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Research Article

Effect of ecological restoration on topsoil phosphorus following afforestation on abandoned ponds in northern Chaohu Lake, China

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Abstract

Afforestation is an approach for ecological restoration. Soil total phosphorus is one of the important ecological and evolutionary elements for carbon cycles and plant growth following afforestation. However, studies on soil total phosphorus of afforestation on abandoned ponds with different slopes are still lacking. Soil total phosphorus and other soil properties from afforestation sites with different slopes were investigated. Soil total phosphorus, total nitrogen, bulk density, soil water contents and pH of poplar (*Populus* spp.) plantation sites (Slope 1) with a steep slope and pond cypress (*Taxodium* spp.) plantation sites (Slope 2) with a flat slope were determined. Soil total nitrogen stocks, soil total phosphorus stocks and the ratio of soil total nitrogen to total phosphorus (N:P) were calculated. Results showed that soil bulk density, soil water content, total phosphorus, total phosphorus stocks and total nitrogen stocks of three soil layers at Slope 1 were significantly lower than those of Slope 2. N:P of Slope 1 was significantly higher, but no significant difference of total nitrogen and pH were found between the two sampling sites. Soil bulk density, soil water content and total nitrogen had significant positive relationships with both total phosphorus and total phosphorus stocks. No obvious correlation was found between pH and total phosphorus or total phosphorus stocks. Redundancy analysis (RDA analysis) suggested that soil water content and bulk density had the most important individual effect on total phosphorus and total phosphorus stocks with values at 59.3% and 59.5%, respectively. It is recommended that afforestation on a flat or gentle slope rather than on a steep gradient could be helpful for accumulation of soil total phosphorus and phosphorus stocks and could decrease the risk of soil phosphorus loss, when afforestation is used for ecological restoration.

Key words: ecological engineer, nitrogen and phosphorus stocks, plantation, slope, soil water content, wetlands

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Introduction

Ecological restoration is defined by the Society for Ecological Restoration (SER) as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Wortley et al. 2013). Theoretically, there are four principles for restoration: ecological integrity, long-term sustainability, societal benefits and engagement and informed by past and future (Suding et al. 2015). However, ecological restoration can be costly and cost-effective approaches should be considered for a better integration between economic and ecological components (Gong et al. 2012; Kimball et al. 2015). As an important ecological restoration approach, afforestation has been widely used for ecological system management and to improve soil quality. Soil total phosphorus (TP) is one of the important ecological and evolutionary elements and the supply and cycles of TP play an important role in carbon emission and uptake (Nottingham et al. 2015; Reed et al. 2015; Zhao et al. 2015) and could impact the carbon uptake and mineralisation due to being a potentially limiting nutrient for plant growth (Wang et al. 2015; Deng et al. 2017; Alewell et al. 2020; Guo et al. 2021). As afforestation with plants can have an effect on soil phosphorus and has been considered as an effective ecological restoration approach to mitigate carbon emissions and increase carbon sequestration in both the Eastern and Western world (Zhao et al. 2015; Lu et al. 2018; Yang et al. 2022), it is necessary to quantify soil TP following afforestation in order to sustain forest management and have better climate change mitigation (Karamian and Hosseini 2015; Liu et al. 2016; Deng et al. 2017).

Vegetation recovery such as afforestation has been a good practice to mitigate soil erosion risk, including soil phosphorus loss (Teng et al. 2019; Chen et al. 2021; Xu et al. 2022). Soil TP loss could result from surface runoff and lead to eutrophication of adjacent freshwater systems (He et al. 2018; He et al. 2019; McDowell et al. 2020). For example, the global soil TP loss from agricultural land reached 6.3 Tg yr^{-1} (Alewell et al. 2020) and the total loss of colloidal phosphorus accounted for 64.3% of surface runoff (He et al. 2019). Afforestation could be one of the alternative restoration approaches for bare and degraded lands (IPCC 2014) and this ecological practice has been implemented in China since the 1970s (Li et al. 2012). Previous results of soil phosphorus following afforestation varied according to different studies. According to some studies, topsoil TP tended to increase from afforestation of bare and degraded lands (Chen et al. 2016; Deng et al. 2017) and farmland (Zhang et al. 2018a). However, some other previous studies argued that TP stocks decreased in both regional and global scales following afforestation, ranging from 7% to 15% in temperate, arid and semi-arid areas, with the exception of afforestation of barren lands (Deng et al. 2017; Li et al. 2019). Additionally, another global systematic analysis reported that afforestation had no overall impacts on soil TP (Guo et al. 2021) nor altered soil phosphorus stocks (Zou et al. 2015). Unfortunately, many previous studies focused on afforestation of agricultural lands (Temesgen et al. 2016; Zhang et al. 2018a), grasslands (Chen et al. 2021), wetlands (Howson et al. 2022) and barren lands (Deng et al. 2017). Few studies on afforestation of abandoned ponds were reported, which could limit our understanding of the soil TP cycle following afforestation.

In-situ conditions, including hydrology, topography, soil and their interactions, may lead to limitations in our understanding of soil phosphorus following afforestation (MacDonald et al. 2012; Sohrt et al. 2017). For example, soil water status could impact soil TP directly or indirectly. Soil water status could directly impact soil TP as the decomposition of phosphorus declined with the increase in rainfall in tropical forests (Sun et al. 2020), while phosphorus losses in runoff could increase with the increase in soil water repellence (McDowell et al. 2020). Indirectly, it could have an impact because soil water status has an effect on slope erosion and hydrology, which could have a positive relationship with phosphorus loss (Chen et al. 2013; Keshavarzi et al. 2015). Previous studies showed that increases in soil moisture and rainfall could decrease the desorption and release of phosphorus from topsoil (Ford et al. 2018; He et al. 2018; Sun et al. 2020). Though higher water repellence (McDowell et al. 2020) could increase phosphorus loss in runoff, other studies suggested that lower precipitation and prolonged drought led to less TP depletion and decreased soil phosphorus release, due to limitation of phosphorus enzymatic activities in the forest (Li et al. 2019; Asensio et al. 2021).

Furthermore, previous studies showed that slope erosion could lead to phosphorus loss (Chen et al. 2013; Keshavarzi et al. 2015) and soil phosphorus content varied in position on the same slope, with the lower position having more phosphorus stocks and available phosphorus (Ide et al. 2007; Amiotti et al. 2013; Zou et al. 2015). However, previous simulation experiments showed that slope had an effect on soil phosphorus loss for different rainfall intensities (Wang et al. 2013; Ramos et al. 2019). For example, soil phosphorus loss of afforested land with a slope of 17% was higher for relatively low rainfall intensity (22 mm h^{-1}), compared to a natural forest with a slope of 19% (Ramos et al. 2019). Much of the soil phosphorus loss was found at the lower slope treatment for heavier rainfall intensity (65 mm h^{-1}). Overall, the complexity of *in-situ* conditions impacting soil TP following afforestation could be greater than our expectations and further study should be given to this. Unfortunately, studies on soil phosphorus and afforestation looking at different *in-situ* conditions, such as different soil water properties and slopes, is still lacking. As a global scale study could be limited for management guidance (Li et al. 2019), the *in-situ* studies on soil phosphorus following afforestation could be necessary for sustainable soil management.

In this study, soil TP and other soil properties (i.e. bulk density, pH, soil water content and total nitrogen) were carried out following afforestation of abandoned ponds. The hypothesis is that micro-topography of different slopes could have an effect on soil TP. The aims are: (1) to investigate the distribution of soil TP in the top 30 cm soil layer with different slopes following afforestation; (2) to estimate the effects of soil properties of different slopes on soil TP following afforestation; and (3) to provide a reference for ecological restoration by afforestation on abandoned lands.

Methods

Study sites

Experiments were carried out in Hefei, Anhui, China from late September to early October 2021. The study area is located in the northern Chaohu Lake area (117.36°E–117.43°E; 31.70°N–31.40°N, Fig. 1), where the afforestation of abandoned ponds by poplar (*Populus* spp.) and pond cypress (*Taxodium distichum* and *Taxodium distichum* var. *imbricatum*) has been undertaken. The soil type is yellow-brown and this area belongs to the northern subtropical monsoon climate with a mean annual temperature of 15.7 °C and mean annual precipitation of 995.4 mm (Huai-Jing 2018). At the poplar site (Slope 1), there are a lot of ditches with a very steep slope (Fig. 1). Poplar trees were planted on the top of the ditches in 2002 with a stand density of about 1066 ha^{-1}. At the pond cypress site (Slope 2), there are no ditches and a flat slope. Pond cypresses were planted on flat ground in 2018 with

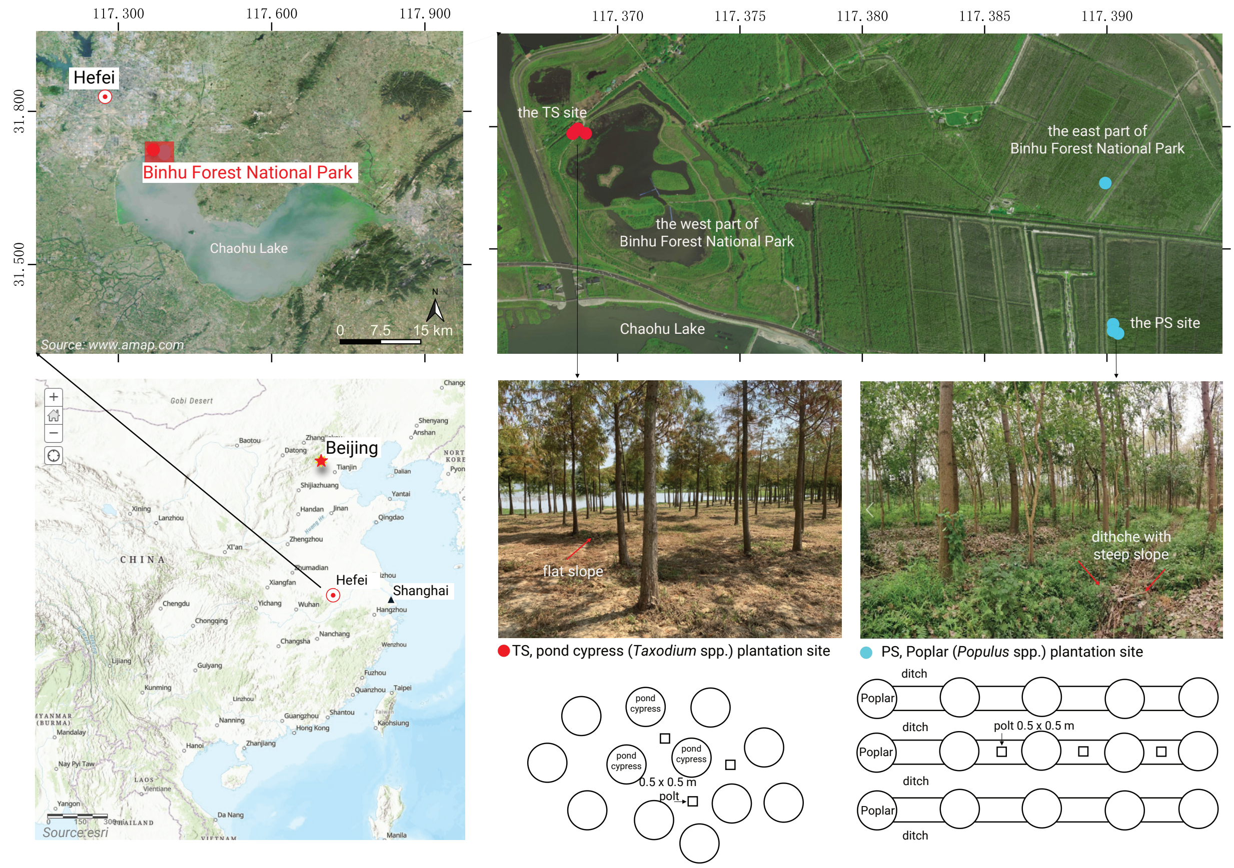

Figure 1. Location of the study area and sampling sites.

a stand density of about 2250 ha^{-1}. These two tree species both belong to FACW (facultative wetland; species are the most reliable vegetation indicators of wetland and many wetlands are characterised by these species), according to the Wetland Indicator Standards (Tiner 1988, 1993). More details are listed in Table 1.

Soil sampling and analysis

For both Slope 1 and Slope 2, there were four sampling sites with three plots as replications. The sampling sites were set randomly and a plot of 0.5 × 0.5 m was set in the area between two adjacent poplar trees or pond cypress trees. Three soil layers (0–10, 10–20 and 20–30 cm) were collected from each plot for analysis of soil physical and chemical properties of each soil layer, in line with previous studies: soil bulk density (BD) was collected by a cutting ring (100 cm^3); total phosphorus (TP), total nitrogen (TN), soil water content (SWC) and soil pH were collected from three soil layers using a corer (Li et al. 2018). Bulk density was measured by oven-dried soil mass (Yang et al. 2007); soil water content was mea-

Table 1. General situation of the sampling sites.

Sites	Mico-topography	Stand density ha^{-1}	Age (yr)	Dominant tree species	Dominant landcover species
Poplar	an obvious and steep slope with ditch	1066	19	*Populus* spp.	*Cyclosorus interruptus*, *Solidago decurrens*, and *Liriope spicata*
Pond cypress	a flat gradient with non-ditch	2250	4	*Taxodium* spp.	*Erigeron annuus*, *Lindernia crustacea*, and *Stellaria media*

sured gravimetrically at 105 °C for 24 h (Shang et al. 2013); pH was determined by a pH analyser (PHS-3C PH METER, Shanghai Puchun Measure Instrument Co., Ltd.). TP was determined by the Alkali Fusion-Mo-Sb Anti-spectrophotometric Method (China 2011.12.16) and total nitrogen was measured by the Kjeldahl Method (China 2015.01.01), according to the Chinese National Standards.

Statistical statistics and analyses

Soil total phosphorus stock (TPS) and total nitrogen stock (TNS) of each soil layer and the average TPS or TNS of three soil layers were calculated as follows (Li et al. 2018):

$$Stock_{ij} = Content_{ij} \times BD_{ij} \times D \times 100 \qquad (1)$$

where, *Stock* is the soil total phosphorus stock (kg ha^{-1}) or total nitrogen stock (kg ha^{-1}) of each soil layer; *Content* is the soil TP content (g kg^{-1}) or total nitrogen content (g kg^{-1}) and BD is the soil bulk density (g cm^{-3}) of each soil layer; D is the soil sampling depth (m); i = TP or total nitrogen; j = 0–10, 10–20 or 20–30 cm of soil layer.

Data statistics

Differences of soil property contents between the two sampling sites (Slope1 and Slope 2) and three soil layers were tested by the Kruskal-Wallis Test and an independent Samples Wilcoxon Test (Wezel et al. 2000) with '*ggplog2*' package, respectively (Fig. 2). Regression between TP or total phosphorus stocks and other soil properties, including bulk density, pH, soil water content and total nitrogen were analysed by a Linear Regression Model (GLM, Fig. 3) with '*ggplog2*' package (Li et al. 2018). The hierarchical partitioning method was used to determine the contribution of each soil property to soil organic carbon with the Redundancy analysis (RDA method, Table 2 and Suppl. material 1) with '*rdacca.hp*' package (Lai et al. 2022). Only $p < 0.05$ was considered statistically significant. Figures and tables were created by R (ver. 4.1.2) language and QGIS (ver. 3.22).

Results

Soil physical and chemical properties

For the same sampling site, only bulk density was found to have a significant difference amongst the three soil layers at both Slope 1 and Slope 2 and bulk density increased significantly with increases in depth ($p < 0.05$, Fig. 2). For the two different sampling sites, bulk density, soil water content and TP of the three soil layers at Slope 1 were significantly lower than those of Slope 2 where there was a flat slope ($p < 0.01$, Fig. 2). For example, the average bulk density at Slope 1 was 1.104 ± 0.040 g cm^{-3} (Mean ± S.E.), which was 78.5% of the value of Slope 2. Similarly, the average soil water content at Slope 1 was 47.4% less than that of Slope 2 with a value of 22.521 ± 0.892%. Additionally, the average TP of Slope 1 was 0.177 ± 0.016 g kg^{-1} with each of the three soil layers measuring 0.190 ± 0.028, 0.158 ± 0.018 and 0.182 ± 0.035 g kg^{-1}, respectively. The average TP of

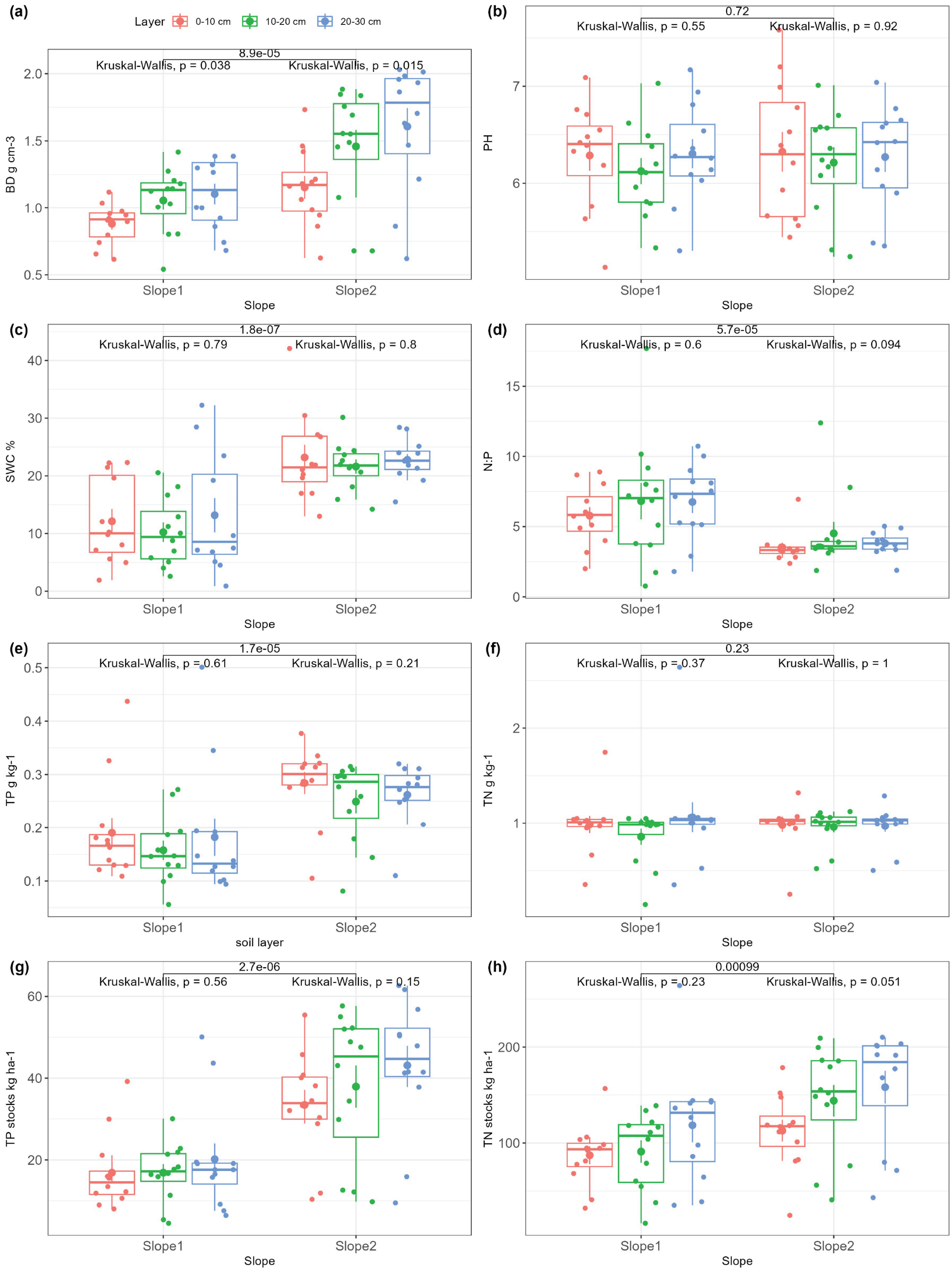

Figure 2. Soil properties of three soil sampling layers. Notes: BD, bulk density; pH, soil pH value; SWC, soil water content; N:P, soil nitrogen to phosphorus ratio; TP, soil total phosphorus; TPS, soil phosphorus stocks; TN, soil total nitrogen; TNS, soil nitrogen stocks; a solid line of each box is the Median value; a solid dot on the bar is the Mean value; the value on top of a solid line at the top of each graph refers to significance between Slope 1 and Slope 2 by Wilcoxon Test; Kruskal-Wallis refers to significance amongst three soil layers at the same Slope site; n = 12 for each soil layer and n = 72 for two sampling sites.

Slope 2 was 0.265 ± 0.011 g kg^{-1} with each of the three soil layers measuring 0.284 ± 0.021, 0.250 ± 0.022 and 0.262 ± 0.017 g kg^{-1}, respectively. However, N:P of each soil layer at Slope 1 (5.779 ± 0.612, 6.817 ± 1.30 and 6.755 ± 0.792 g kg^{-1}) was higher than that of Slope 2 (3.520 ± 0.330, 4.517 ± 0.819 and 3.810 ±

Table 2. Results of RDA analysis of both soil TP and TP stocks in this study.

Variables	TP model					TPS model				
	SWC %	TN g kg^{-1}	BD g cm^{-3}	pH	Total	SWC %	TN g kg^{-1}	BD g cm^{-3}	pH	Total
VIF [a]	1.550	1.023	1.567	1.609	—	1.550	1.023	1.567	1.609	—
Unique	0.253	0.133	-0.004	0.007	0.389	0.096	0.037	0.250	0.004	0.388
Average.shared [b]	0.063	0.017	0.064	-0.001	0.144	0.124	0.016	0.213	0.038	0.392
Individual importance	0.316	0.150	0.060	0.007	0.533	0.220	0.053	0.463	0.043	0.780
I.perc (%)[c]	59.340	28.110	11.310	1.220	100	28.250	6.850	59.470	5.480	100
p-values [d]	0.001	0.001	0.001	0.529	—	0.001	0.001	0.001	0.002	—
F	37.820	27.496	19.298	0.399	—	30.558	29.209	183.667	11.607	—
	Df	Variance	F	Pr (>F)		Df	Variance	F	Pr(>F)	
Model	4	0.005	21.253	0.001		4	219.979	63.760	0.001	
Residual	67	0.004				67	57.789			

Note: TP model, total phosphorus predictive model; TPS model, total phosphorus stocks predictive model; VIF, values of variables used to develop predictive model; TN, soil total nitrogen; BD, bulk density; pH, soil pH value; SWC, soil water content; sampling sites with *a*, variance inflation factor (VIF); *b*, total average shared effects with other predictors; *c*, Individual effect divided by total adjusted R^2 found in column Individual importance; *d*, *p*-values based on permutation test based on 999 randomizations; *n* = 72; Pr (> F), probability of obtaining a value larger than the F-test value.

0.242 g kg^{-1}). No significant differences of pH and total nitrogen were found between Slope 1 and Slope 2. The average pHs of the three soil layers were 6.286 ± 0.157, 6.125 ± 0.134 and 6.304 ± 0.150 for Slope 1, compared to 6.325 ± 0.204, 6.213 ± 0.157 and 6.271 ± 0.154 of Slope 2. The averages of total nitrogen for the three soil layers were 0.986 ± 0.091, 0.855 ± 0.0840 and 1.062 ± 0.158 g kg^{-1} for Slope 1 and 0.979 ± 0.071, 0.959 ± 0.056 and 0.970 ± 0.062 g kg^{-1} for Slope 2.

Soil total phosphorus and total nitrogen stocks

The averages of total phosphorus stocks and total nitrogen stocks of Slope 1 were both significantly lower than those of Slope 2 ($p < 0.01$, Fig. 2). For Slope 1, the average total phosphorus stock was 17.973 ± 1.681 kg ha^{-1} and the values for the three soil layers were 16.883 ± 2.656, 16.868 ± 2.088 and 20.170 ± 3.860 kg ha^{-1}. For Slope 2, the average total phosphorus stock was 38.183 ± 2.644 kg ha^{-1} and the values for the three soil layers were 33.466 ± 3.680, 37.949 ± 5.151 and 43.134 ± 4.732 kg ha^{-1}, respectively. Additionally, the average total nitrogen stock at Slope 1 was 98.917 ± 7.863 kg ha^{-1} (87.223 ± 9.290, 91.040 ± 11.625 and 118.489 ± 17.773 kg ha^{-1} for each of the three soil layers, respectively), compared to 138.382 ± 54.328 kg ha^{-1} at Slope 2 (112.905 ± 11.363, 144.085 ± 16.354 and 158.156 ± 16.986 kg ha^{-1} for each of the three soil layers, respectively). There were no significant differences for both total phosphorus stocks and total nitrogen stocks amongst the three soil layers at the same sampling site.

Regression analysis

Bulk density, soil water content and total nitrogen had significant positive relationships with both TP and total phosphorus stocks ($p < 0.01$, Fig. 3). For example, TP and total phosphorus stocks both increased sharply with the increase of

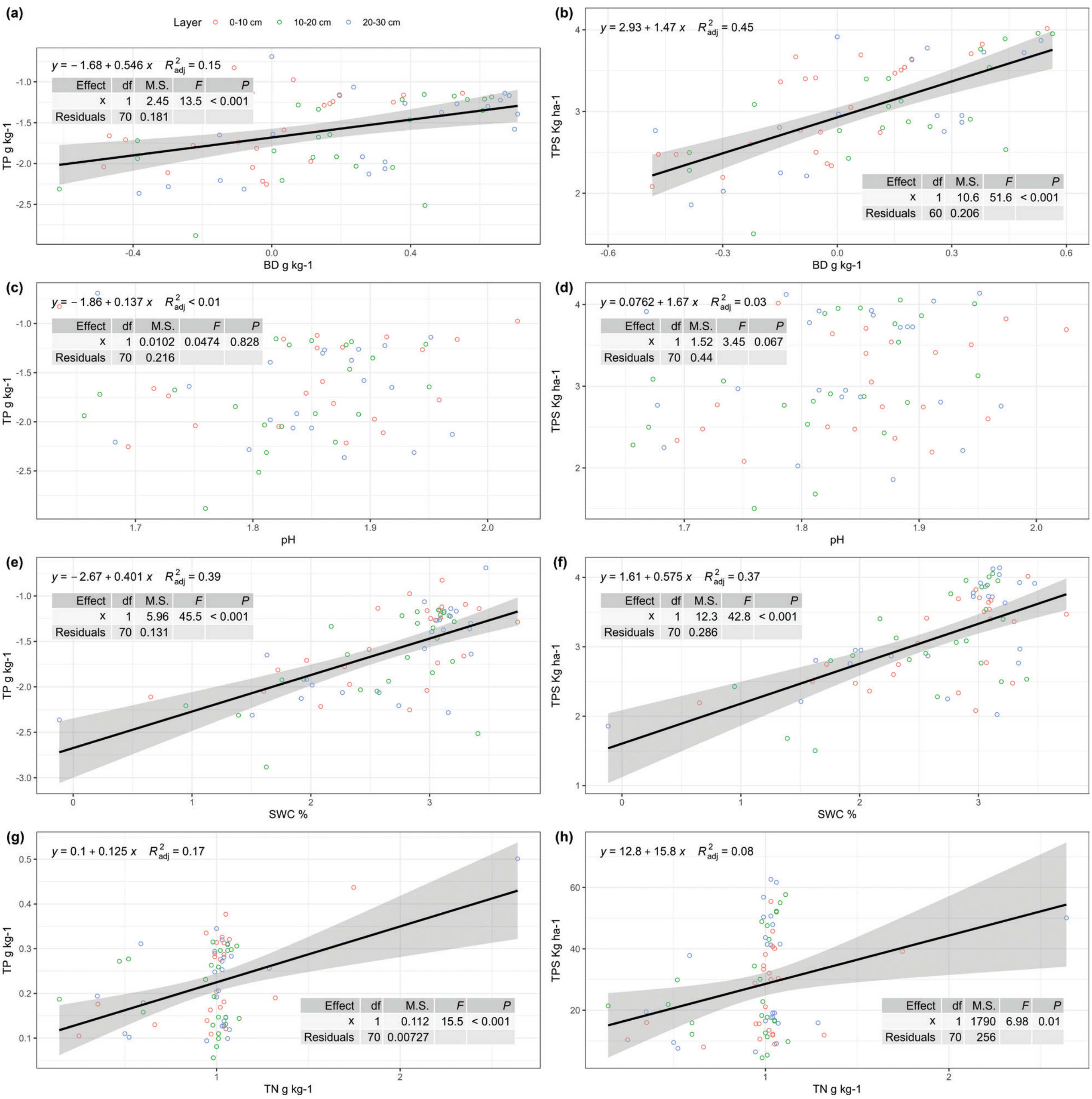

Figure 3. Regression analysis between soil total phosphorus and other soil properties. Note: BD, bulk density; pH, soil pH value; SWC, soil water content; TN, soil total nitrogen; TP, soil total phosphorus; TPS, soil phosphorus stocks; *n* = 72. Values were converted to logarithmic values for (a), (b), (c), (d), (e) and (f).

soil water contents with the value of R^2_{adj} at 0.39 and 0.37, respectively. Similarly, total phosphorus stocks had a significant correlation with bulk density with 0.45 of the R^2_{adj} compared to the R^2_{adj} value 0.15 for TP. However, no obvious correlation was found between pH and TP or total phosphorus stocks.

Results of RDA analysis of soil TP

The variance inflation factor (VIF) of all soil parameters showed in Table 2 were less than 2, indicating a very low possibility of multicollinearity amongst soil water content, total nitrogen contents, bulk density and pH. For soil TP, soil water content had the highest individual importance (59.3% of the total R^2,

Table 2). The total unique contribution of predictor was 53.3% (38.9% + 14.4% = 53.3%). The order from high to low was soil water content (25.3%), total nitrogen (13.3%), pH (0.7%) and bulk density (-0.4%). The F value of the TP predictive model was 21.25 (p < 0.001). For total phosphorus stocks, bulk density had the highest individual importance (59.5% of the total R^2), followed by soil water content at 28.3%, total nitrogen at 6.9% and pH at 5.5% (Table 2). The total unique contribution of predictor was relatively high (78.0%, 38.8% + 39.2% = 78.0%). In order from high to low was bulk density (25.0%), soil water content (9.6%), total nitrogen (3.7%) and pH (0.4%). The F value of the total phosphorus stocks predictive model was 63.76 (p < 0.001).

Discussion

In this study, both soil TP and total phosphorus stocks of the two sampling sites were significantly different with the value of Slope 2 much higher than that of Slope 1 where the slope was higher. One possible reason could be attributed to different soil water content, as soil water content had obvious relationships with soil TP and total phosphorus stocks in this study. This was similar to previous studies on grassland where soil water content had a significant and positive relationship with soil TP (He et al. 2018) and strongly impacted the soil phosphorus pool in the sandy acid sulphate soil (Mayakaduwage et al. 2021). What's more, this was consistent with the RDA analysis that soil water content had the highest individual effect on soil TP compared to other soil properties. Another possible reason could be bulk density, which is an index of soil compaction, as soil bulk density had significant correlation with both soil TP and total phosphorus stocks. This was consistent with a previous study on continental monsoon climate grassland ecosystems (He et al. 2018) and our RDA analysis that bulk density had the highest individual effect on soil total phosphorus stocks followed by soil water content.

The deep soil was excavated to create ditches with a two-sided steep slope before afforestation on the abandoned ponds at Slope 1, where TP and total phosphorus stocks were both lower. This indicated that the higher slope could cause low soil phosphorus, which was consistent with previous studies in the forest system (Karamian and Hosseini 2015; Kumar et al. 2021), agriculture system (He et al. 2019; He et al. 2020b) and simulation experiments in rocky slope protection (Chen et al. 2013). One possible reason could be that it is much harder for water to absorb into a steep slope as soil phosphorus loss increased with increases in slope gradients (He et al. 2020a; He et al. 2020b; Hou et al. 2022). The higher slope increased soil erosion risk and soil phosphorus losses with surface runoff, leading to less soil phosphorus accumulation (Zhang et al. 2018b; Xu et al. 2022). Furthermore, the bulk density of Slope 1 was much lower, which could be attributed to less soil water content. Soil could be less compact under dry rather than moist conditions. Hence, the lower soil water content and bulk density of Slope 1 could be a result from a steeper slope, leading to less TP and total phosphorus stocks accumulation.

Compared to similar studies, TP of Slope 1 was lower than that of West Donting Lake and Songnen Plain study sites where there were ditches with steep slopes (Suppl. material 2). The plantation of poplar in this study was larger than that in Donting Lake, indicating that soil TP might decrease with the increasing of plantation age at a steep slope site. However, data in this field are still lacking. It is suggested that future studies are needed on soil TP afforestation on different slopes.

A previous study suggested that afforestation enhanced soil TP accumulation by vegetation restoration (Zhao et al. 2015) and the authors agree with this argument. However, our result highlighted that soil water content could be another vital factor of afforestation and high slope gradients may offset the effect of afforestation/vegetation restoration on soil TP accumulation. Additionally, N:P at Slope 1 was much higher than that of Slope 2, indicating there could be a phosphorus limitation that hinders tree growth because phosphorus is one of a necessary elements for plants (Elser 2012). Hence, phosphorus limitation could have a negative effect on TP accumulation by vegetation restoration. It is recommended that afforestation on flat rather than steep-sloped lands and avoiding drainage could help to decrease a potential risk of terrestrial soil phosphorus loss and eutrophication from afforestation systems to other ecosystems.

Overall, our results confirmed that low soil water content and steep slopes could be attributed to the low soil TP and may have contributed to the higher soil phosphorus loss risk at Slope 1. Hence, it could be necessary to improve soil water properties by afforesting on flat gradient land or decreasing the steepness of the slope before afforestation, which could be an approach to decrease soil phosphorus loss risks and should be suggested for afforestation on lands similar to Slope 1.

There was no significant difference of soil total nitrogen between the two sites. However, our results confirmed that soil total nitrogen could affect phosphorus cycling, as an obviously positive relationship was found between soil total nitrogen and TP in the present study, which was similar with previous studies on a forest ecosystem where available phosphorus was positively correlated with soil total nitrogen (Lemanowicz 2018) and on warm-humid subtropical monsoon vegetation communities that soil TP on the surface of stone significantly increased with total nitrogen increasing (Wu et al. 2022). Additionally, our results showed that soil total phosphorus stocks increased with soil total nitrogen increases. This was consistent with previous studies where soil phosphorus stocks increased noticeably with soil nitrogen stock increases amongst both different plantation ages up to 50 years (Zhang et al. 2018a; Smal et al. 2019) and soil depth down to 100 cm following afforestation (Zhao et al. 2015). This indicated that soil phosphorus could increase if nitrogen addition was carried out. However, this could lead to a potential soil phosphorus loss risk like at Slope 1, as the higher slope and lower soil water content mentioned above. Hence, it might not be good practice to carry out nitrogen addition at Slope 1 where there was a steep slope. Additionally, it is suggested that any nitrogen addition for the forest management should assess the soil phosphorus loss risk, especially for lands with steep slopes.

Conclusions

Soil bulk density, soil water content, TP, N:P, total nitrogen stocks and total phosphorus stocks all showed significant differences between the two micro-topography sampling sites with different slopes. Higher soil bulk density, soil water content and TP were found at Slope 2 with the flat slope gradient. Both soil TP and total phosphorus stocks strongly correlated with soil bulk density, soil water content and total nitrogen. Soil water content and bulk density had the most important individual effect values at 59.3% for soil TP and 59.4% for total phosphorus stocks, respectively. It is recommended that afforestation on a flat or gentle slope rather than on steep gradient land could be helpful for soil TP or total phosphorus stocks accumulation and decrease soil phosphorus loss risk, when afforestation is used for ecological restoration.

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Additional information

Conflict of interest

No conflict of interest was declared.

Ethical statement

No ethical statement was reported.

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Author contributions

Gang Li: Conceptualisation, Methodology, Investigation, Data curation, Visualisation, Writing-Original draft preparation, Revision; Project administration, Funding acquisition. Shengming Dong: samples. Hao Wang: samples. Yanmei Guan: Samples. Patrick Tyler Deja: Editing and polishing. Wei Nie: Supervisor.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Results of RDA analysis graphic of both soil TP and TP stocks in this study

Authors: Gang Li

Data type: image (Word file)

Explanation note: (a) TP model, total phosphorus model; (b) TPS model, total phosphorus stocks model; TP, soil total phosphorus; BD, bulk density; pH, soil pH value; SWC, soil water content; Individual effect was divided by the adjusted R^2 of each variable found in column Individual importance; n = 72.

Link: https://doi.org/10.3897/natureconservation.53.97873.suppl1

Supplementary material 2

Literature based soil TP at different slopes following poplar and pond cypress afforestation

Authors: Gang Li

Data type: table (Word file)

Explanation note: Lat., latitude; AT, annual temperature; AP, annual precipitation; PA, plantation age; PD, plantation density; SL, soil layer; TN, soil total nitrogen; TP, soil total phosphorus; Ref., reference.

Link: https://doi.org/10.3897/natureconservation.53.97873.suppl2