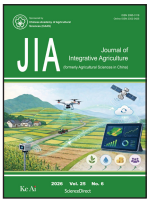
Journal of Integrative Agriculture 2026, 25(6): 2556–2568

Available online at ScienceDirect

KeAi CHINESE ROOTS GLOBAL IMPACT

Journal of Integrative Agriculture



RESEARCH ARTICLE

Alleviating negative home plant–soil feedback in vegetables through phosphorus management

Zitian Pu[1, 2*], Ruifang Zhang[2, 3*], Chi Zhang[2, 3], Hong Wang[2, 3], Xinxin Wang[1, 4#]

[1] *State Key Laboratory of North China Crop Improvement and Regulation, Hebei Agricultural University, Baoding 071001, China*
[2] *College of Resources and Environment, Hebei Agricultural University, Baoding 071001, China*
[3] *College of Land and Resources, Hebei Agricultural University, Baoding 071001, China*
[4] *College of Horticulture, Hebei Agricultural University, Baoding 071001, China*

Highlights

- Low-P soil conditions intensified the negative feedback effects in vegetables.
- High-P application mitigated the negative feedback effects in vegetables.
- Home-PSFs of wild tomatoes exhibited greater sensitivity to soil P levels compared to common tomatoes.

Abstract

Home plant–soil feedbacks (home-PSFs) typically demonstrate negative effects in vegetable crops, substantially inhibiting their growth. Phosphorus (P), an essential plant nutrient crucial for growth, influences vegetable crop growth patterns through soil availability levels. However, the relationship between soil available P levels and home-PSFs in vegetable crops requires further investigation. This study established a home PSF system incorporating 12 vegetable crops from 6 families to examine growth responses under two P conditions (low P level: 40 mg P kg^{-1} soil; high P level: 200 mg P kg^{-1} soil). The findings revealed that low P conditions significantly decreased overall biomass across all vegetables, with preferential biomass allocation to root development. Furthermore, low P conditions enhanced mycorrhizal colonization and rhizosphere acid phosphatase activity while notably decreasing root length. While vegetables generally exhibited negative home PSFs, allium and nonmycorrhizal plants demonstrated positive responses under high P conditions. Wild tomatoes displayed greater variation in feedback values across P levels compared to common tomatoes. Under high-P conditions, mycorrhizal colonization showed positive correlations with feedback values of biomass and P concentration. Root diameter and mycorrhizal colonization demonstrated distinct correlations with these feedback values under low-P conditions. The research concludes that high P levels effectively mitigate negative home-PSFs in vegetables while increasing biomass production. Additionally, high P levels demonstrated superior efficacy in alleviating negative home-PSFs in wild tomatoes compared to common tomatoes.

Keywords: home plant–soil feedback, phosphorus levels, negative feedback, growth strategy, vegetable

1. Introduction

The interaction between plants and soil operates as a feedback mechanism, where plant–soil interactions are mediated by the plant–soil feedback (PSF) process (Wang *et al.* 2025). PSFs describe how plants modify the biological and abiotic properties of soil, subsequently influencing the growth of the same or different plant species (Abiem and Chapman 2025). This mechanism influences the growth and productivity of subsequent plant species (Dias *et al.* 2015). Plants alter soil characteristics through root exudates and plant residues, generating various feedback effects on subsequent vegetation (Yacine *et al.* 2024). These PSFs play essential roles in multiple ecological processes, including vegetation succession, plant invasion, and biodiversity maintenance. PSFs may be neutral, positive, or negative (van der Putten *et al.* 2013; Teste *et al.* 2017). Negative PSFs

Received 9 April 2025; Received in revised form 21 July 2025; Accepted 11 August 2025; Available online 4 September 2025
[#]Correspondence Xinxin Wang, E-mail: xinxinwang.wur@qq.com
[*] These authors contributed equally to this study.

© 2026 CAAS. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/). Peer review under responsibility of Editorial Board of *Journal of Integrative Agriculture*.
doi: 10.1016/j.jia.2025.09.003

can arise from factors including nutrient depletion, soil-borne pathogen accumulation, beneficial microbe reduction, and soil chemistry modifications (Bennett and Klironomos 2019; Schandry and Becker 2020).

Agricultural management practices, encompassing cropping system selection, plant species choice, and soil management techniques with their associated soil legacies, substantially affect soil's physical, chemical, and biological properties, including microbial community composition. These alterations can produce distinct feedback effects on subsequent crop growth and yield (Dias *et al.* 2015). In agriculture, polycultures have historically served to mitigate the negative effects of monocultures and enhance beneficial interspecific interactions (Stagnari *et al.* 2017). However, conventional agronomic practices may generate adverse PSFs within agroecosystems *via* ecological and evolutionary mechanisms (Barber *et al.* 2013). In agricultural systems, home PSFs describe how plants modify soil's biological and abiotic properties, affecting the growth of identical crop species (Veen *et al.* 2018; Kural-Rendon *et al.* 2025). Negative feedback is particularly evident in home PSFs characterized by continuous cropping (Kural-Rendon *et al.* 2025). This practice affects soil quality, subsequently impacting plant growth. Continuous cultivation often produces detrimental effects within the PSF system, impeding sustained cultivation and crop development. These issues stem from interactions among environmental conditions, soil quality, crops, and associated microorganisms (Guo *et al.* 2018; Zhang *et al.* 2019). PSFs frequently depend on environmental context (Smith-Ramesh *et al.* 2017). Studies indicate that extended stationary fertilization has negatively affected sweet potato soil health, increasing soil-borne diseases and allelochemical accumulation (Zhu *et al.* 2024).

Phosphorus (P) represents an essential nutrient required by plants in substantial quantities. Soil phosphorus levels significantly influence plant physiological and biochemical processes, affecting growth strategies (Lambers *et al.* 2008; Shen *et al.* 2011; Lopez-Arredondo *et al.* 2014; Pu *et al.* 2023). Typical root morphology adaptations include increased specific root length and fine root length ratio. These modifications enable the root system to explore larger soil volumes, enhancing water and nutrient absorption efficiency (Postma *et al.* 2014; Haling *et al.* 2018). Plants acquire P through the secretion of organic acid anions, phosphatases, and protons — collectively termed P-activated exudates. These compounds enhance both inorganic and organic phosphorus solubility within the rhizosphere, improving nutrient uptake (Richardson *et al.* 2011; Pang *et al.* 2018). However, the mechanism by which P affects plant–soil feedbacks remains unclear. Fertilizer applications influence soil microorganism function and diversity (de Vries *et al.* 2017), potentially representing a pathway through which P influences these feedback mechanisms.

Low P stress can enhance and accelerate the formation of symbiotic relationships between plant roots and arbuscular mycorrhizal fungi (AMF), thereby increasing phosphorus uptake in most plant species. AMF establish mycelial networks that can access inorganic phosphorus beyond the root depletion zone, thus enhancing nutrient availability for plants (Smith *et al.* 2011; van der Heijden *et al.* 2015). Consequently, AMF likely influence plant–soil feedbacks during succession, with many late successional species exhibiting strong positive growth responses to AMF (Middleton and Bever 2012; Koziol and Bever 2015; Bauer *et al.* 2018). Substantial evidence indicates that AMF composition shifts during succession (Oehl *et al.* 2010; Schnoor *et al.* 2011; House and Bever 2018), and field inoculation with late successional fungi can accelerate plant succession (Middleton *et al.* 2015; Koziol and Bever 2017). AMF can ameliorate the negative home feedback of legumes (Minas *et al.* 2024). Furthermore, the long-term influence of AMF on plant communities is driven by positive plant–AMF feedback dynamics across successional stages (Koziol and Bever 2019).

PSF direction and magnitude are typically species- and variety-specific (Cadot *et al.* 2021; Awodele and Bennett 2022). This variation may stem primarily from reduced crop genetic diversity, resulting in differences in rhizosphere microorganism diversity, root structure, and root exudates of domesticated crops (Schmidt *et al.* 2016; Iannucci *et al.* 2017). Domesticated tomato plants demonstrate greater susceptibility to negative soil feedback compared to their wild counterparts (Carrillo *et al.* 2019). Limited genetic diversity in crops may influence the type, strength, or diversity of below-ground interactions (Perez-Jaramillo *et al.* 2016). Moreover, substantial differences exist in root architecture (Schmidt *et al.* 2016) and root exudates (Iannucci *et al.* 2017) between cultivated crops and their wild relatives. However, the effects of P-mediated feedback during tomato domestication and the interactions between wild tomatoes and soil remain unclear.

This study established a home PSF system incorporating 12 vegetable crops from six families to monitor growth changes at two P levels (low P level: 40 mg P kg^{-1} soil; high P level: 200 mg P kg^{-1} soil). The methodology addresses categorical distinctions among vegetable crops and enhances understanding of intraspecific genetic variation in plant–soil feedbacks, typically examined at the species level (Bukowski *et al.* 2014; Wagg *et al.* 2015; Allen *et al.* 2018). Additionally, by quantifying negative feedbacks within vegetable crops relative to soil, this research aims to mechanistically link compositional changes in soil P levels with functional alterations in plant growth, offering important agricultural implications for continuous vegetable cropping.

2. Materials and methods

2.1. Experimental design

The conditioning phase experiment utilized a randomized complete block design with two factors (Pu *et al.* 2023): (1) vegetable species: 12 vegetable species (detailed information provided in Appendix A), and (2) P supplies: 40 and 200 mg P kg^{-1} soil.

The home-PSF experiment examined two main factors: (1) home PSFs using 12 vegetable crops with their respective home soil feedback systems and (2) P supply levels (as KH_2PO_4), specifically 40 and 200 mg kg^{-1} (Fig. 1).

To minimize accumulation effects from plant residues during the adjustment phase and variations in nutrient uptake from soil nutrients, vegetable crops were cultivated and harvested



Fig. 1 Experimental design for evaluating home-field feedback effects across 12 vegetable species.

in a controlled environment. Sterilized soil was added at a 1:1 ratio for every 5 replicates, effectively increasing the total replicates to 10 (Pu *et al.* 2023). The feedback phase implemented a randomized complete factorial block design with five replicates, totaling 240 pots. Pots were systematically rerandomized weekly to maintain experimental integrity.

2.2. Soil and vegetable species for the experiment

The low-P soil, which had been fallow for two years, was collected from Sungezhuang Village, Dying Town, Xiongxian County, Baoding City, Hebei Province, China (116°09′E, 39°05′N). The soil exhibited the following properties: pH 7.38 (clay to water ratio of 1:2.5); total nitrogen (N), 1.32 g kg^{-1}; available P, 2.29 g kg^{-1}; available potassium (K), 123 g kg^{-1}; and organic matter, 13.6 g kg^{-1}. The soil was sieved, thoroughly mixed, and placed in plastic flowerpots (1.5 kg of mixed soil per pot) with dimensions of 15 cm height, 20 cm top diameter, and 12 cm bottom diameter.

The low-P soil was contained in nylon bags and sterilized using $^{60}Co\gamma$ (Hebei Nuclear Force Tongfang Radiation Technology Co., Ltd., China), with an irradiation dose of 10 kGy 60Coγ-ray.

The study included 12 vegetable species (identical to those used in the conditioning phase experiment), comprising 9 species with AMF symbiotic relationships: allium (*Allium fistulosum* L., Lillaceae), cucumber (*Cucumis sativus* L., Cucurbitaceae), watermelon (*Citrullus lanatus*, Cucurbitaceae), lettuce (*Lactuca sativa* Linn., Compositae), chrysanthemum (*Chrysanthemum coronarium* L., Compositae), pepper (*Capsicum annuum*, Solanaceae), eggplant (*Solanum melongena* L., Solanaceae), and common and wild tomato (*Lycopersicon esculentum*, Solanaceae). Additionally, three non-AM (NM) species were selected: spinach (*Spinacia oleracea* L., Chenopodiaceae), sugar beet (*Beta vulgaris* L., Chenopodiaceae), and rape (*Brassica chinensis* Linn., Brassicaceae). These NM species were chosen for their agronomic importance and distinct P acquisition strategies compared to AM species. The study implemented two P levels using KH_2PO_4: low-P level (LP) at 40 mg kg^{-1} soil and high-P level (HP) at 200 mg kg^{-1} soil. The soil was enriched with nutrients at specific rates (mg kg^{-1}): N 100, K 327, Ca 46, Mg 4.2, Fe 0.88, Na 0.36, Mn 1.8, Zn 2.5, and Cu 0.57, supplied as $(NH_4)_2SO_4$, K_2SO_4 and KH_2PO_4, $CaCl_2$, $MgSO_4$ $7H_2O$, EDTA Fe-Na, EDTA Fe-Na, $MnSO_4$ H_2O, $ZnSO_4$ $7H_2O$, and $CuSO_4$ $5H_2O$, respectively. K_2SO_4 was added according to Appendix B to maintain uniform K concentration across treatments containing 40 mg kg^{-1}. Non-P nutrients were adjusted to ensure P remained the sole variable. Native soil AMF were permitted to colonize crop root systems without additional inoculum introduction.

2.3. Plant growth conditions

The experiment was conducted in a controlled light culture chamber at Hebei Agricultural University's west campus in Baoding, Hebei Province (39°04′N, 116°09′E). Initially, three to six uniformly sized seedlings were planted per pot, later thinned to one plant per pot. Soil moisture was maintained at (60±10)% field capacity through regular weighing. The cultivation period extended from October 8, 2020, to December 8, 2020, encompassing 60 days.

2.4. Harvest and measurements

During harvest, the shoot was separated from the root system using scissors. The fresh shoot biomass was measured and

stored in envelopes. Samples underwent oven drying at 105°C for 30 min followed by 72°C for 48 h. After drying, the shoot biomass was measured. The shoot P concentration was determined using the standard vanado–molybdate method after digesting samples in a H_2SO_4-H_2O_2 mixture at 360°C for 2 h (Bao 2000).

The rhizosphere soil remained attached to the roots. The rhizosphere soil pH (1:2.5, soil:water) was measured using a pH meter (Shanghai REX Instrument Factory, China). After sampling the rhizosphere soil, all visible roots were carefully excised from each pot. The root samples were cleaned with deionized water. The cleaned root samples were arranged in a transparent array of 30 cm×20 cm×3 cm and scanned at 400 dots per inch resolution using an EPSON scanner (Epson Expression 1600 pro, Seiko Epson Corporation, Model EU-35, Japan). Root traits were analyzed using WinRHIZO Pro software (Regent Instruments Inc., Quebec, Canada). Following scanning, the root samples were oven-dried at 70°C for three days to determine root biomass. These data were used to calculate the root-to-shoot biomass ratio. Rhizosphere acid phosphatase activity was quantified using p-nitrophenyl phosphate (p-NPP) (Alvey *et al.* 2001). The p-NPP concentration in the supernatant was measured spectrophotometrically at 405 nm.

Root samples were treated with 10% (w/v) KOH solution and incubated in a 90°C water bath. Following this, the samples were treated with 2% (v/v) HCl solution at room temperature for transparency. The samples were stained with 0.05% (w/v) nonvital Trypan blue solution in a 90°C water bath. After staining, root fragments were immersed in a lactic acid-glycerol-water mixture (v/v/v, 1:1:1) overnight to remove excess stain. Each sample, approximately 1 cm in length, was mounted on two slides for light microscope examination. Mycorrhizal colonization by AMF was assessed following the methodology of Trouvelot *et al.* (1986).

2.5. Statistical analysis

To evaluate the responses of plant traits across 12 vegetable species to different P levels, two-way analysis of variance (ANOVA) was conducted using a randomized block design. The analysis examined the effects of P levels and PSF as main factors, and their interaction, on plant traits. Significant differences among means were determined using the Tukey test at $P<0.05$. A multiple regression model examined relationships between root diameter or mycorrhizal colonization and feedback value. Principal component analysis (PCA) and Spearman's correlation analysis investigated relationships between plant traits and feedback values among the thirteen vegetable species. Statistical analyses were performed using SPSS 26.0 software (IBM Corp., Armonk, NY, USA), and graphs were generated using Origin 2025a (OriginLab, Northampton, MA, USA).

A structural equation model was developed to examine relationships among plant root and shoot traits, mycorrhizal colonization, rhizosphere soil pH, and feedback under different P levels. The structural equation model diagrams were created using Amos 26.0 software from IBM Corporation, Armonk, New York, USA.

We calculated the feedback coefficient for measured parameters using the following equation (Wang *et al.* 2019):

Plant–soil feedback value=ln(Biomass or shoot P content or mycorrhizal colonization in home soil I/Biomass or shoot P content or mycorrhizal colonization in home soil II).

3. Results

3.1. Species-specific trait responses to phosphorus concentrations

Two-way ANOVA revealed a significant effect of vegetable species and P level on biomass (shoot and root), P concentration (shoot and root), and the root:shoot ratio (Table 1). The biomass (of both shoots and roots) of most vegetables demonstrated distinct responses to changes in P levels (Fig. 2-A and B). The reduction in shoot biomass ranged from 85.19% in watermelon to 99.10% in lettuce, indicating these species' sensitivity to phosphorus deficiency. The decline in root biomass varied, with reductions

Table 1 Results of two-way ANOVA for traits among 12 vegetables species and two soil phosphorus (P) treatments

Traits[1)]	Species			P treatment			Species×P treatment		
	df	*F*-value	*P*-value	*df*	*F*-value	*P*-value	*df*	*F*-value	*P*-value
ShB	11	132.46	<0.001	1	1,145.66	<0.001	11	93.98	<0.001
RB	11	194.44	<0.001	1	436.13	<0.001	11	79.77	<0.001
ShP	11	2,704.53	<0.001	1	465.30	<0.001	11	1,363.06	<0.001
RP	11	40.52	<0.001	1	35.07	<0.001	11	54.33	<0.001
RL	11	128.91	<0.001	1	68.27	<0.001	11	198.86	<0.001
RD	11	60.20	<0.001	1	354.88	<0.001	11	47.65	<0.001
RSR	11	46.38	<0.001	1	141.09	<0.001	11	120.36	<0.001
RSP	11	1,709.76	<0.001	1	5,901.51	<0.001	11	192.68	<0.001
A-Pase	11	223.28	<0.001	1	34.20	<0.001	11	4.96	<0.001
pH	11	21.26	<0.001	1	912.83	<0.001	11	67.21	<0.001
MC	8	216.65	<0.001	1	798.52	<0.001	8	312.60	<0.001
PSF (ShB)	11	1,676.58	<0.001	1	6,467.64	<0.001	11	734.58	<0.001
PSF (ShP)	11	132.46	<0.001	1	1,145.66	<0.001	11	93.98	<0.001
PSF (MC)	8	194.44	<0.001	1	436.13	<0.001	8	79.77	<0.001

[1)] ShB, shoot biomass; RB, root biomass; ShP, shoot P concentration; RP, root P concentration; RL, root length; RD, average diameter of roots; RSR, root:shoot ratio; RSP, root P content:shoot P content ratio; A-Pase, acid phosphatase activity in the rhizosheath; pH, rhizosphere soil pH; MC, mycorrhizal colonization (no non-mycorrhizal plants, n=9); PSF (ShB, ShP, MC), feedback value of shoot biomass, shoot P concentration and mycorrhizal colonization (no non-mycorrhizal plants, n=9).

between 55.61% in pepper and 80.65% in chrysanthemum. Notably, cucumber exhibited an exceptional response by significantly increasing its root biomass by 55.58% under low P levels. Under different home-PSFs, shoot and root P concentrations showed distinct responses under high and low P levels (Fig. 2-C and D). Under low P levels, a substantial reduction in shoot P concentration occurred in allium and three nonmycorrhizal plants. In contrast, watermelon and the two other Compositae vegetables demonstrated significantly increased shoot P concentration under the

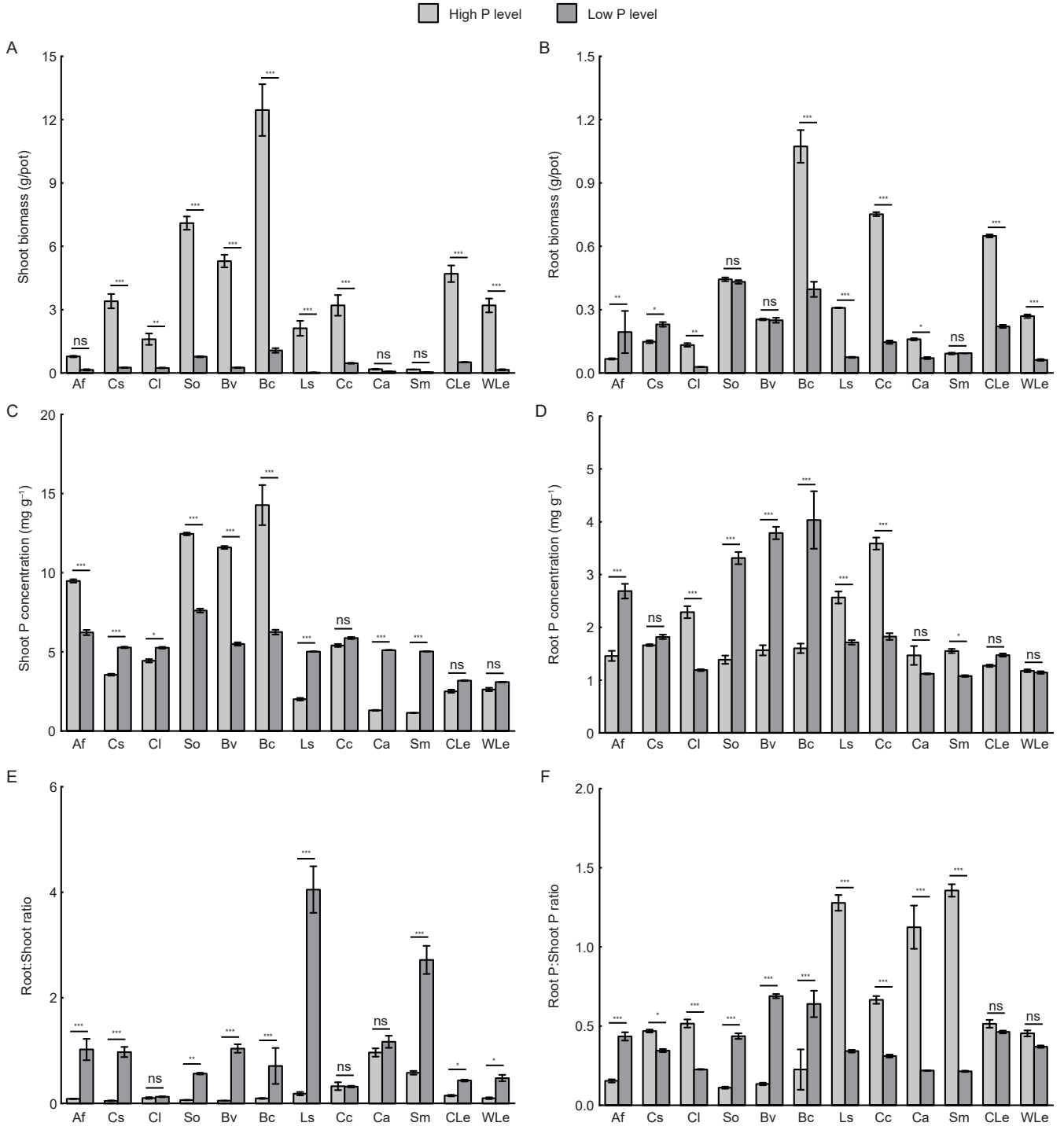


Fig. 2 Variations in biomass (A and B), P concentration (C and D), root:shoot ratio (E) and root P:shoot P content (F) as influenced by phosphorus levels (40 and 200 mg kg^{-1} soil). Af, allium (*Allium fistulosum* L.); Cs, cucumber (*Cucumis sativus* L.); Cl, watermelon (*Citrullus lanatus*); So, spinach (*Spinacia oleracea* L.); Bv, sugar beet (*Beta vulgaris* L.); Bc, rape (*Brassica chinensis* Linn.); Ls, lettuce (*Lactuca sativa* Linn.); Cc, chrysanthemum (*Chrysanthemum coronarium* L.); Ca, pepper (*Capsicum annuum*); Sm, eggplant (*Solanum melongena* L.); CLe, common tomato (*Lycopersicon esculentum*); WLe, wild tomato. Independent-samples *t*-test analyses examining the effects of phosphorus levels within each variety are indicated by asterisks above the bars. Error bars represent SE (n=10). *, P<0.05; **, P<0.01; ***, P<0.001; ns, no significant difference.

same low-P conditions. Regarding root P concentration, low P levels resulted in a substantial increase in allium and three nonmycorrhizal plants, while the root P concentration decreased significantly in watermelon and Compositae plants. Furthermore, cucumber and three Solanaceae vegetables showed significant increases in shoot P concentration, while root P concentration remained relatively stable under low P levels. In the home PSFs, vegetable biomass tended to accumulate more in the roots. However, P content in nonmycorrhizal vegetables and allium specifically accumulated in the roots under high P levels (Fig. 2-E and F).

3.2. Root morphological changes linked to mycorrhizal colonization

Low soil P availability caused a significant reduction in root length among the vegetables studied (Fig. 3-A). The magnitude of root length reduction varied, with decreases ranging from 47.60% in allium to 88.81% in watermelon. Notably, cucumber demonstrated an exceptional response, with a substantial increase in root length of 128.92% under low-P conditions. Root diameter responded differently among vegetable species, depending on the home-PSFs

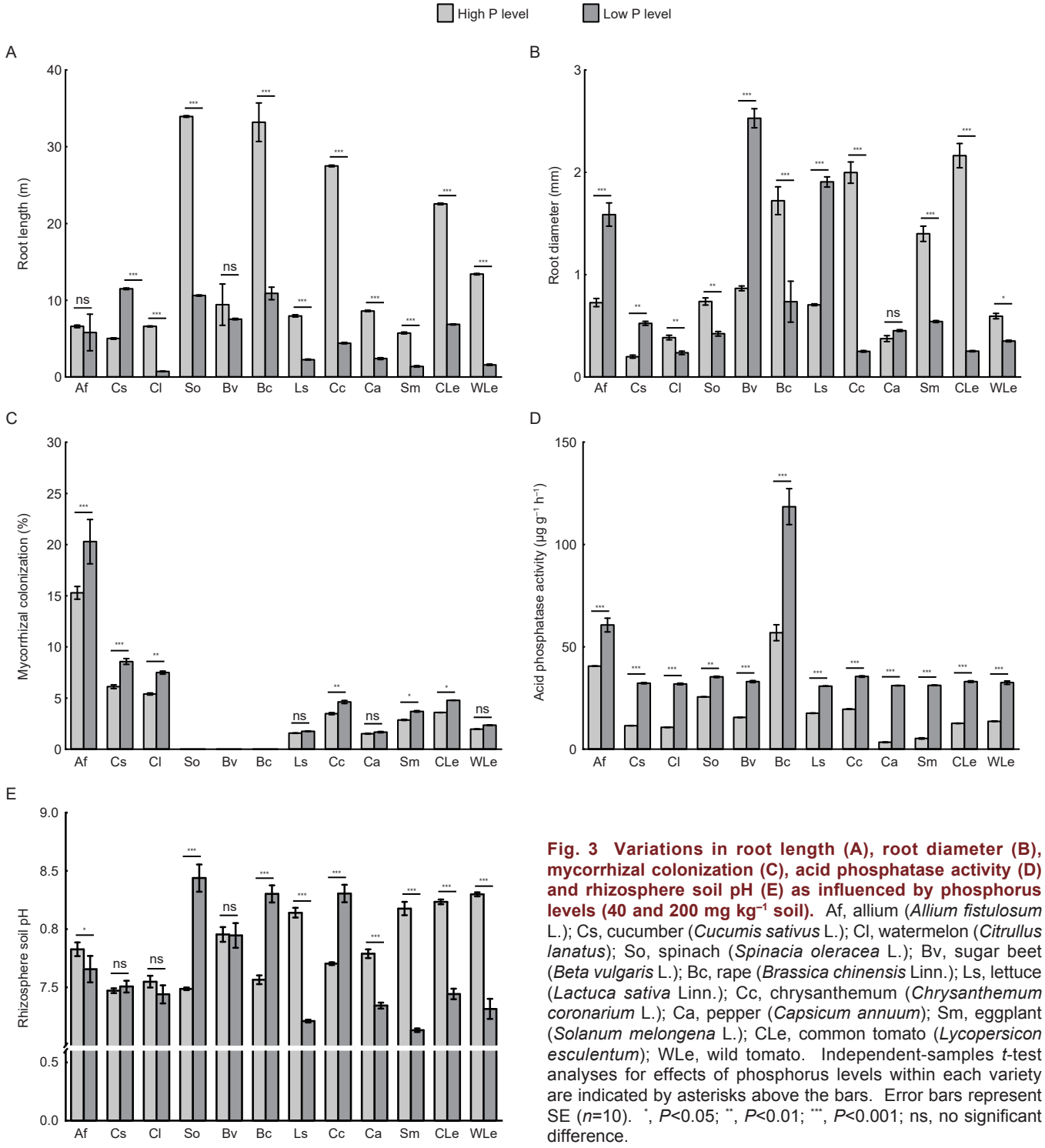


Fig. 3 Variations in root length (A), root diameter (B), mycorrhizal colonization (C), acid phosphatase activity (D) and rhizosphere soil pH (E) as influenced by phosphorus levels (40 and 200 mg kg^{-1} soil). Af, allium (*Allium fistulosum* L.); Cs, cucumber (*Cucumis sativus* L.); Cl, watermelon (*Citrullus lanatus*); So, spinach (*Spinacia oleracea* L.); Bv, sugar beet (*Beta vulgaris* L.); Bc, rape (*Brassica chinensis* Linn.); Ls, lettuce (*Lactuca sativa* Linn.); Cc, chrysanthemum (*Chrysanthemum coronarium* L.); Ca, pepper (*Capsicum annuum*); Sm, eggplant (*Solanum melongena* L.); CLe, common tomato (*Lycopersicon esculentum*); WLe, wild tomato. Independent-samples *t*-test analyses for effects of phosphorus levels within each variety are indicated by asterisks above the bars. Error bars represent SE (n=10). *, P<0.05; **, P<0.01; ***, P<0.001; ns, no significant difference.

under low P levels (Fig. 3-A). Allium, cucumber, beet and lettuce exhibited significant increases in root diameter, whereas spinach, rape, chrysanthemum, and tomato showed significant reductions in root diameter (Fig. 3-B). Under different home-PSFs, low soil P availability significantly enhanced mycorrhizal colonization across most vegetable crops (Fig. 3-C). Specifically, mycorrhizal colonization increased in response to low P levels, ranging from 29.14% in eggplant to 46.09% in allium. Moreover, low soil P availability significantly enhanced A-Pase activity (Fig. 3-D). Under low-P conditions, A-Pase activity varied considerably among vegetable species. For example, rape exhibited the highest A-Pase activity at 127.26 μg g^{-1} h^{-1}, whereas lettuce showed the lowest A-Pase activity at 30.79 μg g^{-1} h^{-1}. Allium, lettuce and 4 Solanaceae crops significantly increased the rhizosphere soil pH, while spinach, rape and chrysanthemum significantly reduced the rhizosphere soil pH at high P levels (Fig. 3-E). These findings demonstrate the complex interactions among nutrient availability, mycorrhizal colonization, and root morphology in various vegetable species.

3.3. Feedback coefficients of vegetable species on plant–soil feedbacks

Feedback coefficients were calculated to evaluate the differential contributions of various vegetable species to the PSF mechanism. The feedback values were determined for shoot biomass, shoot P concentration and mycorrhizal colonization (Fig. 4-A and C). Among the home PSFs of vegetables, most species exhibited negative feedback regarding shoot biomass. However, under high P levels, alliums and three nonmycorrhizal plants demonstrated positive feedback in terms of shoot biomass (Fig. 4-A). The shoot P concentrations of the vegetables displayed various feedback directions. Specifically, under high-P conditions, three nonmycorrhizal vegetables and allium showed positive feedback regarding shoot P concentration. Conversely, at low P levels, eggplant, peppers, and two Compositae vegetables demonstrated positive feedback. Nevertheless, most plants exhibited negative feedback, with high P levels intensifying the negative feedback effect on shoot P concentrations (Fig. 4-B). Additionally, the feedback values for mycorrhizal colonization were significantly higher at low P levels than at high P levels. Notably, low P availability induced stronger negative PSFs for vegetables, while high P levels significantly reduced negative feedback (Fig. 4-C).

The analysis revealed that at low P levels, the feedback values for biomass and mycorrhizal colonization of wild tomatoes were lower than those of common tomatoes. However, at high P levels, no significant difference was observed in the three feedback values between wild and common tomatoes. Consequently, under different P levels, the feedback values of wild tomatoes showed a greater range of variation than those of common tomatoes (Fig. 4-A–C).

3.4. Relationships among plant traits and feedback value

To investigate the influence of vegetable biomass, P concentration, root morphological traits, and rhizosphere A-Pase activity on home PSF values under different P levels, specific indicators were selected for analysis. Principal component analysis (PCA) was conducted on these indicators. At high P levels, principal component 1 (PC 1) accounted for 46.22% of variance, while PC 2 accounted for 19.63%. These two axes demonstrated significant variation in the data (Fig. 5-A). Under low P levels, PC 1 contributed 51.90% of variance, whereas PC 2 contributed 16.85% (Fig. 5-B). At high P levels, three feedback values showed positive correlation with one axis. Under low-P conditions, shoot biomass exhibited positive correlation with one axis, while feedback values of shoot P concentration and mycorrhizal colonization showed negative correlation with one axis.

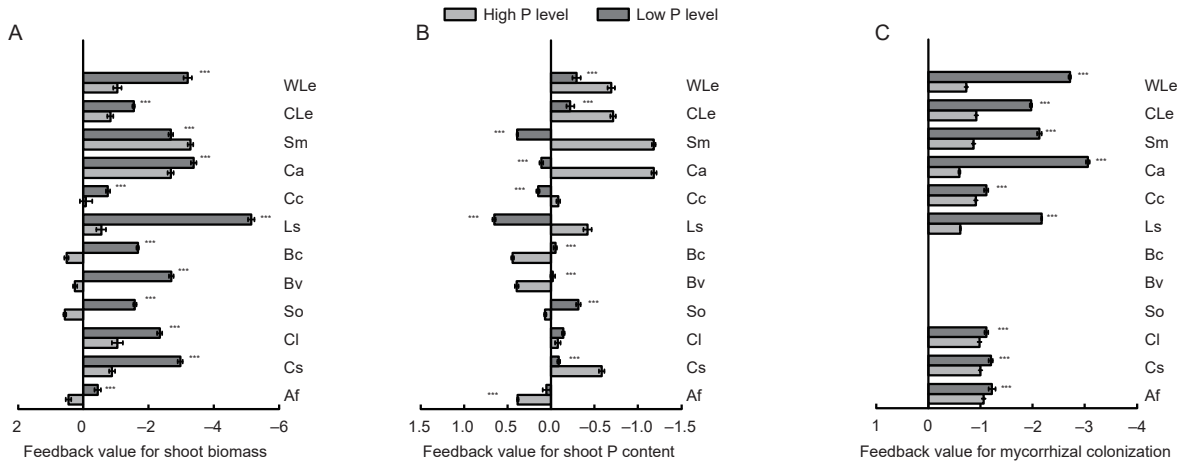


Fig. 4 Plant–soil feedback values for shoot biomass (A), shoot P content (B) and mycorrhizal colonization (C) as affected by phosphorus levels (40 and 200 mg kg^{-1} soil). WLe, wild tomato (*Lycopersicon esculentum*); CLe, common tomato; Sm, eggplant (*Solanum melongena* L.); Ca, pepper (*Capsicum annuum*); Cc, chrysanthemum (*Chrysanthemum coronarium* L.); Ls, lettuce (*Lactuca sativa* Linn.); Bc, rape (*Brassica chinensis* Linn.); Bv, sugar beet (*Beta vulgaris* L.); So, spinach (*Spinacia oleracea* L.); Cl, watermelon (*Citrullus lanatus*); Cs, cucumber (*Cucumis sativus* L.); Af, allium (*Allium fistulosum* L.). Independent-samples *t*-test analyses examining the effects of phosphorus levels within each variety are indicated by asterisks above the bars. Error bars represent SE (n=10). *, P<0.05; **, P<0.01; ***, P<0.001.

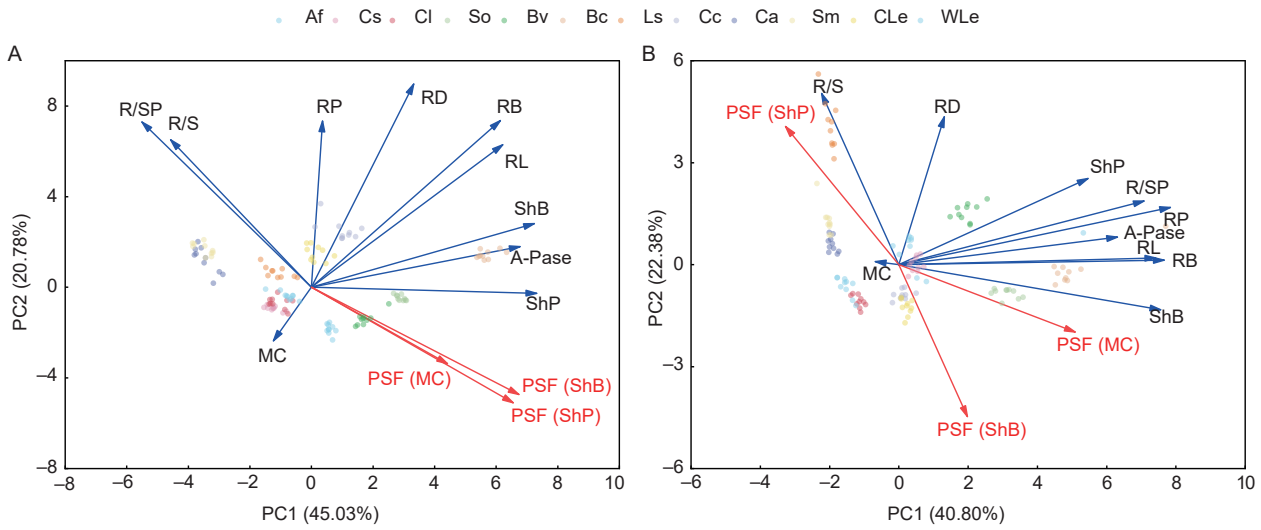


Fig. 5 Principal component analysis of plant traits and plant–soil feedback values under high P level (A) and low P level (B). ShB, shoot biomass; RB, root biomass; ShP, shoot P concentration; RP, root P concentration; RL, root length; RD, average diameter of roots; RSR, root:shoot ratio; RSP, root P content:shoot P content ratio; A-Pase, acid phosphatase activity in the rhizosheath; pH, rhizosphere soil pH; MC, mycorrhizal colonization (no non-mycorrhizal plants, n=9); PSF (ShB, ShP, MC), feedback value of shoot biomass, shoot P concentration and mycorrhizal colonization (no non-mycorrhizal plants, n=9).

3.5. Correlations between changes in root diameter, mycorrhizal colonization and feedback value

Based on the PCA results, multiple regression analysis was performed to examine relationships among root diameter, mycorrhizal colonization and vegetable feedback values (Fig. 6). Under high P levels, no significant correlations emerged between root diameter and the feedback values of shoot biomass (P=0.131, R^2=0.026), shoot P content (P=0.500, R^2=0.004) or mycorrhizal colonization (P=0.131, R^2=0.026). However, A-Pase activity demonstrated positive correlations with feedback values of shoot biomass (P<0.001, R^2=0.459) and shoot P content (P<0.001, R^2=0.541). Mycorrhizal colonization showed positive correlations with feedback values of shoot biomass (P<0.001, R^2=0.267) and shoot P content (P<0.001, R^2=0.494). Conversely, A-Pase activity exhibited negative correlation with the feedback value of mycorrhizal colonization under high P levels (P<0.001, R^2=0.210; Fig. 6-A–H).

Under low P levels, no significant correlations were observed between root diameter and the feedback value of mycorrhizal colonization (P=0.941, R^2<0.001). Similarly, no significant correlations appeared between A-Pase or mycorrhizal colonization and the feedback value of shoot P content (P=0.357, R^2=0.007; P=0.113, R^2=0.025). However, A-Pase activity showed positive correlations with feedback values of shoot biomass (P<0.001, R^2=0.342) and mycorrhizal colonization (P<0.001, R^2=0.124). Additionally, root diameter demonstrated positive correlation with the feedback value of shoot P content (P<0.001, R^2=0.172), and mycorrhizal colonization showed positive correlation with the feedback value of shoot P content (P<0.001, R^2=0.342). Conversely, root diameter exhibited negative correlation with the feedback value of shoot biomass under high P levels (P<0.001, R^2=0.210; Fig. 6-I–P).

3.6. Pathway analysis of plant traits and plant–soil feedback

The direct effects of biomass, P concentration, mycorrhizal colonization, root diameter, rhizosphere soil pH, and acid phosphatase activity on the plant–soil feedback value were analyzed using a structural equation model for vegetables under both high and low P levels (Fig. 7-A and B). Under high P levels, all factors demonstrated direct and significant effects on the plant–soil feedback model (Fig. 7-A). In contrast, at low P levels, the direct feedback pathways associated with root diameter and rhizosphere soil pH to the plant–soil feedback value decreased (Fig. 7-B).

4. Discussion

4.1. Effects of P on vegetable growth under home-PSFs

Under varying P conditions, plant growth characteristics frequently result in changes to biomass distribution across different tissues (Pu *et al.* 2023). Analysis of the home-PSFs demonstrated that low P levels significantly decreased biomass across multiple vegetable components while concurrently increasing the root:shoot ratio of the vegetables (Fig. 2-A, B and E). These observations indicate that within the home-PSFs, low P conditions promote an increased root mass ratio in vegetables. A reduction in root mass ratio in response to AMF inoculation is commonly observed in annual crop species, which are typically short-lived plants adapted to low-P environments (Gavito *et al.* 2000; Guo *et al.* 2006). These modifications may result from changes in carbon allocation between roots and shoots or alterations in plant biomass during growth and development (Poorter *et al.* 2012). The modest changes in root:shoot ratio observed in smaller plants suggest that variations in this ratio are not solely determined by changes in plant size.

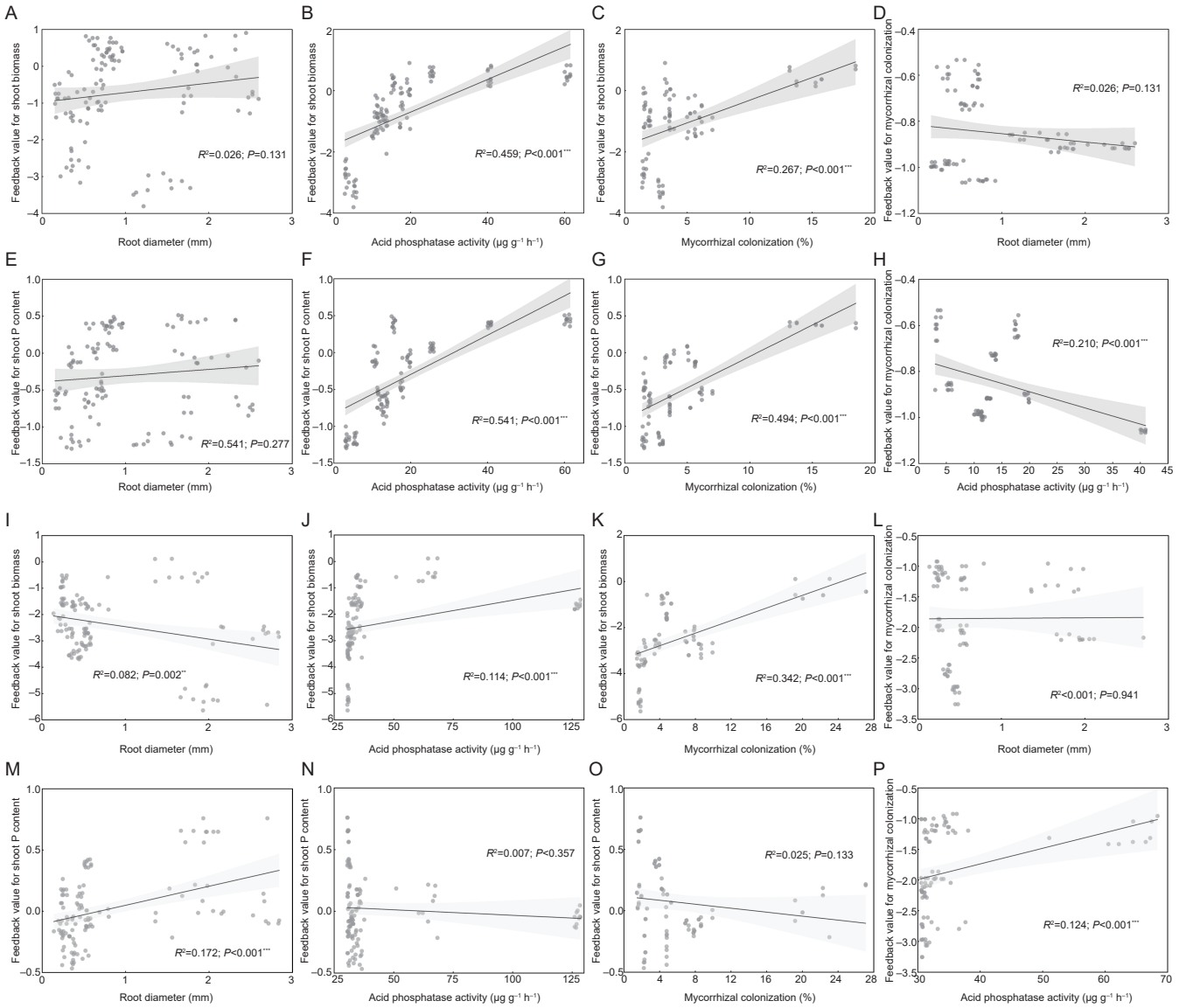


Fig. 6 Univariate relationships between plant traits and plant–soil feedback values. A–H, high P level; I–P, low P level. The functional traits displayed exhibited the highest relative importance and demonstrated standardized estimates with 95% unconditional confidence intervals that did not intersect with 0. For each relationship, the adjusted coefficient of determination R^2 is provided. *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

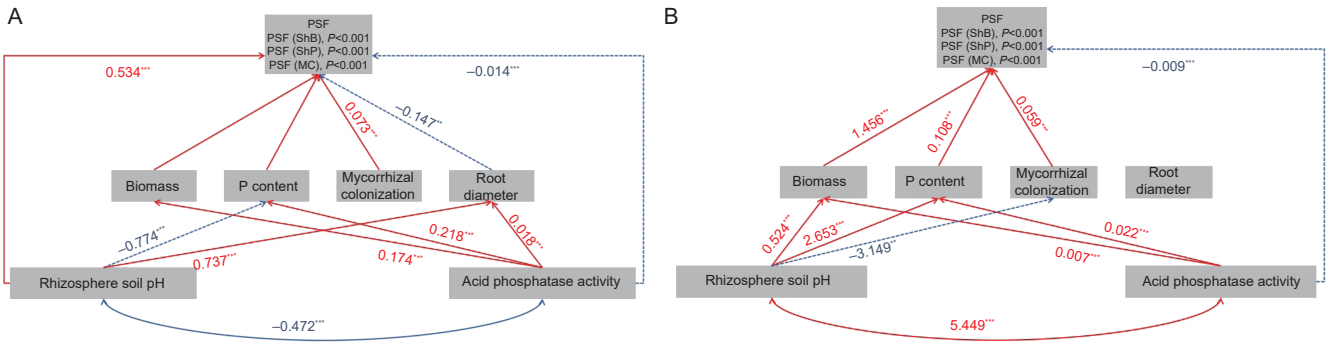


Fig. 7 Biomass, P concentration, mycorrhizal colonization, root diameter, rhizosphere soil pH, and acid phosphatase activity in path analysis for plant–soil feedback value. A, high P level (χ^2/df=2.901, $P<0.001$, RMSEA=0.031, CFI=0.978). B, low P level (χ^2/df=3.646, $P<0.001$, RMSEA=0.063, CFI=0.913). Red arrows indicate a positive relationship, while blue arrows indicate a negative relationship. **, $P<0.01$; ***, $P<0.001$.

The analysis indicated that P concentration in allium and nonmycorrhizal vegetables differed significantly from other vegetable types under varying P availability, particularly evident in root P pools at low P levels (Fig. 2-C and D). This observation suggests enhanced dependence on root exudates by allium and nonmycorrhizal plants within the home-PSFs. Significantly, these four vegetables exhibited increased rhizosphere acid phosphatase activity under low-P conditions, showing a substantial increase (Fig. 3-D). The production of root exudates typically demands increased energy expenditure, and allium species maintain high mycorrhizal infection rates even under these conditions. Under limited nutrient conditions, competition may arise between plants and AMF. For instance, in low N environments, AMF may compete with crops for nitrogen (Wang *et al.* 2018).

4.2. Negative home-PSFs

In the home-PSFs system, most plants exhibited negative biomass feedback under both P levels (Fig. 4-A–C). This observation aligns with numerous home PSF studies that demonstrated significant reductions in crop yield, diminished quality, and impaired plant growth (Sun *et al.* 2021; Qi *et al.* 2022; Wang *et al.* 2023). However, allium and nonmycorrhizal vegetables showed positive feedback responses in biomass and P content at high P levels (Fig. 4-A and B). This response may be attributed to plant legacy effects, where allium root exudates directly influence soil fungi and bacteria (Tsao and Yin 2001). Conversely, certain cucurbit crop exudates (e.g., aldehydes, ketones, phenols, and acids) demonstrate self-toxic properties that inhibit growth (Yu and Matsui 1994; Wang *et al.* 2023). Allium and nonmycorrhizal vegetables produce less acid phosphatase at high P levels (Fig. 3-D), thus reducing carbon source consumption (Liu *et al.* 2021; Luo *et al.* 2022). Vegetable roots may attract more beneficial rhizosphere microorganisms (Chen *et al.* 2019; Cao *et al.* 2025), thereby mitigating negative PSFs. Sufficient P supplementation effectively alleviates negative feedback caused by home feedback. However, Compositae and two Solanaceae vegetables demonstrated positive feedback at low P levels. These findings indicate that plants with weak allelopathic secretion are more affected by legacy effects on soil under high-P conditions compared to low-P conditions (Wiggins and Kinkel 2005). This phenomenon may correlate with the root:shoot P ratio, as vegetables with higher root:shoot P ratios under low-P conditions exhibit weaker negative PSFs. Thus, nutrient distribution may serve as a key regulatory mechanism affecting negative feedback in vegetables. The data suggest that while mycorrhizae in all vegetables show negative feedback, high-P environments can mitigate this effect. However, low P enhances mycorrhizal colonization while increasing negative PSF. In contrast, Minas *et al.* (2024) reported that AMF effectively mitigated negative plant–soil feedback in legumes. This effect may relate to soil environment and arbuscular mycorrhizal fungi origin (Pu *et al.* 2024). AMF typically originates from local soil, with low P levels inducing mycorrhizal colonization. However, low P may also intensify negative effects of continuous cropping, adversely affecting vegetable growth. Root diameter and mycorrhizal colonization demonstrated varying correlations with plant–soil feedback values of biomass and P content at different P levels. Additionally, A-Pase activity showed positive correlation with biomass feedback value and mycorrhizal colonization under low P levels (Fig. 6). Changes in vegetable root morphology and mycorrhizal colonization followed a complementary “P-scavenging” strategy, consistent with studies demonstrating interplay between these approaches (Lambers *et al.* 2008; Shen *et al.* 2011). In the home PSF system, vegetables may rely more heavily on the “P-mining” strategy of A-Pase activity (Raven *et al.* 2018), explaining the observed low soil P levels. Available soil P may be insufficient for normal plant nutrient requirements, leading plants to increase carbon source consumption, root exudate secretion, and mineral phosphorus activation in pursuit of essential nutrients.

4.3. Low-P conditions induced stronger negative home-PSFs in wild-type tomato

Compared with common tomatoes, wild-type tomatoes exhibited stronger plant–soil negative feedback at low P levels (Fig. 4-A–C). This suggests that the domestication process has enhanced certain root traits, enabling domesticated tomatoes to better mitigate negative feedback. These findings differ from those reported by Carrillo *et al.* (2019). The home-PSFs of wild tomatoes showed greater sensitivity to soil P input compared to common tomatoes. This suggests wild-type plants likely generate more residual organic materials that could adversely affect subsequent crops. Furthermore, the influence of soil associations on plants results from a combination of traits related to both soil nutrient exploration and mutualist recruitment. Domestication may affect traits associated with nutrient uptake and resource use efficiency (Roucou *et al.* 2018). Additionally, a meta-analytical review of plant–soil feedbacks indicates that greenhouse studies demonstrate significantly stronger effects than comparable field manipulations (Kulmatiski *et al.* 2008). Under greenhouse conditions’ amplification effect, wild-type tomato plants demonstrated greater negative plant–soil feedback. However, the immediate factors mediating plant–soil feedbacks remain inadequately understood, as research has concentrated primarily on ultimate mechanisms, including plant phylogeny (Mehrabi and Tuck 2015; Fitzpatrick *et al.* 2017) and growth rate (Cortois *et al.* 2016). Therefore, additional research into the mechanisms underlying soil nutrient restriction across different crop genotypes is necessary.

4.4. Response of vegetable growth traits to negative feedback

PCA demonstrated that the feedback values of vegetable biomass and P content appeared in the same quadrant under high-phosphorus conditions, with dispersed distribution across the index (Fig. 5). These results indicate that high P effectively mitigates negative home feedback effects on vegetables. However, the feedback values of vegetable biomass and P content under low-P conditions appear in

the relative quadrant, with the index distribution showing greater inclination toward axis 2. Furthermore, under low-P conditions, vegetable root diameter showed negative correlation with the biomass feedback value. This relationship may constitute a primary factor in the negative feedback effects observed in vegetables, with low P intensifying these adverse effects. These findings correspond with previous studies indicating that low nutrient inputs can amplify barriers associated with continuous cropping (Bennett *et al.* 2019; Schandry *et al.* 2020).

The mixed equation model results revealed that high P levels reduced both the effect of vegetable root diameter on plant soil feedback and the impact of mycorrhizal colonization. However, these effects were reversed under low P levels (Fig. 7). Previous research has demonstrated that vegetable root morphology optimizes for increased performance without nutrient restrictions (Pu *et al.* 2023). However, low P levels significantly increased mycorrhizal colonization, subsequently diminishing the role of vegetable roots in plant–soil feedback. Rhizosphere soil pH serves as a crucial indicator of increased phosphorus availability in the rhizosphere (Geelhoed 1997). Under high P levels, vegetables exhibited varying changes in rhizosphere soil pH (Fig. 3-E). This variation likely relates to different vegetables' root exudates. Under high P levels, without nutrient limitation, some vegetables modify their secretion of organic acids and other exudates. This results in diverse changes in rhizosphere soil pH value. Additionally, rhizosphere pH showed positive correlation with the plant–soil feedback model at high P levels, though this relationship disappeared at low P levels. Thus, high P inputs effectively mitigate negative plant–soil feedback.

5. Conclusion

This study demonstrated that soil P management effectively mitigates negative home-PSFs in vegetable crops. At low P levels, mycorrhizal colonization and rhizosphere A-Pase activity increased significantly, while biomass and root morphological traits decreased. Additionally, severe negative home-PSFs of vegetable crops were observed at low P levels. At high P levels, negative home-PSFs of vegetable crops decreased significantly, particularly in allium and nonmycorrhizal vegetables. Furthermore, home PSFs of wild tomatoes showed greater sensitivity to soil P compared to common tomatoes. This study illustrates the complex interactions among various factors influencing home-PSFs and demonstrates that soil P management effectively mitigates negative home-PSFs in vegetable crops. Consequently, we recommend that agricultural management, particularly in continuous vegetable cropping systems, incorporate appropriate increases in fertilizer P content to mitigate negative home-PSFs caused by continuous cropping. However, given the complexity of plant–soil P feedback in vegetable crops, further systematic analysis is required to enhance understanding of these dynamics.

Acknowledgements

This study was financially supported by the Earmarked Fund for Hebei Agriculture Research System, China (HBCT2023100208 and HBCT 2023100212) and the State Key Laboratory of North China Crop Improvement and Regulation, Hebei Agricultural University, China (NCCIR2021ZZ-18).

Declaration of competing interest

The authors declare that they have no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that they did not use AI in the preparation and writing of this manuscript.

Appendices associated with this paper are available at https://doi.org/10.1016/j.jia.2025.09.003

References

Abiem I, Chapman H M. 2025. Investigating plant–soil feedbacks in tropical montane forest trees. *Journal of Tropical Ecology*, **41**, 1–5.

Allen W J, Meyerson L A, Flick A J, Cronin J T. 2018. Intraspecific variation in indirect plant–soil feedbacks influences a wetland plant invasion. *Ecology*, **99**, 1430–1440.

Alvey S, Bagayoko M, Neumann G, Buerkert A. 2001. Cereal/legume rotations affect chemical properties and biological activities in two West African soils. *Plant and Soil*, **231**, 45–54.

Awodele S O, Bennett J A. 2022. Soil biota legacies of alfalfa production vary with field conditions and among varieties and species. *Agriculture Ecosystems Environment*, **335**, 107944.

Bao S D. 2000. *Soil Agrochemical Analysis Third Edition*. China Agriculture Press, Beijing. (in Chinese)

Barber N A, Kiers E T, Theis N, Hazzard R V, Adler L S. 2013. Linking agricultural practices, mycorrhizal fungi, and traits mediating plant-insect interactions. *Ecological Applications*, **23**, 1519–1530.

Bauer J T, Koziol L, Bever J D. 2018. Ecology of floristic quality assessment: Testing for correlations between coefficients of conservatism, species traits and mycorrhizal responsiveness. *AOB Plants*, **10**, plx073.

Bennett J A, Klironomos J. 2019. Mechanisms of plant–soil feedback: Interactions among biotic and abiotic drivers. *New Phytologist*, **222**, 91–96.

Bukowski A R, Petermann J S. 2014. Intraspecific plant–soil feedback and intraspecific overyielding in *Arabidopsis thaliana*. *Ecology and Evolution*, **4**, 2533–2545.

Cadot S, Gfeller V, Hu L F, Singh N, Sanchez-Vallet A, Glauser G, Croll D, Erb M, Van der Heijden M G A, Schlaeppi K. 2021. Soil composition and plant genotype determine benzoxazinoid-mediated plant–soil feedbacks in cereals. *Plant Cell and Environment*, **44**, 3502–3514.

Cao K P, Zhang L L, Ullah A, Ibrahim M, Zhang Y, Gao D M, Zhou X A, Wu F Z, Liu S W. 2025. Moderate P fertilizer promotes cucumber yields and modulates bacterial community in the wheat cover crop system. *Agronomy-Basel*, **15**, 624.

Carrillo J, Ingwell L L, Li X H, Kaplan I. 2019. Domesticated tomatoes are more vulnerable to negative plant–soil feedbacks than their wild relatives. *Journal of Ecology*, **107**, 1753–1766.

Chen X D, Jiang N, Condron L M, Dunfield K E, Chen Z H, Wang J K, Chen L J. 2019. Impact of long-term phosphorus fertilizer inputs on bacterial *phoD* gene community in a maize field, Northeast China. *Science of the Total Environment*, **669**, 1011–1018.

Cortois R, Schroder-Georgi T, Weigelt A, Van der Putten W H, De Deyn G B. 2016. Plant–soil feedbacks: Role of plant functional group and plant traits. *Journal of Ecology*, **104**, 1608–1617.

Dias T, Dukes A, Antunes P M. 2015. Accounting for soil biotic effects on soil health and crop productivity in the design of crop rotations. *Journal of the Science of Food and Agriculture*, **95**, 447–454.

Fitzpatrick C R, Gehant L, Kotanen P M, Johnson M T J. 2017. Phylogenetic relatedness, phenotypic similarity and plant–soil

feedbacks. *Journal of Ecology*, **105**, 786–800.
Gavito M, Curtis P, Mikkelsen T, Jakobsen I. 2000. Atmospheric CO_2 and mycorrhiza effects on biomass allocation and nutrient uptake of nodulated pea (*Pisum sativum* L.) plants. *Journal of Experimental Botany*, **51**, 1931–1938.
Geelhoed J S. 1997. Effects of sulphate and pH on the plant availability of phosphate adsorbed on goethite. *Plant and Soil*, **197**, 241–249.
Guo R Y, Qin W, Jiang C G, Kang L Y, Nendel C, Chen Q. 2018. Sweet corn significantly increases nitrogen retention and reduces nitrogen leaching as summer catch crop in protected vegetable production systems. *Soil Tillage Research*, **180**, 148–153.
Guo T, Zhang J, Christie P, Li X. 2006. Influence of nitrogen and sulfur fertilizers and inoculation with arbuscular mycorrhizal fungi on yield and pungency of spring onion. *Journal of Plant Nutrition*, **29**, 1767–1778.
Haling R E, Brown L K, Stefanski A, Kidd D R, Ryan M H, Sandral G A, George T S, Lambers H, Simpson R J. 2018. Differences in nutrient foraging among *Trifolium subterraneum* cultivars deliver improved P-acquisition efficiency. *Plant and Soil*, **424**, 539–554.
House G L, Bever J D. 2018. Disturbance reduces the differentiation of mycorrhizal fungal communities in grasslands along a precipitation gradient. *Ecological Applications*, **28**, 736–748.
Van der Heijden M G A, Martin F M, Selosse M A, Sanders I R. 2015. Mycorrhizal ecology and evolution: The past, the present, and the future. *New Phytologist*, **205**, 1406–1423.
Veen G F, Keiser A D, Van der Putten W H, Wardle D A. 2018. Variation in home-field advantage and ability in leaf litter decomposition across successional gradients. *Functional Ecology*, **32**, 1563–1574.
Wagg C, Boller B, Schneider S, Widmer F, Van der Heijden M G A. 2015. Intraspecific and intergenerational differences in plant–soil feedbacks. *Oikos*, **124**, 994–1004.
Iannucci A, Fragasso M, Beleggia R, Nigro F, Papa R. 2017. Evolution of the crop rhizosphere: Impact of domestication on root exudates in tetraploid wheat (*Triticum turgidum* L.). *Frontiers in Plant Science*, **8**, 2124.
Koziol L, Bever J D. 2015. Mycorrhizal response trades off with plant growth rate and increases with plant successional status. *Ecology*, **96**, 1768–1774.
Koziol L, Bever J D. 2017. The missing link in grassland restoration: Arbuscular mycorrhizal fungi inoculation increases plant diversity and accelerates succession. *Journal of Applied Ecology*, **54**, 1301–1309.
Koziol L, Bever J D. 2019. Mycorrhizal feedbacks generate positive frequency dependence accelerating grassland succession. *Journal of Ecology*, **107**, 622–632.
Kulmatiski A, Beard K H, Stevens J R, Cobbold S M. 2008. Plant–soil feedbacks: A meta-analytical review. *Ecology Letters*, **11**, 980–992.
Kural-Rendon C, Ford N E, Hooser K, Wagner M R. 2025. Intraspecific plant–soil feedbacks alter root traits in a perennial grass. *Rhizosphere*, **35**, 101120.
Lambers H, Raven J A, Shaver G R, Smith S E. 2008. Plant nutrient-acquisition strategies change with soil age. *Trends in Ecology Evolution*, **23**, 95–103.
Liu J R, Peng J, Xia H Q, Li P C, Li Z Y, Sun M, Zheng C S, Dong H L. 2021. High soil available phosphorus favors carbon metabolism in cotton leaves in pot trials. *Journal of Plant Growth Regulation*, **40**, 974–985.
Lopez-Arredondo D L, Leyva-Gonzalez M A, Gonzalez-Morales S I, Lopez-Bucio J, Herrera-Estrella L. 2014. Phosphate nutrition: Improving low-phosphate tolerance in crops. *Annual Review of Plant Biology*, **65**, 95–123.
Luo R Y, Kuzyakov Y, Zhu B, Qiang W, Zhang Y, Pang X Y. 2022. Phosphorus addition decreases plant lignin but increases microbial necromass contribution to soil organic carbon in a subalpine forest. *Global Change Biology*, **28**, 4194–4210.
Minas A, Garcia-Parisi P A, Omacini M. 2024. The soil legacy produced by grass- endophyte-mycorrhizae fungi interaction increases legume establishment. *Symbiosis*, **93**, 297–308.
Mehrabi Z, Tuck S L. 2015. Relatedness is a poor predictor of negative plant–soil feedbacks. *New Phytologist*, **205**, 1071–1075.
Middleton E L, Bever J D. 2012. Inoculation with a native soil community advances succession in a grassland restoration. *Restoration Ecology*, **20**, 218–226.
Middleton E L, Richardson S, Koziol L, Palmer C E, Yermakov Z, Henning J A, Schultz P A, Bever J D. 2015. Locally adapted arbuscular mycorrhizal fungi improve vigor and resistance to herbivory of native prairie plant species. *Ecosphere*, **6**, 276.
Oehl F, Laczko E, Bogenrieder A, Stahr K, Bosch R, Van der Heijden M, Sieverding E. 2010. Soil type and land use intensity determine the composition of arbuscular mycorrhizal fungal communities. *Soil Biology Biochemistry*, **42**, 724–738.
Pang J Y, Bansal R, Zhao H X, Bohuon E, Lambers H, Ryan M H, Ranathunge K, Siddique K H M. 2018. The carboxylate-releasing phosphorus-mobilizing strategy can be proxied by foliar manganese concentration in a large set of chickpea germplasm under low phosphorus supply. *New Phytologist*, **219**, 518–529.
Perez-Jaramillo J E, R. Mendes R, Raaijmakers J M, 2016. Impact of plant domestication on rhizosphere microbiome assembly and functions. *Plant Molecular Biology*, **90**, 635–644.
Poorter H, Niklas K J, Reich P B, Oleksyn J, Poot P, Mommer L. 2012. Biomass allocation to leaves, stems and roots: Meta-analyses of interspecific variation and environmental control. *New Phytologist*, **193**, 30–50.
Postma J A, Dathe A, Lynch J P. 2014. The optimal lateral root branching density for maize depends on nitrogen and phosphorus availability. *Plant Physiology*, **166**, 590-U948.
Pu Z T, Hu R L, Wang D D, Wang C, Chen Y L, Wang S, Zhuge Y P, Xie Z H. 2024. The impact of arbuscular mycorrhizal fungi on soybean growth strategies in response to salt stress. *Plant and Soil*, **509**, 929–943.
Pu Z T, Zhang R F, Wang H, Li Q Y, Zhang J H, Wang X X. 2023. Root morphological and physiological traits and arbuscular mycorrhizal fungi shape phosphorus-acquisition strategies of 12 vegetable species. *Frontiers in Plant Science*, **14**, 1150832.
Van der Putten W H, Bardgett R D, Bever J D, Bezemer T M, Casper B B, Fukami T, Kardol P, Klironomos J N, Kulmatiski A, Schweitzer J A, Suding K N, Van de Voorde T F J, Wardle D A. 2013. Plant–soil feedbacks: The past, the present and future challenges. *Journal of Ecology*, **101**, 265–276.
Qi Y B, Zhou R, Nie L C, Sun M T, Wu X T, Jiang F L. 2022. The effects of catch crops on properties of continuous cropping soil and growth of vegetables in greenhouse. *Agronomy-Basel*, **12**, 1179.
Raven J A, Lambers H, Smith S E, Westoby M. 2018. Costs of acquiring phosphorus by vascular land plants: Patterns and implications for plant coexistence. *New Phytologist*, **217**, 1420–1427.
Richardson A E, Lynch J P, Ryan P R, Delhaize E, Smith F A, Smith S E, Harvey P R, Ryan M H, Veneklaas E J, Lambers H, Oberson A, Culvenor R A, Simpson R J. 2011. Plant and microbial strategies to improve the phosphorus efficiency of agriculture. *Plant and Soil*, **349**, 121–156.
Roucou A, Violle C, Fort F, Roumet P, Ecarnot M, Vile D. 2018. Shifts in plant functional strategies over the course of wheat domestication. *Journal of Applied Ecology*, **55**, 25–37.
Schandry N, Becker C. 2020. Allelopathic plants: Models for studying plant-interkingdom interactions. *Trends in Plant Science*, **25**, 176–185.
Schmidt J E, Bowles T M, Gaudin A C M. 2016. Using ancient traits to convert soil health into crop yield: Impact of selection on maize root and rhizosphere function. *Frontiers in Plant Science*, **7**, 373.
Schnoor T K, Lekberg Y, Rosendahl S, Olsson P A. 2011. Mechanical soil disturbance as a determinant of arbuscular mycorrhizal fungal communities in semi-natural grassland. *Mycorrhiza*, **21**, 211–220.
Shen J B, Yuan L X, Zhang J L, Li H G, Bai Z H, Chen X P, Zhang W F, Zhang F S. 2011. Phosphorus dynamics: From soil to plant. *Plant Physiology*, **156**, 997–1005.
Smith S E, Jakobsen I, Gronlund M, Smith F A. 2011. Roles of arbuscular mycorrhizas in plant phosphorus nutrition: Interactions between pathways of phosphorus uptake in arbuscular mycorrhizal roots have important implications for understanding and manipulating plant phosphorus acquisition. *Plant Physiology*, **156**, 1050–1057.
Smith-Ramesh L M, Reynolds H L. 2017. The next frontier of plant–soil feedback research: Unraveling context dependence across biotic and abiotic gradients. *Journal of Vegetation Science*, **28**, 484–494.
Stagnari F, Maggio A, Galieni A, Pisante M. 2017. Multiple benefits of legumes for agriculture sustainability: An overview. *Chemical and Biological Technologies in Agriculture*, **4**, 2.
Sun K, Fu L Y, Song Y, Yuan L, Zhang H R, Wen D, Yang N, Wang X,

Yue Y Q, Li X H, Wang K. 2021. Effects of continuous cucumber cropping on crop quality and soil fungal community. *Environmental Monitoring and Assessment*, **193**, 436.

Teste F P, Kardol P, Turner B L, Wardle D A, Zemunik G, Renton M, Laliberte E. 2017. Plant–soil feedback and the maintenance of diversity in Mediterranean-climate shrublands. *Science*, **355**, 173–176.

Trouvelot A, Kough J, Gianinazzi-Pearson V. 1986. Mesure du taux de mycorhizationVA d'un système radiculaire. Recherche de méthodes d'estimation ayant une signification fonctionnelle. In: GianinazziPearson V, Gianinazzi S, eds., *Physiological and Genetical Aspects of Mycorrhizae*. INRA Press Paris, France. pp. 217–221.

Tsao S, Yin M C. 2001. *In-vitro* antimicrobial activity of four diallyl sulphides occurring naturally in garlic and Chinese leek oils. *Journal of Medical Microbiology*, **50**, 646–649.

De Vries F T, Wallenstein M D. 2017. Below-ground connections underlying above-ground food production: A framework for optimising ecological connections in the rhizosphere. *Journal of Ecology*, **105**, 913–920.

Wang G Z, Van der Putten WH, Klironomos J, Zhang F S, Zhang J L. 2025. Steering plant–soil feedback for sustainable agriculture. *Science*, **389**, 6758.

Wang X X, Hoffland E, Mommer L, Feng G, Kuyper T W. 2019. Maize varieties can strengthen positive plant–soil feedback through beneficial arbuscular mycorrhizal fungal mutualists. *Mycorrhiza*, **29**, 251–261.

Wang X X, Wang X J, Sun Y, Cheng Y, Liu S T, Chen X P, Feng G, Kuyper T W. 2018. Arbuscular mycorrhizal fungi negatively affect nitrogen acquisition and grain yield of maize in a N deficient soil. *Frontiers in Microbiology*, **9**, 418.

Wang Y, Zhou Y Y, Ye J, Jin C Z, Hu Y H. 2023. Continuous cropping inhibits photosynthesis of *Polygonatum odoratum*. *Plants-Basel*, **12**, 3374.

Wiggins B, Kinkel L. 2005. Green manures and crop sequences influence potato diseases and pathogen inhibitory activity of indigenous streptomycetes. *Phytopathology*, **95**, 178–185.

Yacine Y, Kutakova E, Zandt D I, Hadincova V, Semerad J, Cajthaml T, Mvnzbergova Z. 2024. Between-versus within-species variation in plant–soil feedback relates to different functional traits, but exudate variability is involved at both scales. *Functional Ecology*, **38**, 1156–1171.

Yu J Q, Matsui Y. 1994. Phytotoxic substances in root exudates of cucumber (*Cucumis sativus* L.). *Journal of Chemical Ecology*, **20**, 21–31.

Zhang H Y, Hu K L, Zhang L J, Ji Y Z, Qin W. 2019. Exploring optimal catch crops for reducing nitrate leaching in vegetable greenhouse in North China. *Agricultural Water Management*, **212**, 273–282.

Zhu X Y, Zhao P, Wang J, Zhang Q Q, Yu Y C, Liu M, Jin R, Tang Z H. 2024. Long-term stationary fertilization decreased soil health in field-grown sweetpotato by increasing soil-borne diseases or allelochemicals. *Applied Soil Ecology*, **203**, 105658.

Executive Editor-in-Chief Keke Yi
Managing Editor Lujuan Sun