Temporal Impacts of Different Fertilization Systems on Soil Health under Arid Conditions of Potato Monocropping

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ORIGINAL PAPER

Temporal Impacts of Different Fertilization Systems on Soil Health under Arid Conditions of Potato Monocropping

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Abstract
The aim of this study was to determine temporary impacts of different fertilization systems on some labile soil biochemical and biological properties following potato monocropping under arid conditions. Field and incubation experiments were conducted to determine specifically soil organic carbon (SOC); dissolved organic carbon (DOC); dissolved organic nitrogen (DON); microbial biomass C (C_{mic}), N (N_{mic}), P (P_{mic}); bacterial and fungi counts; soil resistance index (SRI); net N mineralization (N_{min}); and some enzyme activity. Levels of SOC; DOC; N_{min}, C_{mic}, P_{mic}; bacteria and fungi counts; and soil respiration (SR) were significantly increased under organic and integrated fertilization systems compared with inorganic nano or NPK fertilization system, while levels of microbial biomass N (N_{mic}) and DON were markedly increased under nano or fertilizers compared to organic or integrated (organic + inorganic) fertilizers. By contrast, higher values of metabolic quotient (qCO_2) were recorded in nano or fertilizer treatments suggesting that microbial biomass was less efficient under high maintenance of soil carbon. Enzyme activities of dehydrogenase (DH), β-glucosidase (βG), and acid phosphatase (Ac-P) were in the order of organic > integrated > inorganic fertilization systems, while enzyme activity of urease (UR) was in the vice versa order. Integrated fertilization system recorded greater levels of SOC; DOC; N_{min}, C_{mic}, P_{mic}; and SR relative to inorganic fertilizers even though applied at lower rates. It is, therefore, important for soils under monocropping system to poise organic and inorganic fertilization system that enhances soil health and soil organic matter build-up.

Keywords Fertilization system · Microbial biomass · Soil respiration · Nanofertilizers · Enzyme activities

1 Introduction

Soil health is considered synonyms and can be interchangeably used as the continued capacity of the soil to function as alive vital ecosystem that sustains plants, animals, and humans (Rinot et al. 2019; Sheidai Karkaj et al. 2019). Monocropping is an agricultural method of farming where fields are often replanted year after year with one type of crop, such as potato. Monocropping of potato in Egypt is a common phenomenon in most governorates of the country being monocropped in fertile soils and endued with intensive fertilization. Consequently, soil health could have been deteriorated since potato productivity has been declining despite high rates of fertilizers applied and high yielding cultivars. Egypt is the largest African country producing potato, and ranks 14th in the world; therefore, authorities and farmers have the scope of increasing the intensification of crop production using intensive fertilization systems as the agricultural year is divided into three planting successive seasons: summer, nili, and winter. Intensive agricultural practices necessitate high fertilizer inputs to achieve high yields and hence improper agricultural intensification joined with careless use of fertilizers has deteriorated soil health. Thus, there is a rising cognizance on the use of eco-friendly sustainable fertilizers that place stress on soil health conservation on short- and long-term bases (Rinot et al. 2019). In addition, current methods of fertilization significantly contribute to greenhouse gas emissions from agricultural sectors; therefore, nanoscience and nanotechnology are being exploited for producing nanofertilizers to ensure nutrient use efficiency even though enhancing crop yields

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(El-Ghamry et al. 2018; Abdelsalam et al. 2019; Eissa 2019).

Fertilizers are organic and inorganic products applied to soil ecosystems for compensating or satisfying the essential nutrient needs for plant growth and health. Inorganic fertilizers play an important role in achieving crop yield targets, yet latent inefficiencies in conventional fertilizer use management can lead to disastrous environmental and economic concerns. Much of the NPK fertilizers applied to farming systems are lost to water and air resulting in harmful environmental impacts such as leached nitrate and phosphate runoff into aquatic ecosystems causing eutrophication and release of N-oxides into the atmosphere (El-Ghamry et al. 2018). Organic fertilizers, for instance composts, trigger continual nutrient availability, microbial activity, and growth due to high content of labile carbon (C) and nitrogen (N) (Bai et al. 2015). Organic fertilizers are progressively decayed in soils providing a continual release of nutrients including C, P, S, and N compared to fast release of nutrient when inorganic fertilizers are used (Abd El-Azeim and Haddad 2017). Although compost application conveys various profits to soil, i.e., increasing soil conservation, improving water holding and soil structure (Celik et al. 2004), compost contributes significantly to greenhouse gas emissions (Jiang et al. 2011).

Intensive agriculture for food production and consequent fluctuations in soil health is a common phenomenon, and hence, there is worldwide interest in rating the shifts in soil health due to agricultural practices (El-Ghamry et al. 2018; Abdelsalam et al. 2019; Haddad et al. 2019). Enhancement of global agricultural production using innovative nanoscience technology to produce new types of nanofertilizers is crucial to meet the coming stresses of population growth. Soil health depends on a large number of physicochemical and biochemical soil properties considered as early indicators for nutrient cycles of N and C and highly sensitive to changes in agricultural management practices such as fertilization systems (Zagal et al. 2009). Soil biochemical properties reflect the size of microbial biomass activity (microbial biomass C, N, and P, respiration etc.) and its related enzymatic activity involved in the C, N, S, and P cycles in soil ecosystem and considered as highly significant for soil ecological functions (Monaco et al. 2008). In addition, changes in soil microbial biomass and enzymatic activities due to changes in soil fertilization types and systems are more rapid and swift (Truu et al. 2008; Abd El-Azeim and Haddad 2017).

Organic carbon and carbon storage in agricultural soils are the major and most labile carbon pools on the earth's mantle ecosystem, and CO_2 exchange between agricultural soils ecosystems and the atmosphere has a significant impact on the carbon cycle in soils (Yang et al. 2018; Song et al. 2019). Among significant factors affecting net soil ecosystem CO_2 exchange and soil organic carbon (SOC) and storage is the fertilization type and method applied (Liu et al. 2016; Yang et al. 2018). Temporary responses of soil microbiological and biochemical properties to different organic and inorganic fertilization systems are considered to be sensitive indicators for detecting changes in soil health (Dinesh et al. 2013; Vega-Ávila et al. 2018). However, data on biochemical and microbiological properties under field conditions of potato monocropping, in response to various organic and inorganic fertilizers compared to nanofertilizers, is still of little research. Different potato fertilization systems in Egypt are followed either exclusively fertilized with chemical NPK fertilizers or applied with a combination of inorganic and organic inputs or it is supplied with only different organic fertilizer types under organic farming systems.

The scientific aim of this research therefore was to determine temporary impacts of different fertilization systems namely organic (compost), inorganic (NPK fertilizers or only NPK nanofertilizers), and integrated fertilization systems (organic + inorganic) on various labile microbial and biochemical soil properties and its interrelationships reflecting soil health of potato monocropping cultivation. It was hypothesized that all fertilization treatments would temporarily affect soil biochemical and biological variables and NPK, or nanofertilizers can be effectively applied individually or integrated with organic fertilizers to deliver nutrients without harming the concocts of soil health.

2 Materials and Methods

2.1 Experimental Site Details and Soil Characteristics

Field experiment was conducted at the experimental farm facilities (28°18′16″N latitude and 30°34′38″E longitude), Faculty of Agriculture, Minya University, Egypt, in order to study the effects of different fertilization systems on biochemical and biological soil properties as sensitive indicators of soil health after monocropping cultivation of potato crop (*Solanum tuberosum* L.). Soil of the experimental site had a clay texture and classified as alluvial soil according to Abd El-Azeim et al. (2016). Prior to the initiation of the field trial, clay soil detailed in Table 1 was collected, air dried, and sieved to < 2.0 mm, and composite sub-samples were used to determine the basic soil physicochemical properties using standard methods derived from Page et al. (1982).

2.2 Experiment Procedures and Fertilization Systems

The soil plot area was 8 m^2, prepared manually after the experimental field was deeply turn over using Chesil plow and then leveled accurately to break soil clods and bring soil to desired tilth. Nine treatments in a randomized complete block design were used with three replicates. Nile compost was added during soil preparation before plowing as organic

Table 1 Physicochemical properties of the soil investigated

Soil property			
Soil chemical properties		Soil physical properties	
pH (1:2.5 water)	7.7 (7.4)[a]	F.C. %	42.45
$CaCO_3$ (g kg^{-1})	17.9	PWP %	13.78
CEC (cmol$_c$ kg^{-1})	37.87	WHC %	48.76
EC (dS m^{-1} at 25 °C)	1.35	A.V. (F.C.–PWP) %	28.67
OM (g kg^{-1})	28.61[b]	A.V. (WHC–PWP) %	34.98
Total N (g kg^{-1})	1.29	Bulk density (BD) g/cm^3	1.31
Total C/N ratio	22.18	Particle density (PD) g/cm^3	2.22
SOC g kg^{-1}	18.48	Clay (%)	56.45
Organic N (g kg^{-1})	0.76	Sand (%)	17.76
Organic C/N ratio	24.31	Silt (%)	25.79
Mineral N (mg kg^{-1})	58.46	Soil texture	Clay
Total P (g kg^{-1})	0.56		
Available P (mg kg^{-1})	13.11		
Total K (g kg^{-1})	4.37		
C_{mic} (mg kg^{-1})	112.89		
N_{mic} (mg kg^{-1})	22.45		
C_{mic}/N_{mic}	5.03		

OM organic matter, *SOC* soil organic carbon, C_{mic} microbial biomass carbon, N_{mic} microbial biomass nitrogen, *F.C.* field capacity, *PWP* permanent wilting point, *WHC* water holding capacity

[a] Figures in parentheses are pH values obtained for soil by $CaCl_2$ extraction ratio of 1:2.5

[b] Organic matter determined by loss on ignition

fertilizer at the rate of 40 m^3 ha^{-1}. Field plots were irrigated 15 days prior to sowing then potato tuber sowing was done at 10 cm depth at the tuber rates of 1500 kg ha^{-1} by opening furrows in lines at a distance of 50 cm among rows, and the distance between hills was 25 cm apart. Potato tubers, cv Cara, were obtained from the Mallawy Agricultural Research Centre (MARC), Ministry of Agriculture, Egypt. Tubers were divided into pieces, averaging approximately 35 g weight, then potato tuber pieces were sterilized with Kapetan 1% at the rate of 1.25 kg/ton for 5 min, then sterilized potato tuber pieces were sown at 10 cm depth in summer season. Intercultural operations other than the abovementioned treatments were followed as per schedule according to the potato cultivation recommendations of the Agricultural Research Centre in Egypt.

The fertilization systems employed were in accordance with the Agricultural Research Centre in Egypt on potato production and are being recommended to the farmers for adoption. The fertilization systems employed were organic where only compost was applied (control), synthetic fertilization system involved solely recommended levels (100%) of chemical NPK fertilizers or solely recommended (100%) of NPK nanofertilizers, and integrated fertilization system involved a mixture of compost as an organic fertilizer plus solely recommended (100%) or lower levels (50% or 25%) of NPK nano or fertilizers. In this experiment, the organic fertilization system using Nile compost was added during soil preparation before plowing as organic fertilizer at the rate of 40 ton ha^{-1}. The nutrient composition and physicochemical properties of the Nile compost are presented in Table 2. Inorganic fertilization system applied contained ammonium nitrate (33%N), triple super phosphate (15% P_2O_5), and potassium sulfate (48% K_2O) used as resources for NPK chemical fertilizers at the recommended levels for potato crop at rates of 350 nitrogen, 85 phosphorus, and 200 potassium kg ha^{-1} as recommended by the Egyptian Ministry of Agriculture, Egypt.

Individual nano-N, nano-P, and nano-K fertilizers in liquid formulations were imported from India containing 19% of each nutrient of NPK. These fertilizers are eco-friendly made through biological process and have been designed to match chemical fertilizers in terms of nutrient content and application rates. These revolutionary nutritional agricultural inputs of nano-N, nano-P, and nano-K fertilizers are developed by a private company (Pratishtha) in India in association with the Indian Council of Agricultural Research as complete nutritional nanofertilizer of NPK for crops. The experimental treatments included therefore were as follows:

1. (Control) = Compost as organic fertilizer at the rate of 40-ton ha^{-1}.
2. (FS1) = 100% NPK fertilizers alone at recommended levels.
3. (FS2) = 100% NPK nanofertilizers alone equal to recommended levels.

Table 2 Nutrient composition and physicochemical properties for the investigated compost

Compost property	Organic Nile compost
Moisture weight %	36.60%
pH (1: 2.5)	7.90
EC (dS m^{-1} at 25 °C)	5.20
CEC (cmol$_+$ kg^{-1})	45.66
Dry solids %	63.40
Ash %	9.90
Total organic carbon (g kg^{-1}) (D.M.)	265.0
Total N (g kg^{-1}) (D.M.)	10.0
C/N Ratio	26.50
Total P (g kg^{-1}) (D.M.)	5.0
N/P Ratio	2.00
Total K (g kg^{-1}) (D.M.)	9.0
Total Ca (g kg^{-1}) (D.M.)	26.3
Total Mg (g kg^{-1}) (D.M.)	6.6

EC electrical conductivity, *CEC* cation exchange capacity

4. (FS3) = 100% NPK fertilizers + compost at the rate of 40-ton ha^{-1}.
5. (FS4) = 100% NPK nanofertilizers + compost at the rate of 40-ton ha^{-1}.
6. (FS5) = 50% NPK fertilizers + compost at the rate of 40-ton ha^{-1}.
7. (FS6) = 50% NPK nanofertilizers + compost at the rate of 40-ton ha^{-1}.
8. (FS7) = 25% NPK fertilizers + compost at the rate of 40-ton ha^{-1}.
9. (FS8) = 25% NPK nanofertilizers + compost at the rate of 40-ton ha^{-1}.

2.3 Soil Sampling and Incubation

At harvest stage, dated after 115 days from planting, a sample of 1-kg soil was taken from each experimental plot for incubation under controlled conditions to determine changes in soil biochemical and biological properties. Soil samples were taken directly before tuber harvest from the inner of each plot, cleared of all root debris and transferred for soil laboratory. Once in the laboratory, the soils were sieved (< 2 mm) and then incubated for 10 days at 30 °C under 65% of soil field capacity.

2.4 Analyses of Soil Biochemical Properties

After incubation, soil samples for the determination of soil biochemical properties were sieved to pass a 0.2-mm mesh and reported means were calculated on soil oven dried bases (105 °C). For determination of net N mineralization (N_{min}), before and after incubation, 10 g soil was extracted with 50 mL of 2 M KCl for 30 min, and by steam distillation using N analyzer (Kjeltech 2100, Foss), NH_4^+-N and total inorganic N (NH_4^+-N and NO_3^--N) were determined (Mulvaney 1996). Soil mineralization capacity was demarcated by differences between values found before and after incubation. Walkley and Black method was used to determine soil organic C (SOC) (Nelson and Sommers 1996) and steam distillation method using N analyzer (Kjeltech 2100, Foss) for mineral N (Mulvaney 1996). Dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) were determined by the method described by Smolander and Kitunen (2002) using multi N/C analyzer (Jena, Germany).

After aerobic incubation, the chloroform fumigation-extraction method of 15 g (oven dried) of moist soil (Vance et al. 1987) was used to determine soil microbial biomass carbon (C_{mic}), microbial biomass nitrogen (N_{mic}) using (multi N/C 2100, analyzer Jena), and microbial biomass phosphorus (P_{mic}) using k_{EC} of 0.45, k_{EN} of 0.54, and k_{EP} of 0.40, respectively. Soil basal respiration (SR) was measured as the cumulative amounts of CO_2 evolved from moist soil, adjusted to 65% water field capacity, and incubated for 10 days at 30 °C in the dark. The CO_2 accumulated was analyzed using gas chromatography technique described by Liu et al. (2012). Metabolic quotient (qCO_2) was calculated as the ratio of basal respiration (SR) to microbial biomass carbon unit (C_{mic}) according to Plaza et al. (2016).

2.5 Analyses of Soil Enzyme Activities

As described by Tabatabai (1994), dehydrogenase (DH) activity was estimated using 2,3,5-triphenyltetrazolium chloride (TTC) as the substrate, urease (UR) using urea as the substrate, acid phosphatase (Ac-P) using ρ-nitrophenyl phosphate as the substrate, and β-glucosidase (βG) using ρ-nitrophenyl-β-d-glucopyranoside as the substrate (Eivazi and Tabatabai 1990). The amount of ρ-nitrophenol released in all these cases was estimated spectrophotometrically, and all enzyme activities were expressed as products per unit of dry soil mass and incubation time.

2.6 SRI and Total Bacteria and Fungi

Plate count technique in accordance with Alef (1995) was used to determine total counts of bacteria and fungi in soil samples after potato monocropping cultivation. On nutrient agar, colony forming units (CFU) of total bacteria was counted, while CFU of total fungi was counted on potato dextrose agar media. The soil resistance index (SRI) was determined as the counts of bacteria or fungi withstand each fertilizer type using the equation developed by Orwin and Wardle (2004) and Haddad et al. (2019):

$$RS\ (t0) = 1 - \frac{2\,|D_0|}{(C_0 + |D_0|)}$$

where D_0 is the difference between undisturbed control (C_0) (organic fertilized soil) and the disturbed soil (F_0) (inorganic fertilized soil) at the end of the disturbance time (fertilization) (t_0), (i.e., time 0 or t_0 at the end of the experiment). This index is symmetrical with the control, as this takes into account differences in the amount of change in soil microbial biomass that a disturbance could cause considering fertilizer type is a disturbance factor. This index of resistance is confined between + 1 and − 1, indicating + 1 treatment had no disturbance effect (greatest resistance), and inferior data show stronger effects (low resistance).

2.7 Statistical Analyses

Experimental treatment means were statistically subjected to variance analysis and presented as mean values. Significance of the differences was estimated and compared using Duncan test at 5% level of probability ($p < 0.05$). Interrelationships between soil parameters was measured using Pearson's correlations, and all the statistical analyses were carried out using SAS system (SAS Institute Inc. 2011) and differences among means evaluated using least significant difference (LSD) methods at $p < 0.05$.

3 Results

3.1 Soil Biochemical Properties

The soil biochemical properties studied were soil pH, OM, CEC, net N mineralization (N_{min}), dissolved organic-N (DON), dissolved organic-C (DOC), and soil total organic carbon (SOC) (Table 3). Soil OM, CEC, mineral N, SOC, and DOC were significantly influenced by different fertilization systems and varied markedly between organic (compost), integrated fertilization system (organic + inorganic), and inorganic (NPK nano or fertilizers). All these soil parameters were significantly greater in organic (control) and integrated fertilization systems compared to inorganic fertilization system except for DON and mineral N where these values were greater in inorganic treatments (NPK nano or fertilizers) than organic treatment. However, soil pH values were not significantly affected by different fertilization systems. Generally, a perusal of data represented in Table 3, a significant use impact of organic and integrated fertilization systems (nano or fertilizers + organic compost) was observed on soil biochemical quality parameters compared to inorganic fertilization system. Soil biochemical characteristics of the investigated soil after potato monocropping cultivation exposed obvious improvements at all organic or integrated fertilization treatments. The experimental results showed among different fertilization treatments, treatment FS8 (25% NPK nanofertilizers + compost at the rate of 40 ton ha^{-1}) resulted in higher increases in most soil parameters compared to other treatments though statistically was at par with treatments FS6, FS5 (50% NPK nano or fertilizers + compost at the rate of 40 ton ha^{-1}), and control.

Means of SOC ranged from 18.49 to 23.40 g kg^{-1} across different fertilization systems, where SOC levels were significantly greater in organic (control, 23.4 g kg^{-1}) followed by integrated (FS7, 22.49 g kg^{-1}), and inorganic treatments of NPK fertilizers (FS1, 18.49) or nanofertilizer (FS2, 20.07 g kg^{-1}). On the other hand, means of DOC ranged from 194.98 to 293.44 mg kg^{-1}, recording obvious significant increase in compost organic treatment (control) over integrated and inorganic treatments. In contrast, inorganic NPK fertilization system and integrated fertilization system positively affected DON levels compared to organic fertilization treatments. A significant use effect of nano and fertilizers alone or integrated with organic compost was observed on the DON at all application rates except for FS1 (100% of NPK fertilizers). DON ranged from 64.68 to 85.11 mg kg^{-1} across treatments, and among treatments, FS4 treatment however at par with FS5 and FS6 resulted in significantly higher DON (85.11 mg kg^{-1}) than other treatments in comparisons. Among treatments, the inorganic NPK treatments (FS1) recorded minimum levels of SOC and DON, while the integrated treatment of FS3 recorded the lowest level (194.98 mg kg^{-1}) of DOC. In general, the ratio of dissolved organic carbon to dissolved organic nitrogen (DOC/DON)

Table 3 Soil biochemical properties as impacted by different fertilization systems

Soil biochemical property									
Treatment		pH (1:2.5 water)	O.M. (g kg^{-1})	CEC (cmol$_c$ kg^{-1})	N_{min} (mg kg^{-1})	SOC (g kg^{-1})	DOC (mg kg^{-1})	DON (mg kg^{-1})	DOC/ DON
Control		7.79	35.38a	40.11bc	78.36f	23.40a	293.44a	68.71bc	4.30a
Inorganic	FS_1	7.76	28.21b	36.44e	112.70de	18.49e	233.38e	64.68c	3.67b
	FS_2	7.77	28.10b	37.39de	119.99cd	20.07cde	196.74f	73.77abc	2.67de
Integrated	FS_3	7.80	34.14a	39.08cd	107.48d	21.41bc	194.98f	76.21abc	2.57e
	FS_4	7.78	34.48a	39.13cd	117.46de	21.56bc	252.45cd	85.11a	2.97cde
	FS_5	7.79	33.64a	38.82cd	129.47bc	19.69de	263.44b	83.78a	3.15bcd
	FS_6	7.75	35.37a	41.44ab	134.75ab	20.99bcd	260.46bc	81.17a	3.26bc
	FS_7	7.75	35.23a	40.03bc	140.44a	22.49ab	246.31d	77.01ab	3.20bcd
	FS_8	7.80	35.70a	41.88a	139.08ab	22.37ab	257.60bc	81.75a	3.16bcd
$LSD_{0.05}$		0.092	2.41	1.465	10.322	1.669	10.433	11.81	0.566

Values followed by the same letter are non-significantly different at $p < 0.05$

OM organic matter, *CEC* cation exchange capacity, N_{min} N mineralization, *SOC* soil organic carbon, *DOC* dissolved organic carbon, *DON* dissolved organic nitrogen was balanced with DOC across all fertilization systems and ranged from 2.57 for FS3 treatment to 4.30 for control (organic treatment).

Also, in this research, the availability of labile C was evaluated by Q_{mic} as the percentage of microbial biomass carbon (C_{mic}) to soil organic carbon (SOC) (Anderson and Domsch 2010; Dinesh et al. 2012; Jian et al. 2016). Results of this research indicated that soil levels of Q_{mic} ranged from 1.187 to 2.057% across different fertilization systems and being higher in the organic fertilization system due to high soil DOC content which conducted more efficient microbial biomass and enzymatic activities.

3.2 Soil Biological and Microbial Biomass Properties

Soil biological properties studied were microbial biomass C (C_{mic}), microbial biomass N (N_{mic}), and microbial biomass P (P_{mic}); soil respiration (SR); metabolic quotient (qCO_2); soil microbial population (bacteria and fungi counts); and enzyme activities of dehydrogenase (DH), urease (UR), β-glucosidase (βG), and acid phosphatase (Ac-P). Microbial biomass carbon (C_{mic}) means ranged from 227.76 to 479.46 mg kg^{-1}, microbial biomass nitrogen (N_{mic}) ranged from 31.04 to 55.23 mg kg^{-1}, and microbial biomass phosphorus (P_{mic}) ranged from 16.44 to 35.48 mg kg^{-1}, reflecting obvious improvements in between different fertilization systems (Table 4). The greatest levels of C_{mic} were recorded in the control treatment (organic fertilizer), while the greatest levels of P_{mic} were in integrated treatment (FS5), and N_{mic} was in integrated fertilizer treatment (FS7). Individual usage of nano or fertilizers (inorganic fertilization system) resulted in a significant drop in C_{mic}, represented by an average 52.5% and 41.76% compared to organic and integrated treatments, respectively. Organic fertilization system (control) recorded the highest significant value of C_{mic} over both full recommended dose of inorganic treatments (nano and non-nano) and all six integrated treatments in comparison (organic + inorganic), even though C_{mic} levels in all integrated treatments were highly significant compared to individual inorganic treatments.

By complete contrast, inorganic fertilization significantly increased N_{mic} levels compared to organic treatment, while integrated treatment N_{mic} levels were significantly higher than both organic and inorganic treatments and it was almost identical among integrated treatments. Similarly, P_{mic} followed the same trend of C_{mic}, where P_{mic} levels in inorganic treatments were lower by 24.41 to 53.66% compared to organic and integrated fertilization systems as it was almost identical and insignificant in between these integrated treatments. Both ratios of C_{mic}/N_{mic} and C_{mic}/SOC (Q_{mic}%) ranged from 5.96 to 15.45 and from 1.187 to 2.057%, respectively, across treatments, being lower in inorganic treatments whether NPK fertilizers compared to organic and integrated treatments. However, higher and significant C_{mic}/N_{mic} and C_{mic}/SOC ratios were recorded by organic treatment (control) compared to both integrated and inorganic fertilization treatments. In contrast to microbial biomass carbon (C_{mic}) and microbial biomass phosphorus (P_{mic}), microbial biomass nitrogen (N_{mic}) levels were obviously cumulated at greater rates in all inorganic fertilization treatments (Table 4). Evidently, after artificial NPK or nanofertilizers, availability of nitrogen increased encouraging soil microbes to immobilize N leading to N_{mic} increases. This was in agreement with the results of Wang et al. (2008), and in disagreement with Omari et al. (2017), they stated that the privilege of inorganic fertilization system, though applied at lower rates, was evident on soil biochemical

Table 4 Soil biological properties as impacted by different fertilization systems

Soil biological property									
Treatment	C_{mic} (mg kg^{-1})	N_{mic} (mg kg^{-1})	P_{mic} (mg kg^{-1})	SR (μg CO_2-C g^{-1} day^{-1})	N_{min} (mg N kg^{-1} per 10 days)	qCO_2 (mg CO_2-C (g biomass C)$^{-1}$ day^{-1})	C_{mic}/N_{mic}	Q_{mic}%
Control (organic)	479.46a	31.04d	30.11d	38.36ab	143.40a	80.01b	15.45a	2.057a
Inorganic FS_1	227.76f	38.21c	16.44c	22.70d	118.49c	99.68ab	5.96f	1.233d
FS_2	237.77f	38.10c	17.74c	23.32d	120.07c	98.09ab	6.24f	1.187d
Integrated FS_3	371.14c	44.14b	33.75b	34.15abc	138.08ab	92.04ab	8.42b	1.734b
FS_4	391.11b	54.48a	32.46a	35.13abc	138.23ab	89.84b	7.18d	1.815b
FS_5	357.79d	53.64a	35.48a	29.47bcd	146.36a	82.16b	6.67e	1.817b
FS_6	364.41cd	45.37b	31.44b	34.75abc	127.66bc	95.41ab	8.04bc	1.740b
FS_7	341.08e	55.23a	32.03a	40.44a	129.15bc	118.86a	6.18f	1.518c
FS_8	354.47d	45.70b	28.55b	29.08cd	122.37c	82.15b	7.76c	1.586c
LSD $_{0.05}$	13.02	2.1	6.69	8.98	10.82	27.36	0.416	0.14

Values followed by the same letter are non-significantly different at $p < 0.05$

C_{mic} microbial biomass carbon, *N_{mic}* microbial biomass nitrogen, *P_{mic}* microbial biomass phosphorus, *SR* soil respiration, *N_{min}* N mineralization, *qCO_2* respiratory quotient, *Q_{mic}* the ratio of microbial biomass carbon to soil organic carbon

properties relative to the reference sites where organic and integrated soil improvement approaches were applied.

Soil respiration (SR) indicating CO_2 influx ranged from 22.70 to 40.44 μg CO_2-C g^{-1} day^{-1} across all treatments being significantly greatest in organic and integrated treatments compared to inorganic treatments. The lowest SR values were recorded by inorganic fertilizer treatment (FS1, 22.7, μg CO_2-C g^{-1} day^{-1}) and nano treatment (FS2, 23.32, μg CO_2-C g^{-1} day^{-1}). The integrated treatment (FS7) registered the highest SR (40.44, μg CO_2-C g^{-1} day^{-1}) among all treatments followed by the organic treatment (38.36, μg CO_2-C g-1 day^{-1}). By contrast to soil respiration ratio (SR) and microbial biomass carbon (C_{mic}), the $q$$CO_2$ levels trend among treatments were in the order of inorganic > integrated > organic fertilization systems. Means of $q$$CO_2$ were significantly higher in treatments with inorganic (FS1 and FS2) compared to organic (control) and integrated fertilization treatments (FS3, FS4, FS5, FS6, FS7, and FS8).

Across all treatments, after incubation, the total inorganic nitrogen mineralized (N_{min}) ranged between 118.49 and 146.36 (mg N kg^{-1} per 10 days) and was greatest in integrated fertilization treatment (FS5, 146.36 mg N kg^{-1} per 10 days) followed by organic treatment (control, 143.40 mg N kg^{-1} per 10 days). Means of N_{min} varied little and insignificantly in between organic (control) and integrated treatments (FS3, FS4, FS5, FS6, FS7, and FS8), while they were significantly higher compared to inorganic treatments (FS1 and FS2) (Table 4).

Ratios of Q_{mic} in soils significantly differentiated in the order of organic > integrated > inorganic. Ratios of Q_{mic} in the soil treated with integrated or inorganic fertilization systems at all application rates were in general below 2% indicating that soil microorganisms were under an environmental stress due to labile carbon deficiency. Under inorganic fertilization system, treatments of FS1 and FS2 recorded the lowest Q_{mic} values of 1.233% and 1.187%, respectively, indicating the lowest labile organic substrate availability but an abundance of labile nitrogen causing luxurious consumption of N beyond their current metabolic requirements.

3.3 Soil Microbial Biomass and Resistance Index

Different fertilization system impacts on soil microbial biomass counting of bacteria and fungi at different application rates are presented in Table 5. The level trends in the counts of bacteria and fungi among treatments were in the order of organic > integrated > inorganic fertilization systems. Means of bacteria or fungi counts were significantly higher in treatments with organic (control) compared to inorganic (FS1 and FS2) and integrated fertilization treatments (FS3, FS4, FS5, FS6, FS7, and FS8). After soil incubation, significant differences were observed between organic and inorganic fertilization systems in the counts of bacteria or fungi reflecting that soil microbial biomass (SMB) activities were temporarily facilitated or inhibited by each fertilization system.

Soil resistance index (SRI) is an effective measure of soil microbial biomass responses to a soil disturbance factor (environmental stress) (Orwin and Wardle 2004). In the present study, a significant effect of different types and rates of fertilizers on the total counts of bacteria and fungi was demonstrated and verified by increasing or decreasing values of the SRI compared to the control (organic treatment). The values of SRI for soil bacteria and fungi were positive throughout the experiment but differed according to the fertilizer dose and type applied (Table 5). Across all treatments, SRI ranged between 0.448 and 1.00 for bacteria and from 0.214 to 1.00 for fungi and was greatest in organic fertilization treatment followed by integrated treatments. Means of SRI were significantly higher in treatments with organic (control) compared to integrated fertilization treatments (FS3, FS4, FS5, FS6, FS7, and FS8) and inorganic (FS1 and FS2). Lower values indicate inhibited influence of fertilization system on the microbial biomass activity and assimilation balance (lower microbial activity). Higher SRI values of bacteria and fungi were prominent in organic (higher microbial activity) than other fertilization systems.

3.4 Enzyme Activities

Soil microorganisms' enzymatic activities were studied as dehydrogenase (DH), urease (UR), β-glucosidase (βG), and acid phosphatase (Ac-P) (Table 6). Dehydrogenase (DH) as an important oxi-reductase enzyme and hydrolytic enzymes participated in carbon (β-glucosidase, βG), nitrogen (urease, UR), and phosphorus (acid phosphatase Ac-P) soil cycles were activated to different degrees according to each fertilizer system (Table 6). In general, enzyme activities of dehydrogenase (DH), acid phosphatase (Ac-P), and β-glucosidase (βG) were significantly differentiated in accordance with each fertilizer type in the order of organic > integrated > inorganic except for FS6 which registered low value of enzyme activity in the case of βG (3.78 μmol p-nitrophenol g^{-1} h^{-1}) and FS3 low value of enzyme activity in the case of Ac-P (6.81 μmol p-nitrophenol g-1 h^{-1}). The lowest values ever were recorded by the inorganic treatments of (FS1 and FS2) regarding enzyme activities of dehydrogenase (DH), acid phosphatase (Ac-P), and β-glucosidase (βG). On the other hand, the activity of urease (UR) significantly differentiated in the order of inorganic > integrated > organic, where the control (organic) treatment recorded the lowest enzyme activity value of 4.36 (μmol NH_3-N g^{-1} h^{-1}).

Table 5 Soil resistance index (SRI) and microbial counts of bacteria and fungi as impacted by different fertilization systems

Treatment		Total counts of bacteria ($\times 10^6$ cfu g^{-1})	SRI	Total counts of fungi ($\times 10^4$ cfu g^{-1})	SRI
Control (organic)		62.63a	1.00	46.30a	1.00
Inorganic	FS_1	44.60cd	0.553	26.23d	0.395
	FS_2	38.77e	0.448	16.33e	0.214
Integrated	FS_3	62.17a	0.985	44.73ab	0.935
	FS_4	55.23b	0.789	40.03abc	0.762
	FS_5	47.23c	0.605	38.77bc	0.720
	FS_6	46.33c	0.587	33.97c	0.579
	FS_7	45.97cd	0.580	37.67c	0.686
	FS_8	40.70de	0.481	19.83de	0.273
L.S.D. $_{0.05}$		7.265		7.0119	

Values followed by the same letter are non-significantly different at $p < 0.05$

4 Discussion

Results of this research revealed that C_{mic}, P_{mic}, DOC, soil bacterial and fungi counts, and SRI values were relatively lower in inorganic fertilization system compared to organic and integrated. One plausible reason to explain why inorganic fertilizers produce marked reductions in most biochemical and microbial properties except for DON and N_{mic}. Solitary application of inorganic fertilizers triggered the negative effects of inorganic fertilization by diminishing soil organic carbon (SOC) and dissolved organic carbon (DOC), resulting in reduction of readily metabolizable carbon needed by soil microorganisms to activate soil microbial and enzyme activities and confidently vice versa which happened in the organic and integrated treatments (Dinesh et al. 2012; Dinesh et al. 2013; Jian et al. 2016; Yang et al. 2018). This demonstrates that the most influential factors affecting soil microbial biomass activities in soils are the availability of dissolved organic substrates (SOC and DOC) as reflected by strong intercorrelations between microbial biomass C and P with dissolved organic substrates in soils (Dinesh et al. 2012).

Integration of different rates of inorganic and organic fertilizers increased soil biochemical and biological property levels in the integrated treatments (FS3, FS4, FS5, FS6, FS7, and FS8) even though it involved inorganic fertilizers, reflecting that different microbial responses were due to variations in the fertilizer type and application rates (Dinesh et al. 2012, 2013; Jian et al. 2016). Interestingly, integration of inorganic fertilizers whether non-nano or nano at lower rates (FS5, FS6 at 50% and FS7, FS8 at 25%) with organic compost enhanced all soil biological parameters than recommended levels of NPK inorganic fertilizers applied alone or integrated with organic compost. This might be attributed to that organic compost was able to offset and alleviate the negative effects of inorganic fertilizers on C_{mic}, N_{mic}, and P_{mic} at lower rates compared to full dose. Liu et al. (2009) revealed that organic

Table 6 Soil microbial enzyme activities in soils as impacted by different fertilization systems

Treatment		Dehydrogenase (nmol TPF g^{-1}soil h^{-1})	Acid phosphatase (μmol *p*-nitrophenol g^{-1} h^{-1})	β-glucosidase (μmol *p*-nitrophenol g^{-1} h^{-1})	Urease (μmol NH_3-N g^{-1} h^{-1})
		Soil microbial enzyme activities			
Control		216.12a	16.71a	10.45a	4.36d
Inorganic	FS_1	127.76f	10.54bc	3.77d	10.37a
	FS_2	117.77f	7.10de	4.41cd	9.66a
Integrated	FS_3	171.14c	6.81e	7.75ab	7.48b
	FS_4	191.11b	11.81b	6.79bc	7.13bc
	FS_5	157.79d	8.64cde	5.48bcd	6.80bc
	FS_6	164.41cd	9.71bcd	3.78d	7.08bc
	FS_7	141.08e	11.89b	6.37bcd	6.77bc
	FS_8	154.47d	12.37b	5.55bcd	5.41cd
LSD $_{0.05}$		12.37	2.86	2.73	1.96

Values followed by the same letter are non-significantly different at $p < 0.05$

amendments with lower rates of chemical fertilizers heightened C_{mic}, N_{mic}, and P_{mic} than recommended levels of chemical fertilizers. Soil concentrations of organic carbon (SOC) and labile organic fractions such as dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) were significantly influenced by the application of different fertilization systems. Different fertilization systems obviously affected dissolved soil organic substrates (DOC and DON) and soil levels of SOC, though at varying degrees according to each fertilizer type. A fertilizer type and rate effect upon soil biochemical properties is well established in the literature by many researchers (Wang et al. 2008; Rifai et al. 2010; Dinesh et al. 2013; Jian et al. 2016; Song et al. 2019). Founded on this research, it is preferable to integrate organic compost plus NPK nanofertilizers on fertilizers due to the priority of lower rates of nanofertilizers on a full dose of NPK fertilizers (El-Sharkawy et al. 2017; Burhan and AL-Hassan 2019).

Organic compost supplied readily metabolizable carbon via SOC and DOC; this in turn provides energy for microbial biomass carbon and phosphorus reflecting soil value increases in C_{mic} and P_{mic}. Positive strong intercorrelation ($p < 0.05$; $n = 27$) was figured between C_{mic} in relation to soil biochemical properties such as SOC ($R^2 = 0.48$) and DOC ($R^2 = 0.41$) (Fig. 1). Also, intercorrelations were found between P_{mic} and SOC ($R^2 = 0.15$) and DOC ($R^2 = 0.11$). In contrast, this study revealed that soil microbial biomass nitrogen (N_{mic}) values were identical and not significantly correlated with soil properties of SOC ($R^2 = 0.0001$) or DOC ($R^2 = 0.0002$) indicating lower microbial and enzyme activities. On the contrary to DOC, inorganic fertilization system enhanced DON levels in the soil under investigation reflected by positive correlation between N_{mic} and DON ($r = 0.57$) and these positive effects have been demonstrated in many literatures (Dinesh et al. 2013; Jian et al. 2016; Song et al. 2019). DON is used as a measure of labile substrate N for soil microorganisms nutrition exactly as labile C as measured by dissolved organic carbon (DOC), even though weak correlation was observed between DOC and DON ($r = 0.1$; $p < 0.05$; $n = 20$).

In this research, soil respiration (SR) rates in organic and inorganic treatments were significantly higher than those in the inorganic fertilizer treatments due to inorganic fertilization (Melero et al. 2006; Dinesh et al. 2010) or due to higher soil microbial biomass activities as reflected by positive high correlation (Fig. 2) between SR and C_{mic} ($R^2 = 0.41$; $p < 0.22$; $n = 24$) (Melero et al. 2006; Dinesh et al. 2010). Lower rates of soil respiration ratios under inorganic fertilization system and across treatments might have resulted from decreased microbial biomass activity as the availability of dissolved and labile organic carbon fractions decreased (Ding et al. 2010). By contrast, under organic and integrated fertilization systems, availability of carbon substrates increased as the carbon pool and microbial biomass activity increased.

Higher qCO_2 values recorded by inorganic fertilization system treatments indicated decreased organic substrate use efficiency as conversion of total soil organic carbon (SOC) into microbial biomass carbon (C_{mic}) is less effectual (Anderson and Domsch 2010). Lower qCO_2 values under organic fertilization system detected in this research reflected by negative correlation between qCO2 and C_{mic} ($r = -0.33$; $p < 0.22$; $n = 24$) is in regular with the remarks of several researchers (Melero et al. 2006; Ding et al. 2010; Dinesh et al. 2013). Metabolic quotient (qCO_2) as CO_2 flux per unit of microbial biomass carbon (C_{mic}) ranged from 80.01 to 118.86 mg CO_2-C (g biomass C)$^{-1}$ day^{-1} (Table 4). The metabolic quotient (qCO_2) supplies the energy requirements for soil microorganisms, where values are above 2 g C-CO_2 h^{-1} kg $C_{mic}{}^{-1}$, being the critical threshold for active performance of soil microorganisms (Anderson 2003). Anderson and Domsch (2010) reported that high qCO_2 values reflected soil system disability to restock carbon lost by respiration resulting in microbial population decline.

Evident effects of different fertilization systems on net N_{min} levels indicate increases in soil microbial population pool (Dinesh et al. 2013; Jian et al. 2016; Song et al. 2019). Greater levels of N_{min} in organic and integrated treatments indicated that more nutrient and organic carbon availability imparted favorable conditions for soil microorganisms reflexed on increases in the counts of bacteria and fungi and fast nutrient turnover (Rivest et al. 2010; Jian et al. 2016). In the case of integrated fertilization system at all application rates, elevated availability of N in the presence of organic carbon can modify the form and decomposition of SOC and finally soil C turnover due to indispensable spousing of C and N in the soil ecosystem (Jian et al. 2016).

Soil resistance index (SRI) for bacteria and fungi in inorganic fertilization system whether non-nano or nano decreased to a minimal extent and caused stronger disturbances for soil microorganisms than integrated or organic systems. Temporal effects of different fertilization systems were more prominent upon the counts of fungi than the counts of bacteria for all treatments and as indicated by the soil microbial biomass SRI. The counts of bacteria and fungi were also more prominent in organic than in integrated at all application rates. Results of this study suggest that the temporal growth of soil microbial biomass may be either partially inhibited or completely facilitated following a fertilization system, depending on fertilizer type and application rate (Anderson and Domsch 2010; Jian et al. 2016; Song et al. 2019).

Inorganic fertilization system boosted urease (UR) activity reflecting the positive effects of this fertilization system on this particular enzyme activity (Allison et al. 2006). On the contrary, organic and integrated treatments showed stronger effects upon dehydrogenase (DH), acid phosphatase (Ac-P), and β-glucosidase (βG), suggesting the availability of a higher quantity of biodegradable substrates and thus

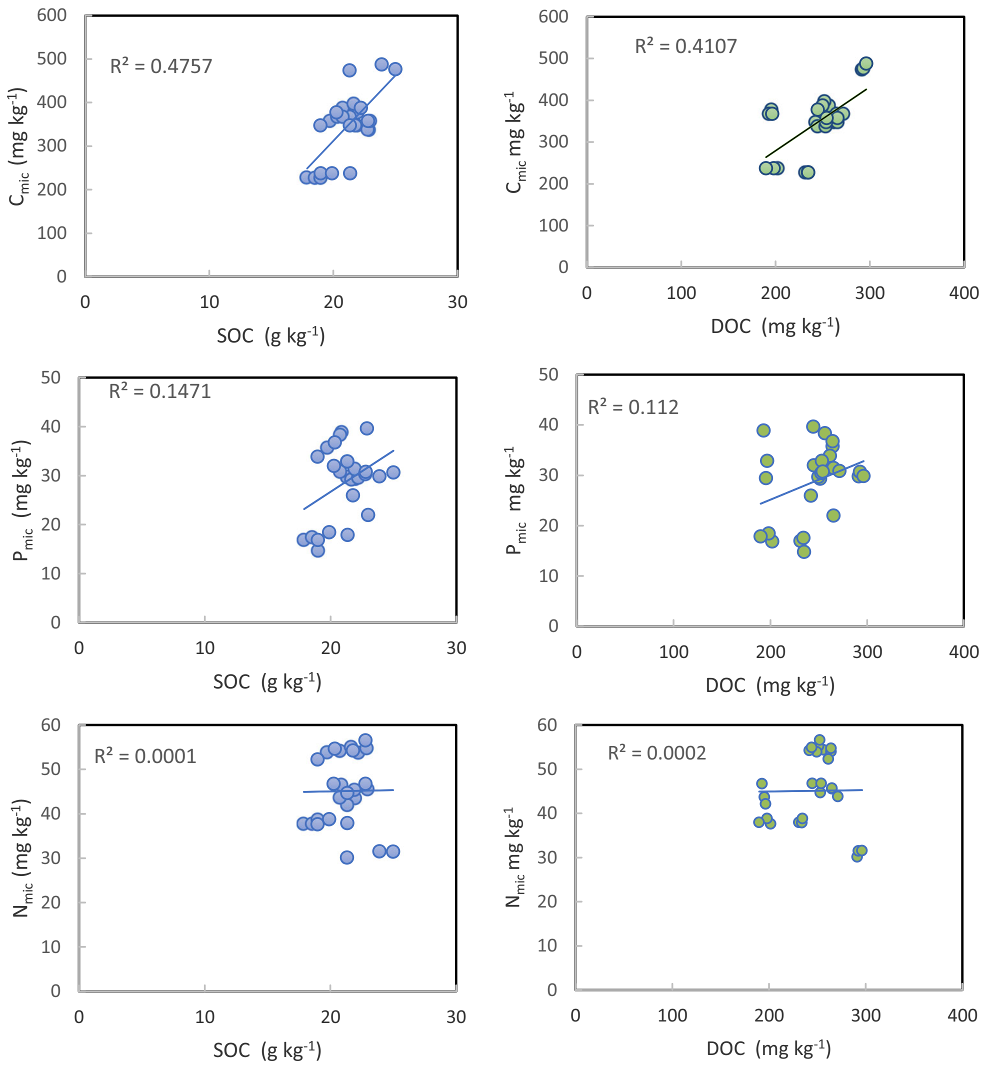

Fig. 1 Temporal changes in soil microbial biomass carbon (C_{mic}), phosphorus (P_{mic}), and nitrogen (N_{mic}) as affected by soil organic carbon (SOC) and dissolved organic carbon (DOC)

improvements in soil biomass and enzyme activities (Anderson and Domsch 2010; Dinesh et al. 2013; Martínez et al. 2018). In general, soil biochemical properties were markedly enhanced under integrated fertilization system in comparison to inorganic system due to higher SOC soil contents. This suggests organic compost application in combination with inorganic NPK nano or fertilizers even at lower rates. Also, integrated fertilization system enhanced N_{min} and DON levels in the soil under investigation reflected by positive correlation between N_{mic} and N_{min} ($r = 0.63$; $p < 0.22$; $n = 27$) and this positive effect has been demonstrated in literature by many researchers (Dinesh et al. 2013; Song et al. 2019). These significant and positive correlations attributed to the role played by extracellular enzymes (dehydrogenase (DH), urease (UR), β-glucosidase (βG), and acid phosphatase (Ac-P)) as the nitrogen fertilization affects the rate of SOC decomposition and the depolymerization of N-containing compounds by regulating extracellular enzyme activities (Dinesh et al. 2013; Jian et al. 2016).

Obvious and significant observations were detected in the soil counts of bacteria and fungi, soil resistance index (SRI), and enzyme activities due to different fertilization systems. The increases in these soil biological parameters provided further evidence of healthier conditions for soil microbial biomass in organic and integrated treatments (Dinesh et al. 2012; Jian et al. 2016) compared to solitary inorganic treatments. The poor influences of inorganic fertilization system on soil microbial and biological properties in comparison to organic or integrated systems might be attributed to rapid inorganic fertilizer diffusion and dispersion causing quick plant uptake, soil particle adsorption and/or leaching into water bodies without inducing temporal changes in soil biochemical properties (Shen et al. 2010; Dinesh et al. 2012; Jian et al. 2016), and this was reflected upon crop yield.

Finally, organic compost or integrated fertilization system recorded significantly higher rates of C_{mic}, P_{mic}, soil respiration ratio (SR), N_{min} and microbial biomass activity (bacterial and fungal counts), SRI, and activities of DH,

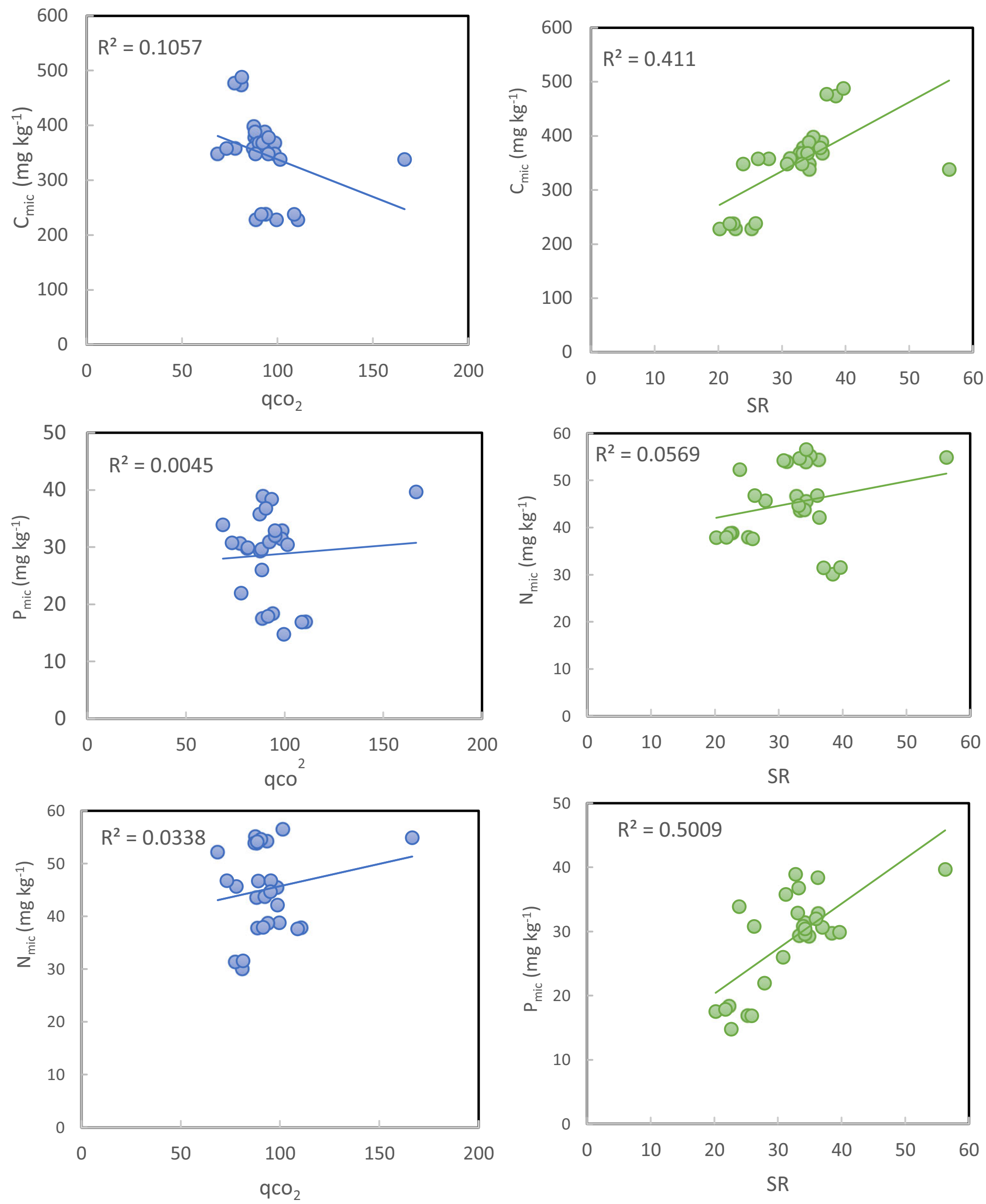

Fig. 2 Temporal changes in soil microbial biomass carbon (C_{mic}), nitrogen (N_{mic}), and phosphorus (P_{mic}) as affected by respiratory quotient (qCO_2) and soil respiration (SR)

Ac-P, and βG owing to the additive impacts of organic compost. On the contrary, inorganic fertilization system whether using nano or fertilizers recorded lower rates of C_{mic}, P_{mic}, SR, N_{min}, DOC, bacterial and fungal counts, SRI, DH, Ac-P, and βG activities but boosted the levels of N_{mic}, DON, UR activity, and qCO_2. Integrated application of organic and inorganic fertilization systems might espouse the positive effects of both effects on microbial activity as evidenced by the paralleled levels of soil biochemical and microbial biomass properties in both fertilization systems. This indicated that fertilizer type and rate affected these soils' properties in different ways probably due to changes in soil dissolved organic substrates and soil microorganism's growth environment under potato monocropping cultivation.

5 Conclusions

In monocropping farms, soils become depleted of certain nutrients used by the same crop. As a result, farmers have to add large quantities and different types of fertilizers to replenish lost nutrients which might result in soil health deterioration. Temporal changes in soil microbial biomass, enzyme activities, and dissolved organic carbon under potato monocropping exposed that different fertilization systems' impacts are influential and critical. This study delivers clear evidence displaying that different fertilization systems significantly induced temporal improvement changes in soil biochemical and biological properties and finally the resultant soil health of the agricultural lands. In general, the privileges of organic and integrated fertilization systems even though applied at lower rates of recommended levels were evident on soil biochemical and biological properties relative to the conventional inorganic fertilization systems whether using nano or fertilizers at the recommended levels. Grounded on this research, it is preferable to integrate organic compost plus NPK nanofertilizers on fertilizers due to the priority of lower rates of nanofertilizers on a full dose of NPK fertilizers. However, using organic compost as single fertilizer resource input in the organic farming system of potato-induced low soil productivity. Therefore, it is imperative to assemble a poise between organic and inorganic sources of fertilizers to optimize a fertilization regime that espouse improvements in soil properties and conservation of soil health under potato monocropping cultivation.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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