues did not affect soil phosphorous (P) or potassium (K) concentrations, except for brown mustard, with significantly higher values of P and K than the control treatment. Calcium (Ca) was significantly higher in the soil of phacelia + pea treatment ($p \leq 0.05$). Buckwheat + pea produced a higher concentration of Ca (1028 mg/kg) followed by buckwheat alone (1006 mg/kg). Analysis of variance (ANOVA) calculated on the results of the field trial showed that the mix treatment that had a mixture of four cover crops significantly increased the SOM content. Buckwheat produced the highest (2.95%) SOM, then brown mustard and timothy. This study concludes that, irrespective of the tillage incorporation methods, the residues from cover crops are a potential source of improvement in soil health, and this practice may promote sustainable agriculture in conditions similar to those in this study.

Keywords: cover crops; greenhouse; organic matter; residue incorporation; sustainable agriculture

1. Introduction

Cover crops form a vital bioresource that contributes to improving soil health. Soil chemical properties including organic matter (SOM), soil pH, and soil macro- and micronutrients contribute to soil health. SOM is universally recognized as a significant factor enabling soils to provide critical services in agroecosystems including food and fiber production and environmental sustainability [1,2]. Additionally, SOM contributes markedly to the soil acid-base buffering capacity, determined by soil pH, and represents an essential source of plant nutrients. The concentration of SOM in agricultural soils is a function of the type and/or method of the incorporated crop residues and the rate of their decomposition [3,4].

A potential strategy to address soil health issues is improving soil chemical properties through planting cover crops with regular field crops [5]. Cover crops reduce nutrient loss and improve soil conditions. They offer an excellent opportunity to increase the diversity of crop rotation between the cultivation of major crops [4,5]. Cover crops also help to reduce the use of herbicides for weed control [6]. The termination and incorporation of cover crops into the soil is another method of promoting microorganism activities for the increased decomposition of crop residues, increasing SOM and soil fertility [7].

Haruna et al. [8] studied the effect of cover crop (cereal rye) and crop rotation (maize-soybean) managed by tillage and no-tillage practices on selected soil chemical properties and found that the relative change in the percentage of SOM was 8% greater in the cover crop management compared with no cover crop treatment. They concluded that the interaction effects of the management practices on the soil chemical properties were difficult to predict throughout the study. Gattullo et al. [9] assessed the effect of a fescue cover crop on soil quality, yield, and grape qualitative parameters and reported that cover crops increased, on average, soil organic carbon, total N, other soil chemical properties. Pokhrel et al. [10] evaluated the impact of cover crops and poultry litter on selected soil chemical properties and yield in dryland soybean production system and found no significant effects of cover crops over the short period of the study.

Potato is the major crop of Prince Edward Island (PEI), Canada. It is an important part of PEI's economy contributing about 10.8% of its gross domestic product (GDP) with more than one billion dollars of direct and indirect economic benefits while engaging 12.1% of the island's total workforce [11]. Currently, PEI produces approximately 20–25% of the total potato crop grown in Canada each year [12]. This production could be further increased through improved soil health that may be sourced from an improvement in SOM [13].

Extensive agricultural activities in PEI including soil plowing, deep tilling, weeding, and the use of synthetic fertilizers pose a severe threat to the SOM of PEI soils that have poor (2–3%) SOM and soil health [14]. There has been little research on the potential of native cover crops to improve SOM and soil health of PEI. Therefore, a research question arises as to whether the cover crops can improve the health of soils of PEI that have been degraded with intensive tillage for potato cultivation and other crops. It is hypothesized that cover crops can play a vital role in improving the health of soils, including the soils of PEI. To answer the research question and test the study hypothesis, this work was designed to examine the effect of various cover crops on the selected soil health indicators. This information can be used to inform potato farmers about the top-performing cover crops to enhance the overall health of their soils.

2. Materials and Methods

This study was carried out in the greenhouse and experimental fields of Agriculture and Agri-Food Canada (AAFC) at the Harrington research farm, Queens County, PEI. This small rural community of Barkley Beach is in the North of Charlottetown, the capital of PEI, which is an Atlantic Canadian province, situated in the Gulf of Saint Lawrence and separated from the other Atlantic provinces. It lies between 46 to 47 °N latitude and 62 to 64 °W longitude. To the South and the West, the Northumberland Strait separates this island from the mainland provinces of Nova Scotia and New Brunswick. Its climate is humid, which is strongly influenced by the surrounding seas and their variants throughout the year. The island winter season is long with a relatively shorter summer season. In winter, the island receives storms and blizzards originating from the North Atlantic or the Gulf of Mexico. Springtime temperatures are cool when the ice generally melts in late April. Summers are moderately warm as the daytime temperature occasionally reaches as high as 30 °C. The island receives the heaviest rainfall spells of the year in late autumn and during early winter. Soils of the study area are deep fine sandy loamy soils, which have been developed from the land which was originally covered with forest.

This study comprises a greenhouse and a field trial. Details of the two trials are summarized in Table 1.

Table 1. Information about the greenhouse and field trials.

Major Protocols	Greenhouse Trial	Field Trial
Date	25 February 2018 to 30 April 2019	25 June 2019 to 10 October 2019
Temperature (minimum, maximum, mean), °C	−20.1, 30.8, 5.94	−20.3, 29.9, 5.97
Total annual precipitation, mm	1149	1101
Environmental conditions	Controlled conditions under a greenhouse of Agriculture and Agri-Food Canada's (AAFC) Charlottetown Research and Development Centre at Harrington, PEI Canada.	The uncontrolled natural environment of an agricultural field of the AAFC Charlottetown Research and Development center at Harrington, PEI Canada.
Nature of the trial	Greenhouse trial arranged on a benchtop where 28 clay pots (14 cm diameter, 20 cm deep) were placed 1.5 m apart on four 8 m wide and 19 m long wooden benches.	Field trial with forty-eight (48) 4 m × 4 m treatment plots arranged in 16 m wide and 69 m long strips with a 1 m buffer zone between and around the strips.
Experimental design	Randomized complete block design.	Strip plot design.
Treatments and replications	Four replications of three cover crops and their three combinations and control (7 treatments) including T1 (brown mustard), T2 (buckwheat), T3 (phacelia), T4 (brown mustard + Pea), T5 (buckwheat + pea), T6 (phacelia + pea), and T7: control/no cover crop.	Four replications of the four cover crops treatments including C1 (timothy), C2 (buckwheat), C3 (brown mustard), and C4 (mix of hairy vetch, annual rye (winter rye), crimson clover).
Irrigation	Automated irrigation @ 150 mL/day to each pot.	No irrigation was provided at all as the crops were grown under rainfed conditions.
Light	Lights of photosynthetic photon flux density below 2000 µmol m^{-2} s^{-1} managed for 16 h/8 h light/dark periods.	Natural light conditions.
Crop husbandry	Weeding, disease symptom monitoring/control, and irrigation scheduling were under standard practices.	Standard practices of weeding, hoeing, disease symptom monitoring/control, nutrient management.
Methods of residue incorporation	Manual	Four methods of residue incorporation, namely, M1 (mow + disc), M2 (mow), M3 (roller crimper), and M4 (glyphosate).
Previous crop and fertilization	No synthetic fertilizer was used.	In 2018 of the cover crop year the previous crop was potatoes, which received fertilizer by banding with N rate of 170 kg N ha^{-1} as 17-17-17 Nitrogen–Phosphorus–Potassium (NPK). In 2019 of the cover crop year, the previous crop was buckwheat, and no fertility was applied.

2.1. The Greenhouse Trial

The soil (of sandy loam texture) was collected from the AAFC Harrington research field and was heat sterilized at 80 °C for 8 h to kill weed seeds, soil insects, plant pathogenic bacteria, and any organisms present in the soil, before packing in the experimental pots [15]. Three subsamples from a composite sample of the soil were analyzed for the soil's chemical properties to be considered as the initial-stage soil health conditions. Pre-cultivation benchmarks of soil chemical properties including SOM, soil pH, and concentrations of soil phosphorous (P), potassium (K), calcium (Ca), copper (Cu), zinc (Zn), and P/Al ratio were determined on experimental soil.

Twenty-eight (28) pots were packed with the above soil to replicate seven experimental treatments (three cover crops and their three mixtures and a control treatment) four times. The pots were arranged under a randomized complete block design. Seeds of the cover crops were sown according to the treatment plan at the sowing rates given in Table 2. The crop husbandry was taken care of until it ripped and was ready for harvesting. At this stage, the crops were terminated, and their residues were deposited back into the soil to decompose. After the decomposition of residues (i.e., 10 months after incorporation), 300 g of soil samples was collected from each experimental pot and analyzed for the selected soil health indicators.

Table 2. Experimental treatments, names of cover crops, and seed sowing rates (kg/ha) for each of the seven treatments for Experiment 1.

Treatments Cover Crops	Sowing Rate kg/ha	Treatments and Cover Crops	Sowing Rate kg/ha
T1: Brown mustard	11.0	T4: Brown mustard + Pea	5.50 + 78.5
T2: Buckwheat	45.0	T5: Buckwheat + Pea	22.5 + 78.5
T3: Phacelia	10.0	T6: Phacelia + Pea	5.00 + 78.5
		T7: Control/no cover crop	N/A

The SOM content was determined using the loss on ignition (LOI) method for which the laboratory used a muffle furnace (Model 550 Isotemp Series, Fisher Scientific, Pittsburgh, PA, USA), and the standard procedure was followed [16]. Soil samples were also analyzed by PEI Analytical Laboratories using the standard methods and protocols [17]. Soil pH was determined using PC titrate [18], and the soil nutrients, including P, K, Ca, Zn, and P/Al, were analyzed using inductively coupled plasma optical emission spectroscopy (ICP-OES 6500; Thermo Fisher, Santa Clara, CA, USA) [19].

2.2. The Field Trial

Field trials were conducted on the AAFC Harrington field in PEI as the soils of this area are suitable for potato cultivation [15]. These are deep fine sandy loam soils, which have been developed from the land that was initially covered with forest. One of the cover crops, buckwheat, was selected as the best performer during the greenhouse trial. The other three crops were the most used cover crops in PEI (Table 1). Each treatment was replicated four times. This experiment was part of an ongoing research project of AAFC [15]. The four experimental cover crops were terminated and incorporated into the soil using various termination methods, i.e., mow + disc, mow, roller crimper, and glyphosate (Table 3).

Table 3. Methods of termination of cover crops and incorporation into the soil for experimental treatments for Experiment 2.

Methods	Termination Technique	Description of Incorporation and Equipment Used for the Specific Purpose
M1	Mow + Disc	Cover crops were mowed with a flail mower and incorporated into the soil with the help of a tractor-mounted disc plow.
M2	Mow only	Cover crops were mowed with a flail mower.
M3	Roller crimper	Roller crimper—front-mounted roller crimper bar (manufactured at Rodale Institute in Pennsylvania) was used for the plowing of cover crops.
M4	Glyphosate	Glyphosate applied @ 2.33 L/ha to terminate cover crop into the soil.

A randomized strip plot design was established with four replications. There were four main plot effects (i.e., four methods of residue incorporation into the soil including mow + disc, mow, roller crimper, and glyphosate, applied at the rate of 2.33 L/ha) and four subplot effects (i.e., three cover crops—namely, timothy; brown mustard; and a mix of hairy vetch, crimson, clover, and annual rye—and a control (no incorporation of cover crops) treatment).

The experimental plots were prepared using disc tillage, which usually follows the plowing of soil with a disk plow mounted behind a tractor. Additionally, disking breaks up clods and surface crusts thereby improving soil granulation and surface uniformity. The seeds of cover crops were planted using plot seeders (Wintersteiger Inc. Ried, Austria). This instrument is used for seeding in small plots.

The crop termination was achieved at the peak flowering stage of the crops. The incorporated residues of the terminated cover crops were left in the soil to decompose for one year. Soil samples were collected from the 0–15 cm layer of each treatment plot, after a year of residue decomposition, to determine the selected soil health indicators [20].

The field trial year (i.e., 2019) had the highest ambient air temperature (~30 °C) of the year during the month of July and the driest days of the growing season during July and August (Figure 1).

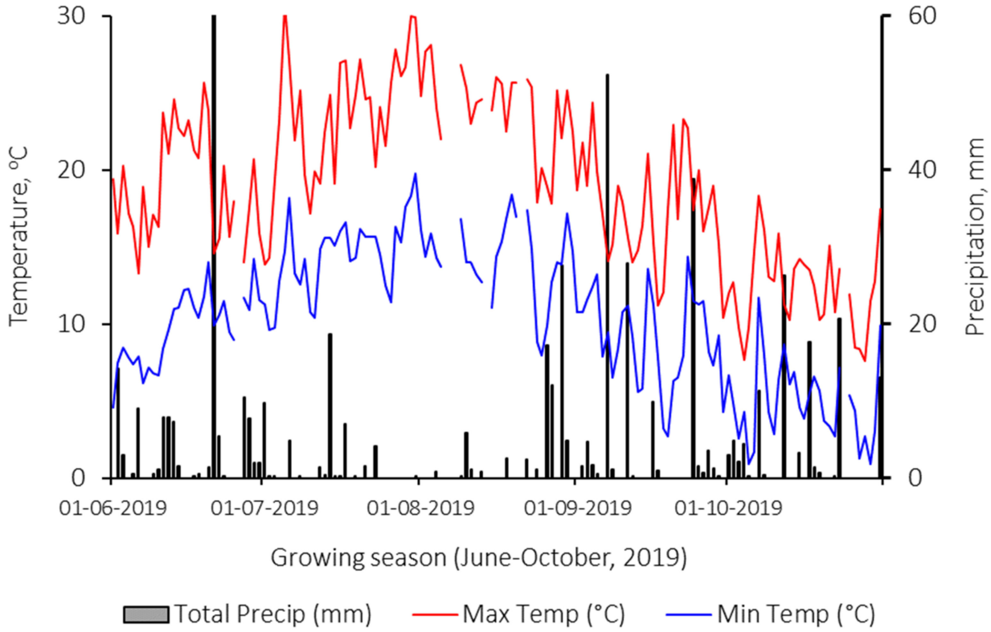

Figure 1. Ambient air temperature (minimum and maximum) and precipitation trends during the trial season (i.e., June–October 2019).

2.3. Statistical Analysis

Minitab 19 was used to perform the statistical analysis [21]. The analysis of variance (ANOVA) was performed to test the significance of experimental treatments on soil health indicators. The data of the greenhouse trial were tested for mean significant differences using Tukey's method. Various assumptions, including normality test, constant variance, and independence of the error, were tested at a 95% confidence interval. The error terms' normal distributions were verified using the Anderson–Darling test at a 95% confidence interval. Constant variance assumption was checked using residuals versus fitted value plots. The independence assumption was verified by applying all the treatments in a random order to the experimental units. Statistical means were considered significantly different at $p \leq 0.05$. Fisher's Least Significant Difference (LSD) was performed on data of field trials to separate means of significant difference.

3. Results

3.1. The Greenhouse Trial

Pre-cultivation benchmarks of the soil chemical properties including SOM, soil pH, and concentration of soil P, K, Ca, Cu, Zn, and P/Al ratio are presented in Table 4.

Table 4. Summary statistics of the pre-sowing soil health parameters of soil used in the greenhouse and field trials.

Soil Properties	Greenhouse Trial		Field Trial	
	Mean ± S.D. [1]	Min–Max	Mean ± S.D.	Min–Max
Soil organic matter, %	2.32 ± 0.31	2.20–3.40	2.71 ± 0.22	2.20–3.00
Phosphorus, mg/kg [2]	366 ± 41.5	289–399	260 ± 21.2	233–305
Potassium, mg/kg	196 ± 53.1	100–289	182 ± 25.1	116–269
pH	6.62 ± 0.30	5.80–7.00	6.60 ± 0.26	6.00–6.90
Calcium, mg/kg	1007 ± 194	823–1400	960 ± 11.9	725–1149
Copper, mg/kg	0.99 ± 0.24	0.70–1.60	0.47 ± 0.19	0.14–0.66
Zinc, mg/kg	1.66 ± 0.70	1.00–4.80	0.91 ± 0.47	0.60–1.80
P/Al [3]	10.4 ± 1.10	7.87–12.0	8.20 ± 1.11	5.80–9.90

[1] Standard deviation, [2] milligram per kilogram, [3] phosphorus/aluminum ratio.

The average percentage of SOM before planting the cover crops was 2.320%, which was not as high as required for optimum potato cultivation, e.g., >3.5%, which enhances the soil's ability to mineralize nitrogen, which is an asset for potato cultivation [22]. Soil pH ranged from 5.8 to 7.0 with an average of 6.31, close to the range of pH of healthy soil [23].

Buckwheat and phacelia produced a larger percentage of SOM (3.12% each) than the other treatments and were significantly different from the control treatment (Table 5). This was approximately a 25% increase in SOM from the benchmark SOM of soil used in the greenhouse trial (2.32%). Tukey's mean separation results indicated that SOM produced in the soil by all cover crops was significantly different from the control treatment that produced a significantly lower SOM (2.32%) across all the seven treatments ($p \leq 0.05$).

Table 5. The post-experiment analysis of variance (ANOVA) generated mean values of concentration of soil health indicators accompanied by standard deviation and Tukey's mean separation least significant difference (LSD) letters (i.e., A, B, C, etc.) for the greenhouse experiment. The means labeled with different LSD letters are significantly different from one another. A non-significant effect of experimental treatments on soil health indicators is labeled as NS.

Soil Properties	Brown Mustard	Buckwheat	Phacelia	Brown Mustard + Pea	Buckwheat + Pea	Phacelia + Pea	Control
Soil organic matter, %	3.07 ^{A} ± 0.20	3.12 ^{A} ± 0.20	3.12 ^{A} ± 0.20	3.00 ^{A} ± 0.10	3.02 ^{A} ± 0.20	3.02 ^{A} ± 0.10	2.32 ^{B} ± 0.10
pH	6.82 ^{A} ± 0.10	6.80 ^{AB} ± 0.30	6.77 ^{AB} ± 0.30	6.75 ^{AB} ± 0.08	6.52 ^{AB} ± 0.10	6.35 ^{AB} ± 0.20	6.30 ^{B} ± 0.20
Phosphorous, mg/kg	372 ^{NS} ± 51.5	366 ^{NS} ± 41.5	366 ^{NS} ± 43.2	366 ^{NS} ± 48.7	367 ^{NS} ± 43.1	356 ^{NS} ± 45.8	368 ^{NS} ± 52.5
Potassium, mg/kg	186 ^{NS} ± 56.9	202 ^{NS} ± 64.3	230 ^{NS} ± 72	180 ^{NS} ± 48.2	184 ^{NS} ± 47.3	201 ^{NS} ± 67.8	189 ^{NS} ± 35.3
Calcium, mg/kg	964 ^{A} ± 236	1003 ^{AB} ± 219	981 ^{B} ± 188	965 ^{B} ± 214	974 ^{B} ± 193	1028 ^{B} ± 249	1133 ^{B} ± 161
Copper, mg/kg	1.10 ^{AB} ± 0.19	1.13 ^{AB} ± 0.35	0.80 ^{AB} ± 0.08	1.30 ^{A} ± 0.2	1.30 ^{A} ± 0.2	0.93 ^{AB} ± 0.93	0.78 ^{B} ± 0.02
Zinc, mg/kg	2.40 ^{NS} ± 1.50	1.30 ^{NS} ± 0.20	1.50 ^{NS} ± 0.40	1.30 ^{NS} ± 0.10	1.80 ^{NS} ± 0.08	1.80 ^{NS} ± 0.30	1.30 ^{NS} ± 0.20
P/Al [1]	11.2 ^{NS} ± 1.14	10.9 ^{NS} ± 0.80	10.8 ^{NS} ± 1.00	10.1 ^{NS} ± 1.0	9.90 ^{NS} ± 1.0	9.30 ^{NS} ± 1.00	10.5 ^{NS} ± 1.30

[1] phosphorus/aluminum ratio. Note: Means that do not share a letter are significantly different. Underlined values are large and significantly different from those represented by different letters in the sequence A > B > C or combinations of these letters.

There was a significant effect of experimental treatments on soil pH ($p \leq 0.05$). The incorporation of biomass of brown mustard resulted in the highest soil pH (6.82) and was significantly different from the control treatment (Table 5). However, the pot soil pH of buckwheat, phacelia, and other cover crops (i.e., phacelia + pea, brown mustard + pea, and buckwheat + pea) was also not significantly different from the control. Calcium concentration in pot soil also had a significant impact of brown mustard that produced higher Ca than the control treatment ($p \leq 0.05$). Additionally, the Cu concentration in the potting soil was significantly affected by the two mixed experimental treatments (i.e., brown mustard + pea and buckwheat + pea produced the highest concentration of Cu (1.30 mg/kg each), which was significantly different from the control treatment ($p \leq 0.05$)).

3.2. The Field Trial

Summary statistics for pre- and post-experimental conditions of the selected soil health indicators are presented in Table 2 (pre-sowing status) and Table 6 (post-harvest status), respectively. The average percentage of SOM present in the soil before planting the cover crops was 2.71 ± 0.22% (Table 2), which increased by 0.07% after the end of the field trial approaching 2.92 ± 0.14% (Table 6). There was a non-significant increase in SOM under the effect of the termination method (tillage) and its interaction with crop type but a significant effect of cover crop type ($p \leq 0.05$).

Table 6. Summary statistics and probability of significance (p-values), calculated from analysis of variance, of the soil health indicators measured after the end of the field trial.

Soil Health Indicators	Post-Harvest Values		*p*-Values for Treatments and Interactions [4]		
	Mean ± S.D. [1]	Range	Tillage	Crop	Tillage × Crop
Soil organic matter, %	2.92 ± 0.14	2.70–3.30	0.473 NS	0.015 *	0.572 NS
pH	6.66 ± 0.26	6.00–7.00	0.971 NS	0.211 NS	0.896 NS
Phosphorus, mg/kg [2]	273 ± 22.2	234 -315	0.832 NS	0.029 *	0.205 NS
Potassium, mg/kg	195 ± 25.7	158–291	0.654 NS	0.016 *	0.633 NS
Calcium, mg/kg	1016 ± 94.1	748–1189	0.795 NS	0.049 *	0.281 NS
Copper, mg/kg	0.50 ± 0.21	0.10–0.90	0.386 NS	0.117 NS	0.699 NS
Zinc, mg/kg	0.95 ± 0.37	0.10–1.80	0.726 NS	0.217 NS	0.094 NS
P/Al [3]	8.15 ± 1.10	5.76–10.1	0.234 NS	0.741 NS	0.004 NS

[1] Standard deviation, [2] milligram per kilogram, [3] phosphorus/aluminum ratio, [4] significant effects of experimental treatments or their interactions are considered for $p \leq 0.05$, * significant, NS non-significant.

The highest percentage of SOM content produced by the mixed cover crop was 3.01%, i.e., the C4 treatment with mixed residues of hairy vetch, annual rye, and crimson clover. Buckwheat (2.96%) and brown mustard (2.88%) treatments (treatments C2 and C3) had the second and the third largest quantities of SOM, respectively. The incorporation of timothy residues produced the lowest SOM content, which was significantly different from the mix cover crop ($p \leq 0.05$). The interaction effect of methods of residue incorporation (i.e., tillage) and cover crop types was also non-significant across all treatments. In addition to SOM, a significant effect of cover crop type was also recorded from concentrations of P, K, and Ca ($p \leq 0.05$), as their values increased by 4.76, 6.67, and 5.51%, respectively (Figure 2).

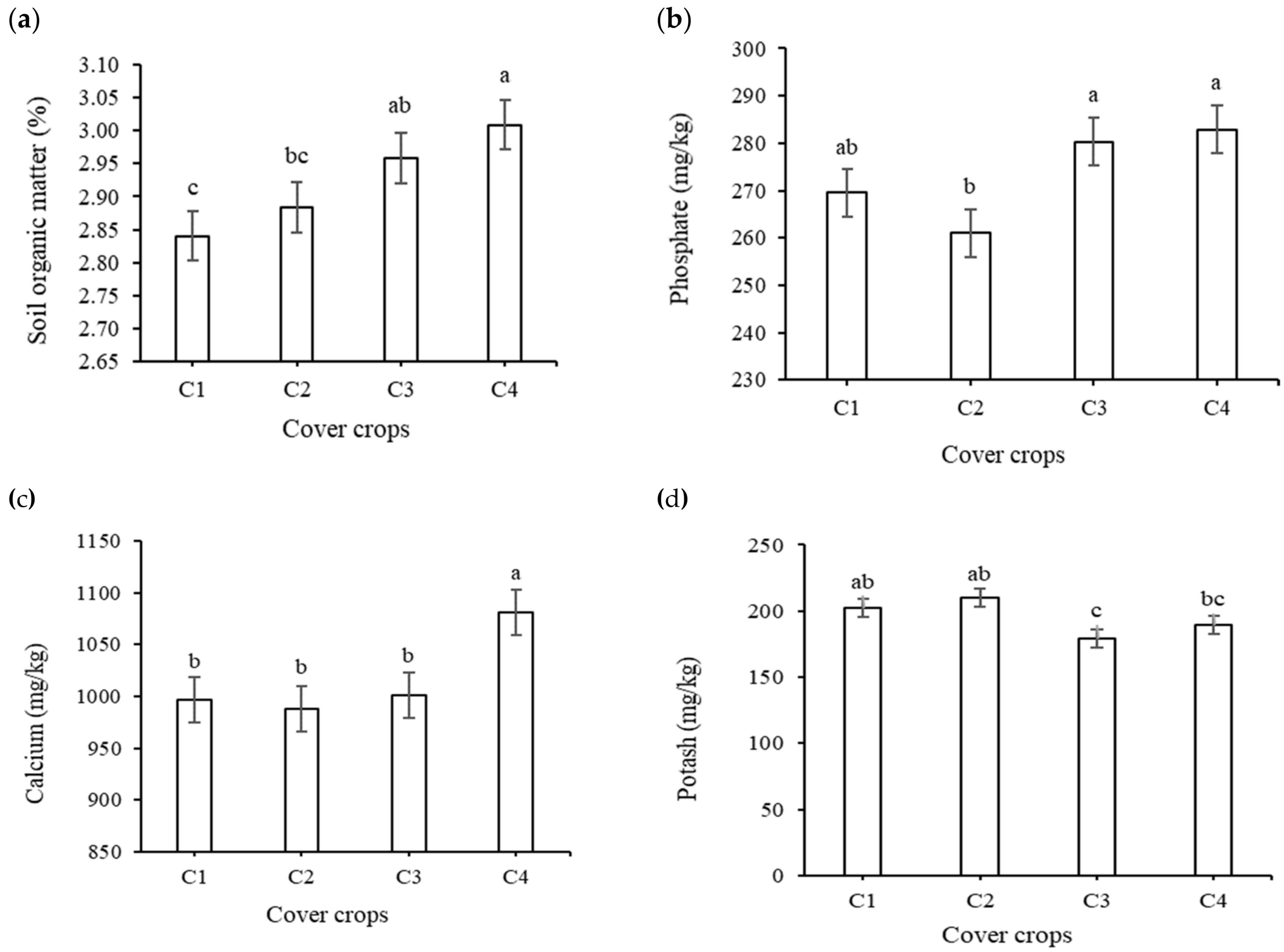

Figure 2. Multiple mean comparisons and standard error bars of (**a**) soil organic matter, (**b**) phosphate, (**c**) potash, and (**d**) calcium concentration in soils of treatments C1 (timothy), C2 (buckwheat), C3 (brown mustard), and C4 (mix (hairy vetch, annual rye, and crimson clover) using Fisher's least significance difference (LSD) method. Treatments labeled with the same or combination of LSD letters (a, b, c) are not significantly different from one another. Treatment means sharing labels with different LSD letters that are significantly different from one another.

The highest and the lowest concentrations of P were produced by mixed cover crops (C4 treatment) and buckwheat, respectively, with a significant difference between the two (Figure 2b). The Ca concentration in the experimental soil also experienced a significant effect of incorporating cover crops ($p \leq 0.05$). The concentration of Ca was the highest for the mixed cover crop treatment (C4) and the lowest for the buckwheat, and they were significantly different from each other (Figure 2c). Likewise, there was a significant effect of cover crop treatments on the soil concentration of K where brown mustard produced a higher concentration of K than the other cover crops and was significantly different from the buckwheat ($p \leq 0.05$; Figure 2d).

The ANOVA results revealed that the main effect of the interaction between cover crops and the residue incorporation methods was non-significant for all cover crop treatments ($p > 0.05$; Table 6). However, the combination of incorporation methods with cover crops (i.e., glyphosate–brown mustard) in soil produced the highest percentage of P/Al among all treatments (Table 7). Furthermore, the interaction effects of mow–disk–timothy and mow–brown mustard produced a higher percentage of P/Al than the rest of the combinations of types of cover crop and methods of residue incorporation. The residue incorporation combination roller crimper–brown mustard produced the lowest and most significantly different percentage of P/Al in the experimental plot ($p \leq 0.05$; Table 7).

Table 7. Multiple mean comparisons of P/Al (%) produced by the different cover crops and their incorporation methods using Fisher's least significant difference (LSD) method.

Tillage × Crops	Mean$^{LSD\ Letters}$	Tillage × Crops	Mean$^{LSD\ Letters}$
Glyphosate brown mustard	9.28 ^{a}	Mow mix	8.33 ^{abc}
Mow disk timothy	9.18 ^{a}	Mow buckwheat	8.28 ^{abc}
Mow brown mustard	9.03 ^{a}	Glyphosate buckwheat	8.14 ^{abc}
Mow disk mix	8.74 ^{ab}	Mow timothy	7.83 ^{abcd}
Mow disk brown mustard	8.54 ^{abc}	Roller crimper mix	7.37 ^{bcd}
Roller crimper timothy	8.43 ^{abc}	Mow disk buckwheat	7.17 ^{cd}
Roller crimper buckwheat	8.42 ^{abc}	Glyphosate timothy	6.62 ^{d}
Glyphosate mix	8.39 ^{abc}	Roller crimper brown mustard	6.60 ^{d}

The means that do not share the same LSD letter (a, b, c, or d) are significantly different from one another.

4. Discussion

Cover crop treatments significantly influenced SOM in greenhouse and field trials. These findings are in concurrence with the literature, which indicates that crop residue incorporation is the primary method for improving SOM. For example, Ding et al. [24] reported that organic carbon content, which is derived from SOM, was the highest in a cover crop system and the lowest in soil with no cover crops. Ramos et al. [25] suggested that cover crops improve soil quality by increasing SOM and improving the soil's chemical and physical fertility. They indicated that there was a significant increase in SOM in all ground cover crop plots they used in their experiments. They further reported that cover crops helped to build SOM and improved water retention. The presence of SOM has physical, chemical, and biological benefits to the soil. Usually, the ideal SOM content for productive soils is 3–6%, and such fertile soils tend to produce more food. There is less deterioration and loss of nutrients when the ideal amount of SOM is present in field soils [26].

The interaction effects of experimental treatments are usually significant when both or one of the two treatments in interaction have a highly significant effect on response variables. None of the studied response variables had an interaction effect on the crop type or method of residue incorporation (tillage) in the field trials. Nascent et al. [27] evaluated the interactions effects of cover crops and tillage systems on SOM, soil nitrogen, and soil carbon, and concluded that cover crops and no-tillage systems increased the soil carbon, calculated from SOM, and soil nitrogen. They also found a change in total SOM in treatments of their two-year study. Cover crops have long been recognized to play an essential role in sustainable agriculture due to their functions in improving soil productivity, suppressing weeds, and preventing soil erosion [24]. De Souza et al. [28] suggested that cover crops become an excellent management option in sandy loam soils. It is worth mentioning here that the soils used in both greenhouse and field trials were sandy loam soils.

Phosphorus binds itself with an active form of aluminum (Al) and iron (Fe) in the soil, which make it available to the plant. Aluminum provides P availability and increases its fixation in the soil [29,30]. Obi [31] reported relative increases of 26 and 112% in SOM and P levels with cover crops, and a significant increase in the Ca levels in the soil cultivated with cover crops. Wissem et al. [32] concluded that rotations of cover crops increased the total P and some labile P pools in the surface of the soil as compared with fallow rotation. However, they reported a positive effect of crop rotation on crop biomass. Fageria et al. [33] reported that cover crops possess a strong ability to absorb low-availability nutrients in the soil profile and can help in increasing the concentration of plant nutrients in the surface layers. Hallama et al. [34] evaluated the possibility of P redistribution into the soil under no-tillage by using cover crops in rotation and found that cover crops increased the availability of P to the soil. Phosphorus fixation is the indication of the low availability of P in the soil, and this happens when P binds itself to iron, or the Al fixes itself in soil [35].

The risk of P loss increases due to its degree of saturation, and in this process, P fixes itself to Al in most of the tilled agricultural soils [36].

As with SOM, the soil pH is not a quickly changeable soil property, and it takes years for a significant change to occur [37]. However, it was observed that only the brown mustard treatment has a significantly greater soil pH than the control treatment. This may be a temporary change in soil pH as the rest of the treatments did not have a significant difference in their pH levels in the greenhouse trial. The ideal soil pH for potato production is between 7 and 9 [38]. Below and above this range, the soils are considered acidic and alkaline, respectively, resulting in adverse impacts on soil productivity and the unavailability of essential nutrients in soils for plant uptake [39].

Calcium contributes to the mitigation of heat stress in potatoes [40]. Groffman et al. [41] studied the Ca cycle in the agroecosystem with winter legumes and concluded that the winter cover crops helped to reduce soil erosion and nutrient leaching and in N fixation in soil by keeping nutrients available to the summer crops. They suggested that winter cover crops have a double benefit in that they fix nitrogen and keep nutrients circulating in the soil and plants. Calcium is a macronutrient and plays a vital role in the potato crop. It helps in the functioning of the potato plant and its structure development [38]. A study indicates that Ca saves the potato crop from different environmental stresses by encoding the appropriate patterns of its genes [42]. The deficiency of P and the toxicity of Al are among the main threats to crop production in acidic soils [43]. An adequate concentration of P is, therefore, added in acidic soils to mitigate Al toxicity.

5. Conclusions

As hypothesized, the cover crops had affected soil health indicators, i.e., the chemical properties of soil of PEI. The augmentation of SOM was greatly influenced by adding cover crops into the soil, which is suspected to be a short-term temporary change. Mixtures of different cover crops added more SOM as compared to others. Other than SOM, other soil nutrients, such as P, K, and Ca, were significantly influenced by cover crops. This means that incorporating residues of cover crops can add P, K, and Ca into the soil for plant uptake. A longer duration experiment is needed to monitor the long-term effect of incorporating cover crop residue on SOM and soil pH. A limitation of this study is that it could not monitor the decomposition rates of the selected crop residues. This is important to do in future investigations. However, the results of this study may be used to formulate the best agricultural management practices to promote sustainable agriculture that is economically viable and environmentally friendly.

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References

1. Martinez-Sabater, E.; Bustamante, M.A.; Marhuenda-Egea, F.C.; El-Khattabi, M.; Moral, R.; Lorenzo, E.; Paredes, C.; Galvez, L.N.; Jorda, J.D. Study of the Evolution of Organic Matter During Composting of Winery and Distillery Residues by Classical 305 and Chemometric Analysis. *J. Agric. Food Chem.* **2009**, *57*, 9613–9623. [CrossRef]
2. Wulanningtyas, H.S.; Gong, Y.; Li, P.; Sakagami, N.; Nishiwaki, J.; Komatsuzaki, M. A cover crop and no-tillage system for enhancing soil health by increasing soil organic matter in soybean cultivation. *Soil Tillage Res.* **2021**, *205*, 104749. [CrossRef]
3. Kauer, K.; Pärnpuu, S.; Talgre, L.; Eremeev, V.; Luik, A. Soil Particulate and Mineral-Associated Organic Matter Increases in Organic Farming under Cover Cropping and Manure Addition. *Agriculture* **2021**, *11*, 903. [CrossRef]
4. Stegarescu, G.; Escuer-Gatius, J.; Soosaar, K.; Kauer, K.; Tõnutare, T.; Astover, A.; Reintam, E. Effect of Crop Residue Decomposition on Soil Aggregate Stability. *Agriculture* **2020**, *10*, 527. [CrossRef]
5. Blesh, J.; Vandusen, B.M.; Brainard, D.C. Managing Ecosystem Services with Cover Crop Mixtures on Organic Farms. *Agron. J.* **2019**, *111*, 826–840. [CrossRef]
6. Teasdale, J.R. Contribution of Cover Crops to Weed Management in Sustainable Agricultural Systems. *J. Prod. Agric.* **1996**, *9*, 475–479. [CrossRef]
7. Lu, Y.C.; Watkins, K.B.; Teasdale, J.R.; Abdul-Baki, A.A. Cover Crops in Sustainable Food Production. *Food Rev. Int.* **2000**, *16*, 121–157. [CrossRef]
8. Haruna, S.I.; Nkongolo, N.V. Tillage, Cover Crop and Crop Rotation Effects on Selected Soil Chemical Properties. *Sustainability* **2019**, *11*, 2770. [CrossRef]
9. Gattullo, C.E.; Mezzapesa, G.N.; Stellacci, A.M.; Ferrara, G.; Occhiogrosso, G.; Petrelli, G.; Castellini, M.; Spagnuolo, M. Cover Crop for a Sustainable Viticulture: Effects on Soil Properties and Table Grape Production. *Agronomy* **2020**, *10*, 1334. [CrossRef]
10. Pokhrel, S.; Kingery, W.L.; Cox, M.S.; Shankle, M.W.; Shanmugam, S.G. Impact of Cover Crops and Poultry Litter on Selected Soil Properties and Yield in Dryland Soybean Production. *Agronomy* **2021**, *11*, 119. [CrossRef]
11. Macdonald Potatoes: A Billion Industry for P.E.I | Local | News | The Guardian. Available online: https://www.theguardian.pe.ca/news/local/potatoes-a-billion-dollar-industry-for-pei-95098/ (accessed on 17 April 2020).
12. Agriculture and Agri-Food Canada (AAFC). Potato Market Information Review, 2018–2019. Available online: http://www.agr.gc.ca/eng/horticulture/horticulture-sector-reports/potato-market-information-review-2018-2019/?id=1578663511988 (accessed on 17 April 2020).
13. Seyedbagheri, M.M. Influence of Humic Products on Soil Health and Potato Production. *Potato Res.* **2010**, *53*, 341–349. [CrossRef]
14. Nyiraneza, J.; Thompson, B.; Geng, X.; He, J.; Jiang, Y.; Fillmore, S.; Stiles, K. Changes in soil organic matter over 18 y in Prince Edward Island, Canada. *Can. J. Soil Sci.* **2017**, *97*, 745–756. [CrossRef]
15. Government of Canada. Agriculture and Agri Food Canada. Available online: https://www.agr.gc.ca/eng/agriculture-and-agri-food-canada/?id=1395690825741 (accessed on 5 March 2021).
16. Sculte, E.E.; Hopkins, B.G. Estimation of Soil Organic Matter by Weight Loss-on-Ignition. *Am. Soc. Agron.* **2015**, *049*, 21–31.
17. Government of Prince Edward Island. Prince Edward Island Analytical Laboratories (PEIAL). Available online: https://www.princeedwardisland.ca/en/information/agriculture-and-land/pei-analytical-laboratories-peial (accessed on 5 March 2021).
18. Titration Analysis Systems | Multi-Parameter Testing Equipment. Available online: https://mantech-inc.com/analysis-systems/automated-titration-analysis/ (accessed on 17 December 2020).
19. Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES)—CA. Available online: //www.thermofisher.com/ca/en/home/industrial/spectroscopy-elemental-isotope-analysis/trace-elemental-analysis/inductively-coupled-plasma-optical-emission-spectrometry-icp-oes.html (accessed on 17 December 2020).
20. Konen, M.E.; Jacobs, P.M.; Burras, C.L.; Talaga, B.J.; Mason, J.A. Equations for Predicting Soil Organic Carbon Using Loss-on-Ignition for North Central U.S. Soils. *Soil Sci. Soc. Am. J.* **2002**, *66*, 1878–1881. [CrossRef]
21. Minitab®19. Minitab. In *Minitab. Rel. 12 for Windows*; Minitab: State College, PA, USA, 1998.
22. Barrett, R. Keeping Your Soils Covered: Environmental and Economic Benefit! Available online: http://peipotatoagronomy.com/wp-content/uploads/2018/04/Cover-Crop-Factsheet-Apr18.pdf (accessed on 10 August 2021).
23. Mann, K.K.; Schumann, A.W.; Obreza, T.A.; Harris, W.G.; Shukla, S. Spatial Variability of Soil Physical Properties Affecting Florida Citrus Production. *Soil Sci.* **2010**, *175*, 487–499. [CrossRef]
24. Ding, G.; Liu, X.; Herbert, S.; Novak, J.; Amarasiriwardena, D.; Xing, B. Effect of Cover Crop Management on Soil Organic Matter. *J. Geoderma.* **2006**, *130*, 229–239. [CrossRef]
25. Ramos, F.T.; Dores, E.F.D.C.; Weber, O.L.D.S.; Beber, D.C.; Campelo, J.H., Jr.; Maia, J.C.D.S. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. *J. Sci. Food Agric.* **2018**, *98*, 3595–3602. [CrossRef]
26. Mcleod, M.K.; Schwenke, G.D.; Cowie, A.L.; Harden, S. Soil Carbon is Only Higher in the Surface Soil under Minimum Tillage in Vertosols and Chormosols of New South Wales North-West Slopes and Plains, Australia. *Soil Res.* **2013**, *51*, 680–694. [CrossRef]

27. Nascente, A.S.; Li, Y.C.; Crusciol, C.A.C. Cover crops and no-till effects on physical fractions of soil organic matter. *Soil Tillage Res.* **2013**, *130*, 52–57. [CrossRef]
28. De Souza, G.P.; de Figueiredo, C.C.; de Sousa, D.M.G. Soil organic matter as affected by management systems, phosphate fertilization, and cover crops. *Pesqui. Agropecu. Bras.* **2016**, *51*, 1668–1676. [CrossRef]
29. Chng, H.Y.; Ahmed, O.H.; Majid, N.M.A.; Jalloh, M.B. Reducing Soil Phosphorus Fixation to Improve Yield of Maize on a Tropical Acid Soil Using Compost and Biochar Derived from Agro-Industrial Wastes. *Compos. Sci. Util.* **2017**, *25*, 82–94. [CrossRef]
30. Tan, K.; Keltjens, W.G. Interaction between Aluminium and Phosphorus in Sorghum Plants—II. Studies with the Aluminium Tolerant Sorghum Genotype SC0283. *Plant Soil* **1990**, *124*, 25–32. [CrossRef]
31. Obi, M.E. The Physical and Chemical Responses of a Degraded Sandy Clay Loam Soil to Cover Crops in Southern Nigeria. *J. Plant Soil* **1999**, *211*, 165–172. [CrossRef]
32. Wissem, H.; Noura, Z.; Ernest, K.; Didier, B.; Frederic, G.; Mongi, S. Effect of the soil properties on the sorption capacity of phosphorus and ammonium by alkaline soils of the semi-arid areas. *Appl. Chem.* **2005**, *8*, 2278–5736.
33. Fageria, N.K.; Baligar, V.C.; Bailey, B.A. Role of cover crops in improving soil and row crop productivity. *Commun. Soil Sci. Plant Anal.* **2005**, *36*, 2733–2757. [CrossRef]
34. Hallama, M.; Pekrun, C.; Lambers, H.; Kandeler, E. Hidden miners—The roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. *Plant Soil* **2019**, *434*, 7–45. [CrossRef]
35. Dean, L.A. Fixation of soil phosphorus. *Adv. Agron.* **2008**, *1*, 391–411.
36. Eric, D.R.; Peter, D.R.; Luiz, A.M.; Luciana, D.C.; Silvia, R.L.; Felipe, F.V.; Edwin, W.; Stephanie, A.S.; Leah, K.V.; Stephen, P. The phosphorus cost of agriculture intensification in the tropics. *Nat. Plants* **2016**, *2*, 16043.
37. USDA/NRCS. Soil ph. Soil Quality Kit—Guides for Educators. Available online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053293.pdf (accessed on 3 October 2021).
38. Waterer, D. Impact of high soil pH on potato yields and grade losses to common scab. *Can. J. Plant. Sci.* **2002**, *82*, 583–586. [CrossRef]
39. Understanding the Effect of Soil pH on Crop Productivity. Available online: http://www.agricura.co.zw/understanding-the-effects-of-soil-ph-on-crop-productivity/ (accessed on 17 June 2021).
40. Whalley, H.J.; Knight, M.R. Calcium Signatures are decoded by plants to give Specific Gene Responses. *New Phytol.* **2013**, *197*, 690–693. Available online: www.newphytologist.com (accessed on 24 February 2021). [CrossRef] [PubMed]
41. Groffman, P.M.; Hendrix, P.F.; Crossley, D.A. Effects of a Winter Legume on Phosphorus, Potassium, Calcium and Magnesium Cycling in a Humid Subtropical Agro Ecosystem. *Agric. Ecosyst. Environ.* **1987**, *18*, 281–289. [CrossRef]
42. Koch, M.; Naumann, M.; Pawelzik, E. The Importance of Nutrient Management for Potato Production Part I. *J. Plant Nutr. Yield* **2020**, *63*, 97–119. [CrossRef]
43. Chen, R.; Zhang, F.; Zhang, Q.; Sun, Q.; Dong, X.; Shen, R.F. Aluminium-phosphorus interactions in plants growing on acid soils: Does phosphorus always alleviate aluminium toxicity? *J. Sci. Food Agr.* **2012**, *92*, 995–1000. [CrossRef] [PubMed]