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Impact of fertilization on chestnut growth, N and P concentrations in runoff water on degraded slope land in South China

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Abstract

Growing fruit trees on the slopes of rolling hills in South China was causing serious environmental problems because of heavy application of chemical fertilizers and soil erosion. Suitable sources of fertilizers and proper rates of applications were of key importance to both crop yields and environmental protection. In this article, the impact of four fertilizers, i.e., inorganic compound fertilizer, organic compound fertilizer, pig manure compost, and peanut cake (peanut oil pressing residue), on chestnut (*Castanea mollissima* Blume) growth on a slope in South China, and on the total N and total P concentrations in runoff waters have been investigated during two years of study, with an orthogonal experimental design. Results show that the organic compound fertilizer and peanut cake promote the heights of young chestnut trees compared to the control. In addition, peanut cake increases single-fruit weights and organic compound fertilizer raises single-seed weights. All the fertilizers increased the concentrations of total N and total P in runoff waters, except for organic compound fertilizer, in the first year experiment. The observed mean concentrations of total N varied from 1.6 mg/L to 3.2 mg/L and P from 0.12 mg/L to 0.22 mg/L, which were increased with the amount of fertilizer applications, with no pattern of direct proportion. On the basis of these experiment results, organic compound fertilizer at 2 kg/tree and peanut cake at 1 kg/tree are recommended to maximize chestnut growth and minimize water pollution.

Key words: chestnut; fertilization; N concentration; P concentration; runoff water; South China

Introduction

N and P are both indispensable and essential nutrients for plant growth. Organic materials such as animal manure and urban organic wastes are being land applied in increasing amounts (Sharpley *et al*., 2001). In addition to organic manures, an excess input of chemical N and P fertilizers into the soil has been observed for several decades (Sharpley *et al*., 1993; Simard *et al*., 1995). However, uptake of nutrients from the soil keeps decreasing. According to Bockman *et al*. (1990), at a global level, 48% of the N-P-K nutrients used by crops in 1970 were derived from the soil, 13% from manure and 39% from inorganic fertilizers. By 1990, the percentages had changed to 30% from soil, 10% from manure and 60% from inorganic fertilizers. The prediction for 2020 is 21% from the soil, 9% from the organic source and 70% from inorganic fertilizers (Ayoub, 1999).

The yearly consumption of chemical fertilizers in China has increased from 16.6×10^6 t in 1983 to 39.8×10^6 t in 1997, and to 46.4×10^6 t in 2004 (MAC, 2005). In the comparatively rich provinces such as Guangdong, Fujian, Zhejiang, and Jiangsu, chemical fertilizers are more heavily applied than in the less developed provinces and regions (Cao, 1998). In addition, livestock and poultry husbandry produced over 17×10^8 t of organic wastes annually. Merely 30%–40% of the wastes are properly treated; the rest are disposed into the neighboring land or water bodies without any treatment. Furthermore, the industrial and household sewage discharge has grown from 12×10^9 t in 1975 to 64×10^9 t in 2003. All these are great threats to soil and water quality.

As just 30%–50% of N fertilizers and 10%–20% of P fertilizers are taken up by the crops in a given season (Ma, 1987), N and P accumulation in the soil caused by excess fertilizer use, inevitably occurs. The nutrient buildup increases potential for surface and/or groundwater pollution and eutrophication (Smith *et al*., 1999). According to Quan and Yan (2002), in China, the paddy soils alone annually contribute 5.94 t N/km^2 to the waters, accounting for 17.5% of the total N loadings in the water bodies. The negative impact of fertilizers on the water quality is likely to grow with time on a national scale.

Because of the increased application of fertilizers and discharges of all kinds of untreated wastewaters, the water

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quality in China continues to deteriorate. The rivers, lakes and reservoirs are all affected by pollutants to different extents (MWRC, 2005). On the basis of monitoring 130 km of 1300 main rivers of China in 2004, in terms of the National Environment Quality Standard for Surface Water (GB3838-2002), 40.6% of the river water is poorer than the class-III water quality and 22% is poorer than class-V. Pollution in Chinese lakes is even worse. Of the 50 lakes monitored, 13 lakes are partially polluted and 19 seriously contaminated (MWRC, 2005). Nutritional evaluations of 49 lakes reveal that 17 lakes are in a mesotrophic state and 32 are in a eutrophic state. Even the reservoirs are partially polluted. In the 332 reservoirs evaluated, 57 have water quality poorer than class-III, accounting for 17.7% of the total reservoirs evaluated, among which 14 have water quality poorer than class-V (MWRC, 2005).

N and P are both nutrients associated with pollution and eutrophication of lakes and rivers (Levine and Shindler, 1989). Surface runoff is one of the most important outlets of N and P loss from soil into the receiving water bodies. Agricultural activities have long been noticed to contribute to the nonpoint source pollution of waters and cause eutrophication (Burwell, 1975; Canter, 1986; Smith *et al.*, 1995). With an increasing amount of fertilizer consumption, the problem of water pollution will inevitably become more serious. Given that many blue-green algae can use N from the air, P is most often the real limiting factor of water eutrophication (Sharpley and Rekolainen, 1997; Withers and Jarvis, 1998). Eliminating P in runoff is believed to be an effective way to control water pollution (Sharpley and Rekolainen, 1997; Withers and Jarvis, 1998). Thus, for prevention of water pollution, it is of great importance to reduce N and P loss via runoff waters in agricultural activities.

Cultivation methods, tillage practices and soil properties are all documented to have obvious impacts on N and P concentrations in surface water (Richardson and King, 1995; Pote *et al.*, 1999; Yuan *et al*, 2002; Abdul *et al.*, 2003; Zhang *et al.*, 2003; Markku *et al.*, 2005). Fertilizer types and application rates also significantly affect N and P losses through runoff water in paddy soils or grain fields (Scholefield and Stone, 1995; Zheng *et al.*, 1999; Zhang *et al.*, 2003; Duan *et al.*, 2004).

South China is referred to as the region covering Guangdong, Guangxi, and Hainan provinces. The annual precipitation is 1500–2000 mm and the annual sunshine time is about 1800 h. The original natural vegetation has been destroyed by agricultural and forestry practices. Slope lands account for a considerable proportion of the total cultivated lands. Fruit growing is a dominant agricultural system on the slope. Organic manures and chemical fertilizers are applied in large amounts in the orchards. With hot and humid climate and intensive cultivation, soil erosion is serious. However, the N and P loss from soil via runoff waters from fruit orchards is rarely reported.

The major objective of the present study is to evaluate the impact of the four fertilizers, i.e., inorganic compound fertilizer, organic compound fertilizer, pig manure compost and peanut cake on the total N and total P concentrations in the runoff waters on the agriculturally degraded slope lands in South China. Influences of fertilizers on chestnut growth and yields are also studied. The practical expectation is to seek a suitable type of fertilizer and to recommend a rate of application for the desirable growth of chestnut and prevent water pollution.

1 Materials and methods

1.1 Experimental site

The experiments were conducted in a Chinese chestnut (*Castanea mollissima* Blume) orchard in Chuantang Town (24°09′N, 114°55′E), Heyuan City, Guangdong Province, China. The experimental site was in the typical southern subtropical monsoon climate zone with an annual mean temperature of 21.1°C and an annual mean precipitation of 1665 mm. The land is slightly sloping (4°–7°) and intensively cultivated, which is a typical feature of the local orchard fields. The soil is clay loamy lateritic red soil derived from red sandstone. The basic properties of the surface soil (0–20 cm) in the experimental site are shown in Table 1. The land is on the upper reaches of the Xinfeng River, the biggest river flowing into the Wanlu Lake. The lake is one of the largest and cleanest water body in the Guangdong Province and supplies drinking water to the Pearl River Delta cities. So, it is of great significance to protect the lake from pollution.

Table 1 Basic properties of surface soils (0–20 cm) in the experiment site

Parameter	Value	Parameter	Value
Bulk density (g/cm^3)	1.45	Organic matter (g/kg)	13.92
Porosity (%)	45.3	Total N (g/kg)	0.25
Field water capacity (g/kg)	209.2	Available N (mg/kg)	42.46
Clay (<0.01 mm) (g/kg)	395.4	Total P (g/kg)	1.2
Soil texture	Clay loam	Olsen P (mg/kg)	0.54
pH (1:2.5 of soil: water)	4.52		

Soil bulk density, porosity, and field water capacity were determined by the core method (Blake and Hartge, 1986). Soil texture was determined according to the gravimeter method (SSBC, 1987). Soil pH value was determined with a pH-meter at a ratio of 1:2.5 (soil:water). Organic matter was determined by titration after digestion with $K_2Cr_2O_7$-H_2SO_4 solution. Total N was determined by Kjeldahl's method. Available N was determined by 1 mol/L NaOH micro-diffusion method, with addition of the reductant $FeSO_4$-Zn (Lu, 2000). Total P was extracted by digestion in sulphuric acid and H_2O_2, and available P by the Olsen extraction-method, and finally both were determined by colorimetric analysis (Lu, 2000).

1.2 Experimental design

An orthogonal experimental design was used to evaluate effects of different fertilizers and application rates on chestnut growth, total N, and total P concentrations in runoff water. Fertilizer sources studied were inorganic compound fertilizer, organic compound fertilizer, pig manure compost and peanut cake, which were all widely used in South

Table 2 Basic properties of the applied fertilizers in the experiments

Fertilizer	pH	Organic matter (g/kg)	Total N (g/kg)	Total P (g/kg)	Total K (g/kg)
Inorganic compound fertilizer	6.34	-	75.5	33.2	63.2
Organic compound fertilizer	5.58	193	42.2	71.7	8.52
Pig manure compost	6.94	336	8.20	21.5	2.60
Peanut cake	6.35	278	18.4	14.6	32.8

China. Their basic properties are shown in Table 2. An L_{16} (4^5) orthogonal table was chosen for the experiment design. The fertilizers (factors) and application rates (levels) are given in Table 3 and the arrangement of the 16 treatments are shown in Table 4. Each treatment had nine replicates (nine trees) and was arranged in a randomized block design to investigate effects on chestnut growth and yield. The runoff water was collected for three replicates to study the effects of different fertilizers and application rates on total N and total P concentrations in the runoff water. The application rates of each fertilizer were determined according to local practice, with the highest rate slightly higher than the largest amount used by local farmers.

The field experiments were carried out for two years. The first was conducted in 2003, in a three-year-old Chinese chestnut plantation and the second in 2004, in a seven-year-old chestnut plantation immediately adjacent. Planting density of the two plantations was 500 trees/hm^2 with 5 m (row) by 4 m (tree) spacing. The fertilizers were applied at a single time each year in early March using the method of groove fertilization. The groove was dug 10 cm deep, 10 cm wide, and 40 cm long along the contour. During the experiment, the soil surface received no management and was covered with natural grasses and shrubs. The variation in the slopes among plots was negligible.

To investigate total N and total P concentrations in runoff water, each plot (tree) was isolated with a soil-built bank 15 cm high and 10 cm wide. The bank circled the trunk of the tree at a diameter of 1.2 m. The bank was covered with thick plastic film. The film was buried to a depth of 15 cm along the outer edge of the bank, to a depth of 5 cm along the inner edge. At the lowest edge of the bank, a 5-L plastic vessel was installed to collect the runoff water. At the end of an effective runoff event, a water sample from each plot was collected. The samples were stored in dark in an air-conditioned car during traffic, and then preserved at 4°C in a refrigerator in the lab before analysis. Five and six runoff events were successfully collected from April to August for the first and second year, respectively.

Table 3 Studied fertilizers and application rates in the experiments

Fertilizer	Application rate (kg/tree)			
	0	1	2	3
Inorganic compound fertilizer	0	0.5	1	2
Organic compound fertilizer	0	2	4	8
Pig manure compost	0	1.5	3	6
Peanut cake	0	1	2	4

Total N and total P concentrations in runoff water were determined colorimetrically on the unfiltered samples according to the Standard Method (APHA, 1995). Prior to the colorimetry, the sample was digested with $K_2S_2O_8$ solution.

In the first experimental year, the cap breadth and height of the three-year-old trees were measured before fertilization (in January) and at the end of a highly growing season (in August). In the second experimental year, the chestnut yield was also measured, including fruit number per tree, single fruit weight, seed number per fruit, single seed weight and seed weight per tree. The experimental data were arranged with Microsoft excel. The analysis of variance (ANOVA) and the Duncan's multiple range test (DMRT) procedure were done with the statistical software SAS8.0 (SAS Institute Inc., Cary, NC, USA).

2 Results and discussion

2.1 Effects of fertilization on chestnut growth and yield

Field application of fertilizers in chestnut showed that the organic compound fertilizer and the peanut cake significantly promoted the height of the young chestnut trees (Table 5). The peanut cake increased the single fruit weight of the chestnut and the organic compound fertilizer promoted the single seed weight. However, inorganic compound fertilizer and pig manure compost did not result in significant effects on chestnut growth or yield compared to the control (Table 5).

Table 4 The L_{16} (4^5) table–arrangement of the 16 treatments (kg/tree)

Treatment No.	Inorganic compound fertilizer	Organic compound fertilizer	Pig manure compost	Peanut cake	Treatment No.	Inorganic compound fertilizer	Organic compound fertilizer	Pig manure compost	Peanut cake
1	0	0	0	0	9	1	4	0	4
2	0	2	1.5	1	10	1	8	1.5	2
3	0	4	3	2	11	1	0	3	1
4	0	8	6	4	12	1	2	6	0
5	0.5	2	0	2	13	2	8	0	1
6	0.5	0	1.5	4	14	2	4	1.5	0
7	0.5	8	3	0	15	2	2	3	4
8	0.5	4	6	1	16	2	0	6	2

Table 5 Effects of fertilizer application on growth and yield of the chestnut trees

Fertilization level	Inorganic compound fertilizer	Organic compound fertilizer	Pig manure compost	Peanut cake
	Cap breadth (m), 2003 experiment			
3	0.68a	0.73a	0.72a	0.68a
2	0.73a	0.71a	0.75a	0.68a
1	0.76a	0.72a	0.69a	0.74a
0	0.70a	0.71a	0.72a	0.77a
	Height (m), 2003 experiment			
3	0.67a	0.82a	0.64a	0.83a
2	0.74a	0.62b	0.66a	0.60b
1	0.65a	0.69b	0.73a	0.64b
0	0.59a	0.51c	0.62a	0.56b
	Single seed weight (g), 2004 experiment			
3	14.45a	18.50a	15.78a	16.09a
2	15.43a	14.54b	14.56a	15.10a
1	15.44a	14.02b	15.77a	15.31a
0	15.97a	14.20b	15.17a	14.77a
	Single fruit weight (g), 2004 experiment			
3	71.26a	67.18a	74.49a	88.42a
2	71.33a	79.07a	77.16a	66.03b
1	80.21a	76.92a	70.70a	72.80b
0	67.36a	67.00a	67.82a	62.92b
	Seed weight per tree (g/tree), 2004 experiment			
3	3356.4a	3382.6a	2476.5a	2634.9a
2	3554.8a	3583.7a	3695.5a	3185.5a
1	2769.6a	2860.0a	3601.6a	3343.3a
0	2091.6a	1946.2a	1998.9a	2608.8a

In a column, data followed by the same letter are not significantly different at the 5% level according to DMRT.

The height of a young chestnut tree generally increased with increasing the amount of organic compound fertilizer, with the fertilization level 3 resulting in the biggest height growth. The level 3 of the fertilizer also resulted in the greatest single seed weight. The fertilization level 3 of the peanut cake produced significantly higher (P=0.05) height growth of young chestnut trees and single fruit weight than levels 0, 1 and 2. However, the height growth was not significantly different (P=0.05) among levels 0, 1 and 2. Fertilization effects on yield in the present study were observed to be less significant than those on other crops (Scholefield and Stone, 1995; Liu *et al*., 2004). However, it was a rather common occurrence in fertilization experiment in forestry, because many factors can play roles in fruit and seed formations.

2.2 Effects of fertilization on total N and total P concentrations in runoff water

The total N concentrations in the runoff water in the experimental area in 2003 and 2004 were 0.16 to 8.33 mg/L and 0.05 to 7.43 mg/L, with an average of 2.97 mg/L and 2.42 mg/L, respectively. The total P concentrations in 2003 and 2004 were 0.03 to 0.40 mg/L and 0.02 to 0.45 mg/L, with an average of 0.14 mg/L and 0.17 mg/L, respectively. The concentrations were within the municipal sewage treatment discharge standard of China (GB18918-2002), but the total N concentrations by far exceeded 0.35 mg/L, recommended to keep the algal biomass below the nuisance level of 100 mg/m^2 in freshwater (Smith *et al*., 1999). Total P concentrations were also higher than 0.1 mg/L, the generally accepted critical total P concentration for water degradation and eutrophication (Sharpley *et al*., 1996). Because the runoff water quantity should be similar for different fertilizer applications, total N and total P concentrations in runoff water could illustrate the impact of different fertilizers on water eutrophication.

2.2.1 Total N concentration

In the first experimental year (2003), runoff water samples were collected five times from April to August. Statistical analysis showed that total N concentrations of runoff water were significantly affected by different fertilizer applications, except organic compound fertilizer (Table 6). The inorganic compound fertilizer significantly increased total N concentration in each runoff event in contrast to the no-fertilization treatment. The pig manure compost enhanced total N concentrations only in the first runoff event. The peanut cake significantly raised total N concentrations in the fourth runoff event. The organic compound fertilizer, however, produced no significant increase of total N concentration in runoff water during the whole first year sampling season compared to the no-fertilization treatment.

In the second experimental year (2004), the runoff water samples were collected six times from April to August. The fertilization caused significant N concentration increase in runoff water compared to the no-fertilization treatment (Table 6). The inorganic compound fertilizer increased total N concentration in four of the six runoff events. The organic compound fertilizer significantly raised total N in the last three runoff events. The pig manure compost increased N concentration only in the first two runoff events. And the peanut cake increased total N concentrations in the second, fourth and last runoff events.

As far as mean concentration was concerned, all fertilizers significantly (P=0.05) increased total N concentrations in runoff water in the two experimental phases. DMRT revealed that the mean total N concentrations in the surface runoff water of the two experiment years generally increased with an increase in the fertilizer application rate, but the increments were not proportional to the fertilization rate growth. Pig manure compost application at 1.5 kg/tree (level 1) and 3 kg/tree (level 2), peanut cake at 1 kg/tree (level 1) produced no significant effects on total N concentrations compared to the control. Organic compound fertilizer at 2 kg/tree (level 1) resulted in a higher total N concentration than the control, but the difference was small. However, inorganic compound fertilizer application significantly increased total N concentrations even at the lowest application rate.

2.2.2 Total P concentration

According to the ANOVA results, in the first experimental phase (2003), inorganic and organic compound fertilizers increased total P concentrations in runoff water in the first and last runoff events (Table 7). Pig manure and peanut cake significantly enhanced total P concentration in runoff water merely in the last runoff event.

In the second experimental phase (2004), the inorganic compound fertilizer increased total P concentration in

Table 6 Effects of fertilizer application on total N concentrations in runoff water sampled for various dates (mg/L)

Fertilizer	Level	First experimental year (2003)					Second experimental year (2004)						Mean
		Apr. 11	May 13	May 19	June 20	Aug. 15	Apr. 7	May 8	May 27	June 3	July 13	Aug.10	
Inorganic	3	7.24a	5.55a	4.02a	4.53a	4.80a	5.20a	5.46a	1.80a	2.26a	1.50a	2.26a	3.19a
compound	2	5.50b	4.45b	2.64b	3.97b	3.39b	3.23b	3.25b	1.38a	1.69b	1.14b	2.44a	2.45b
fertilizer	1	3.91c	3.59c	1.52c	3.65b	2.35c	2.26c	2.59c	1.34a	1.95ab	1.42ab	2.66a	2.09c
	0	2.11d	1.63d	1.39d	2.08c	1.08d	1.41d	1.56d	1.69a	1.57b	1.08b	2.54a	1.57d
Organic	3	4.52a	4.06a	2.13a	3.47a	2.81a	2.71a	3.17a	1.82a	2.34a	1.73a	4.29a	2.70a
compound	2	4.35a	3.86a	2.23a	3.62a	3.11a	2.86a	3.11a	1.61a	2.10ab	1.32b	2.61b	2.36b
fertilizer	1	4.90a	3.82a	2.00a	3.41a	2.87a	2.66a	3.43a	1.46a	1.72bc	1.16bc	1.78c	2.24b
	0	4.99a	3.47a	2.20a	3.73a	2.81a	2.89a	3.16a	1.32a	1.31c	0.93c	1.23c	2.00c
Pig	3	6.75a	3.89a	2.34a	3.42a	2.98a	3.11a	3.89a	1.89a	2.07a	1.27a	2.73a	2.61a
manure	2	5.06b	3.95a	2.06a	3.37a	2.81a	3.12a	3.43b	1.43a	1.79a	1.34a	2.42a	2.33b
compost	1	3.95c	3.73a	2.17a	3.81a	3.02a	2.69a	2.79c	1.59a	1.75a	1.29a	2.48a	2.28b
	0	2.99d	3.63a	1.99a	3.64a	2.80a	2.18b	2.75c	1.31a	1.86a	1.24a	2.27a	2.09b
Peanut	3	4.56a	3.80a	1.99a	5.57a	2.86a	2.67a	3.49a	1.55a	2.70a	1.45a	3.44a	2.71a
cake	2	4.97a	4.00a	2.23a	4.03b	2.94a	2.72a	3.72a	1.84a	1.72b	1.19a	2.44b	2.44b
	1	4.46a	3.80a	2.19a	2.82c	2.94a	2.88a	2.82b	1.49a	1.83b	1.19a	2.02b	2.13c
	0	4.77a	3.60a	2.15a	1.82d	2.87a	2.83a	2.84b	1.33a	1.23c	1.31a	2.00b	2.02c

In a column and for the same fertilizer, data followed by the same letter are not significantly different at the 5% level according to DMRT.

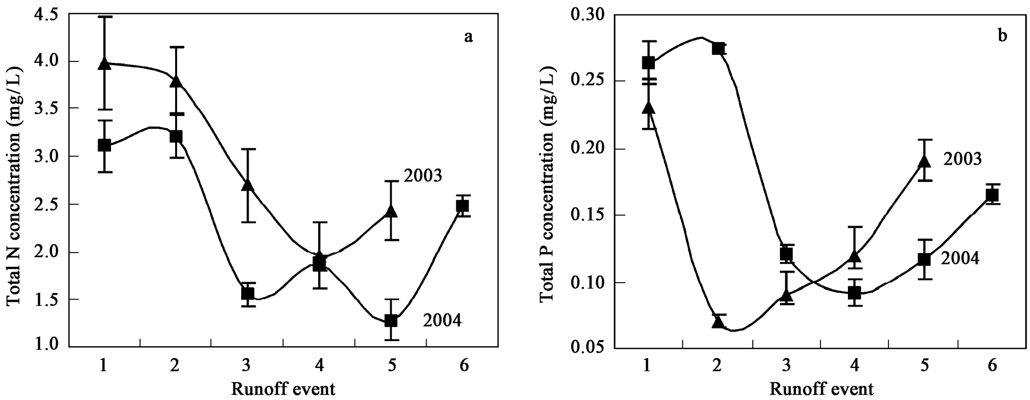

Fig. 1 Dynamics of total N (a) and total P (b) concentrations in runoff water with the successive runoff events.

the first four runoff events. Organic compound fertilizer increased total P concentrations in the second and last runoff events, and had no obvious effects in the other four runoff events. Pig manure compost increased total P concentration in the surface water in the first three runoff events and had no significant effects in the other three. Peanut cake showed the same influence trends as the organic compound fertilizer did.

DMRT results showed that with increasing fertilizer application rates, the mean total P concentrations went up obviously. This was true of almost all the fertilizers applied. The inorganic compound fertilizer did not result

Table 7 Effects of fertilizer application on total P concentrations in runoff water sampled for various dates (mg/L)

Fertilizer	Level	First experimental year (2003)					Second experimental year (2004)						Mean
		Apr. 11	May 13	May 19	June 20	Aug. 15	Apr. 7	May 8	May 27	June 3	July 13	Aug.10	
Inorganic	3	0.157a	0.084a	0.109a	0.191a	0.366a	0.388a	0.342a	0.123b	0.143a	0.135a	0.162a	0.216a
compound	2	0.139b	0.083a	0.106a	0.279a	0.330b	0.333b	0.322b	0.141a	0.096b	0.096a	0.179a	0.195b
fertilizer	1	0.106c	0.075a	0.098a	0.254a	0.308c	0.215c	0.274c	0.117b	0.078b	0.121a	0.158a	0.161c
	0	0.077d	0.067a	0.091a	0.196a	0.287d	0.119d	0.160d	0.103c	0.048c	0.114a	0.163a	0.118d
Organic	3	0.113a	0.064a	0.103a	0.269a	0.379a	0.272a	0.284a	0.120a	0.082a	0.148a	0.305a	0.202a
compound	2	0.116a	0.094a	0.099a	0.267a	0.346b	0.261a	0.289a	0.124a	0.093a	0.126a	0.167b	0.177b
fertilizer	1	0.119a	0.078a	0.099a	0.234a	0.303c	0.262a	0.270ab	0.114a	0.097a	0.091a	0.111c	0.157c
	0	0.129a	0.063a	0.103a	0.249a	0.265d	0.260a	0.256b	0.126a	0.093a	0.101a	0.079d	0.153c
Pig	3	0.175a	0.066a	0.105a	0.260a	0.373a	0.301a	0.304a	0.133a	0.105a	0.131a	0.164a	0.190a
manure	2	0.135b	0.085a	0.128a	0.197a	0.324b	0.273b	0.285b	0.123a	0.099ab	0.096a	0.157a	0.172b
compost	1	0.098c	0.076a	0.137a	0.250a	0.315b	0.232c	0.268b	0.122a	0.086ab	0.132a	0.167a	0.171b
	0	0.070d	0.072a	0.105a	0.215a	0.280c	0.249c	0.241c	0.106b	0.076b	0.106a	0.174a	0.156c
Peanut	3	0.115a	0.066a	0.069a	0.269a	0.389a	0.269a	0.290a	0.123a	0.095a	0.135a	0.236a	0.191a
cake	2	0.113a	0.080a	0.066a	0.219a	0.354b	0.266a	0.280a	0.124a	0.090a	0.112a	0.168b	0.172b
	1	0.128a	0.085a	0.077a	0.198a	0.294c	0.262a	0.271ab	0.122a	0.092a	0.111a	0.150b	0.169bc
	0	0.121a	0.068a	0.082a	0.236a	0.255d	0.259a	0.257b	0.116a	0.093a	0.107a	0.108c	0.157c

In a column and for the same fertilizer, data followed by the same letter are not significantly different at the 5% level according to DMRT.

in obviously higher mean P concentration than other fertilizers at low application rates (level 1), but caused considerably greater P loss than other fertilizers at higher fertilization rates (levels 2 and 3). In addition, pig manure compost at 1.5 kg/tree and peanut cake at 1 kg/tree caused no significant increase in total P concentration over the control. Such a result suggested that organic fertilizer application at low rates had no significant risk to water P pollution. However, with increase of application rates, total P concentrations increased and became significantly higher than the control. Such a trend was observed by Zhang *et al*. (2003), in their experiment evaluating P losses in runoff from paddy soils in the Taihu Lake region.

2.3 Dynamics of total N and total P concentrations in runoff waters

When considering the dynamics of the mean total N and total P concentrations during the whole period of the experiment, both total N and total P concentrations were high in the first or first two runoff events, then dropped sharply, and rose again to a relatively high concentration in the end (Fig.1). This might be the result of the dynamic balance among plant uptake, organic fertilizer decomposition, soil adsorption, desorption and runoff loss. Though concentrations of total N and P exhibited similar change trends, it was observed that in May, June and July, when chestnut and groundcover vegetation prospered, fertilization had no obvious impact on P concentration compared to the control. This was particularly true in 2003, and for organic fertilizers in 2004 (Table 7).

3 Conclusions

Some positive effects of fertilizers on the growth of young chestnut trees were observed with organic compound fertilizer and peanut cake, but the differences in yields were not statistically significant among the rates of application.

The mean concentrations of total N and total P in the surface runoff waters varied from 1.6 to 3.2 mg/L and from 0.12 to 0.22 mg/L, respectively. Application of all the four fertilizers had a significant impact on the mean concentrations of total N and total P in the surface runoff waters within the period of study, except that the organic compound fertilizer had no significant effect on the total N in 2003. The mean concentrations of total N and total P in runoff waters increased with increasing application rates of fertilizers. Total N and total P in runoff were highest in the first or the first two runoff events, and then dropped gradually. At the end, relatively high concentrations of N and P re-emerged.

On the basis of the data of plant growth and measurements of nutrient concentrations in runoff in 2003, organic compound fertilizer and peanut cake would be a good choice for both chestnut growth and water pollution control. A similar conclusion for 2004 can be made in harmony with the results of 2003. In other words, organic compound fertilizer at 2 kg/tree is the best, followed by peanut cake at 1 kg/tree for increasing the growth of chestnut, whereas limiting the losses of nutrients to the water environment by runoff waters.

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