Journal of Environmental Management 253 (2020) 109717

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

Effects of different mulching and fertilization on phosphorus transformation in upland farmland

Hongyan Cheng [a,b], Xiaozhen Zhu [b], Ruxiao Sun [b], Yinan Niu [b], Qiang Yu [a,**], Yufang Shen [a,b,*], Shiqing Li [a]

[a] State Key Laboratory of Soil Erosion and Dry-land Farming on the Loess Plateau, Northwest A&F University, Yangling, 712100, China
[b] College of Natural Resources and Environment, Northwest A&F University, Yangling, 712100, China

ARTICLE INFO

Keywords:
Surface mulching
Organic fertilizer
Phosphorus transformation
Spring maize
Growth period

ABSTRACT

In the present study, the impact of different soil surface mulching, fertilization on phosphorus mineralization and bio-availability of spring maize at various growth stages and soil layers (0–20 and 20–40 cm soil layer) were evaluated. The results indicated that the contents of total P and Olsen-Phosphorus (Olsen-P) in the soils of 0–20 cm soil layer were significantly higher than those in the 20–40 cm soil layer at different stages. The addition of organic fertilizer significantly increased the soil total P and Olsen-P content in the 0–20 cm soil layer. The different surface mulching, no mulching (NM), gravel mulching (GM) and film mulching (FM) were significantly affected by the content of Olsen-P in both soil layers during the critical growth period of spring maize. The Ca_{10}–P contents in both soil layers were the maximum in terms of the inorganic phosphorus content in soils with different surface mulching and different fertilization. Surface mulching significantly affected the transformation of inorganic phosphorus in different soil layers of dry-land farmland, and accelerated the increase of Ca_2–P content (first phosphorus source) in 0–20 cm soil layer by GM and FM. In addition, phosphorus combined with inorganic nitrogen fertilizer increased Ca_8–P (second Olsen-P source) to a certain extent, and reduced the relative content of Ca_2–P (first phosphorus source). Compared with phosphate (P), nitrogen and phosphorus (NP) treatments, manure and nitrogen and phosphorus (MNP) treatments increased the contents of Ca_2–P (first phosphorus source) and Ca_8–P (second effective phosphorus source), while it reduced the insoluble phosphorus source (O–P) content.

1. Introduction

Phosphorus is one of the important nutrients required by plants and it plays an essential function in their evolution and assimilation. However, at present, agricultural production is faced with the contradiction between the need for continuous input of phosphate fertilizer and the shortage of existing phosphorus reserves. Excessive input of phosphate fertilizer can also lead to environmental pollution (Turrión et al., 2018; Merino et al., 2019). Therefore, improving the utilization rate of phosphate fertilizer is of great significance to the sustainable development of agriculture and protection of the natural environment. The largest reservoir of phosphorus in the ecosystem is soil, where the total phosphorus (TP) content is 0.02–0.2%; however, the Olsen-phosphorus (Olsen-P) in soil only accounts for a small part of the TP (Guo et al., 2008; Lang et al., 2016). The soil texture in the semi-arid region of the loess plateau is mainly calcareous, hence, this region is one of the main areas that has deficiencies in Olsen-P (Malik et al., 2012). How to efficiently utilize the phosphorus accumulated in farmland soil and how to increase the Olsen-P content in farmland soil are the key questions to be answered and the problems associated with them should be solved urgently.

The dry farming area is usually very rich in light and heat resources. The adoption of certain technical measures and agricultural practices to maintain the soil moisture content and make full use of the limited natural rainfall can improve the water use efficiency and increase the effective use of soil nutrients (Zhang et al., 2012; Yan et al., 2018). Most of previous studies have shown that the soil surface significantly affects the temperature of water, and due to changing soil hydrothermal condition, the nutrients dynamics in the soil can be altered. Thus, improving the efficiency of water and nutrients use (Keller et al., 2012; Annaheim et al., 2015; Yan et al., 2016), has become a key strategy to increase the

* Corresponding author. College of Plant Nutrition, Northwest A&F University, Yangling, Shaanxi Province, 712100, PR China.
** Corresponding author.
E-mail address: shenyufang@nwafu.edu.cn (Y. Shen).

https://doi.org/10.1016/j.jenvman.2019.109717
Received 30 March 2019; Received in revised form 11 October 2019; Accepted 14 October 2019
Available online 23 October 2019
0301-4797/

List of abbreviation

Al–P	Aluminum phosphate
Ca	Calcium
Ca_{10}–P	Deca-calcium phosphate
Ca_2–P	Dicalcium phosphate
Ca_8–P	Octa-calcium phosphate
Ca–P	Calcium phosphate
Fe–P	Iron phosphate
FM	Film mulching
GM	Gravel mulching
MNP	Manure and nitrogen and phosphorus
NM	No mulching
NP	Nitrogen and phosphorus
Olsen-P	Olsen-Phosphorus
O–P	Insoluble phosphorus source
P	Phosphate
PT	Maize sowing
R1	Silking stage
R3	Milking stage
R6	Ripening stage
TP	Total phosphorus
V10	Jointing stage
V10	Trumpet (10 leaves) top dressing
VT	Tasseling period topdressing

agricultural yield, e.g. the loess plateau dry farming region (Guo et al., 2008; Xue et al., 2013). In the crop-soil system, soil microorganisms directly drive the conversion and circulation of soil phosphorus by means of dissolution, mineralization, fixation and symbiosis with plants (Du et al., 2008).

Soil microorganisms can promote the dissolution of insoluble phosphorus in the form of calcium, aluminum and iron phosphate (Malik et al., 2012; Wang et al., 2019). Sato et al. (2005) reported that, higher amounts of P and Ca containing manure Olsen-P application elevated the pH of the soil due to the formation of various Ca–P precipitates. In another study, Zhu and Li (2018) identified that those soil primarily comprise greater percentage of Ca (calcareous soil) and its characteristics played a significant role to control the different forms of soil P. The calcium carbonate minerals patch up with P via the mechanism of precipitation or adsorption. Previous studies have observed that higher dosage of organic manure and chemical fertilizer Olsen-P application can considerably reduce the soil pH in alkaline or highly calcareous soils (Hao et al., 2008; Romanyà and Rovira, 2009; Cheng et al., 2018).

However, different agricultural practices also affect the transformation of phosphorus in soil and the absorption and utilization of crops by changing the soil properties, the soils environmental factors and the soil biological factors (Zamuner et al., 2008; Peters et al., 2011; Zhu and Li, 2018). Therefore, an extended duration of experimental treatments, i.e. at different time scales, is necessary to provide robust evidence for identifying the effects of certain management measures on P fractions in soil. First, decadal time scales after a shift in land use (arable land to forest) were associated with redistribution of soil P fractions and this did not affect the labile phosphorus concentrations in soil (Giri et al., 2018; Rosa et al., 2019). Second, the total phosphorus concentrations along with labile phosphorus availability in soil decreased with ongoing pedo-genesis (Yan et al., 2016; Merino et al., 2019). The shift in land use from traditional grassland management (50 years ago, no fertilizer) to mulching or succession is not associated with pronounced changes in soil pH due to the good buffering capacity of the soils or soil organic matter (SOM) concentrations (Yan et al., 2018).

Therefore, it still remains unclear whether the effects of straw mulching is an effective method to improve the soil quality, which can reduce external damage to the soil, improve the water use efficiency and inhibit soil temperature changes. The phosphate fertilizer utilization efficiency of maize can increase by 16.9% when it is combined with chemical fertilizer. The main aim of this study was to evaluate the impact of long-term land cover use and various fertilization treatments on phosphorus morphological transformation and availability of soil in spring maize farmland under dry farming conditions in the loess plateau. The study also provides a basis for determining appropriate agricultural measures/practices to improve the availability of different phosphorus forms in this region.

2. Materials and methods

2.1. Site location

The investigation was conducted in Changwu loess plateau ecological agriculture experimental station of Northwest A&F University, Yangling, China. The site is located in the central and southern loess plateau (North latitude 35° 12 ′, longitude 107° 40 ′, at an altitude of 1200 m^{-2}), at the junction of Shaanxi and Gansu province, which is a typical dry-land and rained agricultural area located in the central part of the loess plateau, China. The test station is a well-known national agro-ecological experimental station, with a mean annual temperature of 9.1 °C, while the frost-free period and annual average rainfall were 171 days and 584 mm, respectively. The precipitation during the months of July to September accounted for 57% of the annual rainfall, and they are categorized as semi-dry, early sub-humid monsoon climate. The Yuan ground geomorphology unit accounts for 35%, while the gully landform unit accounts for 65%. The soil parent material in this area is middle loam marlin loess, and the soil is black thorn soil, with good texture. In this area, the ground water table is around 50–80 mm, without irrigation condition. Thus, the agricultural production is mainly dependent on natural precipitation and soil water storage.

2.2. Experimental design and research methods

2.2.1. Experiment design

The experiment was performed in $8m \times 7\,m = 56\,m^2$, random block design with triplicate for each treatment. Maize variety (Xianyu 335) was sown in a wide, narrow and horizontal manner (60:40) in order to compare the changes of soil phosphorus content and effectiveness under different surface covering conditions. Three types of soil surface managements were tested: treatment 1 (NM) - no mulching; treatment 2 (FM) - full film coverage; and treatment 3 (GM) - fully covered with sand. Sand and gravel was screened and removed before sowing and then covered with sand and gravel after sowing and seedling. During the growing period of spring maize, fertilizer treatments were consistent, with N, P and K Olsen-application and the sowing density was 65,000 plants per ha^{-1}. In order to compare the influence of distinct fertilization treatments on soil phosphorus content and effectiveness under mulching, the following three different fertilization treatments were selected in the localization test: treatment 4 (P) - Olsen-P applied with a single phosphate fertilizer; treatment 5 (NP) - fertilizer N and P Olsen-P application; treatment 6 (MNP) - organic manure was combined with chemical nitrogen and phosphate fertilizer.

The organic manure used in the treatments was local muck manure (C/N ratio - 20) and 30 t ha^{-1} Olsen-P was applied once a year before sowing spring maize. During the growing period of spring maize, the soil surface managements were the same, i.e. full film cover, seeding density were 85,000 plants per ha^{-1}, and Olsen-P was applied with potassium fertilizer. The nitrogen fertilizer was urea with a nitrogen content of 46.4%, and Olsen-P was applied three times. Other parameters were as follows: base fertilizer - 40%; powder dressing (V10) - 30%; tasseling period topdressing (VT) - 30%; phosphate fertilizer - 16% superphosphate containing P_2O_5; pure P was Olsen-P $-40\,kg\,ha^{-1}$. The base fertilizer and seed fertilizer was Olsen-P that was applied once to all the plots. Potassium fertilizer was in the form of potassium sulfate containing 50% K_2O, and $80\,kg\,ha^{-1}$ of pure potassium (Olsen-P) was applied per hectare, while K was applied at $80\,kg\,ha^{-1}$

2.2.2. Soil samples

The soil samples were poised in different layers (0–20 and 20–40 cm) according to the five-point sampling method before maize sowing (PT), jointing stage (V10), silking stage (R1), milking stage (R3) and ripening stage (R6). The soil from the same layer in each plot was mixed and 500 g of thoroughly mixed soil was collected as a sample for soil analyses. After screening the coarser fractions, the soil water content was measured. After sieving (2 mm), the soil Olsen-P content was determined. The samples were sieved using 0.15 mm mesh size to determine the soil TP, Olsen-P and inorganic phosphorus.

2.2.3. Assay methods

The basic physical and chemical properties of soil (pH, organic matter, TP and Olsen-P) were analyzed according to the soil agricultural chemical analysis method recommended by Leytem and Mikkelsen (2005). The soil pH was measured in 1:2.5 soil-water suspensions (on a dry weight basis) using a pH meter and a glass electrode (INESA PHSJ-3F, China). The total P content in the soil was determined using the molybdenum-blue method after digestion with concentrated $HClO_4$–H_2SO_4, while the available P was determined using the Olsen method (Kuo, 1996). The inorganic phosphorus morphology was determined by the inorganic phosphorus grading method proposed by John (1966). The soil phosphatase activity was analyzed by the method of *P*-nitrophenyl phosphate disodium, expressed in terms of the number of milligrams of phenol per kilogram of soil (Yang et al., 2010).

2.3. Data analysis and statistics

SPSS 19.0 was used for statistical analysis of the test data, and the least significant difference (LSD) was used for estimating the significant effects. Analysis of variance (ANOVA) was performed on the experimental data, while the Duncan's multiple range test was used to determine the statistical significance at a confidence level of $P < 0.05$ to $P < 0.001$. The Origin Pro 2015 software was used to plot the graphs.

3. Results

3.1. Influence of mulching and fertilization on soil total P of dry-land spring maize at the PT and R6 stages

The effect of different soil surface cover on TP in different soil layers of the experimental dry-land spring maize farmland is shown in Fig. 1a and b. The TP content in the 0–20 cm soil layer varied from 820 to $842\,mg\,kg^{-1}$ during the period R6. According to different coverage treatments, there was no significant effects in soil TP between 0 and 20 cm soil surface in PT period ($P > 0.05$), and FM treatment as well as

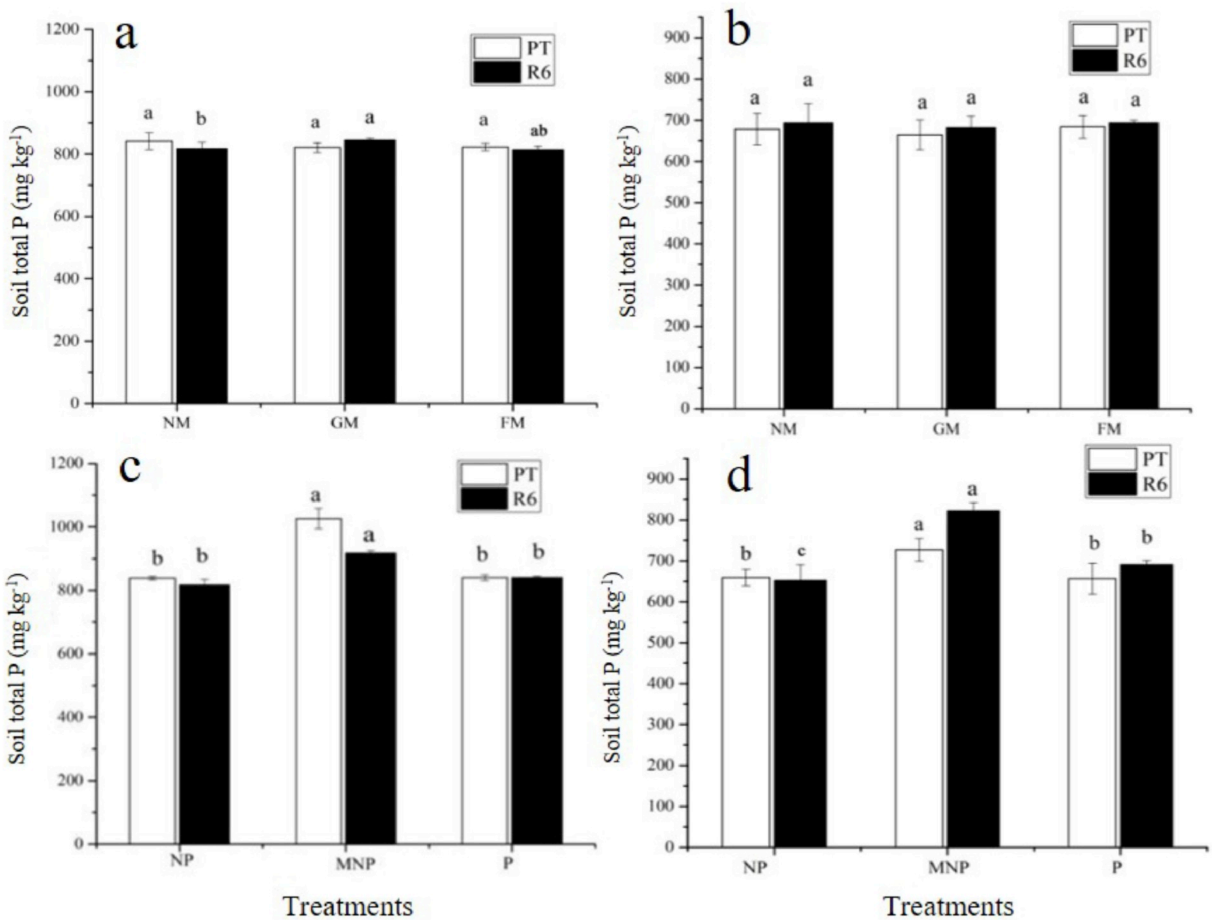

Fig. 1. Effect of mulching (a in 0–20 cm and b in 20–40 cm soil layer) and fertilization (c in 0–20 cm and d in 20–40 cm soil layer) on soil total P of dry-land spring maize at the PT and R6 stages. NM: No mulching; GM: Gravel mulching; FM: Film mulching; P: Phosphate; NP: Nitrogen and phosphorus; MNP: Manure and nitrogen and phosphorus.

other two treatments during period R6. It can be seen from Fig. 1b that, between the three treatments of NM, GM and FM, during the PT period of dry spring maize, the TP content in the 20–40 cm soil layer varied from 660 to 690 mg kg^{-1}, while this variation during period R6 period was 680–700 mg kg^{-1}. There was no significant variation in the soil TP content, in the 20–40 cm soil layer among all the treatments during periods PT and R6. It can also be seen that treatment NM, GM, and FM and their three surface coverage did not significantly affect the TP content of both soil layers after sowing and harvesting the spring maize.

It can be observed from Fig. 1c that, under the three different fertilization treatments of NP, MNP and P, during period PT of dry spring maize, the TP content in the 0–20 cm soil layer varied from 830 to 1100 mg kg^{-1}, but the range of variation during period R6 was significantly lower (810–920 mg kg^{-1}). The growth period had no significant effect on the TP content, i.e. in the 0–20 cm soil layer. From the distinct fertilization treatments, the TP content in the 0–20 cm soil surface of periods PT and R6 showed that the MNP treatment was considerably greater than that of P and NP treatment ($P < 0.05$), and the variance between P and NP treatment was not significant (Fig. 1d). The TP content in the 20–40 cm soil layer varied from 650 to 730 mg kg^{-1} during period PT of spring maize but the variation during period R6 was significantly greater (650–830 mg kg^{-1}). During period PT, the soil phosphorus content of MNP treatment was the highest, and the variation among NP and P was found to be significant ($P > 0.05$) under the different fertilization treatments. During period R6, the soil phosphorus content in the MNP was the highest and considerably greater than those observed during P treatment under the different fertilization treatments. When comparing Fig. 1c and d, it was observed that, under different fertilization treatments, the TP content in the 0–20 cm soil layer was greater than the values observed in the 20–40 cm soil layer (i.e. during the same growth period).

3.2. Influence of mulching and fertilization on the soil Olsen-phosphorus content during the dry-land spring maize growing season

The effect of different surface cover and fertilization on soil Olsen-P in two distinctive soil layers, in various growth phases, of spring maize is shown in Fig. 2. It can be observed that, under different growth periods, the soil Olsen-P content in the 0–20 cm soil layer decreased and then increased among the different treatments. From period PT to R1, the soil Olsen-P content gradually decreased and reached the lowest value in R1 period, while the Olsen-P content in NM, GM and FM were considerably greater (8.15, 9.30 and 6.23 mg kg^{-1}) than all other treatments. During period R6, the soil Olsen-P in GM and FM treatments increased significantly compared to period R3 ($P < 0.05$), and the change of soil Olsen-P content in NM treatment showed no significant effect. According to the different soil surface managements, during period PT, the soil Olsen-P content in the FM treatment was considerably lower than the NM and GM treatments ($P < 0.05$).

On the other hand, during period V10 and the FM treatment, the soil content was significantly lower than those observed during GM treatment. In addition, during period R1, the soil Olsen-P content in FM and

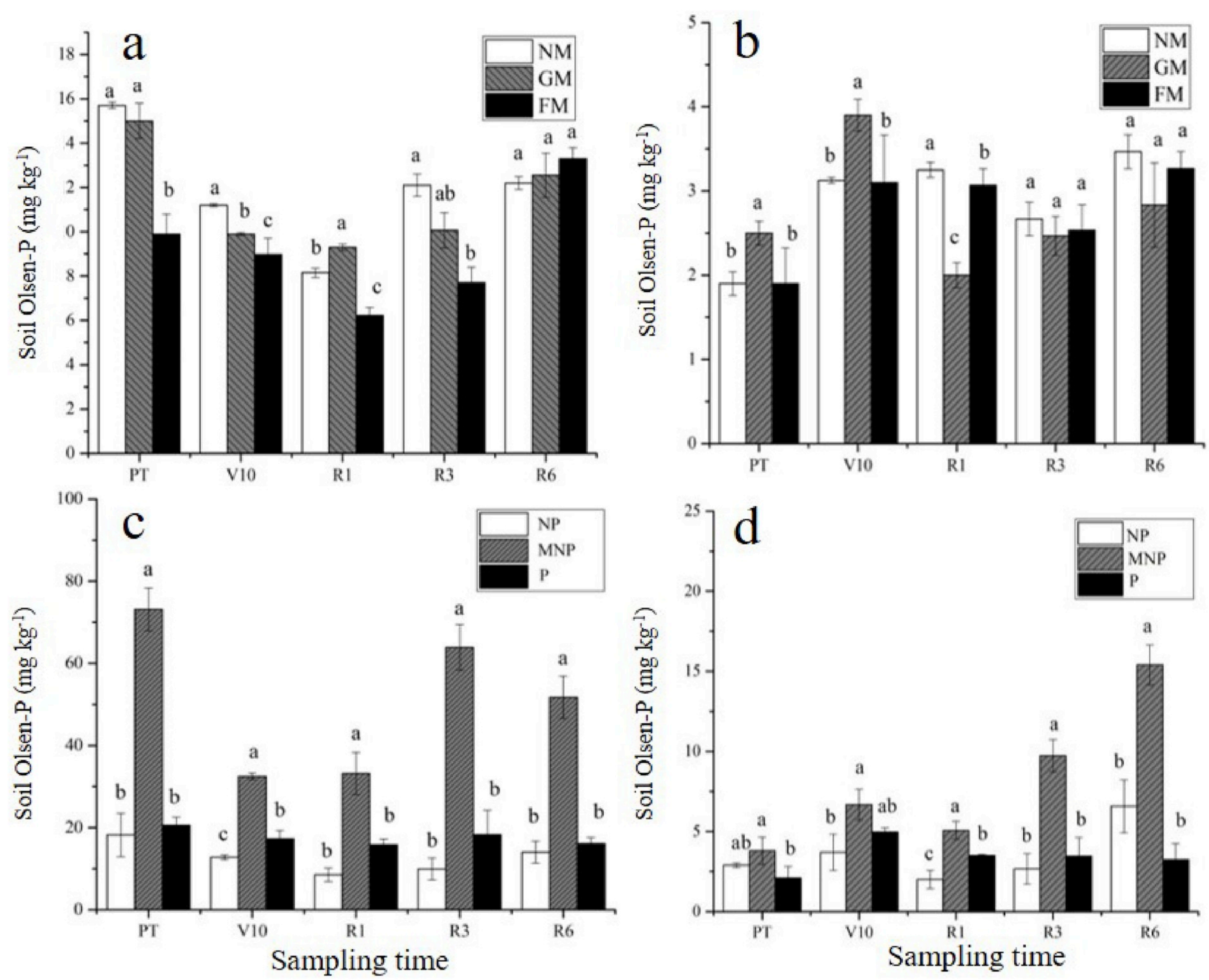

Fig. 2. Effect of mulching (a in 0–20 cm and b in 20–40 cm soil layer) and fertilization (c in 0–20 cm and d in 20–40 cm soil layer) on soil Olsen-P during dry-land spring maize growing season. PT: Maize sowing; V10: Jointing stage; R1: Silking stage; R3: Milking stage; R6: Ripening stage; NM: No mulching; GM: Gravel mulching; FM: Film mulching; P: Phosphate; NP: Nitrogen and phosphorus; MNP: Manure and nitrogen and phosphorus.

GM treatments were significantly lower than the values observed in NM treatment. Anew, during period R3, the FM treatment soil had the lowest Olsen-P content. The difference between FM and GM treatments was not significant (Table S1), but significantly lower than the values observed during NM treatment ($P > 0.05$). During period R6, the Olsen-P content of NM, GM and FM treatments were 12.25, 12.55 and 13.30 mg kg^{-1}, respectively, where the difference was not statistically significant ($P > 0.05$). As illustrated in Fig. 2b, the soil Olsen-P content in the 20–40 cm soil layer changed significantly with the growth period and it was affected by the different coverage treatments. The content of Olsen-P in GM and FM treated soil was considerably greater than PT and V10 of dry farming and the variation among the two treatments was not significant. During period R1, the Olsen-P content was considerably lower than that of the FM treatment. During periods R3 and R6, different surface coverage treatments showed GM < FM < NM, but the variation among the all treatments was not significant. From Fig. 2a and b, it was observed that the soil Olsen-P content in the 0–20 cm soil layer was higher than the 20–40 cm soil layer; and the variation of Olsen-P content in different coverage treatments were also significant. However, in the pre-fertility period, the difference was not significant during period R6.

The influence of different fertilization treatments on soil Olsen-P in two soil layers of spring maize in various growth stages are shown in Fig. 2c. During the different growth stages, the soil Olsen-P content in the 0–20 cm soil surface under distinctive fertilization treatments showed the highest during period PT, and then it decreased with the growth period (Fig. 2c), and reached the lowest value during periods V10 and R1. According to the different fertilization treatments, the soil Olsen-P content in the 0–20 cm soil layer treated by MNP was significantly greater than those observed during treatment periods NP and P ($P < 0.01$). The NP and P treatments were significantly different in period V10 ($P > 0.05$), and the variation was not significant in other periods. In addition, from Fig. 2d, it can be observed that the soil Olsen-P content in the 20–40 cm soil layer significantly varied with the growth period and also influenced by different fertilization treatments (Table S2).

Subsequently, the soil Olsen-P in MNP and NP treatment increased first, then decreased and finally increased in different growth stages, while the P-treated soil Olsen-P increased first and then decreased, and finally changed. However, the NP, MNP, and P soil fertilization treatments had the lowest content of Olsen-P (2.00, 5.07, and 3.50 mg kg^{-1}) during period R1. Under distinctive fertilization amendments, the soil Olsen-P content in the 20–40 cm soil layer (treated with MNP) was higher than that of NP and P treatments during different growth stages of periods of R1, R3 and R6, respectively. From Fig. 2c and d, it can be observed that the soil Olsen-P content of the 0–20 cm soil, during different fertility treatment farms, were higher than the 20–40 cm soil layer, but during MNP treatment there were variations in the different growth stages. The soil Olsen-P content in both the soil layers (0–20 and 20–40 cm) was considerably greater than the other two treatments; however, the difference between NP and P treatments were found to be insignificant ($P > 0.05$).

3.3. *Influence of mulching on soil (Ca_2–P, Ca_8–P and Ca_{10}–P) and (Al–P, Fe–P and O–P) during dry-land spring maize growing season*

Among the various inorganic phosphorus forms, Ca_2–P is the most bioavailable in the soil, and most easily absorbed phosphorus by crops (Cheng et al., 2018). From Fig. 3a and b, it can be observed that the variation of Ca_2–P content in both the soil surface (0–20 and 20–40 cm) under distinctive surface coverage is between 15.38 and 27.05 mg kg^{-1} and 14.88 and 17.75 mg kg^{-1}. During different growth periods, the 0–20 cm soil layer showed an overall trend of increasing first and then decreasing during the different sampling periods, with maximum values of 27.00, 25.38 and 25.13 mg kg^{-1}, respectively, but the soil Ca_2–P in the 20–40 cm soil layer did not change much in the all treatments. According to the different surface cover treatments, during period V10, the soil Ca_2–P content in GM and FM treatments significantly increased; however, during period R3, the soil Ca_2–P content significantly reduced

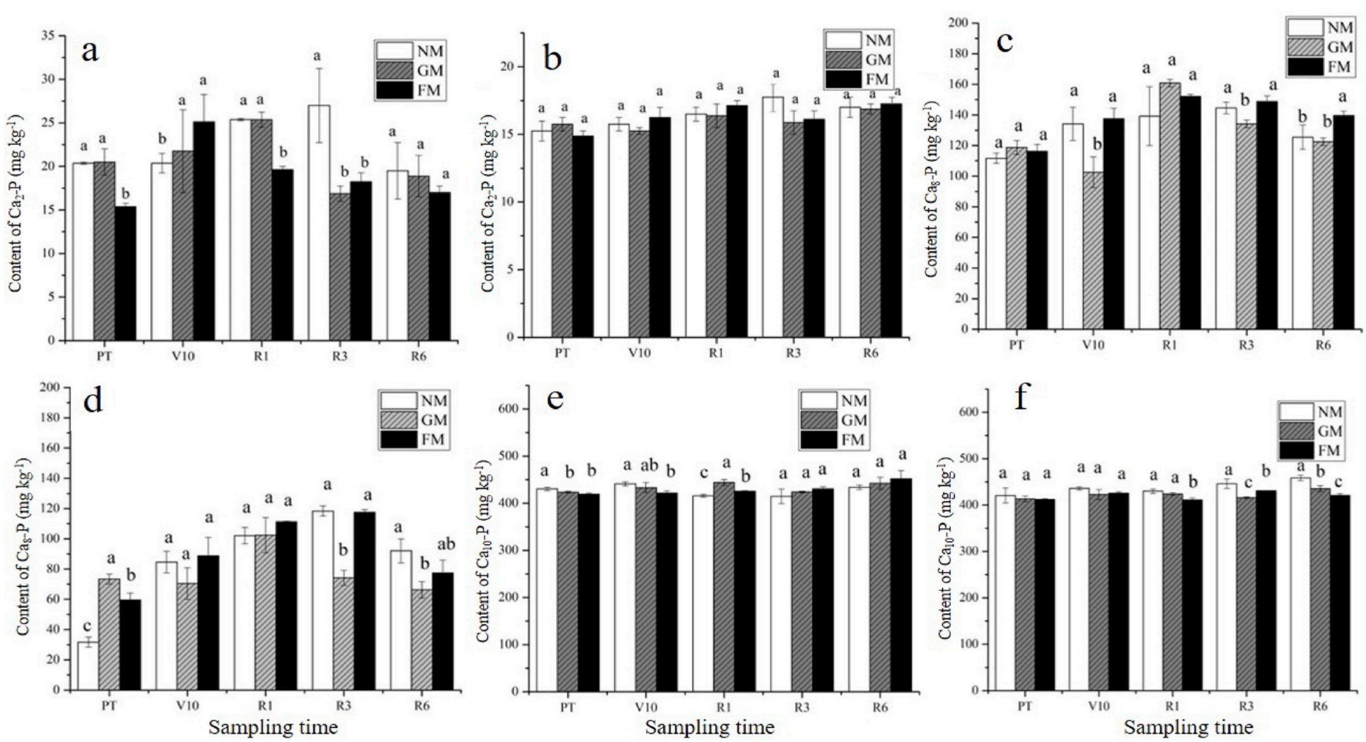

Fig. 3. Effect of mulching on soil Ca_2–P (a in 0–20 cm and b in 20–40 cm soil layer), Ca_8–P (c in 0–20 cm and d in 20–40 cm soil layer), Ca_{10}–P (e in 0–20 cm and f in 20–40 cm soil layer) during dry-land spring maize growing season. PT: Maize sowing; V10: Jointing stage; R1: Silking stage; R3: Milking stage; R6: Ripening stage; NM: No mulching; GM: Gravel mulching; FM: Film mulching.

as compared to the NM treatment. On the other hand, during periods PT and R1, the Ca_2–P content in the FM treated soil was considerably less than the NM and GM treatments. During period R6, the variation of soil Ca_2–P concentration in various treatments was not significant. In the 20–40 cm soil layer, the change of Ca_2–P content in each treatment was not obvious during the sampling period, and the difference between the different treatments was not significant. Consequently, the soil Ca_2–P content during treatments NM, GM and FM increased compared with treatment PT. Furthermore, the Ca_2–P content in the 0–20 cm soil layer of GM and FM treatments increased the Olsen-P rapidly with the growth period than the NM treatment.

In a recent study, Wang et al. (2019) reported that Ca_8–P can be used as a slow-acting phosphorus source for plants and it could be considered as the second most effective source of phosphorus because it plays a key role in nutrient absorption by the crops. Fig. 3c and d indicate that different coverage treatments and crop growth periods significantly affect the Ca_8–P content in the 0–20 and 20–40 cm soil layers of the farmland. During the different growth stages, the content of Ca_8–P in both soil layers significantly increased with the growth period, although the overall trend showed an increasing and then decreasing profile. During period R3, at the 0–20 cm soil layer of treatment NM, the maximum value of Ca_8–P was 144.57 mg kg^{-1}. On the other hand, treatments GM and NM reached the maximum values during period R1, i.e. 160.8 and 152.07 mg kg^{-1}. In the 20–40 cm soil layer, NM and FM treatment reached the maximum value during period R3, with values of 118.33 and 117.5 mg kg^{-1}, respectively, and treatment GM reached the maximum value of 102.5 mg kg^{-1} during period R1.

From the different surface cover treatments, it was clearly evident that there was no considerable variation between the treatments in the 0–20 cm soil layer and in period PT. During periods V10 and R3, the Ca_{10}–P content in the GM treated soil was considerably lower than those observed during treatment NM. During period R6, the Ca_8–P content in the FM treated soil increased significantly when compared with the NM and GM treatments. In the 20–40 cm soil layer, during period PT, the Ca_8–P content in the GM treated soil was considerably greater than the values observed in treatment FM. Similar comparison can be made for the different treatments undertaken in this study. These good results confirm the fact that, compared with treatments NM and GM, the Ca_8–P content period R6 of treatment FM (0–20 cm soil layer) was considerably greater than all other treatments. Ca_{10}–P in soil is a relatively stable and insoluble calcium phosphate salt. It belongs to Olsen-P and has low chemical activity. It is the most difficult form of various inorganic phosphorus that can be absorbed and utilized by plants. Ca_2–P and Ca_8–P can be converted to Ca_{10}–P under certain environmental conditions, while Ca_{10}–P is difficult to be converted into Ca_2–P or Ca_8–P. Therefore, Ca_{10}–P can only be used as a potential phosphorus source.

From the different growth stages, it was observed that, in the 0–20 cm soil layer of period R6, the Ca_{10}–P content of the GM and FM treatment soil increased significantly and reached values of 442.23 and 451.63 mg kg^{-1} in the 20–40 cm soil layer. Compared with treatment PT and period R6, the contents of Ca_{10}–P in the soil treated by NM, GM and FM increased significantly and reached values of 458.33, 435.24 and 420.93 mg kg^{-1}, respectively. As shown in Fig. 3e and f, during period R1, the Ca_{10}–P content in the GM and FM treated soils (0–20 cm soil layer) increased significantly when compared with treatment NM, while in period R6, GM treatment showed significantly higher content. On the other hand, in the 20–40 cm soil layer, there was no significant variation in the Ca_{10}–P content when compared to other treatments (PT and V10). Compared with the NM and GM treatments, the content of Ca_{10}–P in the FM treated soil decreased significantly during period R1, however, in period R3, the content of Ca_{10}–P in the GM treated soil decreased significantly, and those in period R6 also decreased.

Similar to Ca_8–P, the A1-P is less impressive than Ca_2–P in soil and belongs to the second effective phosphorus source for crop growth. Fig. 4a and b shows that the Al–P content in the soil of the 0–20 cm soil layer was higher that the contents observed in the 20–40 cm of soil layer during the growth period. Compared with period PT, the A1-P content in the 0–20 cm soil surface of period R6 decreased significantly by 37.63, 38.75 and 40.50 mg kg^{-1}, respectively. On the contrary, during NM treatment, the Al–P content of the 20–40 cm soil layer increased during

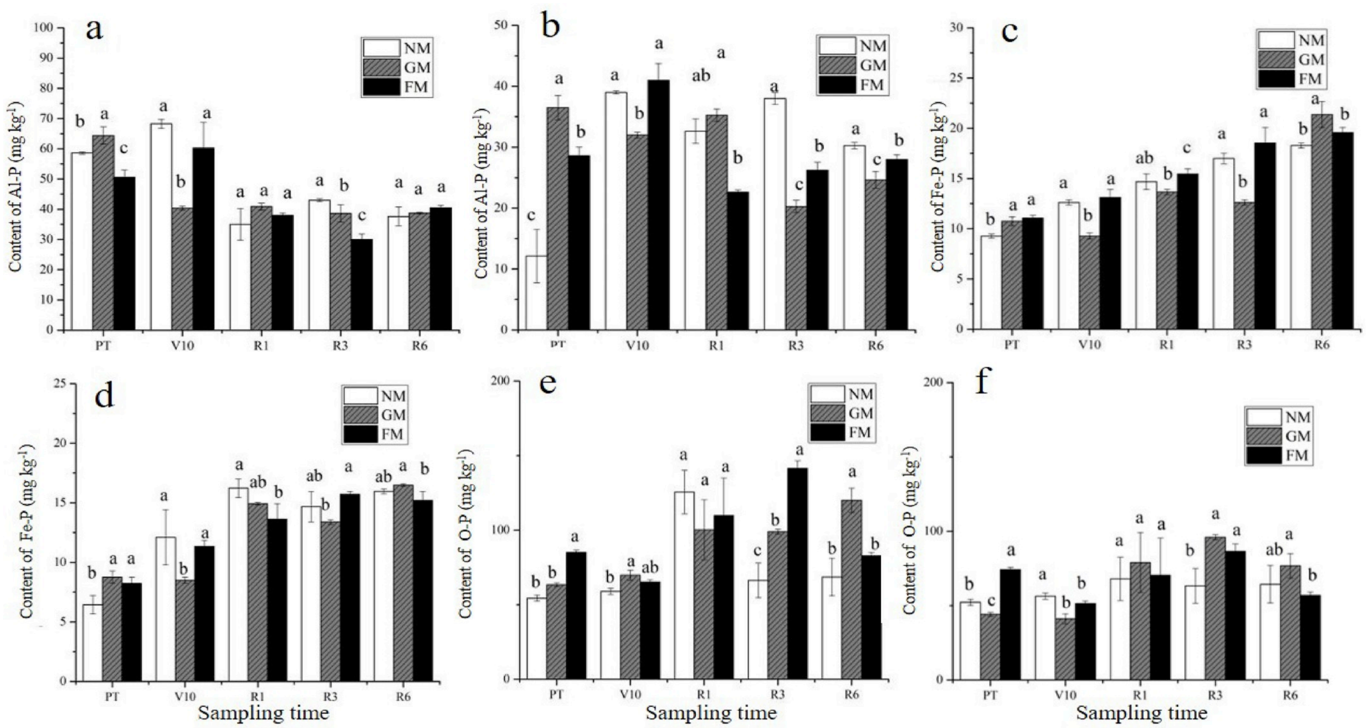

Fig. 4. The effect of mulching on soil Al–P (a in 0–20 cm and b in 20–40 cm soil layer), Fe–P (c in 0–20 cm and d in 20–40 cm soil layer), O–P (e in 0–20 cm and f in 20–40 cm soil layer) during dry-land spring maize growing season. PT: Maize sowing; V10: Jointing stage; R1: Silking stage; R3: Milking stage; R6: Ripening stage; NM: No mulching; GM: Gravel mulching; FM: Film mulching.

period R6 by 18.12 mg kg^{-1}; however, the A1-P content of treatment GM treatment decreased significantly by 11.87 mg kg^{-1} and the A1-P content of FM treatment increased. Concerning period V10, the A1-P content in the treated soil decreased significantly when compared with treatments NM and GM, but in the case of FM treatment, the Al–P content did not change significantly. During period R3, the A1-P content in the GM and FM treated soils decreased significantly as compared with the NM treated soil; while in periods R1 and R6, there was no considerable variation in the A1-P content. In the 20–40 cm soil layer, compared with the NM treatment, the A1-P content in GM and FM treated soils increased significantly compared to NM treated ones and during periods R3 and R6, the A1-P content significantly ($P < 0.05$) reduced. On the other hand, compared with NM and FM treatments, the Al–P content in the GM treated soil also significantly reduced during periods V10, R3 and R6.

As seen from Fig. 4, the different growth periods of the test crop had significant effects on the Fe–P content in both soil layers. With the promotion of the crop growth period, the Fe–P content of both soil layers (0–20 and 20–40 cm) of spring maize farmland generally increased during period PT when compared to period R6. Compared with the PT period, the soil Fe–P content of the 0–20 cm soil layer treated by NM, GM and FM increased by 9.01, 10.63 and 8.5 mg kg^{-1} in the 0–20 cm soil layer, while in the NM and FM treatments, the Fe–P content of the soil during the adjacent growth period of PT to R3 increased to a significant level ($P < 0.05$). In the 20–40 cm soil layer, the Fe–P content of the soil during periods V10 to R3 of the GM and FM treatments also reached a significant level of $P < 0.05$. From Fig. 4c and d, it is evident that, from different surface cover treatments in the 0–20 cm soil layer, the Fe–P content in the soil treated by GM and FM are greater than those observed from the NM treatment during period PT, while in periods V10-R3, the GM treated soils Fe–P content was significantly lower than both NM and FM treatment. In addition, during period R, GM was significantly higher than NM and FM treatment but the difference between NM and FM treatment was not significant. The Fe–P content in the 0–20 cm soil layer under GM treatment decreased first and then increased. On the other hand, in the 20–40 cm soil layer, compared with NM treatment, in GM and FM treatments the soil Fe–P content significantly increased during period PT. It is noteworthy to mention that, during period R6, the difference in the Fe–P content between GM and NM treatment was not significant.

Concerning the soil O–P content, from Fig. 4e and f it is evident that the soil O–P percentage in the 0–20 cm soil layer of the experimental dry-land spring maize field was greater than the 20–40 cm soil, where the soil Olsen-P content was significantly affected by the growth period and the cover treatment. Compared with different growth stages, the Olsen-P content of both soil layers in FM treatment increased first and then decreased, while the maximum values of Olsen-P peaked during period R3, with values of 141.50 and 86.47 mg kg^{-1}, respectively. During period R6, the 0–20 cm soil layer showed high Olsen-P content (56.67 mg kg^{-1}) compared with the PT period; while in 20–40 cm soil layer of the GM and FM treatments these changes was also significant and the Olsen-P content increased up to 32.56 mg $kg^{-1}$and thereafter decreased to 17.3 mg kg^{-1}. In different surface cover treatments and the 0–20 cm soil layer, the soil O–P content during period PT was considerably greater than those observed during GM and NM treatments, but the variation among the NM and GM treatments was not significant. During period V10, however, there was no considerable variation among NM, GM and FM treatment than during period R1, while in R3, the soil Olsen-P content followed the order: FM > GM > NM. In the 20–40 cm soil layer, the soil Olsen-P content during PT period followed the order: FM > NM > GM order, and the difference between the treatments was also significant. Thus, during periods R3 and R6, the soil Olsen-P content was the highest in GM treatment.

3.4. Influence of mulching and fertilization on the inorganic P content during dry-land spring maize growing season

Fig. 5a and b shows that, in the 0–20 cm soil layer, there is a difference in the inorganic phosphorus content during different periods of dry spring maize growing season. During period PT, the relative content of inorganic phosphorus in NM and GM treatments followed the order: Ca_{10}–P > Ca_8–P > Al–P > O–P > Ca_2–P > Fe–P order, while in the FM treatment it was: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P. Fig. 5a clearly shows that, during FM treatment, the relative content of Olsen-P increased during period PT, compared to the NM and GM treatments. In period V10, the relative content of inorganic phosphorus in various forms of NM treatment was: Ca_{10}–P > Ca_8–P > Al–P > O–P > Ca_2–P > Fe–P, while in the GM and FM treatments, the following order was observed: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P. When compared with the NM treatment, in GM and FM treatments, the relative content of Olsen-P increased during period V10, however, with a reduced Al–P content. During periods R1, R3 and R6, the relative contents of inorganic phosphorus in NM, GM and FM were as follows: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P.

In 20–40 cm soil layer, the relative content of inorganic phosphorus in different periods of dry spring maize growing season is shown in Fig. 5b. The comparative percent of inorganic phosphorus in NM treatment followed the order: Ca_{10}–P > O–P > Ca_8–P > Ca_2–P > Al–P > Fe–P. However, the relative content of inorganic phosphorus in the GM treatments was as follows: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P, and the FM treatment was: Ca_{10}–P > O–P > Ca_8–P > Al–P > Ca_2–P > Fe–P. This clearly proves the fact that GM treatment improves the Ca_2–P and Al–P in the 20–40 cm soil layer during period PT when compared with NM treatment. On the other hand, during periods V10 and R1, the relative contents of inorganic phosphorus in the treatments NM, GM and FM followed the order: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P. This clearly indicates that during periods V10 and R1, the inorganic phosphorus content was relatively stable. Similar observations could be made during periods R3 and R6 periods during NM, FM and GM treatments.

The changes in the relative content of inorganic phosphorus in different fertilization treatments under the mulching treatment is shown in Fig. 5c and d. From Fig. 5c, it can be observed that in the 0–20 cm soil layer, the relative contents of inorganic phosphorus in NP, MNP and P treatments followed the order:Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P during period PT period. During period R1, the relative content of inorganic phosphorus in each form of NP treatment was Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P, while in the MNP treatment it followed the order: Ca_{10}–P > Ca_8–P > O–P > Ca_2–P > Al–P > Fe–P. Although the relative content of Al–P during period R1 decreased, in period R3, the relative content of inorganic phosphorus in NP treatment followed the order: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P, and for MNP treatment it followed the order: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P, As shown in Fig. 5d, in the 20–40 cm soil layer, the relative content of inorganic phosphorus during NP treatment (period PT) followed the order: Ca_{10}–P > O–P > Ca_8–P > Al–P > Ca_2–P. The relative contents of inorganic phosphorus present in Fe–P, MNP and P treatments followed the order: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P. Thus, it was ascertained that the MNP treatment increased the Ca_8-during sowing time. In periods V10, R1, R3 and R6, the relative contents of inorganic phosphorus in NP, MNP and P treatments were: Ca_{10}–P > Ca_8–P > O–P > Al–P > Ca_2–P > Fe–P. During the process of fertility, the inorganic phosphorus in the soil of the 20–40 cm soil layer was relatively stable, but in the 0–20 cm soil layer, the relative content of inorganic phosphorus in each form changed significantly during period PT. However, when compared with P, MNP treatment increased, and the relative content of Ca_2–P in periods R1 and R6 were found to be significantly higher. The relative content of Ca_8–P reduced in Olsen-P treatment during period R6. When compared with the P treatment, the MNP treatment reduced the relative content of Al–P and Fe–P during periods

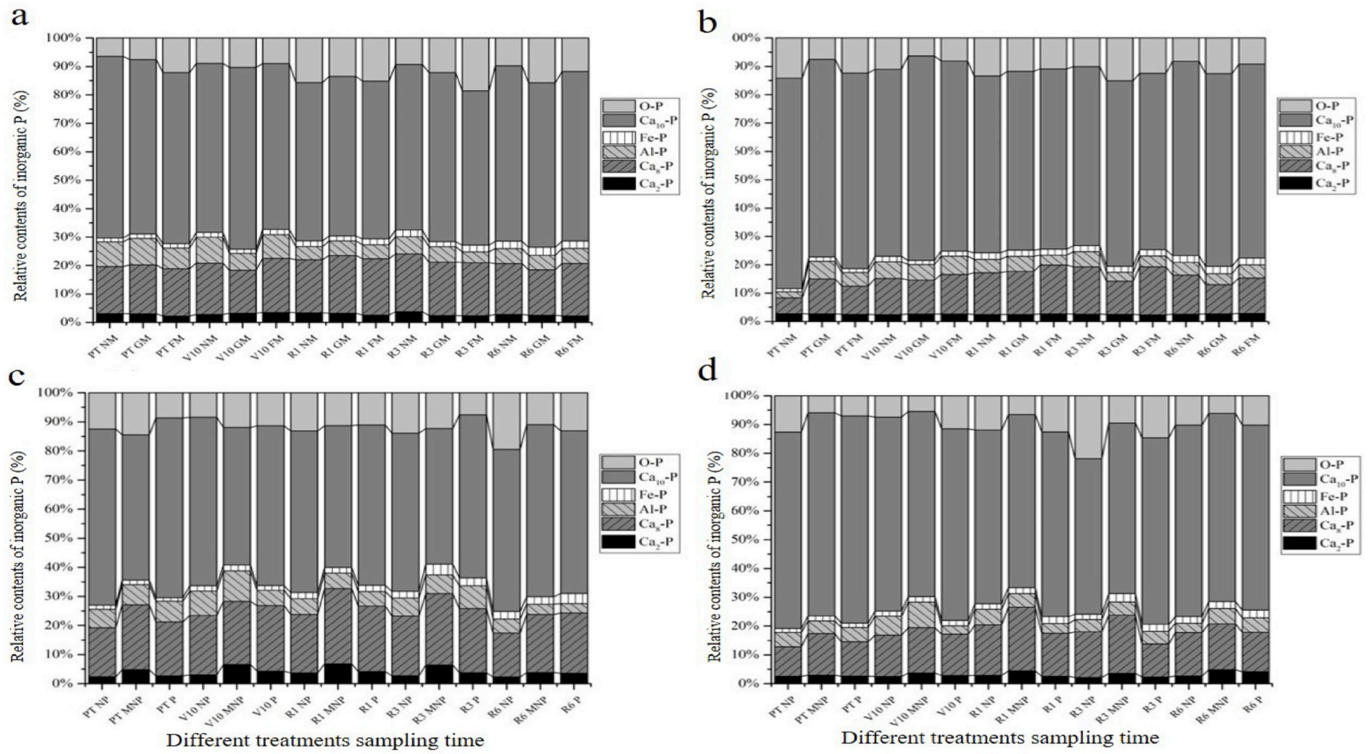

Fig. 5. The effect of mulching (a in 0–20 cm and b in 20–40 cm soil layer) and fertilization (c in 0–20 cm and d in 20–40 cm soil layer) on the relative of inorganic P during dry-land spring maize growing season. PT: Maize sowing; V10: Jointing stage; R1: Silking stage; R3: Milking stage; R6: Ripening stage; NM: No mulching; GM: Gravel mulching; FM: Film mulching.

R3 and R6, respectively. Thus, the results of the present study indicates that the amendment of organic fertilizer can increase the relative content of the first (Ca_2–P) and second effective phosphorus source (Ca_8–P) which is considered to be the key growth period of spring maize to a certain extent. However, when compared with the P treatment, the NP treatment increased the second effective phosphorus source and the potential phosphorus source to some extent, and reduced the relative content of the first phosphorus source. The influence of fertilization on soils Ca_2–P, Ca_8–P, and Ca_{10}–P and Al–P, Fe–P, and Olsen-P during the dry-land spring maize growing season is discussed in the Supplementary Information.

4. Discussion

According to the results of this study, the content of Olsen-P in the 0–20 cm soil is considerably greater than the 20–40 cm soil layer during different growth stages. However, during periods PT ~ V10, the soil Olsen-P in the 0–20 cm is reduced, and in 20–40 cm soil layer increased. When the late maturity period was reached, the soil Olsen-P concentration in the two different soil layers increased, and the variation in soil Olsen-P content in distinctive soil treatments showed no significant effects. The trend of soil Olsen-P in different soil layers can be related to the nutrient uptake of crops and most of previous studies have confirmed that the roots are the main part of plants that absorb these nutrients (Bu et al., 2013; Zhan and Lynch, 2015; Rosa et al., 2019). In the present study, after soil fertilization during periods V10 and R1, the nitrogen content in the soil increased, and this increase of nitrogen content significantly promoted the growth of the plant, which not only increased the absorption of Olsen-P, but at the same time, it also decreased the content of Olsen-P in the soil. Hence, some researcher believes that the utilization rate of phosphate fertilizer in plants increases during the flowering season (Han et al., 2011; Cheng et al., 2018). When plants entered period R3 during grain formation, plant growth slowed down and subsequently the utilization of Olsen-P also decreased. In addition to this growth period, higher soil moisture and temperature conditions enhanced the soils microbial activity, which could be beneficial to the change of the soils phosphorus form and the Olsen-P content. Due to the weak mobility of soil phosphorus and Olsen-P, the soil exhibited agglomeration in the 0–20 cm soil layer (Vu et al., 2008; Zhu and Li, 2018).

In this study, under the three types of fertilization treatments, i.e. NP, MNP and P, the TP content in the 0–20 cm soil layer was significantly greater than the 20–40 cm soil layer. The soil phosphorus content under MNP treatment was the highest, while NP and P were significantly lower than the MNP treatment. It can be seen that different nitrogen and phosphorus treatments have significant effect on the 0–20 cm soil layer. Anew, in the 0–20 cm soil layer, the soil phosphorus content of NP treatment during different growth stages was lower than that of the P treatment, and the difference in V10, R1 and R3 increased, which could be during the growth of spring maize. Most of the previous studies indicated that the amendment of nitrogen fertilizer can promote the growth of corn plant and increase the weight of dry matter on the ground, but phosphorus is also one of the important nutrient that is required for plant growth and development (Hao et al., 2008; Peters et al., 2011; Rosa et al., 2019). Some previous studies have reported that its consumption gradually increased with plant growth cycle, because the absorption and utilization of phosphorus is higher than nitrogen (Liu and Li, 2010; Giri et al., 2018).

Organic fertilizer is an important reservoir of phosphorus in soil, which can significantly increase the TP content of soil in the 0–20 cm soil layer. After a growth cycle, despite the absorption and utilization of crops, the TP content of soil treated by MNP was greater than that of NP and P treatment in the 20–40 cm soil layer. Under the three different fertilization treatments, the Olsen-P content in the 0–20 cm soil was significantly higher than the 20–40 cm soil layer, however, the Olsen-P content in both soil layers of the MNP treated soil increased significantly as compared to the NP and P treatment. Turner et al. (2014) and Zhao and Chen (2013) observed that organic fertilizer combined with phosphate fertilizer can promote the conversion of ineffective phosphorus to Olsen-P, but after plant grain formation, the plant basically no longer grows, and the soil phosphorus consumption also decreases. Therefore, the soil Olsen-P content also increased subsequently as a result of this change. The Olsen-P content of the MNP treated soil (20–40 cm layer) was greater than other treatments, which could be due to the distribution of phosphorus in the vertical direction by the Olsen-application of organic fertilizer. Some studies have pointed out that the long-term use of organic fertilizer can possibly lead to a downward migration in the 0–20 cm soil layer (i.e. phosphorus content), and its migration ability is more obvious in some soils with weak phosphorus fixation ability (Prietzel et al., 2016).

The present study indicated that, compared with the NM and GM treatment, the Ca_8–P content of the 0–20 cm soil layer during period R6was higher than those observed in other treatments. However, when compared with different periods of dry spring maize, the FM treatment significantly enhanced the Ca_{10}–P content in the 0–20 cm soil layer. When compared with the NM and FM treatment, GM treatment has significantly higher soil Fe–P content during period R6. This behavior could be due to the GM and FM treatments that formed a closed microenvironment in the 0–20 cm layer of the soil compared to the NM treatment, which prevents the Olsen portion of water from the soil, while at the same time increasing the soil temperature (Liang et al., 2012; Rosa et al., 2019). In addition, the microbial activity increased with the soil moisture content, and the activity of enzymes could be also enhanced which eventually supported the increased soil nutrients level and existence of soil phosphate-dissolving microorganisms. These phosphate-dissolving microorganisms could accelerate the mineralization and decomposition of organic phosphorus (Chen, 2003; Bol et al., 2016; Giri et al., 2018). Previous research works have reported that a part of the active phosphorus Olsen-P applied to the soil is absorbed and utilized by the plant, and some of it is fixed by the soil as insoluble phosphorus, while the remaining part is adsorbed by the soil colloid or aggregate structure (Guo et al., 2008; Lou et al., 2018).

This part of the adsorbed phosphorus and the active phosphorus in the soil are in a state of dynamic equilibrium, which could support the phosphorus cycle in the soil. This behavior clearly indicates that, compared with bare ground planting, film mulching and gravel mulching treatments are more conducive to the activation and transformation of soil Olsen-P, slow-acting phosphorus and potential phosphorus sources, which have a significant impact on the absorption of phosphorus in spring maize. This is mainly due to the fact that the mulching and grit mulching treatment changes the physical and chemical properties of soil permeability, pH and soil temperature (Sakurai et al., 2008; Yan et al., 2016). On the other hand, when the ground temperature raises, a suitable water and gas environment is maintained, which in turn promotes the activities of soil microbes, thereby strengthening the ammoniation, nitrification and nitrogen fixation of the soil by the decomposition of organic matter and the mineralization of the soil nutrients in different forms of nitrogen and phosphorus (Saha et al., 2008; Chan et al., 2011).

Therefore, the relative content of inorganic phosphorus in various forms also changes significantly during the growth of maize (Annaheim et al., 2015). The quantity and morphological changes of phosphorus in the soil are a comprehensive response involving physical, chemical and biological factors. The pH, soil calcium, iron and magnesium contents, mineral surface area and its characteristics and soil moisture content are the main factors affecting the fixation and release of inorganic phosphorus (Amador et al., 1997; Pierzynski et al., 2005; Giri et al., 2018), which clearly shows that the conversion of phosphorus in soil is a more complicated process. However, most of the previous studies have proved that fertilization not only increases the content of TP, organic phosphorus and inorganic phosphorus in soil, but it also affects the composition, distribution and transformation of inorganic and organic phosphorus in soil. However, when Olsen-P containing fertilizer is applied with organic fertilizers, the effect is more pronounced (Darilek et al., 2010; Vu et al., 2008). Yan et al. (2016) reported that the effect of nitrogen Olsen-P application on soil phosphorus conversion is related to the soil phosphorus status, and such application promotes the mineralization of organic phosphorus in soil with low Olsen-P content, but in soil with high Olsen-P content, the addition might reduce organic phosphorus mineralization. Zhu and Li (2018) showed that the amendment of chemical fertilizers and organic fertilizers significantly increased the Olsen-P in soil. Several previous studies have indicated that organic fertilizers have a good effect in improving the soil nutrient content and can increase the water-soluble phosphorus and Olsen-P content of soil tillage (Zhu and Li, 2018). In addition, Lou et al. (2018) reported that Olsen-P application of livestock manure can increase the soil organic matter and Olsen-P, as well as the TP content. In another study, Chan et al. (2011) observed that soil organic matter accumulation is closely related to the phosphorus use efficiency by plant. Liang et al. (2011) observed that both phosphate and organic fertilizers can increase the level of Olsen-P, and the combination of the two can significantly improve soil fertility (Wang and Lu, 2006; Turner et al., 2014; Giri et al., 2018). This may be mainly due to the presence of some metal ions such as Fe and Al or some organic chelates in the organic fertilizer, which increases the utilization of Ca_2–P and Ca_8–P in the soil. The increased inorganic Ca_2–P and Ca_8–P can then be easily absorbed and utilized by crops, which makes the crops grow better and absorb more Olsen-P from the soil (Rosa et al., 2019).

In summary, the effect of different soil surface mulching and fertilization on temporal trends of P fractions and their bioavailability to total P in soil were significantly comparable between different treatments and their layers. The results of the present study is in agreement with the findings of the temporal development of P fractions in soil during pedogenesis developed by Walker and Syers (1976), which was recently revisited by Turner and Condron (2013). In their conceptual view, labile P fractions derived from surface mulching and fertilization on phosphorus are increasingly transformed into organic and accumulated P fractions over the years. In this study, it was confirmed that such mineralization are visible at decadal time scales, especially at the 0–20 cm layer of soil. However, long-term research or chronosequence observation with the application of organic fertilizer and their comparison with mulching and full film coverage are necessary to prove the underlying mechanisms. "Space for time" studies at one site cannot replace long-term studies over decades. Nevertheless, temporal trends of transformation of labile to moderately labile/stable/Olsen-P fractions were more pronounced in the succession treatment with mulching and distinct fertilization. Therefore, mulching increased the bioavailable P fractions over time in upper surface of soil. The overall increasing trends in P availability in soil is in contrast to other studies where mulching or succession were associated with so called "auto eutrophication" (Dolezal et al., 2011; Moog et al., 2002; Römermann et al., 2009). The focus on nitrogen (N) transformation as part of the Ellenberg indicator values (Moog et al., 2002; Römermann et al., 2009) might serve as one of the best explanation. The N cycle is predominated by biological mineralization, whereas abiotic component also plays an important role in the P cycle. Therefore, the N cycle might respond more sensitively to different land coverage on mulching and fertilization on phosphorus transformation in upland farmland.

5. Conclusion

The contents of TP and Olsen-P in the 0–20 cm soil layer was significantly greater than those in the 20–40 cm soil layer at different growth stages. Olsen-P application of organic fertilizer could significantly enhance the content of TP and Olsen-P in the spring maize farmland under the mulching condition in the 0–20 cm soil layer. The three different land cover methods namely NM, GM and FM significantly affected the content of Olsen-P in both soil layers during the critical vegetation time of spring maize. During the growth period, the content of Ca_8–P in the 0–20 cm soil layer first increased and then attenuated, while the Fe–P content in both soil layers also increased. Surface covering treatment can significantly affect the transformation of inorganic phosphorus in different soil layers in upland farmland, and accelerate the increase of Ca_2–P content in the 0–20 cm soil layer treated by GM and FM, reaching maximum values during periods V10 and R1. The content of secondary phosphorus sources and potential phosphorus sources, such as Al–P, Ca_8–P and O–P, in the 20–40 cm soil layer during the key growth period of dry land spring maize increased to promote the absorption and utilization of phosphorus in the soil by crops. Phosphorus and inorganic nitrogen fertilizer increased the Ca_8–P, while it decreased the relative content of Ca_2–P to a certain extent. The results of path analysis showed that Ca_8–P had the maximum direct influence on the activity of basic phosphoric acid, and the direct influence of Ca_2–P and Al–P was positive under the indirect influence, indicating that the indirect influence on the activity of Al–P could not be ignored.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgment

The authors are thankful to the National Key Research and Development Program (2017YFD0201807), National Natural Science Foundation of China (41671307, 512779197), the Natural Science Basic Research Plan in Shaanxi Province of China (2017JM3011), and the Open Fund of the State Key Laboratory of Soil Erosion and Dry-land Farming on the loess plateau (A314021402-1605).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.109717.

References

Amador, J.A., Glucksman, A.M., Lyons, J.B., Gerres, J.H., 1997. Spatial distribution of soil phosphatase activity within a riparian forest. Soil Sci. 162, 808–825.
Annaheim, K., Doolette, A., Smernik, R., Mayer, J., Oberson, A., Frossard, E., Bünemann, E., 2015. Long-term addition of organic fertilizers has little effect on soil organic phosphorus as characterized by 31P NMR spectroscopy and enzyme additions. Geoderma 257–258, 67–77.
Bol, R., Julich, D., Brödlin, D., Siemens, J., Kaiser, K., Dippold, M.A., Spielvogel, S., Zilla, T., Mewes, D., von-Blanckenburg, F., 2016. Dissolved and colloidal phosphorus fluxes in forest ecosystems-an almost blind spot in ecosystem research. J. Plant Nutr. Soil Sci. 179, 425–438.
Bu, L.D., Liu, J.L., Zhu, L., Luo, S.S., Chen, X.P., Li, S.Q., Lee, H., Robert, Z.Y., 2013. The effects of mulching soil surface mulching on maize growth yield and water use in a semi-arid region. Agric. Water Manag. 123, 71–78.
Chan, K.Y., Conyers, M.K., Li, G.D., 2011. Soil carbon dynamics under different cropping and pasture management in temperate Australia: results of three long-term experiments. Soil Res. 49, 320–328.
Chen, H., 2003. Phosphatase activity and P fractions in soils of an 18-year-old Chinese fir (*Cunninghamiala nceolata*) plantation. For. Ecol. Manag. 178, 301–310.
Cheng, Y., Li, P., Li, Z., Gao, H., Zhao, B., Wang, T., Wang, F., Cheng, S., 2018. Effects of soil erosion and land use on spatial distribution of soil total phosphorus in a small watershed on the loess plateau, China. Soil Res. 184, 142–152.
Darilek, J.L., Huang, B., Li, D.C., 2010. Effect of land use conversion from rice paddies to vegetable fields on soil phosphorus fractions. Pedosphere 20, 137–145.
Du, F., Liang, Z., Xu, X., Zhang, X., Shan, L., 2008. Spatial heterogeneity of soil nutrients and aboveground biomass in abandoned old-fields of loess hilly region in Northern Shaanxi, China. Acta Ecol. Sin. 28, 13–22.
Dolezal, J., Maskova, Z., Leps, J., Steinbachova, D., de Bello, F., Klimesova, J., Tackenberg, O., Zemek, F., Kvet, J., 2011. Positive long-term effect of mulching on species and functional trait diversity in a nutrient-poor mountain meadow in Central Europe. Agric. Ecosyst. Environ. 145, 10–28.
Giri, S., Qiu, Z., Zhang, Z., 2018. Assessing the impacts of land use on downstream water quality using a hydrologically sensitive area concept. J. Environ. Manag. 213, 309–319.
Guo, S.L., Dang, T.H., Hao, M.D., 2008. Phosphorus changes and sorption characteristics in a calcareous soil under long-term fertilization. Pedosphere 18, 248–256.
Han, M.Y., Zhang, L.X., Fan, C.H., Liu, L.H., Zhang, L.S., Li, B.Z., Alva, A.K., 2011. Release of nitrogen, phosphorus, and potassium during the decomposition of Olsen-P apple (*Malusdomestica*) leaf litter under different fertilization regimes in loess plateau, China. Soil Sci. Plant Nutr. 57, 549–557.
Hao, X., Godlinski, F., Chang, C., 2008. Distribution of phosphorus forms in soil following long-term continuous and discontinuous cattle manure Olsen-applications. Soil Sci. Soc. Am. J. 72, 90–97.
John, E.A., 1966. Influence of mulches on runoff, erosion, and soil moisture depletion. Proc. Soil Sci. Soc. Am. 1, 110–114.
Keller, M., Oberson, A., Annaheim, K.E., Tamburini, F., Mäder, P., Mayer, J., Frossard, E., Bünemann, E.K., 2012. Phosphorus forms and enzymatic hydrolyzability of organic phosphorus in soils after 30 years of organic and conventional farming. J. Plant Nutr. Soil Sci. 175, 385–393.
Kuo, S., 1996. Phosphorus. In: Sparks, D.L. (Ed.), Methods of Soil Analysis: Chemical Methods. Part 3. Soil Science Society of America, Madison, WI, pp. 869–919.
Lang, F., Bauhus, J., Frossard, E., George, E., Kaiser, K., Kaupenjohann, M., Krüger, J., Matzner, E., Polle, A., Prietzel, J., 2016. Phosphorus in forest ecosystems: new insights from an ecosystem nutrition perspective. J. Plant Nutr. Soil Sci. 179, 129–135.
Leytem, A.B., Mikkelsen, R.L., 2005. The nature of phosphorus in calcareous soils. Better Crops 89 (2), 11–13.
Liang, B., Yang, X., He, X., 2012. Long-term combined Olsen-P application of manure and NPK fertilizers influenced nitrogen retention and stabilization of organic C in loess soil. Plant Soil 353, 249–260.
Liang, B., Yang, X.Y., He, X.H., 2011. Effects of 17-year fertilization on soil microbial biomass C and N and soluble organic C and N in loess soil during maize growth. Biol. Fertil. Soils 47, 121–128.
Liu, S., Li, F.C., 2010. Soil water dynamics and water use efficiency in spring maize (*Zea mays* L.) fields subjected to different water management practices on the loess plateau, China. Agric. Water Manag. 97, 769–775.
Lou, H., Zhao, C., Yang, S., Shi, L., Wang, Y., Ren, X., Bai, J., 2018. Quantitative evaluation of legacy phosphorus and its spatial distribution. J. Environ. Manag. 211, 296–305.
Malik, M.A., Marschner, P., Khan, K.S., 2012. Addition of organic and inorganic P sources to soil. Effects on P pools and microorganisms. Soil Biol. Biochem. 49, 106–113.
Merino, A., Jiménez, E., Fernández, C., Fontúrbel, M.T., Campo, J., Vega, J.A., 2019. Soil organic matter and phosphorus dynamics after low intensity prescribed burning in forests and shrub land. J. Environ. Manag. 234, 214–225.
Moog, D., Poschlod, P., Kahmen, S., Schreiber, K.F., 2002. Comparison of species composition between different grassland management treatments after 25 years. Appl. Veg. Sci. 5, 99–106.
Peters, K., Jensen, L.S., Hjorth, M., Magid, J., 2011. Carbon, nitrogen and phosphorus distribution in particle-size fractionated pig and cattle slurry. J. Environ. Qual. 40, 224–232.
Pierzynski, G.M., McDowell, R.W., Sims, J.T., Sharpley, A.N., 2005. In: Sims, J.T., Sharply, A.N., Pierzynski, G.M., Westermann, D.T., Cabrera, M.L., Powell, J.M., Daniel, T.C., Withers, P.J.A. (Eds.), Chemistry, Cycling, and Potential Movement of Inorganic Phosphorus in Soils. Phosphorus: Agriculture and the Environment. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, pp. 53–86.
Prietzel, J., Klysubun, W., Werner, F., 2016. Speciation of phosphorus in temperate zone forest soils as assessed by combined wet-chemical fractionation and XANES spectroscopy. J. Plant Nutr. Soil Sci. 179, 168–185.
Romanyà, J., Rovira, P., 2009. Organic and inorganic P reserves in rain-fed and irrigated calcareous soils under long-term organic and conventional agriculture. Geoderma 151, 378–386.
Rosa, J.M.D., Jiménez-Morillo, N.T., González-Pérez, J.A., Almendros, G., Vieira, D., Knickera, H.E., Keizer, J., 2019. Mulching-induced preservation of soil organic matter quality in a burnt eucalypt plantation in central Portugal. J. Environ. Manag. 231, 1135–1144.
Römermann, C., Bernhardt-Römermann, M., Kleyer, M., Poschlod, P., 2009. Substitutes for grazing in semi-natural grasslands – do mowing or mulching represent valuable alternatives to maintain vegetation structure? J. Veg. Sci. 20, 1086–1098.
Saha, S., Mina, B.L., Gopinath, K.A., 2008. Relative changes in phosphatase activities as influenced by source and Olsen-P application rate of organic composts in field crops. Bioresour. Technol. 99, 1750–1757.
Sakurai, M., Wasaki, J., Tomizawa, Y., Shinano, T., Osaki, M., 2008. Analysis of bacterial communities on alkaline phosphatase genes in soil supplied with organic matter. Soil Sci. Plant Nutr. 54, 62–71.
Sato, S., Solomon, D., Hyland, C., Ketterings, Q.M., Lehmann, J., 2005. Phosphorus speciation in manure and manure-amended soils using XANES spectroscopy. Environ. Sci. Technol. 39, 7485–7491.
Turner, B.L., Wells, A., Condron, L.M., 2014. Soil organic phosphorus transformations along a coastal dune chronosequence under New Zealand temperate rain forest. Biogeochemistry 121, 595–611.
Turner, B.L., Condron, L.M., 2013. Pedogenesis, nutrient dynamics, and ecosystem development: the legacy of TW Walker and JK Syers. Plant Soil 367, 1–10.
Turrión, M.-B., Bueis, T., Lafuente, F., López, O., José, S.E., Eleftheriadis, A., Mulas, R., 2018. Effects on soil phosphorus dynamics of municipal solid waste compost addition to a burnt and unburnt forest soil. Sci. Total Environ. 642, 374–382.
Vu, D.T., Tang, C., Arm, S.R.D., 2008. Changes and availability of P fraction s following 65 years of P Olsen-P application to a calcareous soil in a Mediterranean climate. Plant Soil 304, 21–33.

Wang, L., Ameluang, W., Prietzel, J., Willbold, S., 2019. Transformation of organic phosphorus compounds during 1500 years of organic soil formation in *Bavarian alpine* forests – a 31P NMR study. Geoderma 340, 192–205.

Walker, T.W., Syers, J.K., 1976. Fate of phosphorus during pedogenesis. Geoderma 15, 1–19.

Wang, X.C., Lu, Q., 2006. Beta-glucosidase activity in paddy soils of the Taihulake region, China. Pedosphere 16, 118–124.

Xue, Q.Y., Shamsi, I.H., Sun, D.S., Ostermann, A., Zhang, Q.C., Zhang, Y.S., Lin, X.Y., 2013. Impact of manure Olsen-P application on forms and quantities of phosphorus in a Chinese Cambisol under different land use. J. Soils Sediments 13, 837–845.

Yan, Z., Chen, S., Dari, B., Sihi, D., Chen, Q., 2018. Phosphorus transformation response to soil properties changes induced by manure Olsen-P application in a calcareous soil. Geoderma 322, 163–171.

Yan, Z., Chen, S., Li, J., Alva, A., Chen, Q., 2016. Manure and nitrogen Olsen-P application enhances soil phosphorus mobility in calcareous soil in greenhouses. J. Environ. Manag. 181, 26–35.

Yang, L., Li, T., Li, F., Lemcoff, J.H., 2010. Long-term fertilization effect on fraction and distribution of soil phosphorus in a plastic-film house in China. Commun. Soil Sci. Plant Anal. 42, 1–12.

Zamuner, E.C., Picone, L.I., Echeverria, H.E., 2008. Organic and inorganic phosphorus in Mollisol soil under different tillage practices. Soil Res. 99, 131–138.

Zhang, A., Chen, Z., Zhang, G., 2012. Soil phosphorus composition determined by 31P NMR spectroscopy and relative phosphatase activities influenced by land use. Eur. J. Soil Biol. 52, 73–77.

Zhao, B.Z., Chen, J., 2013. How different long-term fertilization strategies influence crop yield and soil properties in a maize field in the North China Plain. Soil Sci. Plant Nutr. 176, 99–109.

Zhu, J., Li, M., 2018. Phosphorus activators contribute to legacy phosphorus availability in agricultural soils: a review. Sci. Total Environ. 612, 522–537.

Zhan, A., Lynch, J.P., 2015. Reduced frequency of lateral root branching improves N capture from low N soils in maize. J. Exp. Bot. 66, 2055–2065.