Land-use changes from arable crop to kiwi-orchard increased nutrient surpluses and accumulation in soils

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Abstract

The potential environmental risk associated to nutrient surpluses after changing arable crops to kiwi-orchards was assessed in the Yujiahe catchment of Shaanxi, China. This was achieved by surveying 242 kiwi-orchards and 21 croplands and determining their nutrient inputs and outputs as well as the soil nutrient status for the over 2 years. The total inputs of nitrogen (N), phosphorus (P) and potassium (K) from fertilizers, manures, deposition, and irrigation in kiwi-orchards were 1201, 268 and 615 kg ha^{-1} yr^{-1}, respectively, which were higher than the rates of 425, 59 and 109 kg ha^{-1} yr^{-1} in wheat-maize fields. The mean annual apparent nutrient surpluses in kiwi-orchards were 1081 kg N ha^{-1} yr^{-1}, 237 kg P ha^{-1} yr^{-1} and 491 kg K ha^{-1} yr^{-1}. Within comparison to the croplands, the soil organic matter (SOM) and total N (TN) in the topsoil (0–20 cm) increased in kiwi-orchards, and soil pH decreased. The average contents of Olsen-P, and available K in 0–20 cm soils of the orchards were 86 mg kg^{-1}, and 360 mg kg^{-1}, which were higher than recommended levels. The nitrate-N accumulation in the 0–100 cm and 0–200 cm soil layers in kiwi-orchards were 466 and 793 kg N ha^{-1}, respectively. The high proportion of nitrate-N in deeper soil profiles of kiwi-orchards poses a great risk for nitrate leaching and subsequent ground water pollution. It is concluded that changing arable crops to kiwi-orchards increased the environmental burden of the catchment due to excessive fertilizer application in kiwi-orchards.

Keywords: Kiwi-orchard; Nutrient input; Soil nutrients; Nitrate accumulation

1 Introduction

The agricultural production has increased rapidly since the 1980s in China, greatly reducing food shortages in this populous country (Erismanet al., 2008). This is mainly achieved by increasing crop yield on the same area of land by using synthetic fertilizers, irrigation, and pesticides (Zhang et al., 1996; Fan et al., 2010). At the same time, the rapid growth of China's agriculture comes at a high environmental costs, including emissions of greenhouse gases, loss of biodiversity, and degradation of land and freshwater (Ju et al., 2006; Sutton et al., 2013; Norse and Ju, 2015). Therefore increasing agricultural production while reducing nutrient losses to the environment is a major challenge for China, and other countries with a similar situation.

Nutrient additions to cereal crops in China far exceed those in the United States and Northern Europe (Vitousek et al., 2009; Chen et al., 2014; Davidson et al., 2015). The over-fertilization leads to a reduction in nutrient use efficiency, and an increased risk of environmental pollution (Gao et al., 2012). Ju et al. (2007) reported that substantial mineral nitrogen (N) and available phosphorus (P) and potassium (K) accumulated in the soil and leached down the soil profile.

Furthermore, the concentrations of heavy metals increased in soil due to the excessive fertilizer and manure applications (Ju et al., 2007). Over-fertilization also resulted in soil acidification (Cui et al., 2013) and soil salinization (Patriquin et al., 1993; Gao et al., 2012), which may adversely affect plant growth, production, and crop quality.

In recent years, large areas of conventional cereal production in China have been transferred to growing crops with a high economic value (e.g., fruit trees and vegetables). For example, the area under fruit trees has increased from 1.78 M ha in 1980–12.2 M ha in 2013. These crops are associated with excessive nutrient and irrigation application in comparison to cereal crops (Fan et al., 2010; Qiu et al., 2010). The causes for such bad management practices include the low education levels of the farmers, and not enough research work conducted in regard to rational fertilizer recommendations for fruit trees, so that existing recommendations are inadequate (Ju et al., 2006; Lu et al., 2012).

The kiwifruit (*Actinidia deliciosa*), a species native to the hills and mountains of Central and Southern China, was domesticated for commercial production in New Zealand early last century (Smith et al., 1994). The domesticated kiwifruit has been commercially introduced to the northern slope region of the Qinling Mountains in Shaanxi since the early 1990s. This region has become the most important kiwifruit production belt in China, accounting for 30% of the total kiwifruit cultivation area in the world and 60% of that in China (Sun and Fu, 2009). In comparison to wheat and maize rotation, which was traditionally grown in the region before the 1990s, the kiwifruit orchards have a greater profit. Therefore, since the 1990s, farmers began to shift arable lands (wheat-maize rotations) to kiwifruit orchards, and applied large amounts of fertilizer and manure to ensure high yields. Now, kiwifruit has become the main crop and is an important source of income for local farmers. Therefore it is important to understand the effects of land-use change from arable land to kiwi-orchards on the soil nutrient budget and their potential associated environmental risks.

Yujiahe catchment was selected as a typical representative of intensive kiwifruit cultivation area in Shaanxi province of China. Our specific objectives were: (1) to investigate the nutrient budgets in grain crops and kiwi-orchards, and (2) to evaluate the potential environmental impacts after converting the cropland to kiwifruit orchards.

2 Materials and methods

2.1 Site description and cropping systems

The study site was in the Yujiahe catchment (33°42′–34°14′ N, 107°39′–108°37′ E), Zhouzhi county, Shaanxi province (Fig. 1a), which is located on the northern slope of the Qinling Mountains. It is characterized by a V-shaped gully topography with about 85% of the arable lands on a 2–15° slope (Fig. 1b). The whole catchment covers an area of 412.4 ha. This region is typical of a warm-temperate sub-humid continental monsoon climate with a mean annual temperature of 13.2 °C and an average annual precipitation of 713 mm (from 1957 to 2012), with 61–84% occurring between July and September.

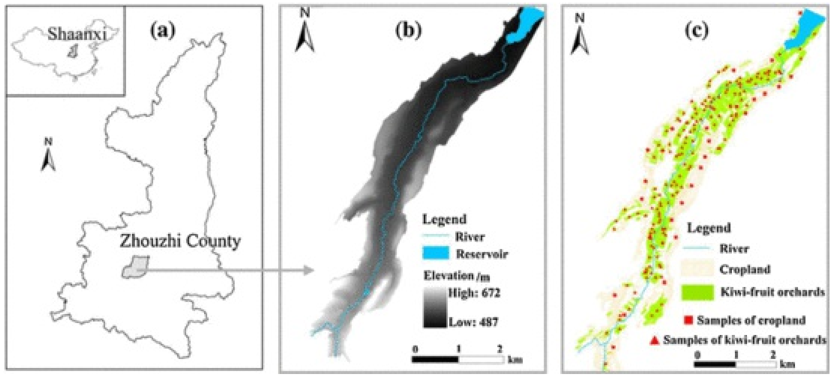

Fig. 1 The location (a), digital elevation model (DEM) (b), land use status, and survey sites of the two cropping systems (c) in Yujiahe catchment.

alt-text: Fig. 1

The main arable crops in the catchment are winter wheat (*Triticum aestivum L.*) and summer maize (*Zea mays L*); and kiwifruit (*A. deliciosa*) vines are main fruit crops. Wheat and maize are sown on sloping land or terraces on the top parts of the catchment, accounting for 20% of the total area of this catchment, where no irrigation system is available and crops depend on rainfall. Winter wheat is usually sown in late September or early October and harvested in early June in the following year; then maize is sown, and harvested in early October. The kiwifruit vines are planted on terraces of the lower parts of the catchment, covering about 40% of the catchment's surface, where they can be irrigated. The kiwifruit vines were mainly established from 1993 to 2010 at a density between 1667 and 2220 vines ha^{-1}. Vines are trained on a T-bar trellis system. Kiwifruit is usually harvested in early October. During the winter of each year, fallen leaves are left in the orchards whereas pruned wood is removed from the orchards. Irrigation frequency of kiwi-orchards depends on the precipitation rate and frequency in each year. There are usually 3–4 irrigation events, with an irrigation depth between 100 and 150 mm each time. The mean precipitation, reference evapotranspiration (ET_0), and irrigation in this catchment between 2012 and 2013 are shown in Fig. 2. The irrigation water in the catchment is pumped from the wells with a depth of 80–200 m. To evaluate the water quality, a total of 19 groundwater samples were taken during the irrigation season in 2015, and water samples were stored in a fridge at 4 °C for analysis. The concentrations of NO_3^--N and NH_4^+-N were measured by a continuous flow analyzer (Bran and Luebbe AA3, Norderstedt, Germany). The concentrations of Ca^{2+}, Mg^{2+}, K^+ and Na^+ were measured by an atomic absorption spectrophotometer (Z-2000, ICP-AES). The information about water quality is shown in Table 3.

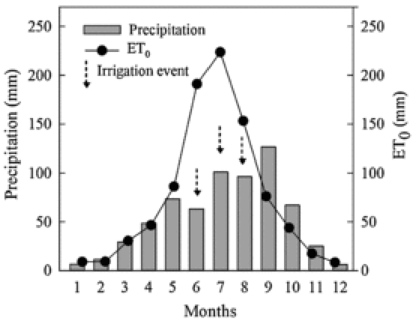

Fig. 2 Mean monthly precipitation, reference evapotranspiration (ET_0), and irrigation amount over 2012 and 2013 years in this catchment.

alt-text: Fig. 2

2.2 Survey and sampling

To evaluate nutrient inputs and outputs in wheat-maize croplands and kiwi-orchard systems, A total of 242 kiwi-orchards were surveyed in 2012 and 2013, and 21 wheat-maize croplands were surveyed for the period of 2012–2013 (Fig. 1c). The information surveyed included the area of the field, the types and the rates of inorganic and organic fertilizers applied, the age of the kiwifruit vine and fruit yields, and the total biomass of wheat and maize (including grain and straw). The main inorganic fertilizers used in the two systems were urea, ammonium bicarbonate, superphosphate, ammonium phosphate, potassium sulfate and various compound fertilizers. The main types of manure used by local farmers are chicken, cattle, swine and farmyard manure. To estimate nutrient inputs from the different manures, total N, P, and K concentrations in the different manures, including chicken manure, cattle manure, swine manure, and farmyard manure (mixtures of manure and loess) were analyzed according to the methods of Gao et al. (2012). The nutrient contents of the manures in this study are listed in Table 1.

Table 1 Nutrient concentrations (with standard deviation in brackets) of the different manures (dry weight).

alt-text: Table 1

Manure	N (g N kg^{-1})	P (g P kg^{-1})	K (g K kg^{-1})
Chicken manure (n = 6)	25.30 (8.81)	11.06 (2.75)	16.18 (0.96)
Cattle manure (n = 6)	16.28 (2.93)	4.54 (0.36)	12.78 (1.97)
Swine manure (n = 6)	24.65 (7.82)	8.83 (0.65)	17.01 (7.17)
Farmyard manure (n = 7)	2.17 (0.97)	0.85 (0.49)	5.64 (1.26)

A total of 70 mature kiwi-orchards (8–15 years old) from the investigated above and all investigated croplands were selected to take soil samples in early October 2012, after kiwifruit and maize were harvested. Soil profile samples were collected from three locations down to 200 cm depth in 20 cm intervals at each of the selected kiwi-orchards and wheat-maize fields. And the three sites were randomly selected for the fields with relative flat terraces; for sloping land, the three sites were selected from upper, central and bottom part of the fields. The triplicate samples were mixed to obtain a composite sample from each soil depths and placed in labelled plastic bags, sealed and stored immediately at 4 °C.

To calculate nutrients in fruits, 46 orchards were randomly selected out of the above 70 kiwi-orchards for sampling during harvesting in early October 2013. Nutrient concentrations were analyzed from between 10 and 15 fruits which were taken from each of the 46 orchards. The all pruned branches in 27 kiwi-orchards out of the above 46 orchards were collected and weighed, sampling the mixed branches to analyze their nutrient concentrations during the winter pruning. The nutrient concentrations in grains and straws of wheat and maize were from a field experiment of ours in the catchment during the 2012–2013.

2.3 Sample analyses

Fresh soil was extracted with 1 mol L^{-1} KCl (soil: solution ratio, 1:10) by shaking for 1 h to determine the concentrations of NH_4^+-N and NO_3^--N using a continuous flow analyzer on the extracts (Bran and Luebbe AA3, Norderstedt, Germany). The moisture of the fresh soil samples was measured gravimetrically by drying soil at 105 °C. Soil was air-dried, ground and passed through 1 mm and 0.15 mm sieves for the measurement of soil organic matter (SOM), total N (TN), Olsen-P, available K, and pH. SOM was measured with the dilution heat $K_2Cr_2O_7$ oxidation volumetric method, TN by the Kjeldahl method, soil pH in water with a 1:2.5 soil to water ratio, available P (Olsen-P) by extraction with 0.5 mol L^{-1} $NaHCO_3$, and available K by extraction with 1 mol L^{-1} NH_4OA_C.

Soil bulk densities (BD) were measured in 20 cm intervals to a depth of 60 cm from 3 orchards and wheat-maize fields. In each of the selected orchards and fields a profile was selected in the upper, central and bottom slope resulting in a total of 9 BD measurements for each agricultural system. The BDs of 60–200 depths was considered the same as for 40–60 depths due to the small variations for deep soils (Yang et al., 2015). The mean BDs in 0–60 soil depths at the interval of 20 cm were 1.28, 1.42, and 1.43 g cm^{-3} for the kiwifruit orchards, and 1.37, 1.45, and 1.47 g cm^{-3} for the wheat-maize field.

The plant samples were cut into pieces, dried at 60–70 °C, crushed into powder (particle size: 0.25 mm), weighted and then digested with H_2SO_4 and 30% H_2O_2. Nitrogen was measured by the Kjeldahl method, P was determined colorimetrically the ammonium–vanadate–molybdate method (Gericke and Kurmies, 1952), and K was measured by Atomic absorption spectrophotometer (Z-2000, ICP-AES). The nutrient concentrations of plant materials are shown in Table 2.

Table 2 Nutrient concentrations (with standard deviation in brackets) of different plant organs in the two systems (dry weight).

alt-text: Table 2

Nutrients	Kiwifruit vine		Winter wheat		Summer maize	
	Fruit (%)	Pruning (%)	Grain (%)	Straw (%)	Grain (%)	Straw (%)
Nitrogen (N)	0.86 (0.10)	0.76 (0.09)	2.54 (0.15)	0.61 (0.05)	1.38 (0.03)	0.75 (0.08)
Phosphorus (P)	0.29 (0.04)	0.10 (0.04)	0.25 (0.06)	0.024 (0.007)	0.32 (0.06)	0.16 (0.02)
Potassium (K)	1.43 (0.18)	0.69 (0.11)	0.40 (0.03)	0.86 (0.12)	0.31 (0.02)	0.79 (0.09)

2.4 Calculation of nutrient inputs and outputs

Nutrient apparent balance in soil was calculated by the following formula (Ju et al., 2006):

Apparent nutrient surplus = input components (chemical fertilizer + manure + seed + deposition + irrigation) − output components (nutrient removal by straw and grain).

Nutrients input from chemical fertilizers or manure were estimated by multiplying their application rates by the actual concentrations of nutrients. Furthermore, nutrient inputs from wet and dry deposition were assumed to be 29 kg N ha^{-1} yr^{-1} based on the results from Liang et al. (2014) in the two cropping systems. N input by irrigation was not considered in wheat-maize rotations because no irrigation was applied. As for kiwi-orchards, N input by irrigation (41 kg N ha^{-1}) was considered in the budget, but the input of P and K were ignored because of their low contents (Table 3). N input from wheat and maize seeds was 5.40 kg ha^{-1}, while the amount of P and K were negligible (Table 2).

Table 3 The characteristics (with standard deviation in brackets) of the 19 samples of irrigation water from deep well (depth of 80–200 m) in this catchment.

alt-text: Table 3

Well depth (m)	NO_3^--N (mg/L)	NH_4^+-N (mg/L)	PO_4^{3-}-P (mg/L)	K (mg/L)	EC (µs/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	pH
80–200	7.32 (6.01)	0.10 (0.04)	0.081 (0.035)	1.15 (0.53)	544.26 (122.97)	83.56 (21.01)	16.10 (3.79)	18.46 (1.26)	8.10 (0.40)

The gross nutrients output included nutrients removed by fruits at the harvest stage, the pruning in winter, and nutrients from the increased biomass of vines in kiwi-orchards. Nutrients removal by fruit harvest were estimated by multiplying nutrient concentrations in fruit (dry weight) by the fruit yields and the water contents. The uptake of nutrients by branches and roots after the growing season were estimated using the average results (37.1 kg N ha^{-1} yr^{-1}, 8.7 kg P ha^{-1}, and 9.0 kg K ha^{-1}) of mature kiwifruit vines for this study region from Wang et al. (2010). Nutrients in pruned branches were calculated by multiplying their concentrations (dry weight) by their total weight and water contents. Nutrient outputs by the removal of grain and straw for wheat and maize were calculated according to their nutrient concentrations and the biomasses. The fallen leaves in orchards and residual straw in cropland are returned to the system and therefore were not considered within the budget.

2.5 Statistical analysis

The data was analyzed using Microsoft Excel 2007. Figures were drawn in Origin 9.0. The difference of fertilizer inputs, soil nutrient concentrations, soil pH, and mineral-N accumulations within the soils between the two cropping systems were analyzed using the Duncan multiple comparison test (SSR) at the 1% and 5% level in SAS software version 8.1.

3 Results

3.1 Nutrient input and output

The additions of manures and inorganic fertilizers in each cropping system were very variable among individual fields (Table 4). About 65% of the investigated kiwi-orchards received manures; manure was not applied to any wheat-maize fields. The annual average N, P and K inputs from chemical fertilizers and manures in the kiwi-orchards were all significantly higher than those in the wheat-maize system ($P < 0.01$). Inorganic fertilizers were the main source of nutrients in kiwi-orchards, contributing 74.2% of the total N input, 62.7% of the total P input and 72.5% of the total K input.

Table 4 Comparisons of nutrient inputs of inorganic fertilizers and manures in kiwi-orchards (in 2012–13) and wheat and maize system in 2013.

alt-text: Table 4

Cropping system	No. of Sites	Descriptive statistics	Yield [a] (t ha^{-1} yr^{-1})	Inorganic fertilizer (kg ha^{-1} yr^{-1})			Manure (kg ha^{-1} yr^{-1})		
				N	P	K	N	P	K
Kiwi- orchards	242	Average	36.8	891	168	446	240	100	169
		Range	9.8–75.0	94–3991	0–1052	0–1591	0–739	0–456	0–873
		SD	11.9	274	77	169	203	86	143
Wheat-maize	21	Average	8.2	391	59	109	0	0	0
		Range	5.3–12.0	211–739	31–160	0–249	0	0	0
		SD	2.2	134	26	54	0	0	0
Significance				**	**	**			

** Significant differences ($P < 0.01$) between the two cropping systems.

[a] Kiwifruit yields expressed as an annual fresh fruit weight yield, and the grain yields of wheat and maize on an air-dry basis.

Nutrients outputs in kiwifruit orchards were far less than the total nutrients inputs (Table 5, $P < 0.01$). The amount of N, P and K outputs in kiwi-orchards was 120 kg N ha^{-1}, 31 kg P ha^{-1} and 124 kg K ha^{-1}, accounting for only 10.0%, 11.6% and 20.2% of the total inputs. The amount of N, P and K outputs in wheat-maize rotations was 220 kg N ha^{-1}, 31 kg P ha^{-1} and 98 kg K ha^{-1}, accounting for 51.8%, 52.5% and 89.9% of the total inputs, respectively. In comparison to the wheat-maize system, very large surpluses of N, P and K were found in the kiwi-orchards.

Table 5 Average values (with standard deviation in brackets) for annual apparent nutrient balances in the kiwi-fruit orchard and wheat and maize systems in kg ha^{-1} yr^{-1}.

alt-text: Table 5

Nutrients	Inputs [a]		Outputs [b]		Surpluses[c]	
	Kiwi-orchards	Wheat-maize	Kiwi-orchards	Wheat-maize	Kiwi-orchards	Wheat-maize
Nitrogen	1201 (285)	425 (134)	120 (22)	220 (32)	1081 (274) A	205 (49) B
Phosphorus	268 (89)	59 (26)	31 (6)	31 (7)	237 (76) A	28 (5) B
Potassium	615 (182)	109 (54)	124(36)	98 (22)	491 (169) A	11 (8) B

[a] Inputs from chemical fertilizers, manures, deposition, irrigation and seeds.

[b] Outputs in kiwi-orchard referred to the removal of fruit harvest (53.3 ± 21.3 kg N ha^{-1}, 17.9 ± 7.2 kg P ha^{-1}, 88.6 ± 35.5 kg K ha^{-1}), pruning in winter (29.2 ± 6.8 kg N ha^{-1}, 3.9 ± 0.9 kg P ha^{-1}, 26.5 ± 6.2 kg K ha^{-1}), and N of vine

biomass gain during the growth season in mature kiwi-orchards applied as the data from literature (Wang et al., 2010). In wheat-maize fields, outputs referred to the nutrient removal by aboveground (grain and straw) of wheat and maize, which were calculated from the nutrient concentrations in each harvested component and the biomass.

[c] Different uppercase letters for nutrient surpluses in the two systems indicate significant differences at $P < 0.01$.

3.2 Soil organic matter, total N, N stocks, and pH

The contents of SOM and TN at a depth of 0–20 cm were 16.97 g kg^{-1} and 1.20 g kg^{-1} in kiwi-orchards, respectively, which were significantly higher than those in wheat-maize system. Similarly, N stocks in the soil depth of 0–20 cm in kiwi-orchards was also significantly higher than that in wheat-maize fields (Table 6, $P < 0.01$). No significant difference of SOM, TN, and N stocks in the 20–40 cm soil depth was observed between the two systems.

Table 6 Comparison between the two cropping systems in soil organic matter (SOM) and total nitrogen (TN) at 0–20 cm and 20–40 cm depth.

alt-text: Table 6

Cropping system	Descriptive statistics	N stocks (kg ha^{-1})		SOM (g kg^{-1})		TN (g kg^{-1})	
		0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
Kiwifruit orchards (n = 70)	Average	3051	2306	16.97	11.59	1.20	0.81
	Range	1920–4915	3607–1363	10.98–28.73	7.51–19.46	0.75–1.92	0.48–1.27
	SD	566	368	3.81	2.22	0.22	0.13
Wheat-maize (n = 21)	Average	2313	2129	10.66	9.88	0.84	0.73
	Range	1428–3096	1314–2949	7.54–16.01	7.50–12.97	0.52–1.13	0.45–1.01
	SD	511	446	1.93	1.30	0.19	0.15
Significance		**	ns	**	ns	**	ns

**Differences between the two systems in nutrients contents are significant at $P < 0.01$. ns = no significant differences.

The soil pH in 0–20 cm depth was significantly lower in kiwi-orchards than in wheat-maize fields (Fig. 3a, $P < 0.05$); and again there was no significant difference at a depth of 20–40 cm (Fig. 3b).

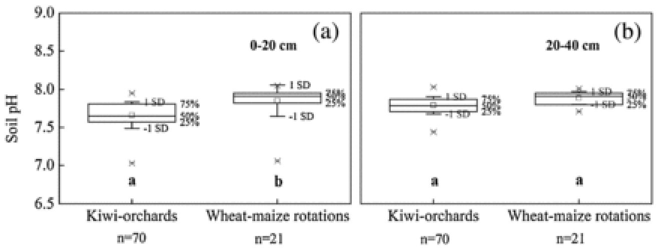

Fig. 3 Box-and-whisker diagrams showing mean, 25, 50, and 75 percentiles and the standard deviation (SD) for soil pH in the 0–20 cm (a), 20–40 cm depth (b) in kiwi-orchards and wheat-maize systems. □ indicates the mean, – indicates the maximum and minimum values, and × indicates the 1st and 99th percentiles. Note: The different bold letters in the same panel indicate significant difference at $P < 0.05$.

alt-text: Fig. 3

3.3 Mineral N accumulation in soil profiles

Nitrate-N concentrations in 0–200 cm soil profiles of kiwi-orchard were significantly higher than in the wheat-maize system ($p < 0.01$) (Fig. 4a). The average amount of nitrate-N accumulated in the 0–100 cm soil depths accounted for 466 kg N ha^{-1} in kiwi-orchards. This value was 5.9 times greater than that in wheat-maize fields (79 kg N ha^{-1}) (Fig. 5a), and accounted for 58.7% of the total nitrate-N in the 0–200 cm soil depths (793 kg N ha^{-1}) (Fig. 5b).

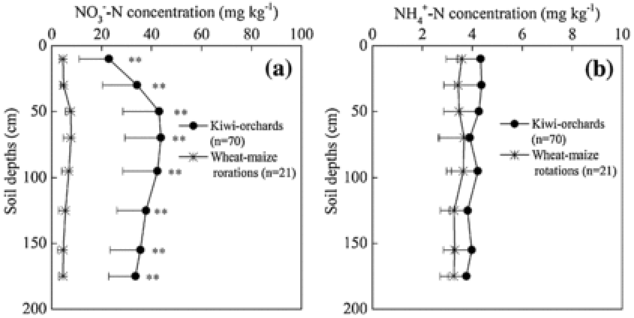

Fig. 4 Distribution of soil mineral–N in the 200 cm profiles of kiwi-orchards and the wheat-maize rotations. Note: "**" indicates that the difference between the two systems in nutrients contents are significant at $P < 0.01$.

alt-text: Fig. 4

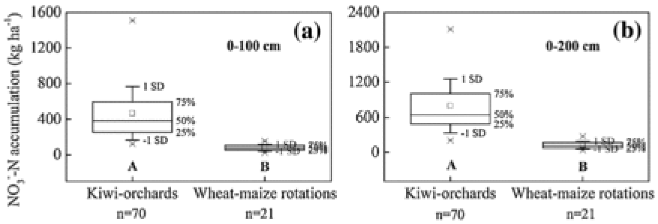

Fig. 5 Nitrate–N accumulation in 0–100 cm (a), 0–200 cm (b) soil depths in kiwi-orchards and wheat-maize systems. Note: box-and-whisker diagrams showing mean, 25, 50, and 75 percentiles and the standard deviation (SD). □ indicates the mean,–indicates the maximum and minimum values, and × indicates the 1st and 99th percentiles. The different bold letters in the same panel indicate significant difference at $P < 0.01$.

alt-text: Fig. 5

The contents of NH_4^+-N in 0–200 cm soil depths were also higher in kiwi-orchards than in wheat-maize fields (Fig. 4b), but their differences was much smaller than the differences in NO_3^--N. The average NH_4^+-N accumulation in 0–200 cm soil depths was 92.0 kg N ha^{-1} in kiwi-orchards, compared to 71.0 kg N ha^{-1} in wheat-maize fields (Fig. 6).

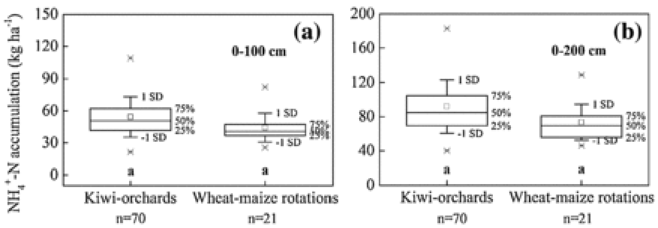

Fig. 6 Ammonium–N accumulation in 0–100 cm (a), 0–200 cm (b) soil depth in kiwi-orchards and wheat-maize systems. Note: box-and-whisker diagrams showing mean, 25, 50, and 75 percentiles and the standard deviation (SD). □ indicates the mean,–indicates the maximum and minimum values, and × indicates the 1st and 99th percentiles.

alt-text: Fig. 6

3.4 Olsen-P and available-K

The contents of Olsen-P in 0–20 cm and 20–40 cm depths of the kiwi-orchards were 87.7 mg kg^{-1}, and 51.5 mg kg^{-1}, respectively. These were significantly higher than those in the wheat-maize system (10.1 mg kg^{-1} and 7.6 mg kg^{-1}, respectively, $P < 0.05$) (Fig. 7a, 7b).

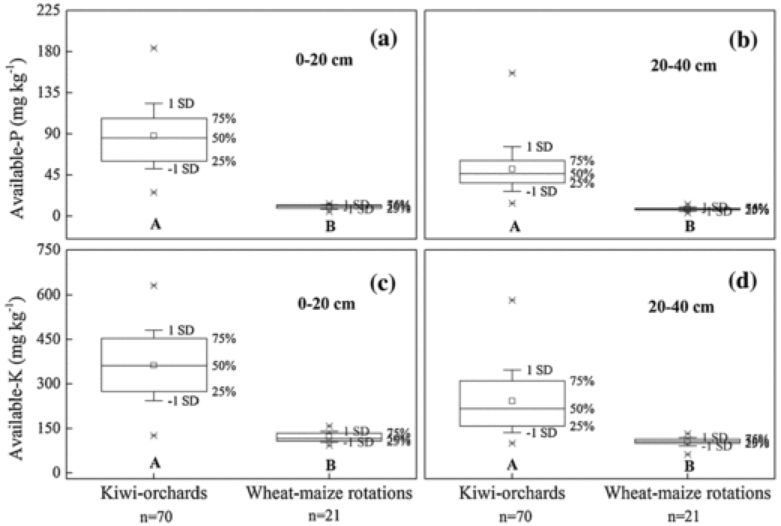

Fig. 7 Concentrations of soil available P (a and b) and available K (c and d) in the 0–20 cm, 20–40 cm soil depths in kiwi-orchards and wheat-maize systems. Note: box-and-whisker diagrams showing mean, 25, 50, and 75 percentiles and the standard deviation (SD). □ indicates the mean,–indicates the maximum and minimum values, and × indicates the 1st and 99th percentiles. The different bold letters in the same panel indicate significant difference at $P < 0.01$.

alt-text: Fig. 7

The available K contents in kiwi-orchards, reaching 361.9 mg kg^{-1} in 0–20 cm and 241.7 mg kg^{-1} in 20–40 cm, were also significantly higher compared to 122.0 mg kg^{-1} and 105.3 mg kg^{-1} in wheat-maize system ($P < 0.05$) (Fig. 7c and d).

4 Discussion

4.1 Nutrient budgets in the two systems

The fertilizer inputs in kiwi-orchards in our investigated catchment averaged 1131 kg N ha^{-1}, 268 kg P ha^{-1} and 615 kg K ha^{-1} (Table 4). The application rates were far more than recommended rates of 350–500 kg ha^{-1} for N, 80–120 kg ha^{-1} for P and 230–290 kg ha^{-1} for K (Lu et al., 2015). In comparison, the fertilizer N, P and K inputs to the wheat-maize fields were 420, 59 and 109 kg ha^{-1}, respectively, which are close to the recommended values (N: 300–400 kg ha^{-1}, P: 50–90 kg ha^{-1} and K: 50–105 kg ha^{-1}) (Zhang et al., 1996; Ju et al., 2006). The excessive fertilization was very severe in kiwi-orchards in this region. Another study in Shaanxi Province also indicated that nutrients overuse in kiwi-orchards were common. For instance, a survey of 766 orchards in Shaanxi Province reported that the overall average annual N input from chemical fertilizer and manure reached up to 927 kg N ha^{-1}, resulting in an N surplus of 876 kg N ha^{-1}. Among the different kinds of orchard, kiwi-orchard exhibited the highest N input rate (1433 kg N ha^{-1}) and the highest N surplus (1187 kg N ha^{-1}) (Zhao et al., 2014).

There are many reasons for nutrient surplus problems for the intensive horticultural systems in China. One reason is that compared to arable crops, intensive horticultural crops usually have a greater profit for farmers. To guarantee their income, farmers usually add more nutrients in organic and inorganic forms to these crops (Gao et al., 2012). Furthermore, there have been few studies related to evaluating sound fertilizer recommendations for kiwi-orchards in this area. Lastly, farmers have very small and fragmented land holdings, which also result in bad nutrient management by impeding technology adoption including mechanization, which are often only viable at greater scales (Smith and Siciliano, 2015).

In the European Union (EU) and the United States strict regulation exists to discourage over-application of manures and chemical fertilizers in agricultural systems. This has been achieved by a variety of legislations and recommendations. For example in the EU, pollution of water bodies by nitrate is specifically regulated by the Nitrate Directive; and a more general protection of the water quality and aquatic ecosystems is by the Water Framework Directive and Marine Strategy Framework Directive. In the USA, the principal federal regulatory includes the Clean Water Act and Safe Drinking Water Act. These regulations have led to significant reduction in N surplus from agriculture over the past decades (Department for Environment Food and Rural Affairs (Defra), 2010; Van Grinsven et al., 2015). However, there is no national or regional legislation in China on governing use of nutrients in manures or synthetic forms on agricultural land to prevent the risk of nutrient losses into the environment. Therefore, comprehensive measures, including technical, economic, and social efforts, are required to solve the nutrient surplus problems in China.

4.2 Environmental effects of land-use change from arable crops to kiwifruit orchard

Land use change from wheat-maize to kiwi-orchards increases the environmental burden considerably as is demonstrated in this study. Generally, the high fertilizer inputs inevitably lead to high nutrient surpluses in the soil, resulting in losses via leaching, runoff and erosion (Ju et al., 2004; Gao et al., 2012). Leaching is a particular issue for nitrate-N, which is highly mobile in soil and can be found at much higher levels in deeper soil layers in fruit orchards compared to wheat-maize fields (Fig. 4a). One major reason for nitrate leaching, of course, is the excessive nitrogen application which was far beyond the need of plants. Thorburn et al. (2003) used ^{15}N techniques to monitor nitrogen concentration of groundwater, and found that 14–21% of the wells in intensive agricultural areas of Northeastern Australia were contaminated with N and nearly 50% N in these wells was derived from N fertilizers. In kiwi-orchards leaching is further aggravated by the fact that the root systems tend to be shallow and the majority (78%) of roots are present in a soil depth of 0–40 cm, 15% at a depth of 40–60 cm and only a few roots at a depth of more than 100 cm (Wang et al., 2010). This facilitates the movement of nitrate out of the root zone. Nitrate leaching is also encouraged by heavy rainfall and excessive irrigation (Gheysari et al., 2009; Sharma et al., 2012; Yang et al., 2015) as is the case in our study region, where the amount of irrigation in kiwi-orchards is very high, with usually between 100 and 150 mm per irrigation event. Additionally, runoff losses of nutrients are further mediated by the slopes of the region. Generally, the assessment of environmental pollution risks associated to runoff was not part of this study and requires further investigation. Equally, atmospheric N losses were not assessed, which will be a considerable pathway for N losses hence contributing to greenhouse gas emissions.

The high accumulation of P in kiwi-orchards means that there is a large reservoir of P available for transfer to water by surface runoff. The “change point” value is usually used to define the potential for transfer of P from soil to water (Haygarth and Jarris, 1999). Heckrath et al. (1995) reported that the “change point” value for Olsen-P was 60 mg kg^{-1}, above which there was a much-enhanced tendency to release P to land drains. The average content of Olsen-P in 0–20 cm soil of the orchards was as high as 86 mg kg^{-1} (Fig. 7a), indicating a high risk for P in the orchards to loss, either by runoff or leaching.

Unlike N and P, the accumulation of K in soils may have no direct negative influence on soil and water environments. However, overuse of K fertilizer wastes nutrient resources, and decreases farmer’s profits. Furthermore, the high K concentration could affect the ion balance in the soil. Some studies have shown that high K concentration can trigger magnesium (Mg) deficiency for crops due to the antagonism between K and Mg (Neilsen and Neilsen, 2011; Chen et al., 2013). Therefore, over application of K fertilizer should also be avoided.

The soil pH (0–20 cm) in kiwi-orchards was significantly lower than the wheat-maize fields, which is related to soil acidification caused by the long-term application of large amounts of N fertilizers and manures in the kiwi-orchards (Guo et al., 2010; Cui et al., 2013).

Generally, it is widely reported that excessive application of fertilizers does not increase crop yield and improve fruit quality (Raese and Drake, 1997; Nava et al., 2008; Dariusz, 2011), but greatly reduces fertilizer use efficiency, resulting in a waste of resources (Zhu et al., 2005; Wang et al., 2011; Yang et al., 2015) and environmental pollution (Ju et al., 2007; Norse and Ju, 2015). It is predicted that without appropriate control measures the situation of over fertilization will become worse as the area under fruits is increasing with time (Fan et al., 2010). Therefore, monitoring soil and water quality is needed to evaluate the long-term impacts of over-application nutrients in the region.

5 Conclusions

Our study indicates that compared to arable lands, the nutrient surpluses in kiwi-orchards was more acute and severe. The N, P, and K outputs by fruits harvest, pruning, and vine absorption only accounted for very low rates as compared to the total nutrients input in kiwi-orchards, and it resulted in high accumulation of nutrients in the orchard soils. Therefore, land-use change from arable crops to kiwifruit orchards in the study catchment increases the environmental burden, especially nitrate leaching and P transfer to the water body. So, there is a need to decrease N and P fertilizer application in the kiwi-orchards. Meanwhile, it is critical to make growers understand the harmful effects of over-application of nutrient on their crops, and environment; and take different measures (e.g., “4R” technology, using controlled release fertilizers) to increase the nutrient efficiency. Our study also confirms that comprehensive measures, including technical, economic, and social ones, are needed to address the excessive nutrient inputs in intensive production systems.

Uncited references

Buttel (2003) and Ribaudo et al. (2001).

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Highlights

- Nutrient budgets of kiwi-orchard and arable crop systems in a catchment were compared.
- Nutrients accumulated in soils of the two systems were determined.
- Very large surpluses of N, P and K were found in the kiwi-orchards.
- High amount of nitrate-N was accumulated in deeper soil profiles of kiwi-orchards.
- Changing arable crops to orchards increased the environmental burden of the catchment.

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