Effects of different fertilizations on fruit quality, yield and soil fertility in field-grown kiwifruit orchard

Zhao Zuoping[1,2,3], Duan Min[1,2,3], Yan Sha[1,3], Liu Zhifeng[1,2,3],
Wang Qi[3], Fu Jing[3], Tong Yan'an[2*]

(1. *College of Chemical and Environmental Sciences, Shaanxi University of Technology, Hanzhong 723001, Shaanxi, China*;
2. *College of Natural Resources and Environment, Northwest A & F University, Yangling 712100, Shaanxi, China*;
3. *Qinba Mountains of Bio-Resource Collaborative Innovation Center of Southern Shaanxi Province, Hanzhong 723001, Shaanxi, China*)

Abstract: Kiwifruit yield and quality and soil nutrients were investigated in a kiwifruit orchard after long-term fertilization to understand the relationship between kiwifruit growth and soil nutrition. Seven fertilization treatments with three replications were applied in a continuous four-year period, including no fertilizer (CK); phosphorus (P) and potassium (K) fertilizers (PK); N and K fertilizers (NK); N and P fertilizers (NP); N, P and K fertilizers (NPK); 1.5 times of N, P and K fertilizers (1.5NPK); and chemical fertilizers plus swine manure (NPKM). Fertilization increased kiwifruit yield at the rate of 450 kg N/hm^2, 225 kg P_2O_5/hm^2, 300 kg K_2O/hm^2. The average yield decreased in a descending order for NPKM (44.6 t/hm^2), 1.5NPK (42.6 t/hm^2), NPK (42.0 t/hm^2), NK (38.0 t/hm^2), NP (36.7 t/hm^2), PK (36.4 t/hm^2) and CK (34.1 t/hm^2). The sugar to acid ratio (S:A) was the highest (10.9) in 2012, and the soluble sugar increased by 15.7% after four-year NPKM fertilization. The NPKM fertilization also significantly increased the vitamin C, soluble solid and firmness. The soil organic carbon contents at 0-20 cm, 20-40 cm and 40-60 cm in depth under the NPKM treatment were 27%, 29% and 139% higher than that of the CK treatment, respectively. The available N contents at 0-20 cm, 20-40 cm and 40-60 cm in depth in the 1.5NPK treatment were 180%, 114% and 133% higher than that in the CK treatment, respectively. Balanced fertilization with N, P, K and organic manure is important to soil fertility, which may increase yield and improve quality in field-grown kiwifruit orchard.

Keywords: different fertilizations, kiwifruit yield, quality, soil fertility
DOI: 10.3965/j.ijabe.20171002.2569

Citation: Zhao Z P, Duan M, Yan S, Liu Z F, Wang Q, Fu J, et al. Effects of different fertilizations on fruit quality, yield and soil fertility in field-grown kiwifruit orchard. Int J Agric & Biol Eng, 2017; 10(2): 162–171.

1 Introduction

China is reported the world's largest producer, consumer and importer of chemical fertilizers, which consumed over 1/3 of the world's chemical fertilizers and accounted for about 90% of the global fertilizer consumption increase since 1981[1]. However, fertilizer use efficiency has been reported to decline continuously in the past four decades. For example, nitrogen use efficiency (NUE) for major cereal crops was reported to range from 28% to 41%, but it was 35% on average in the early 1990s[2]. Currently the average NUE for rice, wheat and maize was only 28% based on field experiments conducted during 2001-2005 across China[3]. The NUE is even lower in the regions with intensive agricultural production. Cui et al.[4,5] reported that only 18% of applied fertilizer was used by winter wheat and 15% by summer maize in the Northern China. Zhu et al.[4-6] reported that only 10% of the applied N was

Received date: 2016-09-06 **Accepted date:** 2016-12-24
Biographies: Zhao Zuoping, PhD, research interest: agricultural environmental protection and crop nutrition, Email: zhaozuoping@126.com; **Duan Min**, PhD, research interest: soil carbon and nitrogen cycling greenhouse gas emissions land reclamation, Email: duanmin0517@163.com; **Yan Sha**, Lecturer, research interest: ecological mathematical model, Email: Yansha6688@126.com; **Liu Zhifeng**, PhD candidate, Associate Professor, research interest: soil microbiology, Email: lzhifeng2005@163.com; **Wang Qi**, Associate Professor, research interest: phytobiology, Email: wangqis6@163.com; **Fu Jing**, PhD, research interest: food safety, Email: 18740661182@139.com.
***Corresponding author: Tong Yan'an**, Professor, research interest: plant nutrition. College of Resources and Environmental Sciences, Northwest A & F University, Yangling 712100, Shaanxi, China. Email: tongyanan@nwsuaf.edu.cn.

recovered in above-ground biomass in hot pepper, and about 52% was lost from the plant-soil system, approximately a loss of over 620 kg/hm^2.

The production of kiwifruit plays an important role in economic development in Shaanxi Province of China. Kiwifruit plantations reached 60 600 hm^2 with a production of 700 000 t/a, which was the highest in China[7]. In those areas, fertilizers are often applied to the soil to increase kiwifruit yield. Zhao et al.[8] reported that N fertilizer application rate averaged 927 kg/hm^2 in the orchard region in Shaanxi Province. The application rates in the orchards were almost 3 times higher than the amount they needed. The nutrient uptakes of total N, P and K by kiwifruit in a kiwifruit orchard with a production of 40.2 t/hm^2 were 217 kg/hm^2, 137 kg/hm^2 and 168 kg/hm^2, respectively[9]. Nearly 95% of the kiwifruit orchards had surplus N, with an average surplus of 876 kg/hm^2. Approximate 58% of the orchards had a N surplus of more than 500 kg/hm^2, while more than 27% of the orchards had a N surplus of more than 1000 kg/hm^2. Among different kinds of orchards, kiwifruit orchards had the highest N input rate and the highest amount of surplus N. Liu et al.[10] reported that N fertilizer application rates averaged 750 kg/hm^2 in apple orchards in Hebei Province. Kou et al.[11] found that the peach orchards had a N surplus of more than 746 kg/hm^2 in Shandong Province. The amount of N surplus was positively correlated with the N application rate in those orchards. High N inputs to orchards led to very high soil N loading.

Overuse and low uptake efficiency of fertilizers, especially N, have resulted in N losses through volatilization as ammonia (NH_3), leaching as nitrate (NO_3^-), nitrite (NO_2) and dissolved organic nitrogen (DON), emissions as dinitrogen (N_2), N_2O, and nitric oxide (NO) during nitrification/denitrification, which have induced a series of environmental problems[12-19]. Tong et al.[20] estimated that the excessive fertilization has lost 0.122 Mt/a in Shaanxi Province through runoff, leaching and emission of N_2O.

This study was conducted to develop sustainable nutrient management practices suitable for field-grown kiwifruit orchard in Shaanxi Province. Annual leaf analysis was required to properly manage the kiwifruit tree nutrition by different fertilizers. The indexes to evaluate kiwifruit quality included soluble sugar, titratable acids, vitamin C, soluble solid, sugar-acid ratio, firmness. Recommendation for rational fertilizer application rates will be given to get the desirable kiwifruit yield and quality based on long-term field experiments.

2 Materials and methods

2.1 Site description

The experiment started in 2008 at Yangling (34°17′51″N, 108°00′48″E), Shaanxi Province, China, which is the main region in this Province for kiwifruit production. The region has a temperate, semi-humid climate with a mean annual temperature of 13°C, annual precipitation of 520 mm and potential evaporation of 1400 mm. The soil is classified as Eum-Orthic Anthrosol (Udic Haplustalf in the USDA system). The soil texture is silty clay loam. Using 10-year old kiwifruit of the 'Qinmei' variety on a rootstock, the kiwifruit trees were planted at 2 m × 3 m spacing. The main properties of the soil (0-60 cm in depth) sampled from the site in September 2008 were presented in Table 1.

Table 1 Soil properties of kiwifruit orchard before fertilization (2008, Oct.)

Soil depth /cm	SOM^a /g·kg^{-1}	Available N^b /mg·kg^{-1}	Available P^c /mg·kg^{-1}	Available K^d /mg·kg^{-1}	pH^e
0-20	13.6	17.5	43.9	246.1	8.2
20-40	7.7	17.0	41.4	105.4	8.1
40-60	3.4	16.3	37.8	88.8	8.2

Note: ^{a}K_2CrO_4 oxidation method; ^{b}2M KCl extracted N; ^{c}$NaHCO_3$ extracted P; ^{d}NH_4OAC extracted K; ^{e}pH instrument.

2.2 Experimental design

The experiment is a randomized block design with three replications. The experiment included seven treatments: (1) no fertilizer (CK); (2) P and K fertilizers (PK); (3) N and K fertilizers (NK); (4) N and P fertilizers (NP); (5) N, P and K fertilizers (NPK); (6) 1.5 times N, P and K fertilizers (1.5NPK) and (7) chemical fertilizers plus swine manure (NPKM). Each plot had 8 kiwifruit trees. Total amounts of N, P, and K applied from inorganic and organic sources to individual tree under each treatment arepresented in Table 2. Urea, calcium superphosphate, and potassium chloride were used as sources of N, P and K, respectively. In the NPKM treatment, the manure was applied at a rate of 15 $t/hm^2 \cdot a$ by dry cattle manure. The manure contained organic carbon 183 g/kg, quick-acting nitrogen 6.61 g/kg, quick-acting phosphorus 4.02 g/kg and quick-acting potassium 4.45 g/kg, on a dry weight basis. The manure was applied as basal fertilizer after kiwifruit harvest every year. Calcium superphosphate, potassium chloride and urea were applied in three times: one-third as basal fertilizer after harvest, one-third in the next spring before sprouting and the remaining one-third at the swollen stage. The total amount of fertilizer applied was the same every year from 2008 to 2012. All the treatments received the same management except for the fertilizer treatments.

Table 2 Treatments applied to kiwifruit trees and corresponding nutrient additions each year from 2008 to 2012

Treatments	Nutrient content/$kg \cdot hm^{-2}$			
	Dry cattle manure	N	P_2O_5	K_2O
CK	0	0	0	0
PK	0	0	225	300
NK	0	450	0	300
NP	0	450	225	0
NPK	0	450	225	300
1.5NPK	0	675	337.5	450
NPKM	15 000	350+100[a]	165+60[a]	235+65[a]

Note: [a]The amount of N/P/K contained in dry cattle manure (The nutrients of N, P and K in dry cattle manure were 6.61, 4.02 and 4.45 g/kg, respectively.)

2.3 Soil and plant samplings and analyses

Leaves of kiwifruit trees in different treatments were collected each month from April to September in 2012. The samples were dried at 105°C and ground to pass through 200 mesh. After digested by H_2SO_4-H_2O_2, total N and P concentrations were determined by Tector 5020 using flow injection analysis machine, while total K concentration was determined by a flame photometry. Kiwifruits in different treatments were collected after harvest in October every year. A total of 100 fruits were picked randomly from each treatment. Soluble sugar, titratable acids, vitamin C, soluble solid and firmness were determined. Each fruit was weighed for yield measurement.

The soil samples were collected at 0-20 cm, 20-40 cm and 40-60 cm in depth from each plot after kiwifruit harvest in October 2012. Three soil cores within each plot were mixed by depth. A total of 63 composite soil samples were collected. Soil samples were dried and sieved (<2 mm) after identifiable crop residues, root material, and stones were removed. The quick-acting N was extracted with 2 mol/L KCl (soil: KCl=1:4) for 1 h and analyzed by Tector 5020 flow injection analysis machine; SOC was determined by potassium dichromate ($K_2Cr_2O_7$) oxidation at 170°C-180°C followed by titration with 0.1 mol/L ferrous sulfate. Quick-acting P were extracted with sodium bicarbonate, and determined by the molybdenum-blue method. Quick-acting K were extracted with in ammonium acetate, and then determined by flame photometry[21].

2.4 Statistical analyses

A one-way analysis of variance (ANOVA) and LSD multiple comparison were applied to examine the statistical significance of responses of kiwifruit to fertilization, and to evaluate effects of fertilization on foliar and soil nutrient concentrations at α value of 0.05. Before performing the ANOVA analysis, the normality of distribution and homogeneity of variance were tested. All statistical analyses were conducted with the SPSS 13.0 software.

3 Results

3.1 Foliar nutrient concentrations

The N concentration in leaves changed with time (Table 3). The N concentration in leaves decreased from May to September for all treatments as a result of internal remobilization. At early stage, the N in the leaves partitioned to roots, stems, and fruits. The N concentration in leaves in the NPKM treatment decreased slowly from May to September, probably because the organic fertilizer supplemented soil nutrients directly in orchard. The N concentrations in the NK, NPK and 1.5NPK treatments were significantly higher than the control treatment (CK) and PK treatment at early stages, and at the late stage the N concentration in the NPKM, 1.5NPK and NPK treatments were significantly higher than the control treatment (CK). There was no significant difference between NPK and 1.5NPK treatment at the same growing period.

The phosphorus concentration in leaves was significantly higher at early stage than that in the late stage. But P concentration decreased from June to July, which could be attributed to internal remobilization. Wang et al.[22] reported that the nutrient uptakes in leaves occurred in the prophase and the amount of nutrient accumulated in kiwifruit tree from spike formation to maturing stage accounted for above 70% of total nutrients absorbed.

The potassium concentration in leaves decreased from May to September, which was due to the internal remobilization. The K concentration was significantly lower in the CK and NP treatmentsthan the other treatments in the same growing period, likely as the fruits need more nutrients at enlargement period. There was no significant difference in K between NPK and 1.5NPK treatment.

Table 3 Nutrient concentrations in leaves after four-year of application in different fertilizer treatments in 2012

Treatments	Nutrient concentrations in leaves/mg·kg^{-1}											
	N				P				K			
	May	June	July	Sep.	May	June	July	Sep.	May	June	July	Sep.
CK	30.29c*	21.70c	18.53c	18.87b	2.04b	1.05c	1.06b	0.81c	14.07b	14.2b	11.80c	6.51c
PK	34.32b	30.19b	21.18b	21.81ab	2.44ab	1.48b	1.01b	0.84c	16.55ab	13.76b	14.00b	8.77b
NK	40.41a	27.50b	26.93ab	21.83ab	2.02b	1.53b	1.46a	0.86c	19.25a	16.31b	14.71b	9.23ab
NP	37.66a	31.54ab	28.61ab	23.65a	2.96ab	1.97a	1.57a	0.96bc	15.69b	14.93b	13.55b	7.07b
NPK	38.48a	28.76b	26.57ab	22.28a	2.56ab	1.60b	1.15b	1.11b	18.79a	15.53b	14.86b	9.01ab
1.5NPK	38.98a	29.86b	26.10ab	24.33a	3.24a	1.54b	1.31a	1.13b	17.86ab	14.42b	14.21b	10.72a
NPKM	34.22b	33.30a	30.41a	22.41a	2.60ab	1.97a	1.41a	2.50a	17.31ab	20.98a	17.8a	10.71a

Note: *Values followed by different letters in the same column indicate significant difference at 5% level.

3.2 Kiwifruit yields

Fertilization increased kiwifruit yields during the four-year period (Table 4). The mean annual yield followed a descending order for NPKM (44.6 t/hm^2), 1.5NPK (42.6 t/hm^2), NPK (42.0 t/hm^2), NK (38.0 t/hm^2), NP (36.7 t/hm^2), PK (36.4 t/hm^2) and CK (34.1 t/hm^2). The yield increased by 6.74% to 30.79% in different fertilizer treatments compared with the control. However, with the extension of experiment, the nutrient-deficient treatments (PK, NK and NP) may lead to a decline in yield compared with balanced nutrient fertilization (NPK). For treatment PK, NK and NP, over four years, the kiwifruit yield averaged less than 40 t/hm^2, and there was no significant difference between them. But for NPK, 1.5NPK and NPKM treatments the average yield reached higher than 40 t/hm^2. There was a significant difference between the NPKM treatment and the other treatments, and the increase trend in the NPKM treatment was relatively stable. It was 30.79% greater in the NPKM treatment than that in the CK treatment. We also found that there was no significant difference between the NPK and 1.5NPK treatments. In other words, the higher fertilizer applied did not promote the yield increase, which maybe attributed to soil quality decline and serious environment problems induced by the excessive fertilization. The highest yield was achieved in the NPKM treatment, which may due to improved soil fertility, such as concentrations of SOC and of macro and micro-nutrients. In contrast, application of chemical fertilizer only increased kiwifruit yields by directly supplying nutrients required for kiwifruit tree growth.

Table 4 Effects of different fertilizations on kiwifruit yields during the year of 2009-2012

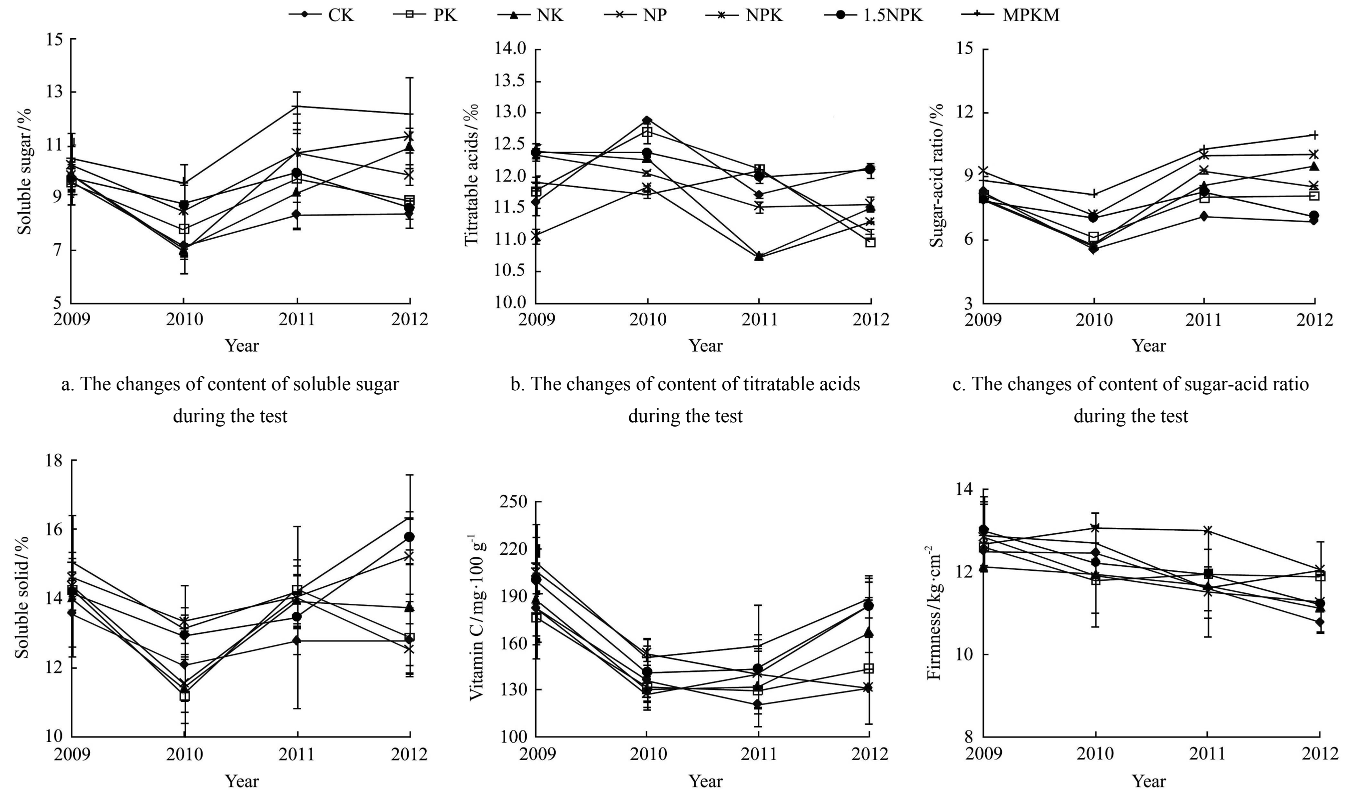
Treatment	Fruit yield/t·hm^{-2}				Average yield/t·hm^{-2}	Increased percentage/%	Average value /10^4 Yuan·hm^{-2}	Fertilization investment /10^4 Yuan·hm^{-2}	Net income /10^4 Yuan·hm^{-2}
	2009	2010	2011	2012					
CK	31.7b	36.8c	37.0c	30.8c	34.1c	—	16.37	0.00	16.37
PK	36.5ab	40.4bc	36.9c	31.7c	36.4bc	6.74	17.47	0.30	17.17
NK	34.7ab	36.8c	41.5b	38.6b	38.0b	11.44	18.24	0.31	17.93
NP	31.4b	36.2c	41.5b	37.8b	36.7bc	7.62	17.62	0.43	17.19
NPK	34.8ab	44.8ab	46.6ab	41.7ab	42.0ab	23.17	20.16	0.52	19.64
1.5NPK	34.9ab	42.7b	44.1ab	48.7a	42.6ab	24.88	20.44	0.78	19.66
NPKM	38.5a	47.7a	47.8a	44.6ab	44.6a	30.79	21.41	1.13	20.28

Note: (1) Kiwifruit price: 4.8 Yuan/kg (2012), price of N, P_2O_5, K_2O and organic manure are 4.78 Yuan/kg, 4.17 Yuan/kg, 7 Yuan/kg and 0.5 Yuan/kg, respectively; (2) The net income analysis does not include other cost except fertilizer cost; (3) Values followed by different letters in the same column represent significant difference at 5% level, and the same below.

The NPKM treatment got the desirable economic benefits, the net income reached above two hundred thousand by subtracting the fertilizer inputsper hectare. Although there was no fertilizer input for CK treatment, the yield was the lowest compared with other treatments, so the economic benefit was the minimum.

3.3 Kiwifruit quality

The rational fertilization could promote the kiwifruit quality (Figure 1). The contents of soluble sugar, soluble solid, vitamin C and firmness in the NPK and NPKM treatments increased over time, which were higher than those in the CK and other treatments (PK, NK and NP) in the same year (Figures 1a, 1d, 1e and 1f). The soluble sugar, vitamin C, soluble solid and sugar-acid ratio of kiwifruits was lower in 2010 compared with in other years, and the titratable acids in all treatments reached the highest in 2010 (Figures 1a-1e). It was mainly because of increasing annual precipitation in 2010. It was greater than 749 mm, especially the rainfall mainly distributed in July and September. After 2010, soluble sugar, vitamin C, soluble solid and sugar-acid ratio remained a steady upward trend in the rational fertilization treatment. The titratable acids in the CK and other treatments were significantly higher than other balanced fertilization treatments in the same year except in 2010.



a. The changes of content of soluble sugar during the test

b. The changes of content of titratable acids during the test

c. The changes of content of sugar-acid ratio during the test

d. The changes of content of soluble solid during the test

e. The changes of content of vitamin C during the test

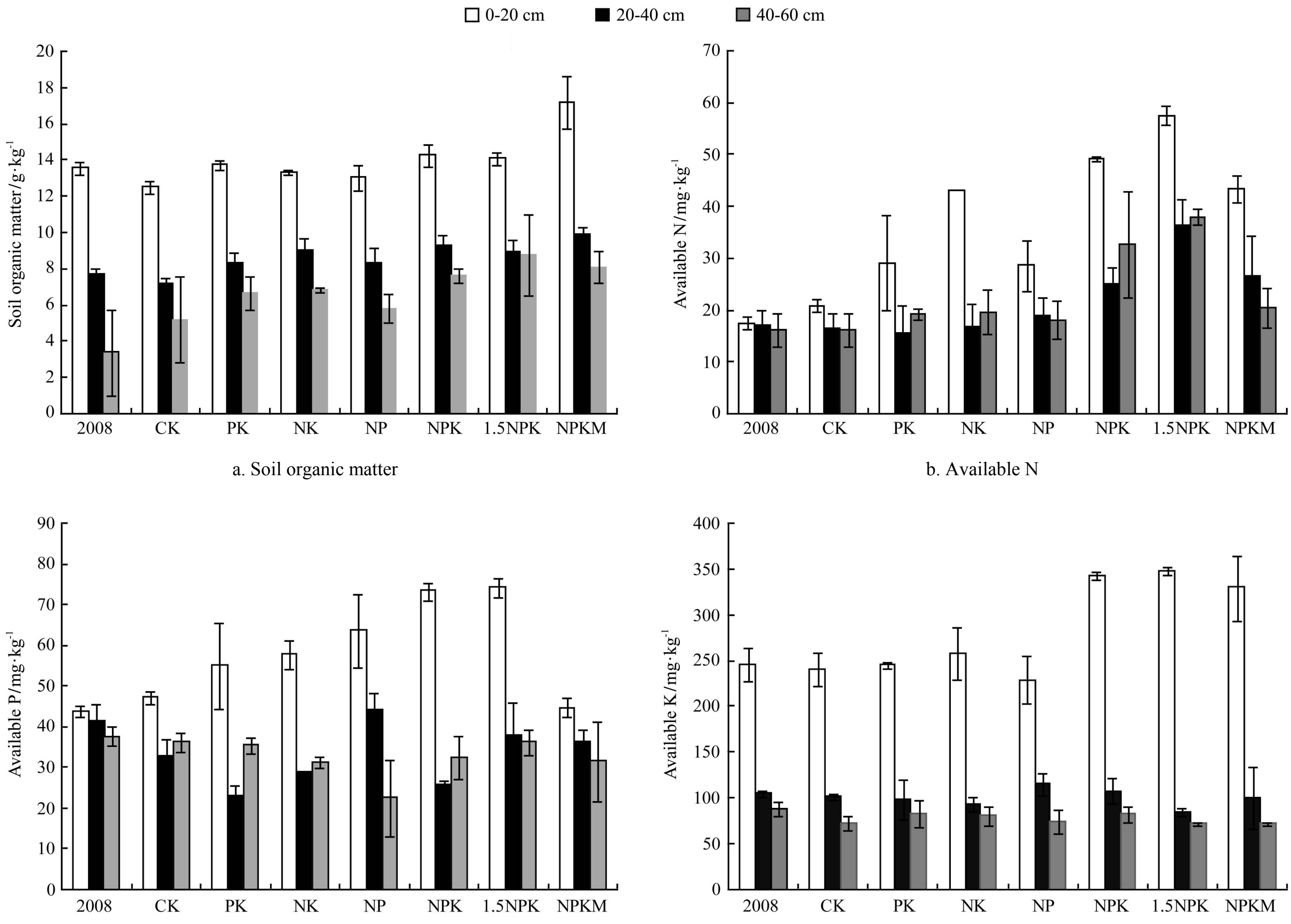
f. The changes of content of firmness during the test

Figure 1 Effects of different fertilization treatments on kiwifruit quality during the four years

The soluble sugar, soluble solid, vitamin C, sugar-acid ratio and firmness were higher in the NPK treatment compared with the NPKM treatment at the beginning of the experiment (Figure 1), but the NPKM treatment showed a steady increase trend during the four years except in 2010. The sugar-acid ratio was highest and reached 10.9 in 2012. The soluble sugar in the NPKM treatment increased by 15.7% after four-year fertilization. We also found that there was no difference of kiwifruit quality between the 1.5NPK and NPK treatments, even though the absolute value was lower in the 1.5NPK treatment. The soluble sugar, soluble solid and vitamin C contents in the CK and NP treatments were lower than those in other treatments in the same year. This is likely because K could promote the transform of starch into sugars, thus K deficiency was not favorable for the improvement of fruit quality. Firmness was an important index for kiwifruit shelf life, but there was no significant difference between the seven treatments. The firmness was higher in the NPKM treatment than in other treatments (Figure 1f). Although it fluctuated during the four-year study, it maintained slightly stable between 11 kg/cm^2 and 13 kg/cm^2 in general.

3.4 Soil organic matter and quick-acting nutrients

The concentration of SOC in different soil layers was affected in the NPKM treatment (Figure 2a). Compared to the soil properties in 2008, the SOC at 0-20 cm, 20-40 cm and 40-60 cm in depth in the NPKM treatment were increased by 27%, 29% and 139%, respectively. The trend was attributed to more C being sequestered in the soil amended with manure than that only chemical fertilizer used. The concentration of SOC was declined by 8% in the CK treatment after four years. No differences were found in SOC concentration throughout the 0-60 cm soil layers among the PK, NK and NP treatments and the soil properties in 2008 (Figure 2a). The lack of significant differences in SOC concentration may be due to low C input and the enhanced fertilizer-induced decomposition of SOC[23]. The NPK and 1.5NPK treatments also enhanced SOC concentration, which could be attributed to more organic matter in the forms of fallen leaves and decomposed roots when more inorganic fertilizers were applied during the four-year period.



a. Soil organic matter b. Available N

c. Available P d. Available K

Figure 2 Effects of different fertilization treatments on the distribution of soil nutrients with depth after four years of the experiment, which was measured in 2012 (Soil depths were 0-20 cm, 20-40 cm and 40-60 cm)

The quick-acting N in soil was significantly increased in fertilization treatments. Compared with the soil properties in 2008, the quick-acting N at 0-20 cm, 20-40 cm and 40-60 cm in depth in the 1.5NPK treatment were increased by 180%, 114% and 133%, respectively. The quick-acting N at 0-20 cm, 20-40 cm and 40-60 cm in depth were increased by 140%, 62% and 26% in the NPK treatment, by 112%, 56% and 25% in the NPKM treatments, respectively. The quick-acting N concentration in subsoil layers was the highest in the 1.5NPK treatment, which indicated that leakage had been taken place. The quick-acting P was significantly increased in the fertilizer treatments (PK, NK, NP, NPK and 1.5NPK) in surface soil compared with the soil properties in 2008. The quick-acting P concentration in surface layers (0-20 cm in depth) increased by 69.7% in the 1.5NPK treatment. However, there was no difference among all treatments in the subsoil layers. The available K showed the same trend as for quick-acting P at 0-20 cm in depth. It was significantly affected by NPK, 1.5NPK and NPKM for four years (Figure 2d). Compared to the soil properties in 2008, the quick-acting K in the NPK, 1.5NPK and NPKM treatments increased by 39.3%, 41.4% and 34.1% at 0-20 cm in depth, respectively, but for NP treatment it decreased by 6.7% at 0-20 cm in depth. There were no differences among all treatments for subsoil layers.

4 Discussion

The results indicated that rational application of fertilizers significantly increased kiwifruit yield, quality and SOC concentration and the available soil nutrients. Zhao et al.[24] reported that with an average production of 40 t/hm^2 kiwifruit, the total N, P and K uptake were about 217 kg/hm^2, 137 kg/hm^2 and 168 kg/hm^2, respectively. In our study, we obtained the high kiwifruit yield and desirable economic benefits with the fertilizer rates of N 450 kg/hm^2, P_2O_5 225 kg/hm^2 and K_2O 300 kg/hm^2. The yield of kiwifruit was up to 44.6 t/hm^2 and the net income reached above ￥200 000 RMB by subtracting the fertilizer inputs when balanced fertilizers and organic manure were applied. Zhong et al.[25] reported that crop yields could be increased to a very limited extent through only chemical fertilizers. They found a significant relationship between grain yields plus straw and soil organic C content, and thus concluded that amendment with organic materials was essential for further improving soil fertility and increasing crop yield. Our results showed that application of organic manure plus balanced fertilizers greatly increased kiwifruits yield. The yield in the NPKM treatment increased by 31% compare with the CK treatment. Application of mineral NPK and 1.5NPK fertilizers also increased kiwifruits yields by 23.2% and 24.8%, respectively. There was no difference between NPK and 1.5NPK treatments for kiwifruit yield. The yield increased by directly supplying nutrients plant required for crop growth. Manna et al.[26] reported that farmyard manure (FYM) and NPK treatments increased crop yields significantly compared with no fertilizer control in a long-term fertilizer experiment. Similar effects of the application of FYM and inorganic fertilizer (INF) on crop yields have also been reported in China[27-29].

Wang et al.[22] reported that the nutrient uptakes in leaves occurred in the prophase and the amount of nutrients in kiwifruit tree were accumulated from spike formation to maturing stage, which accounted for above 70% of total nutrients absorbed. In their study, the N accumulation in leaves increased by 23.01 kg/hm^2 from March 28 to May 18. High P absorption was observed from May 18 to September 8. In our study, the nutrient concentrations in leaves decreased in all treatments from May to September, likely as a result of internal remobilization, partition of the absorbed nitrogen in leaves to roots, stems, and especially fruits. The nutrient concentrations in the NPKM treatment were falling slowly from May to September, which was likely because the organic fertilizer directly supplemented soil nutrients in orchard, adjust the release rate and intensity of soil nutrients.

Some studies have reported that manure application could increase the apple quality, such as the sugar-acid ratio, vitamin C, soluble solid and firmness[30]. In our study, the kiwifruit quality increased by rational fertilizer application. Compared with the beginning of the experiment, the sugar-acid ratio increased by 24.2% in the NPKM treatment. Lai et al.[7] reported that with the application of organic manure plus balanced fertilizers increased kiwifruit quality by 44.8%, probably because the amounts of manure applied in their treatments were higher than that in our study. The same trends in soluble solid and firmness were found, which were greater in the NPK and NPKM treatments than in other nutrient-deficient treatments (PK, NK and NP).

The increased soil nutrient contents can promote the increase of kiwifruit productivity. The results in our study indicated that the concentrations of SOC were significantly increased by the application of organic manure (NPKM) compared with the initial SOC concentration. The soil organic Carbon contents at 0-20 cm, 20-40 cm and 40-60 cm in depth in the NPKM treatment were increased by 27%, 29% and 139%, respectively. These results showed that beneficial effects of manure were not only limited to the surface layer, but also in the subsoil layer. Chen et al.[31] found that the concentration of SOC in conservation tillage management was primarily enhanced in the upper layer, and the concentration of SOC in the subsoil was unaffected for 11 years. However, in our study the concentration of SOC in the subsoil had the greatest increase, which could be attributed to different fertilizing modes. We chose deep placement of fertilizer over 50 cm. Wang et al.[22] reported that the roots of kiwifruit tree were mainly distributed at 60-100 cm in depth, which prompted us to change the original way of fertilizing.

Blair et al.[32] reported that FYM increased concentrations of SOC by 165% compared to those of the control treatment in the broad balk wheat experiment at Rothamsted, UK. Banger et al.[33] observed that a sandy soil amended with FYM contained 36.1% more SOC and 24.4% more TN concentrations at 0-15 cm in depth than soil in the CK under a 16-year rice-cowpea cropping system in semi-arid tropics. Similar beneficial effects of FYM on SOC have been observed in other experiments elsewhere[34-38]. The magnitude of the effects, however, varies depending on the application rate of manure, soil texture, cropping system, climate, and duration of the experiment. Furthermore, the application of chemical fertilizers in the 1.5NPK treatment did not significantly increase kiwifruit yield and quality compared with the NPK treatment, but it could increase the soil quick-acting nutrients. For example, the quick-acting N concentration in subsoil layer had been increased by 133%. This trend indicated that a part of mineral N applied may have been lost via ammonia volatilization (44.1% of applied N), leaching (14.8%), and denitrification (4.4%) in the wheat/maize system on the North China Plain, as was reported by Ju et al.[18]

The stability of kiwifruit yield and quality under nutrient-deficient treatments (PK, NK and NP) was decreased and was easily influenced by the change of climate. The middle and micro-elements, such as magnesium, sulphur andzinc could be absent under application of chemical fertilizer alone. Application of organic manure plus balanced fertilization with N, P and K was propitious to coordinate the balance of carbon and nitrogen pools, and then increased crop productivity[39]. Our study validated that the amendment with organic manure was essential for improving soil organic C content and soil fertility, and in particular for enhancing kiwifruit yields and quality.

5 Conclusions

Continuous application of NPKM for four years significantly increased kiwifruit yield and quality. Concentrations of SOC, quick-acting N, P and K in surface and subsoil layers were significantly increased by the application of organic manure (NPKM) compared with those measured in 2008. Application of chemical fertilizer alone was not sufficient to increase SOC and soil N, P and K relative to those in 2008. There was no significant difference between NPK and 1.5NPK for kiwifruit yield. Thus application of chemical fertilizer combined with organic manure is a rational and feasible fertilization technique in kiwifruit field-grown in Shaanxi Province, China.

Acknowledgements

This work was financially supported by IPNI (International Plant Nutrition Institute), 2011collaborative technology innovation in Shaanxi Province (QBXT-Z(P)-15-5) and Key Laboratory for Agricultural Environment, Ministry of Agriculture Open Foundation (2015). We also thank Dr. Jian Liu at the Swedish University of Agricultural Sciences for constructive comments and linguistic improvement.

[References]

[1] Liu J G, Diamond J. China's environment in a globalizing world. Nature, 2005; 435: 1179–1186.

[2] Zhu Z L. Efficient management of nitrogen fertilizers for floodedrice in relation to nitrogen transformations in flooded soils. Pedosphere, 1992; 2: 97–114.

[3] Zhang Q. Strategies for developing Green Super Rice. Proc. Natl. Acad. Sci., 2007; 104: 16402–16409.

[4] Cui Z, Zhang F, Chen X, Miao Y, Li J, Shi L, et al. On-farm evaluation of an in-season nitrogen management strategy based on soil N_{min} test. Field Crops Res., 2008; 105: 48–55.

[5] Cui Z, Chen X, Miao Y, Zhang F, Schrode J, Zhang H, et al. On-farm evaluation of the improved soil N_{min}-based nitrogen management for summer maize in North China Plain. Agron. J, 2008; 100: 517–525.

[6] Zhu J H, Li X L, Christie P, Li J L. Environmental implications of low nitrogen use efficiency in excessively fertilized hot pepper (*Capsicum frutescens* L.) cropping systems. Agric. Ecosyst. Environ., 2005; 111: 70–80.

[7] Lai Y, Tong Y A, Chen L L, Gao Y M, Yang J F. Effect of fertilization on kiwifruit yield and quality. Journal of Northwest A&F University (Nat. Sci. Ed.), 2011; 39: 171–176.

[8] Zhao Z P, Tong Y A, Liu F, Wang X Y. Assessment of the current situation of household fertilization on apple in Weibei Plateau. Chinese Journal of Eco-Agriculture, 2012; 20: 1003–1009.

[9] Zhao Z P, Gao Y M, Liu F, Wang X Y, Tong Y A. Effects of organic manure application combined with chemical fertilizers on the leaf nutrition, quality and yield of Fuji apple. Acta Horticulturae Sinica, 2013; 40, 2229–2236.

[10] Liu J L, Liao W H, Zhang Z H, Sun J S. The change of soil nutrition and the status of distribution in the apple orchard in the south and central part of Hebei Province. Acta Horticulturae Sinica, 2006; 33: 705–708.

[11] Kou C L, Ju X T, Zhang F S. Nitrogen balance and its effects on nitrate-N concentration of ground water in three intensive cropping systems of North China. Chinese Journal of Applied Ecology, 2005; 16, 660–667.

[12] Jin X C. Lake eutrophication in China, in: Jin X C (Ed.), Lake Environment in China. Oceanic Press, Beijing, China, 1995; pp.267–322. (in Chinese)

[13] Zhang W L, Tian Z X, Zhang N, Li X Q. Nitrate pollution of groundwater in northern China. Agric. Ecosyst. Environ., 1996; 59: 223–231.

[14] Duan S W, Zhang S, Huang H Y. Transport of dissolved inorganic nitrogen from the major rivers to estuaries in China. Nutr. Cycl. Agroecosyst, 2000; 57: 13–22.

[15] Chen J S, Gao X M, He D W, Xia X H. Nitrogen contamination in the Yangtze River system, China. J. Hazardous Mater, 2000; 73: 107–113.

[16] Zhu Z L, Chen D L. Nitrogen fertilizer use in China-contributions to food production, impacts on the environment and best management strategies. Nutr Cycl Agroecosyst, 2002; 63: 117–127.

[17] Li D, Daler D. Ocean pollution from land-based sources: East China Sea, China. Ambio, 2004; 33: 107–113.

[18] Ju X T, Xing G X, Chen X P, Zhang S L, Zhang L J, Liu X J, et al. Reducing environmental risk by improving N management in intensive Chinese agricultural systems. Proc Natl Acad Sci, 2009; 106: 3041–3046.

[19] Miao Y X, Stewart B A, Zhang F S. Long-term experiments for sustainable nutrient management in China: A review. Agron. Sustain. Dev., 2011; 31: 397–414.

[20] Tong Y A, Emteryd O, Zhang S L, Liang D L. Evaluation of over-application of nitrogen fertilizer in China's Shaanxi Province. Scientia Agricultura Sinica, 2004; 37: 1239-1244.

[21] Bao S D. Soil agricultural chemistry. Beijing: China agricultural press, 2000; 302–316.

[22] Wang J, Tong Y A. Study on absorption, utilization and storage of nitrogen of kiwifruit tree. Plant Nutrition and Fertilizer Science, 2008; 14: 1170–1177.

[23] Wu T Y, Schoenau J J, Li F M, Qian P Y, Malhi S S, Shi Y C, et al. Influence of cultivation and fertilization on total organic carbon and carbon fractions in soils from the Loess Plateau of China. Soil Till Res., 2004; 77, 59–68.

[24] Zhao Z P, Yan S, Liu F, Ji P H, Wang X Y, Tong Y A. Effects of chemical fertilizer combined with organic manure on Fuji apple quality, yield and soil fertility in apple orchard on the Loess Plateau of China. Int J Agric & Biol Eng, 2014; 7: 45–55.

[25] Zhong W H, Cai Z C, Zhang H. Effects of long-term application of inorganic fertilizers on biochemical properties of a rice-planting red soil. Pedosphere, 2007; 17: 419–428.

[26] Manna M C, Swarup A, Wanjari R H, Mishra B, Shahi D K. Long-term fertilization, manure and liming effects on soil organic matter and crop yields. Soil Till Res., 2007; 94: 397–409.

[27] Fan T L, Xu M G, Song S Y, Zhou G Y, Ding L P. Trends in grain yields and soil organic C in a long-term fertilization experiment in the China Loess Plateau. J. Plant Nutr. Soil Sci, 2008; 171:448–457.

[28] Zhang W J, Xu M G, Wang B R, Wang X J. Soil organic carbon, total nitrogen and grain yields under long-term fertilizations in the upland red soil of Southern China. Nutr. Cycl. Agroecosyst, 2009; 84:59–69.

[29] Liu C A, Li F R, Zhou L M, Zhang R H, Yu J, Lin S L, et al. Effect of organic manure and fertilizer on soil water and crop yields in newly-built terraces with loess soils in a semiarid environment. Agricultural Water Management, 2013; 117: 123–132.

[30] Zhao Z, Tong Y, Wang J. Nutrient uptake and distribution in field-grown Kiwifruit vines. Acta Hort. (ISHS), 2013; 984: 219–226.

[31] Chen H Q, Hou R X, Gong Y S, Li H W, Fan M S, Kuzyakov Y. Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess

Plateau of China. Soil Till Res., 2009; 106: 85–94.

[32] Blair N, Faulkner R D, Till A R, Poulton P R. Long-term management impacts on soil C, N and physical fertility part I: Broadbalk experiment. Soil Till Res., 2006; 91: 30–38.

[33] Banger K, Kukal S S, Toor G, Sudhir K, Hanumanthraju T H. Impact of long-term additions of chemical fertilizers and farm yard manure on carbon and nitrogen sequestration under rice-cowpea cropping system in semi-arid tropics. Plant Soil, 2009; 318: 27–35.

[34] Gong W, Yan X Y, Wang J Y, Hu T X, Gong Y B. Long-term manuring and fertilization effects on soil organic carbon pools under a wheat-maize cropping system in North China Plain. Plant Soil, 2009; 314: 67–76.

[35] Hati K M, Swarup A, Dwivedi A K, Misra A K, Bandyopahhyay K K. Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. Agric. Ecosyst. Environ., 2007; 119: 127–134.

[36] Liang B, Yang X Y, He X H, Murphy D V, Zhou J B. Long-term combined application of manure and NPK fertilizers influenced nitrogen retention and stabilization of organic C in Loess soil. Plant Soil, 2012; 353: 249–260.

[37] Lu K G, Zhu S H, Zhang L Z. The effect of bio-fertilizer on soil property and fruit quality of red Fuji apple. Journal of Shi he zi University, 2003; 7: 205–208. (in Chinese)

[38] Yan D Z, Wang D J, Yang L Z. Long-term effect of chemical fertilizer, straw, and manure on labile organic matter fractions in a paddy soil. Bio Fertil Soils, 2007; 44: 93–101.

[39] Kaur T, Brar B S, Dhillon N S. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize-wheat cropping system. Nutr Cycl Agroecosyst, 2007; 70: 110–121.