

Chapter 4

Comparison of Soil Phosphorus Status and Organic Matter Composition in Potato Fields with Different Crop Rotation Systems

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Abstract Cropping management practices influence soil phosphorus (P) availability and soil organic matter (SOM) quality. This chapter summarizes the impact of cropping systems and water management on soil phosphorus status and organic matter characteristics after the first full cycle of the 3-year crop rotations. These data indicated that the 3-year crop rotations impacted more on labile P and organic matter fractions and relevant biochemical parameters (i. e. water extractable P and organic matter, mild modified Morgan soil test P, microbial biomass C and P, phosphatase and urease activities). However, these influences were not always consistent and statistically significant ($P=0.1$ or 0.05). Generally, irrigation had a greater influence on stable P and organic matter fractions than crop rotations. Continuous analysis of P and SOM from soils after the completion of the second rotation cycle of the 3-year crop rotations would provide more insights on the improvement of soil fertility and biochemical quality for potato production by crop rotations.

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4.1 Introduction

Phosphorus (P) is an essential element for plant growth. Its input to cropland is necessary to maintain profitable production. Potato is a species with a great demand for soil P (Pursglove and Sanders 1981). For this reason, it was estimated that more P fertilizer is probably used in potato production than for any other crop in British agriculture (Cogliatti and Clarkson 1983). However, the high P demand is not due to a high content of P in potato plant, rather due to the low efficiency of acquiring soil P by the potato plants (Pursglove and Sanders 1981; Alvarez-Sanchez et al. 1999). By isotopic labeling of inorganic fertilizer P, Pursglove and Sanders (1981) found only 64–50% of P entering the potato organs were from fertilizer at 43 and 63 days after planting, and that only 4% of fertilizer P was recovered by potato plants. McArthur and Knowles (1993) characterized morphological and biochemical aspects of P deficiency in potato as affected by vesicular-arbuscular mycorrhizal fungi. They found that these fungi partially alleviated P deficiency stress, but did not completely compensate for inadequate abiotic P supply. Leggewie et al. (1997) cloned cDNAs of two potato phosphate transporters. They found that one phosphate transporter is expressed in roots, tubers, source leaves as well as floral organs, and another is mainly expressed in root organs when plants are deprived of P. It is no doubt that all these studies are useful to understand the mechanism, and improve the efficiency of P uptake by potatoes. However, the dramatic improvement of P up-take efficiency would be limited due to the intrinsic limitation of sparse rooting systems.

In order to increase P uptake, some plants can directly modify the rhizosphere in order to gain access to previously unavailable soil P pools through developing more extensive root systems, exuding organic acids and phosphatases, or through association of roots with mycorrhiza (Li et al. 1997; Vosatka and Gryndler 1999; Dechassa et al. 2003). Furthermore, it is reasonable to hypothesize that these P-efficient plants will also improve soil P availability for other plants planted after them as the organic acids, phosphatase activity, and biomass (natural organic matter) exudated by these plant roots and associated microorganism (fungi) remain in soil for a while. In other words, rotation plants could improve the P uptake by potato plants. However, this kind of information is not available at present time.

Cropping management practices influence soil organic matter (SOM) content and quality (Ohno et al. 2009, 2010). Parts of SOM can be sequentially extracted by water (water extractable organic matter, WEOM) and pyrophosphate (pyrophosphate extracted organic matter, PEOM) (Kaiser and Ellerbrock 2005; Kaiser et al. 2007). In functional characterization of SOM fractions from different cropping practices including potato-winter rye rotation management, Kaiser and Ellerbrock (2005) found that the composition of both WEOM and PEOM fractions depended on the type of crop as WEOM and PEOM from soils with maize and winter rye cropping differed in their C=O content. Furthermore, WEOM represents a less stable and younger SOM fraction whereas PEOM represents a higher proportion of total SOM and more carboxylic group than WEOM fraction. Thus, Kaiser et al. (2007) proposed that Fourier transform infrared (FT-IR) analysis of the C=O groups

Table 4.1 Total soil P (mg kg⁻¹ of dry soil) in rainfed and irrigated potato fields with continuous potato (*PP*), *status quo* potato-barley (*SQ*), disease suppressive (*DS*), soil conserving (*SC*), and soil improving (*SI*) crop systems

	Rainfed		Irrigated	
	A	SE	A	SE
PP	1,671	111	1,628	121
SQ	1,672	89	1,664	83
DS	1,616	91	1,517	128
SC	1,758	36	1,614	86
SI	1,693	57	1,531	108
Means	1,682	23	1,592	29

Data are presented in average (*A*) of five field replicates with standard error (*SE*, $n=5$) (He et al. 2011c)

in the PEOM fraction is preferable over WEOM or unrestricted soil samples for identifying long-term effects of crop rotation and fertilization. However, they cautioned that for crop rotations with potatoes, possible short-term soil management-induced effects on composition of PEOM required further studies.

Potato yield in Maine U.S.A. has remained relatively constant for over 50 years. To identify and quantify constraints to potato productivity, we established five different potato crop management systems, designed to address specific management goals of soil conservation, soil improvement, and disease suppression, as well as a system representing a typical rotation and a non-rotation control, under both rainfed and irrigated management. These systems are named as Soil Conserving (*SC*), Soil Improving (*SI*), Disease Suppressive (*DS*), Status Quo (*SQ*), and Continuous Potato (*PP*), respectively. Each system is evaluated by our interdisciplinary team for plant growth and productivity, soil chemical-physical-biological properties, tuber diseases, soil borne diseases, foliar diseases, economics, and their interactions (see Chap. 2 for the overview of this case study). Based on published data (He et al. 2010, 2011a, b, c), this chapter summarizes the impact of cropping system and water management on soil phosphorus status and organic matter after the first full cycle of the 3-year crop rotations, and discusses the correlations between potato yields and several relevant soil parameters.

4.2 Soil Phosphorus Status in Potato Fields

4.2.1 Total Soil Phosphorus Levels

The concentration of total soil P in the ten potato fields was around 1,600 mg kg⁻¹ of soil (Table 4.1). Whereas some additional P from compost might have been added to the Soil Improving plots, the total soil P level was not changed. Indeed, all differences in total soil P among different cropping rotations were smaller than the

standard errors of the five replicate plots with the same cropping rotation. In addition, there was no statistically significant difference between the rainfed soil and irrigated soil with the same cropping systems. However, the total soil P level in the rainfed soil was consistently higher than that in the corresponding irrigated soils. The means of the total soil P in the five rainfed and five irrigated cropping systems were 1,682 and 1,591 mg kg⁻¹ of soil with comparable standard errors of 23 and 29, respectively. The difference of 91 mg kg⁻¹ of soil suggested that 3-year irrigation lowered the surface (0–20 cm) soil P by an average of 5.4% in these fields (He et al. 2011c).

4.2.2 Soil Test Phosphorus Levels

Three types of soil tests for P in soil have been evaluated (He et al. 2011a). For Olsen P content, soils (1.0 g) were extracted by 25 mL of 0.5 M NaHCO₃ (pH 8.5) for 30 min. For ammonium oxalate extractable P (oxalate P), soils (2.0 g) were extracted by 200 mL of 0.2 M (NH₄)C₂O₄ (pH 3.0) for 4 h in the dark. For modified Morgan P (MMP), soils (4.0 g) were extracted by 20 mL of 0.62 M NH₄OH / 1.25 M CH₃COOH (pH 4.8) for 15 min. Ammonium oxalate extracted P was the highest with a level of more than 1,400 mg P per kg of dry soil. Olsen P was modest in a range from 100 to 120 mg P per kg of dry soil. Modified Morgan P was lowest with a level not more than 10 mg P per kg of dry soil. Similar to the total soil P, neither Olsen P nor ammonium oxalate extractable P was significantly changed by the 3-year potato cropping rotation and irrigation. These observations suggest that these differences are small enough so that it may not be necessary to monitor P levels annually. Evaluation of these changes after one or more complete cycles of crop rotation would be appropriate (He et al. 2011a).

Unlike total soil P, however, the MMP levels were significantly impacted by crop rotation (He et al. 2011a). Figure 4.1 presents MMP_i concentrations measured by ICP (MMP_i) and measured by the colorimetric method (MMP_c). A previous study on soil MMP in the Northeast USA reported that the ICP method measured average 1.5 mg kg⁻¹ more MMP than colorimetry (Heckman et al. 2006). In our samples, we found that MMP_i were twice that of MMP_c. Regression analysis of the 10 paired data revealed a linear relationship of $MMP_i = 1.42 MMP_c + 4.64$ ($R^2 = 0.702$, $p < 0.01$). Although the high correlation existed in the two sets of MMP data, the significantly different MMP levels measured by the two methods should be a further research topic as the different values may lead to a different recommendation for P fertilizer application (Ohno et al. 2007).

The greatest concentration of MMP in the SI plot could be due to extra labile P applied from the compost. This observation suggested the compost amendment had a greater impact on mild soil test P than total soil P as the latter was not affected by the compost amendment (Table 4.1). Plant-available P (i. e. soil test MMP) has been previously observed to be higher in soils from compost- and animal manure-amended potato fields than in unamended potato soils (Erich et al. 2002). The other eight rainfed and irrigated fields had received the same amounts

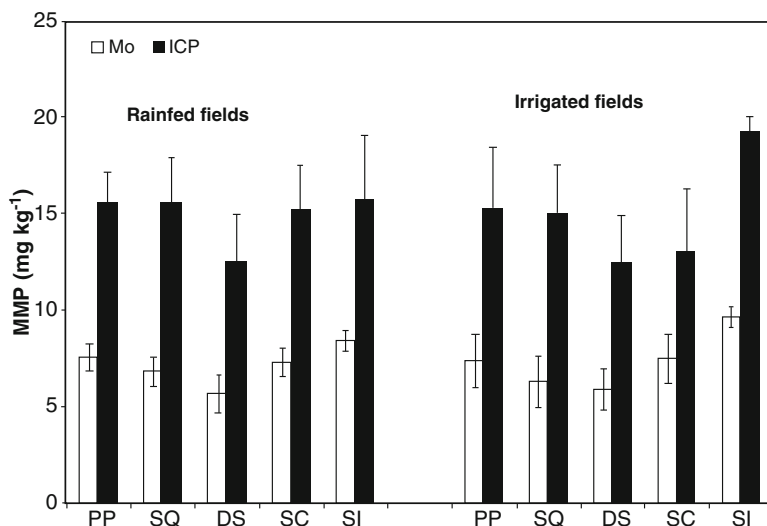


Fig. 4.1 Modified Morgan P (*MMP*) in potato fields after the end of the 3-year rotations. *MMP* was measured by both modified molybdate blue method (*Mo*) and ICP-AES. Rotation systems were (1) continuous potato (*PP*); (2) Status Quo (*SQ*); (3) disease suppressive (*DS*); (4) soil conserving (*SC*); and (5) soil improving (*SI*) (Data are presented in average with standard deviations (n=5) He et al. 2011a)

Table 4.2 Linear regressions between *MMP* (P_i or P_t) and relative potato yields (Y) in rainfed and irrigated field with same annual rates of P application (He et al. 2011a)

	Linear regression	R ²
Rainfed	$Y = -0.112P_i + 1.849$	0.919 ^a
	$Y = -0.052P_t + 1.841$	0.602
Irrigated	$Y = -0.158P_i + 2.285$	0.774 [^]
	$Y = -0.0022P_t + 1.250$	0.0005
Both	$Y = -0.139P_i + 2.099$	0.614 [*]
	$Y = -0.040P_t + 1.720$	0.178

^a Symbol [^], and * represent statistical significance at $P=0.1$, and 0.05, respectively

of fertilizer P. Thus, *MMP* changes in these fields reflected the impacts of the crop rotation management. The change of the *MMP* levels in the eight rainfed and irrigated fields was in the reverse order of the yields of potato tuber harvested in the season prior to the soil sample collection. In other words, the decrease of the *MMP* levels seemed due to more P up take by potato. Therefore, we quantitatively compared the Spring-sampled *MMP* levels with the previous year's potato yields in these fields (Table 4.2). The linear but negative regressions indicated that MMP_i was more related to the potato yield than MMP_t . In other words, MMP_i is a better indicator to reflect P taken up by the potato plants in these soils although more research is needed to confirm it.

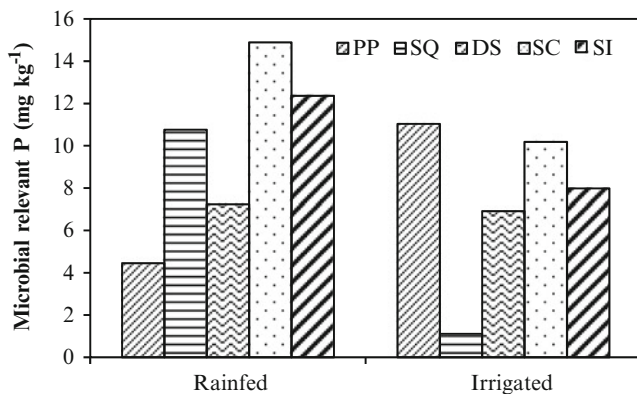


Fig. 4.2 Microbial biomass relevant P in potato fields after the end of the 3-year rotations. Soil samples were chloroform fumigated (The data are the differences in Olsen P between untreated and treated soil samples adapted from He et al. (2011a))

4.2.3 Microbial Biomass Phosphorus Levels

For soil microbial biomass P measurement, soil samples were treated by chloroform fumigation or microwave irradiation prior to extraction. When microwaved soils were used to measure microbial biomass P, the P contents in these samples were lower than that of the corresponding untreated soils. Therefore, this result demonstrated that the microwave method was not appropriate for microbial biomass P determination. On the other hand, fumigated soils showed greater P contents than their corresponding untreated soils, indicating that fumigation was more effective than microwaving in releasing microbial biomass P (He et al. 2011a). Based on all soils including those of rotation crops, fumigation increased extracted P by approximately 10.8 and 7.0 mg kg⁻¹ soil under rainfed and irrigated management, respectively. As the fumigation-extraction method may underestimate microbial P due to the incomplete release of microbial P during fumigation and adsorption of released microbial P onto the mineral soil surface, a correction factor ranging from 0.33 to 0.57 has been suggested (McLaughlin et al. 1986). Thus, it was estimated that the rainfed soil contained microbial biomass P in a range from 18.9 to 32.7 mg kg⁻¹, and the irrigated soil contained microbial biomass P in a range from 12.3 to 21.2 mg kg⁻¹ (He et al. 2011a). Similar levels have been reported by Wu et al. (2007).

Figure 4.2 presents the microbial biomass relevant P in the five potato fields. Compared to the PP system, crop rotation increased microbial P in the rainfed fields. However, crop rotation negatively impacted microbial levels in the irrigated fields. Further comparison of these two sets of data revealed that irrigation increased microbial biomass relevant P by 6.58 mg P kg⁻¹ in the Continuous Potato soils. However, irrigation decreased microbial biomass relevant P in other four field soils by 9.65, 0.33, 4.71 and 4.37 mg P kg⁻¹, respectively.

4.2.4 *Sequentially Extracted Phosphorus Fractions*

Sequential fractionation is a common method used in evaluating the impacts of soil management practices on P distribution in soil and other environmental samples (Toth et al. 2011). The extracted P fractions typically comprised H_2O -P, 0.5 M $NaHCO_3$ - P_i and $-P_o$, 0.1 M $NaOH$ - P_i and $-P_o$, 1 M HCl - P_i , and residual-P fractions. Negassa and Leinweber (2009) review more than 100 articles published in soil science and related journals in the past 25 year related to the subject. To improve on our understanding on the mechanisms of change of P lability in these different cropping systems and irrigation, soil P in the 10 potato fields were sequentially extracted and separately quantified (He et al. 2011c). Phosphorus in these soils distributed in the five pools separated by the sequential fractionation in the order H_2O -P < residual P < $NaHCO_3$ -P \approx HCl -P < $NaOH$ -P. Whereas the relative concentrations of P_o in the sequentially extracted H_2O , $NaHCO_3$, and $NaOH$ fractions of the soils with the potato production was comparable to those in previous studies (He et al. 2004a; Waldrip-Dail et al. 2009), substantial enzymatically-hydrolyzable P_o amounts were not observed in the three fractions (He et al. 2011c). These data supported that, as inorganic fertilizer was applied to these fields, these management practices mainly impacted the distribution of inorganic P fractions, with little significant changes of organic P fractions.

With the sequential fractionation procedure, only the most labile H_2O extractable P pool was statistically impacted by the cropping systems as the highest water extractable P found in the PP and the SI cropping systems (He et al. 2011c). This observation implies that the labile portion of soil P, either water extractable P or MMP_i , was changed by short-term (3-year) cropping managements, thus impacting the plant uptake and runoff potential. However, this change would not reflect on more stable and recalcitrant soil P pools that accounted for the majority of soil P.

Interestingly, irrigation impacted P distribution in these soils with a pattern different from that of crop rotations as irrigation impacted P fractions in the order of $NaOH$ > HCl > residual > $NaHCO_3$ > H_2O fractions. As $NaOH$ -P was the most abundant pool in most soils, it is believed that it is the primary sink of soil P in fields and laboratory incubation with animal manure (He et al. 2004b, 2006b; Zheng et al. 2004). In these potato soils, irrigation seemed to mobilize and redistribute this portion of $NaOH$ -P. The average reduced amount in the $NaOH$ fractions by irrigation was 199 mg P_i kg^{-1} soil. The mobilized P portion was partly converted to P_o in the same $NaOH$ fractions with the majority transferred to more stable or recalcitrant HCl and residual fractions (Table 4.3). The combined increase of P_i in the HCl fractions and P_o in the $NaOH$ fractions was 116 mg kg^{-1} soil, accounting for 58% of P_i decrease in the $NaOH$ fractions. In other words, another 42% of P_i in the $NaOH$ fractions reduced by irrigation might have been transferred to $NaHCO_3$ and H_2O fractions. As P in these two fraction was more labile, this portion of P from $NaOH$ - P_i did not accumulate in the two fractions, but was rather lost by plant uptake, runoff, or leaching from the irrigated soils. A complementary pattern of changes of P in H_2O , $NaHCO_3$, and $NaOH$ fractions observed in laboratory incubation

Table 4.3 Impacts of irrigation on soil P fraction distribution

	Inorganic P		Organic P		Total P	
	R	I	R	I	R	I
H ₂ O	7.1	7.4 ^a	3.9	3.4 ^{ns}	11.0	10.9 ^{ns}
NaHCO ₃	176	153 ^{**}	86	83 ^{ns}	262	236 [*]
NaOH	771	572 ^{***}	303	350 ^{ns}	1061	922 ^{***}
HCl	175	235 ^{***}	ND ^b	ND	175	235 ^{***}
Residual	NA ^c	NA	NA	NA	170	189 ^{**}

Data are presented in the means of P concentrations (mg kg⁻¹ of dry soil) in the five cropping systems under rainfed (*R*) or irrigation (*I*) (He et al. 2011c)

^aSymbols ns, *, ** and *** are for not statistically significant, and statistically significant at $P=0.05$, 0.01 and 0.001, respectively

^bND not detected

^cNA not applicable

experiments could support this hypothesis (He et al. 2004b, 2006b; Waldrip-Dail et al. 2009). Another possibility was that the downward movement of P in the irrigated surface soils was faster than that in the rainfed surface soils. This downward movement has been observed with long term P fertilization (Wang et al. 2007; He et al. 2009c) although there are no reports on the effect of irrigation.

4.3 Soil Phosphatase and Urease Activities

Soil phosphatase activity is a significant mechanism for plant and microbial use of organic P in soil environments by converting organic P compounds into bioavailable inorganic phosphate (Yadav and Tarafdar 2003; Senwo et al. 2007). Similarly, urease activity could be an indicator of the potential rate of degradation of nitrogen compounds in soil (Banik et al. 2006) as it is an important enzyme in soil that mediates the conversion of organic N to inorganic N by hydrolysis of urea to ammonia. Thus, acid phosphatase (acPase), alkaline phosphatase (alPase), phosphodiesterase (diPase), and urease activities were measured to evaluate the impact of potato crop rotations on these soil enzymes (He et al. 2010).

4.3.1 Phosphatase Activities

In the rainfed PP plot, the three soil phosphatase activities were 0.691 mg p-NP g⁻¹ dry soil for acPase, 0.116 mg p-NP kg⁻¹ dry soil for alPase, and 0.122 mg p-NP kg⁻¹ dry soil for diPase. All three enzyme activities increased in the soils with crop rotations (Fig. 4.3). The increase was relatively greater for alPase and diPase activities than for acPase activity although the specific activity of the latter was 3–5 fold greater than alPase and diPase. For all three enzymes, the smallest increase was observed in soil with the SC rotation, and the greatest increase was in soil with the SI rotation. Where the rotation crops and planting sequences were exactly the same

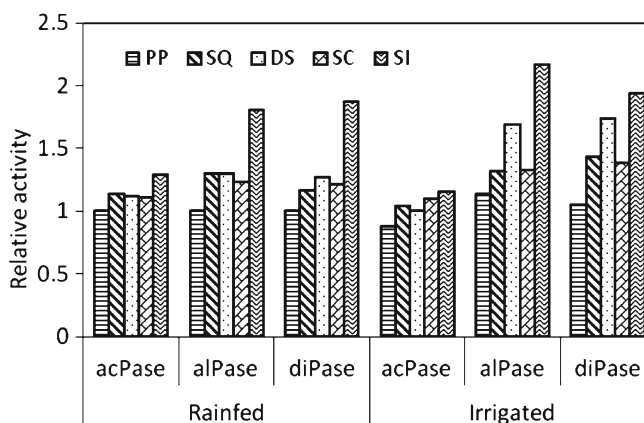


Fig. 4.3 Effect of cropping systems on soil phosphatase activities under rainfed and irrigation managements. The relative activity is based on $0.691 \text{ mg p-NP kg}^{-1} \text{ dry soil h}^{-1}$ for acid phosphatase (*acPase*), $0.116 \text{ mg p-NP kg}^{-1} \text{ dry soil h}^{-1}$ for alkaline phosphatase (*alPase*), and $0.122 \text{ mg p-NP kg}^{-1} \text{ dry soil h}^{-1}$ for phosphodiesterase (*diPase*) (Data are adapted from He et al. (2010))

for the SC and SI rotations, the only difference was addition of compost in each crop phase of the SI rotation, indicating the increased phosphatase activities were directly attributable to compost addition. Similar patterns of crop rotation impacts on soil phosphatase activities were observed in soils collected from the irrigated fields. Activity of alPase were 14% greater and activity of diPase was 31% greater in the DS systems, compared to the Continuous Potato system.

Although crop rotation increased phosphatase activities in soils under both rainfed and irrigated management, irrigation impacted phosphatase activities in different ways (Fig. 4.3). Soil acPase activity in all five cropping systems decreased with irrigation. The least negative impact was observed in the soil with the SC system (2% decrease) whereas a 9–12% decrease was observed in soils of the other four cropping systems. Irrigation had positive impacts on soil alPase activity although these increases were only substantial in the soils in POT (14%), DS (31%), and SI (15%) systems. Irrigation increased soil diPase activity by 18% in the BP rotation, but less than 1% in the SI rotation.

4.3.2 Urease Activities

Soil urease activity could be measured under either buffered (pH 9.0) or non-buffered conditions (Banik et al. 2006). The activity in the Continuous Potato system ranged from $88 \text{ mg NH}_3\text{-N kg}^{-1} \text{ dry soil } 20 \text{ h}^{-1}$ under non-buffered conditions to $110 \text{ mg NH}_3\text{-N kg}^{-1} \text{ dry soil } 20 \text{ h}^{-1}$ under buffered conditions (He et al. 2010). Cropping system influenced soil urease activity, with the most dramatic difference between the PP and SI systems. A higher soil urease activity in PP was observed with irrigation than with rainfed management, ranging from $100 \text{ mg NH}_3\text{-N kg}^{-1} \text{ dry soil } 20 \text{ h}^{-1}$ under

non-buffered conditions to $138 \text{ mg NH}_3\text{-N kg}^{-1} 20 \text{ h}^{-1}$ under buffered conditions. Antonious (2003) reported soil urease activity in the rhizosphere of potato plants under different soil management practices in Kentucky ranged from 42 to $92 \text{ mg NH}_3\text{-N kg}^{-1} \text{ dry soil } 24 \text{ h}^{-1}$. Kandeler et al. (1999) reported soil urease activity to be lower in soils following potato compared to rotation crops of sugar beet, winter wheat, spring barley, and alfalfa. It is possible that increased soil urease activity in the SQ, DS and SC systems reflected greater secretion of urease by the rotation plants than potato.

4.4 Soil Organic Matter Composition

4.4.1 Microbial Biomass C Measurement

Soil microbial biomass C was determined based on the chloroform fumigation extraction method described by Horwath and Paul (1994). Soil microbial biomass C under rainfed management increased from 69 mg kg^{-1} in the PP system to 155 mg kg^{-1} in the SI system (Fig. 4.4). Irrigation seemed to increase soil microbial activity compared to rainfed management in PP (Fig. 4.4). However, when analyzed across all cropping systems, soil microbial biomass C did not differ among irrigated cropping systems (He et al. 2010).

Under rainfed management, microbial biomass C was highly correlated with phosphatase and urease activities (Table 4.4a). These enzyme activities were also significantly correlated ($P \leq 0.05$), indicating the possible microbial origins of these enzymes. The poor but certain correlation ($P = 0.1$) with potato yields implies that soil microbial activity made some contributions to improving soil fertility. In contrast to microbial biomass C, the data of microbial biomass P was not related ($P \leq 0.1$) to

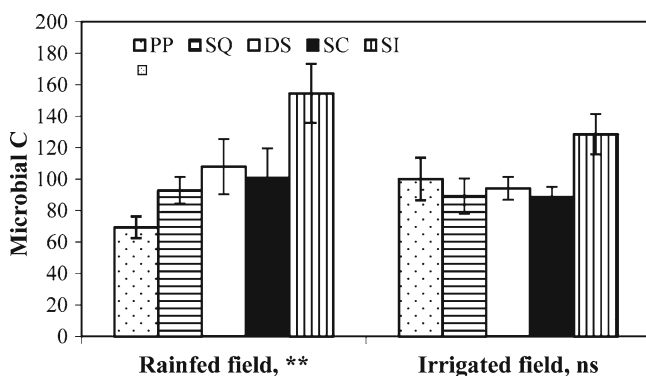


Fig. 4.4 Soil microbial biomass C levels under rainfed and irrigated management. Data represent the average of five field replicates with standard error bars (He et al. 2010). The symbol ** or ns indicates statistical significance at $P = 0.01$ or no significance at $P = 0.05$, respectively

Table 4.4 Correlation coefficients among soil biochemical parameters and potato yield

	Microbial C	acPase	alPase	diPase	Urease-u	Microbial P
<i>(A). Rainfed management</i>						
Microbial C	1					
acPase ^a	0.960**	1				
alPase ^b	0.980**	0.989*	1			
diPase ^c	0.984**	0.945*	0.981**	1		
Urease-u ^d	0.969**	0.917*	0.966**	0.992**	1	
Microbial P	0.536	0.592	0.518	0.466	0.356	1
Yield	0.852 [^]	0.855 [^]	0.870 [^]	0.831 [^]	0.848 [^]	0.145
<i>(B). Irrigated management</i>						
Microbial C	1					
acPase ^a	0.400	1				
alPase ^b	0.801	0.689	1			
diPase ^c	0.580	0.753	0.946*	1		
Urease-u ^d	0.147	0.821 [^]	0.487	0.562	1	
Microbial P	0.216	-0.236	-0.005	-0.262	0.196	1
Yield	0.467	0.036	0.651	0.661	-0.203	-0.368

Data are adapted from He et al. (2010, 2011a)

Symbol [^], *, and ** represents statistical significance at $P=0.1$, 0.05 and 0.01, respectively

^a acPase, acid phosphatase

^b alPase, alkaline phosphatase

^c diPase, phosphodiesterase

^d Urease-u, urease activity measured under non-buffered conditions

any of these parameters in Table 4.4a. It seems that microbial biomass relevant P is not a good indicator of soil microbial activities. This is probably partly due to the interference of microbial P measurement by the high back ground Olsen P in the soils (He et al. 2011a). A recent report (Zhao et al. 2008) suggested that the part of Olsen P, if $>60 \text{ mg kg}^{-1}$, should be removed by either anion resin or 0.5 M sodium bicarbonate (NaHCO_3) solution (pH 8.5) prior to fumigation. Adoption of the pretreatment could improve the accuracy and statistical significance in future evaluation of the long-term impacts of the potato crop rotation and irrigation on the microbial biomass P levels. While strong correlations were found under rainfed management, much weaker correlations were observed for irrigated management (Table 4.4b). Reasons for this observation cannot be elucidated with the current data. However, these data imply that water management had a dramatic influence on soil enzymes and microbial biomass C and P in this study.

4.4.2 *Elemental Analysis of Water and Pyrophosphate Extracted Soil Organic Matter*

Water extractable organic matter (WEOM) fraction is the most labile and mobile fraction of soil organic matter (SOM) (Gregorich et al. 2003; Ohno et al. 2009). Sodium pyrophosphate extractable organic matter (PEOM) fraction is a relative

Table 4.5 Selected elemental contents in water extracts of rainfed and irrigated soils from the continuous potato (*PP*), status quo (*SQ*), and disease suppressive (*DS*), soil conserving (*SC*), and soil improving (*SI*) systems

	C	N	P	Na	K	Ca	Mg	S	Al	Fe
mg kg ⁻¹ dry soil										
Rainfed										
PP	130.9	28.3	3.37	9.37	28.7	33.8	16.8	18.3	4.00	4.07
SQ	114.4	42.1	2.73	2.87	30.1	35.0	19.1	16.9	4.53	5.73
DS	114.2	40.7	3.00	3.03	34.1	34.1	18.3	17.0	2.07	2.70
SC	89.7	35.6	2.43	5.80	35.4	34.3	17.7	17.2	2.72	3.40
SI	139.0	41.6	2.60	6.93	51.7	64.8	26.5	28.4	5.93	7.20
SI-d ^a	147.1	4.6	1.20	0.80	0.57	8.1	2.0	14.4	4.30	5.9
Irrigated										
PP	112.9	24.7	3.20	14.17	15.7	25.3	12.8	16.8	3.00	4.00
SQ	120.1	40.9	3.30	10.37	27.8	36.1	18.8	17.6	6.57	8.83
DS	186.2	49.2	3.93	16.77	58.6	51.0	27.6	26.8	2.17	2.47
SC	133.4	58.0	3.93	16.77	58.6	51.0	27.6	26.8	2.17	2.47
SI	174.6	42.4	2.60	8.33	43.4	55.0	26.1	23.8	3.20	4.27
SI-d	153.0	9.4	1.50	0.90	0.93	10.2	3.0	20.3	6.70	9.07

Data are adapted from He et al. (2011b)

^aSI-d, dialyzed against water in cellulose dialysis tubing (Molecular weight cutoff: 12,000) for four times (12 h each) prior to elemental analysis

labile SOM pool (Ellerbrock et al. 2005; Kaiser et al. 2007). To investigate the impact of management practices on SOM compositions, WEOM and PEOM from the 10 potato field soils were sequentially extracted (He et al. 2011b).

The elemental contents of water extracts of the 10 soil samples are listed in Table 4.5. The major elements in these soil water extracts were C, N, K, Ca, Mg, and S, with the concentrations in mg L⁻¹ of extracts or tens mg kg⁻¹ of dry soil. P, Na, Al, and Fe were in the middle levels of tenths mg L⁻¹ of extracts or mg kg⁻¹ of dry soil. Although the levels of these elements varied among the five systems, clear differences among the treatments, except for Na ion, was not observed. Irrigation seemed to consistently increase the water extractable Na levels of all five production systems. The C levels in the 10 water extracts were comparable to those in water extracts of four types of Italian soils (Provenzano et al. 2010) and a calcareous soil in the French Mediterranean region (Hassouna et al. 2010). There are no data reported on the other elemental contents of WEOM, either in un-treated water extracts (Ohno et al. 2009; Provenzano et al. 2010) or purified fractions (Kaiser et al. 2007; Hassouna et al. 2010). Dialysis did not change the C content of rainfed and irrigated SI extracts. However, the contents of N, Na, K, and Mg were reduced greatly by an order of magnitude, indicating that these elements were mainly in the inorganic forms, and not associated with the WEOM. The contents of other measured elements were partially reduced or not changed at all. This observation indicated that parts of these elements were associated with WEOM, either directly trapped in the complicated structures of organic matter or complexing through organo-mineral bridging bonding.

Table 4.6 Selected elemental contents in pyrophosphate-extracted organic matter of rainfed and irrigated soils from the continuous potato (*PP*), status quo (*SQ*), disease suppressive (*DS*), soil conserving (*SC*), and soil improving (*SI*) systems

	C	N	P	Na ^a	K	Ca	Mg	S	Al	Fe
	% of dry matter		mg kg ⁻¹ of dry matter							
Rainfed										
PP	24.4	2.13	62.4	1159	14.2	16.1	7.0	73.5	178	288
SQ	24.5	2.14	79.5	1179	11.1	15.0	6.0	61.9	152	325
DS	30.0	2.70	63.2	1149	14.4	12.9	6.6	72.5	161	237
SC	39.5	3.67	66.1	1118	12.2	12.0	5.7	67.5	136	207
SI	41.9	3.35	51.3	1119	8.4	17.9	4.9	80.7	65	107
Irrigated										
PP	32.6	2.86	45.6	1165	20.3	16.1	5.5	61.2	100	202
SQ	23.8	1.97	68.0	1167	9.2	17.4	5.5	62.2	123	292
DS	30.6	2.54	56.7	1152	10.6	16.4	5.6	71.2	98	156
SC	22.6	1.82	53.7	1115	8.9	13.2	4.9	65.5	86	133
SI	31.0	2.17	39.8	1122	8.1	18.0	4.6	72.8	56	86

Data are adapted from He et al. (2011b)

^aNa was from 0.05 M NaOH used to dissolve the organic matter solid

The elemental contents of the 10 PEOM samples are listed in Table 4.6. The contents of C and N were in the ranges from 22.6% to 41.9% and from 1.8% to 3.7% of dry matter, respectively. Under rainfed conditions, soil conservation and improving practices seemed to increase the C content of PEOM. Although these organic matter samples were extracted by pyrophosphate, P in these samples were very low (<80 mg kg⁻¹ of dry matter). The P level was indeed lower than P content in some humic fractions in which case P level may be up to 2 g kg⁻¹ of dry matter (He et al. 2006a, 2009b). The P concentration in a peat humic acid extracted by alkaline pyrophosphate solution (0.1 M NaOH+0.1 M Na₄P₂O₇) was as high as 84.7 g kg⁻¹ of dry matter, but the humic acid from the same peat source extracted by 0.1 M alone contained less than 100 mg kg⁻¹ of dry matter (Francioso et al. 1998). The difference suggests incorporation of pyrophosphate in the peat humic acid during alkalized pyrophosphate extraction (Francioso et al. 1998). The much lower P concentration in PEOM samples from the potato soils implied that the pyrophosphate incorporation into PEOM did not occur apparently due to the neutral pyrophosphate extraction conditions.

The Na concentration reported in Table 4.5 was apparently from 0.05 M NaOH (i.e. 1.15 g Na L⁻¹ of organic matter solution) that was used to dissolve the samples. The contents of Al and Fe were the highest with the levels > hundreds mg kg⁻¹ of dry matter in most samples. Compared to the limited literature on element contents of purified OM, the contents of Ca, Mg, Al, and Fe measured in soil mobile humic acid and recalcitrant Ca humate fractions extracted by 0.1 M NaOH (He et al. 2009b) were generally higher than those in these PEOM samples. The contents of Ca, Mg, Fe, Cu, Mn, and Zn measured in peat humic acid extracted by alkaline pyrophosphate solution (Francioso et al. 1998) were also higher than the corresponding contents of these PEOM samples. This observation implied the neutral pyrophosphate solution

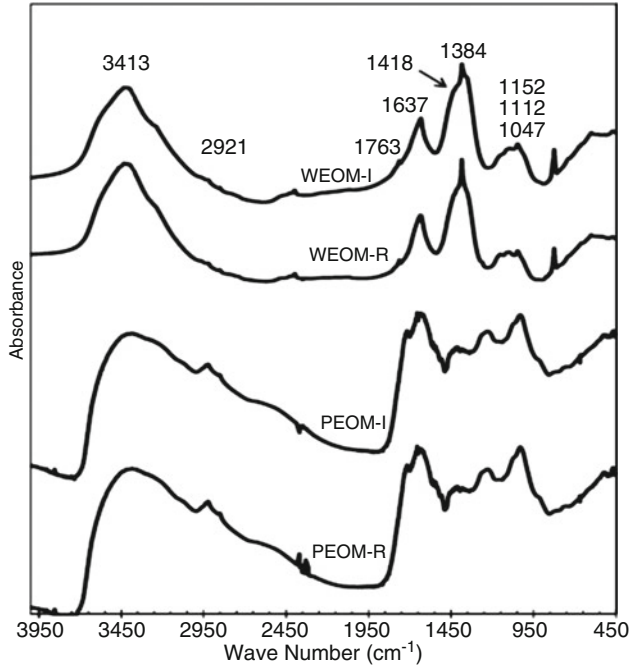


Fig. 4.5 FT-IR spectra of water extracted organic matter (WEOM) and pyrophosphate extracted organic matter from rainfed (*R*) and irrigated (*I*) soils with Soil Improving rotation (Data are adapted from He et al. (2011b))

might be less capable of extracting metal-organic matter complexes than alkaline solution. Whereas the impacts of cropping managements on most elements were not observed, the contents of Al and Fe were lower in SC and SI PEOM samples than in the other three soil management systems. In addition, irrigation seemed to lower the two metal contents in PEOM. Francioso et al. (1998) found that Fe was much more concentrated in the high molecular weight peat humic fractions. Thus, these management practices might have increased the low molecular weight PEOM fractions and/or decreased the high molecular weight PEOM fractions (He et al. 2011b).

4.4.3 *FT-IR Spectroscopic Analysis of Water and Pyrophosphate Extracted Soil Organic Matter*

The typical Fourier transform infrared (FT-IR) spectra of WEOM and PEOM are shown in Fig. 4.5. Except for the sharp band at 1384 cm^{-1} (inorganic nitrate), these features of these soil WEOM samples were typical to those of plant- and animal manure-derived WEOM samples (He et al. 2009a), but different from those of

Table 4.7 Relative FT-IR band heights of soil water (*WEOM*)- and pyrophosphate (*PEOM*)-extractable organic matter samples from soils from the continuous potato (*PP*), status quo (*SQ*), disease suppressive (*DS*), soil conserving (*SC*), and soil improving (*SI*) systems

	Band A/Band C ^a		Band B/Band C	
	WEOM	PEOM	WEOM	PEOM
	Rainfed			
PP	0.23	0.28	1.40	4.28
SQ	0.23	0.30	1.17	4.31
DS	0.12	0.31	1.79	4.32
SC	0.10	0.32	3.39	4.18
SI	0.11	0.30	2.69	4.51
	Irrigated			
PP	0.26	0.28	0.91	4.58
SQ	0.02	0.30	1.84	4.57
DS	0.16	0.30	1.33	4.45
SC	0.05	0.31	2.31	4.20
SI	0.02	0.30	2.13	4.61

Data are adapted from He et al. (2011b)

^aTwo bands in 3,020–2,800 cm⁻¹ were grouped Band A. Two bands in 1,740–1,600 cm⁻¹ were grouped Band B. A band at 1,100–1,030 cm⁻¹ was named Band C

humic substances (Stevenson and Goh 1971; He et al. 2006a). Compared to those of WEOM, FT-IR spectra of PEOM did not show the sharp peak at 1,384 cm⁻¹ as soluble nitrate compounds should be associated with the purified PEOM. PEOM samples showed more apparent band intensities at 2,921, 1,715, 1,231, and 1,028 cm⁻¹. Stevenson and Goh (1971) assigned infrared spectra of humic acids and related substances to three types. Type I spectra show equally strong bands at 1,720 cm⁻¹ and 1,600 cm⁻¹ with no discernible absorption being evident at 1,640 cm⁻¹. Type II spectra show a very strong 1,720 cm⁻¹ band, a shoulder at 1,650 cm⁻¹ and the absence of a 1,600 cm⁻¹ band. Type III spectra are similar to Type I with additional strong bands between 2,900 and 2,840 cm⁻¹. Therefore, the spectra of the PEOM samples were similar to those of Type III, but with less band intensity at 1,715 cm⁻¹. It is reasonable that the spectra of PEOM, not WEOM, were closely similar to that of humic acid as PEOM should be a more humified SOM fraction than the most labile WEOM pool (He et al. 2011b).

Semi-quantitative FT-IR analysis showed management practices impacted the relative abundance of both aliphatic (2,921–2,853 cm⁻¹) and aromatic groups (1,635 cm⁻¹) (Table 4.7). In the five rainfed samples, the relative heights of band A and B were in a complementary mode. That is, the band A/band C ratio was the highest in the PP and SQ WEOM samples, but the band B/band C ratio was the highest in the SC and SI WEOM samples. In addition, the ratio of band B to band C is also the highest with the two soil conserving systems. These data suggested that aromatic groups were increased in the WEOM fractions of soil conserving and improving fields. Irrigation reduced the relative intensities of both band A and B in PP, DS, SC and SI samples, but the intensity pattern was similar to that of rainfed samples. This observation implied that irrigation might have lowered both aliphatic

and aromatic fractions in the WEOM pool. Compared to its rainfed counterpart, irrigated SQ WEOM showed a much lower band A/band c ratio, but increased the band B/band C ratio. Thus, irrigation seemed enriching aromatic fraction in the SQ WEOM, which may need to be further investigated and confirmed.

The relative intensities of both band A and B relative to the internal reference band C were higher in the spectra of PEOM samples than WEOM samples, indicating more stable aliphatic, aromatic, and carboxyl groups in stable PEOM than in labile WEOM fractions of soil organic matter (He et al. 2011b). However, the values of band A/band C and band B/band C were basically the same among the 10 PEOM samples. These data indicated that neither 3-year crop rotation nor irrigation affected the structural composition of PEOM, although long-term (20 year) tillage management can significantly change the chemical characteristics of SOM fractions (Ding et al. 2002). Kaiser et al. (2007) characterized WEOM and PEOM extracted from soils of two (sandy and clayey) of the oldest agronomic long-term field experiments in Germany. These rotations include a 2-year winter rye-potato, a 4-year sugar beet-summer barley-potato-winter-wheat, and an 8-year sugar beet-summer barley-potatoes-winter wheat-alfalfa-alfalfa-potato-winter wheat. Whereas their work suggested that analysis of the stable PEOM is preferable for the long-term (about 40 years or longer) impacts of potato crop rotation on SOM, the work by He et al. (2011b) complementarily demonstrated that WEOM is more labile to a short-term effect of crop rotations.

4.5 Conclusion

Appropriate evaluation of soil P availability is a prerequisite for best P management in potato production systems. A 3-year crop rotation and irrigation treatment did not significantly change soil total P in the sandy loam potato fields in Maine, USA. However, the modified Morgan P level differed between soils samples with different rotation management. Correlation analysis revealed that the impact of crop rotation on the modified Morgan inorganic P was negatively correlated to the previous year's potato yield for fields receiving the same amount of P fertilizer, indicating that the modified Morgan P was a better soil test P for evaluating the P nutrient requirement for potato grown in these fields. Sequential fractionation of P in these soil samples revealed that the distribution of P in different labile pools had changed under these crop management practices. Crop rotation mainly increased water extractable inorganic P. Irrigation had a greater impact as it caused stable P pools in NaOH and HCl fractions inter-changed.

Compared to continuous potato production, crop rotation practices consistently increased microbial biomass C and P, soil phosphatase and urease activities in rainfed soils, and somewhat correlated to the potato yield ($P=0.1$), suggesting the improvement of soil biochemical quality by crop rotations. FT-IR analysis revealed that the impacts of rotation and irrigation practices reflected on the changes of aliphatic groups and aromatic compounds of WEOM samples. The 3-year crop

rotation and irrigation changed the relative abundances of these functional groups only in WEOM, not in PEOM. Continuous analysis of P and SOM from soils after the completion of the second round of the 3-year crop rotations would provide more insights on the improvement of soil fertility and biochemical quality for potato production by crop rotations.

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