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

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Abstract: To evaluate the effects of chemical fertilizer combined with organic manure on apple yield, quality and soil fertility, an experiment was conducted in an apple orchard on the Loess Plateau of China. Six treatments, i.e., 1) no nitrogen (N) with chemical phosphorus (P) and potassium (K) (PK), 2) no P with chemical N and K (NK), 3) no K with chemical N and P (NP), 4) N, P and K chemical fertilizers only (NPK), 5) swine manure (M) only (M), and 6) half chemical fertilizers combined with half swine manure (NPKM) were included with three replications for each. The NPKM treatment achieved 36.9 t/ha average annual yield, which was 42.5% greater than the yield of PK treatment. The average annual yields followed the sequence of NPKM>NPK>M>NK>NP>PK. In NPKM treatment 71.3% of the collected apples had an apple diameter greater than 80 mm compared with 58.2%, 41.5 % and 37.2% in NK, PK and NP treatments, respectively. The sugar to acid (S:A) ratio was the greatest in NPKM treatment. The results of Vitamin C, soluble solid and firmness showed that NPKM treatment had the highest values. The concentration of soil organic carbon (SOC) in the 0 to 20 cm depth of soil was significantly affected by addition of M. Compared to the antecedent soil properties, the SOCS in the NPKM and M treatments were increased by 28.8%, 29.4%, and TN contents were 56.5, 49.8% more for soil at 0–20 cm depths, respectively. The major soil nutrients of N, P and K were also significantly increased by M and NPKM treatments in surface soil for five years. The data support the conclusion that, for a production of 35-40 t/ha in an apple orchard on the Loess Plateau of China, the 25-30 t/ha organic manure, 160-200 kg/ha N, 100-150 kg/ha P_2O_5 and 120-160 kg/ha K_2O were the most suitable fertilizer application. The finding will be helpful for harmonious development of apple production technology, economic income increase for farmers, and improvement of the apple orchard ecosystem.

Keywords: organic manure, mineral fertilizer, apple yield, quality, soil fertility
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1 Introduction

Until the mid 19th century organic manures were the only way of returning plant nutrients to soil and in some countries, organic manures are still the principal source of nutrients. The increasing use of chemical fertilizers during the last 150 years has made a major contribution to increasing food production worldwide. China had long

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utilized organic materials for agricultural production. However, with the consecutive increase of the population from 1950s, mineral fertilizers were introduced to maintain or improve crop yield with shrinking cropland and limited resources and have since rapidly increased in usage. Also many factors account for the tremendous increases in agricultural production since the end of the Great Famine in 1961. Application of chemical fertilizer has played a crucial role, making a 32%–50% contribution to crop yield increase[1,2]. Since 1981, traditional farming systems in China have been gradually abandoned and nutrient management shifted to over-reliance on synthetic fertilizers. China has become the largest producer, consumer and importer of chemical fertilizers in the world, accounting for 90% of the global increase in fertilizer use[3]. However, the improper use of fertilizer has increased, which leads to widespread losses in crop yield, decrease in food quality and prevalence of environment damage across the country. Mismanagement of chemical fertilizers (especially N) and low uptake efficiencies have resulted in N losses through volatilization as ammonia (NH_3), leaching as nitrate (NO_3^-), nitrite (NO_2^-) and dissolved organic nitrogen (DON), nitrification / denitrification as dinitrogen (N_2), N_2O, and nitric oxide (NO) emissions, which has been causing a series of environmental problems[4-6].

Mulvaney, et al[7] hypothesized that soil organic carbon (SOC) loss can also lead to soil N loss, because microbial C and N cycling is coupled. These two elements in soils are dominantly in organic forms, and their mineralization is closely correlated. So application of chemical fertilizer combined with organic manure is an important approach to maintaining and improving soil fertility, and increasing fertilizer use efficiency. Hence it is very useful to study the effect of application of organic manure combined with chemical fertilizer on the nutrient absorption, soil fertility change, and reduction of fertilizer loss, which have been the research focuses worldwide[8-15]. Application of organic manure could improve soil quality and is more effective for environment protection compared with application of chemical fertilizer alone[9]. Soil with organic manure continually applied has lower bulk density and higher porosity values and buffering capacities[16]. Application of organic manure combined with chemical fertilizer is associated with increased soil fertility and improved soil physical and chemical properties, thus it can increase crop production. Zhao et al.[17] observed that the amount of manure applied to apple orchard was low for surveyed orchardists in Shaanxi Province. Furthermore, the soil organic matter content in apple orchards was very low in Shaanxi Province. Wang, et al.[18] found that the organic matter content in apple orchards in Weibei dry-land, Shaanxi Province ranged between 10 g/kg and 15 g/kg, whereas the organic matter content in American apple orchards generally was above 20 g/kg. Hence, the application of manure may be of great value for apple production in Shaanxi. However, application of organic manure combined with chemical fertilizer in apple orchard in Shaanxi Province is rarely reported. Most orchards rely on chemical fertilizer application[19-23]. Therefore, the aim of the present study was to investigate the effects of chemical fertilizer combined with organic manure application on Fuji apple quality, yield and soil fertility in apple orchard in Shaanxi Province, and also to find out the most suitable fertilizer application technology from controlling the soil environment in order to adjust the appropriate productivity. The final purpose of this research is to offer scientific guidance for harmonious development of apple production technology, increase economic income of farmers, and improve the apple orchard ecosystem.

2 Materials and methods

2.1 Field site description

The field trial was conducted in Weibei Dry land Experimental Station of Northwest A&F University (109°58′33″E, 134°59′16″N), Heyang County, Shaanxi Province, Southeast of the Loess Plateau, China. The site was located in the warm temperate zone of semiarid continental monsoon climate zone with annual rainfall 550-730 mm, sunlight 1 900-2 533 h, elevation 950 m, and average annual temperature 11.5℃. The experiment was carried out in September 2004 after apples were harvested. According to the USDA textural classification system, the soil at this site is silt loam and according to the FAO−UNESCO soil map. Soils are classified as Chromic Cambisols (FAO-UNESCO 1974). The main soil properties (0−100 cm depth) of the site sampled in Octor 2004 were as follows (Table 1). The apple variety was Fuji with intermediate stock M26 and M. micromalus Makino of stock. The apple orchard was planted at 3 m × 4 m spacing. The age of the apple trees was 11 years old.

Table 1 Soil properties of apple orchard before fertilization (October, 2004)

Soil depth /cm	SOM[a] /g·kg^{-1}	Total N[b] /g·kg^{-1}	Available N[c] /mg·kg^{-1}	Available P[d] /mg·kg^{-1}	Available K[e] /mg·kg^{-1}
0-20	14.6	1.13	55.4	19.8	187.7
20-40	9.1	1.07	39.9	11.6	112.6
40-60	6.2	0.86	29.5	5.9	54.5
60-80	5.9	0.58	32.9	5.3	43.8
80-100	5.2	0.57	27.6	3.3	46.5

Note: a, K_2CrO_4 oxidation method; b, H_2SO_4-H_2O_2; c, 2M KCl extracted N; d, $NaHCO_3$ extracted P; e, NH_4OAC extracted K.

2.2 Experimental design

The experiment was designed as a randomized block with three replications. The experiment included six treatments: (1) PK (without nitrogen, applied inorganic P and K fertilizer); (2) NK (without phosphorus, applied inorganic N and K fertilizer); (3) NP (without potassium, applied inorganic N and P fertilizer); (4) NPK (applied inorganic N, P, K fertilizer); (5) M (applied only cattle manure) and (6) NPKM (half inorganic and half cattle manure by nutrient). The size of each plot (each treatment included 9 apple trees) was 9 apple trees, total 162 apple trees for six treatments with three replications, and set guard trees between each plots. The total amounts of N, P, and K applied from inorganic and organic sources to individual trees under each treatment were included in Table 2. Urea, calcium superphosphate, and potassium chloride were used as the sources of N, P and K, respectively. Cattle manure in the M treatment at dry weight 55 t/ha was applied each year. The manure contained 183, 6.01, 4.02 and 4.41 g/kg C, N, P and K, respectively on a dry weight basis. All the treatments with the same management by orchardist, calcium superphosphate, potassium chloride and organic manure were applied as basal fertilizer after harvesting. Urea as basal fertilizer with 220 kg/ha was applied after harvesting and the other 110 kg/ha was applied in next spring. Amounts of fertilizer applied were the same each year from 2004 to 2009.

Table 2 Treatments applied to apple trees and corresponding nutrient additions each year from 2004 to 2009

Treatments	Nutrient content/kg·ha^{-1}			
	Dry cattle manure	N	P_2O_5	K_2O
PK	0	0	220	240
NK	0	330	0	240
NP	0	330	220	0
NPK	0	330	220	240
M	55000	330.5[a]	221.1[a]	242.5[a]
NPKM	27500	165+165.3[a]	110+110.5[a]	120+121.3[a]

Note: [a] The amount of N/P/K contained in organic manure.

2.3 Sample collection and analysis

Apple leaf samples of six treatments were collected each month from April to August in 2009. The N, P, and K contents in the leaves were measured after drying. The total N and P contents were determined by Tector 5020 flowing injection analysis machine, while K concentration was determined by a flame photometry.

Apple fruits of six treatments were collected after harvest each year, and 60 apples were picked from each treatment randomly. Apple quality indicators including apple diameter, soluble sugar content, titratable acids, vitamin C content, soluble solid content, and apple firmness were determined.. Average weight of apples of each treatment was obtained.

The soil samples were collected at 0–20, 20–40, 40–60, 60–80 and 80–100 cm depths from each of 18 test plots after apple harvest in October 2009. Three soil cores within each plot were well mixed and composited by depth. A total of 90 composite samples represent six fertilizer treatments, five depths, and three field replicates. Fresh soil samples were taken to laboratory for mineral N analyses. Mineral N was extracted with 2 mol/L potassium chloride (soil: KCl=1:4) for 1 h and then by Tector 5020 flowing injection chemical analyzer. Soil samples were dried and sieved (<2 mm) after identifiable crop residues, root material, and stones were removed for chemical analyses. Total N was determined by Tector 5020 flowing injection chemical analyzer. SOC was determined by potassium dichromate ($K_2Cr_2O_7$) oxidation at 170–180℃ followed by titration with 0.1 mol/L ferrous sulfate. Available P was extracted with sodium bicarbonate, and then determined by the molybdenum-blue method. Available K was extracted with ammonium acetate, and then determined by flame photometry[24].

2.4 Data statistics and analysis

One−way ANOVA was used to analyze differences in tested parameters in six treatments with three replicates at $P<0.05$, with separation of means by the least significant difference (LSD). All statistical analysis was performed with SPSS 13.0 for Windows.

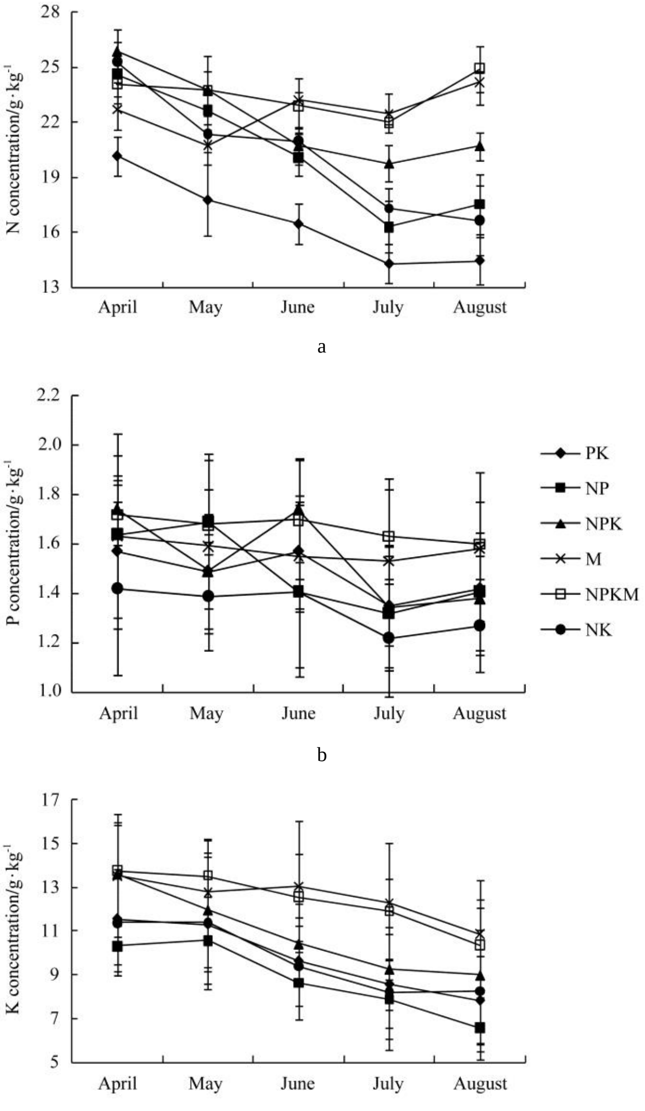
3 Results

3.1 Vegetative growth traits

The nitrogen concentration in leaves changed with seasons (Figure 1a). The results showed that the nutrients concentration for treatments NPK, M, NPKM were significantly higher than PK treatment in the same growing period. The N concentration in leaves decreased for all treatments except M treatment from April to August likely as a result of internal remobilization. At early stage the absorbed nitrogen in leaves partitioned to roots, stems, and especially fruits. We also found nitrogen accumulation in the NPK treatment was higher than that in the treatments with organic manure added at early stage, while the phenomenon was contrary at late stage, possibly because the N accumulation in the treatments with organic manure added was released at late stage.

The phosphorus in leaves of apple tree showed the same trend as for nitrogen (Figure 1b). From April to August the phosphorus showed a small loss during the period. The decreased phosphorus concentration in leaves could be attributed to internal remobilization. Fan et al.[25] reported that the nutrients uptake in leaves occurred mostly in the prophase and the amount of nutrients accumulated in apple plant from spike formation to maturing stage accounts for above 70% of total nutrients absorbed.

Potassium content in leaves decreased from April to August which might be due to the internal remobilization. Especially for NP treatment, the potassium content was significantly lower than the other treatments in the same growing period likely as the fruits need more nutrients at enlargement period. Potassium is usually regarded as a “quality element” in fruit production[26]. More specifically, the cycling and recycling of K in the plant plays an important role in maintaining cation-anion balance[27], and provides the K required for proper functioning of phloem loading. Although much attention has been paid to the cycling and recycling mechanism of K in plants, information on biomass and K accumulation is still lacking due to the limited research in this area.



a

b

c

Figure 1 Nutrient concentration in leaves after five years’ application of mineral fertilizer combined with organic manure in 2009

3.2 Apple yield

The rational fertilization could increase apple yield during the five years study (Table 3). However, with the extension of experiment, irrational application of fertilizer may lead to a decline in apple yield and quality. For PK, NK and NP treatments over five years, the apple yield decreased by 13.4%, 9.9% and 11.9% in 2009 compared with 2005, respectively. Apple yield averaged above 35 t/ha for the other fertilizer treatments. The NPK, M and NPKM treatments all increased apple yield, and there was a significant difference between the NPKM treatment and the other treatments in 2009. Apple yield was 42.5% greater in NPKM treatment than that in PK treatment. The average annual yield followed the sequence of NPKM (36.9 t/ha) > NPK (35.4 t/ha) > M (34.9 t/ha) > NK (28.5 t/ha) > NP (27.9 t/ha) > PK (25.9 t/ha). Fan et al. (2008)[25] reported that farm yard manure (FYM) and NPK treatments increased wheat and maize yields significantly compared to no fertilizer control in a 26-year fertilizer management experiment in China's Loess Plateau. We obtained the same trend, with M added treatment improving soil fertility including concentrations of SOC and of macro- and micronutrients and physical properties. In contrast, the application of chemical fertilizer only increased apple yield by directly supplying plant nutrients required for apple tree growth.

Table 3 Effects of different fertilization on apple yield during the year 2005-2009

Treatment	Fruit yield/t ha^{-1}					Average yield /t ha^{-1}	Increased percentage /%
	2005	2006	2007	2008	2009		
PK	28.4 b	26.1 c	27.2 c	23.2 c	24.6 d	25.9 c	——
NK	29.9ab	29.7 c	29.6 b	26.6 b	26.9 c	28.5 b	10.2
NP	30.2 ab	26.7 c	29.5 b	26.5 b	26.6 c	27.9 b	7.7
NPK	31.9 a	37.4 a	33.5 ab	38.7 a	35.8 b	35.4 ab	36.7
M	31.2 a	33.4 b	35.3 a	38.1 a	36.4 b	34.8 ab	34.4
NPKM	31.5 a	33.8 b	36.6 a	40.4 a	42.1 a	36.9 a	42.5

Note: Values followed by different letters in the same column are significant in difference at 5% level, and the same below.

3.3 Apple quality

3.3.1 Fruit size

Application of chemical fertilizer combined with organic manure could increase fruits sizes greatly. In NPKM treatment 71% of the collected apples had an apple diameter greater than 80 mm compared with 68.5% in NPK treatment and 58.2%, 41.5% and 37.2% in NK, PK and NP treatments, respectively (Table 4). Furthermore, with NPKM treatment 5% of collected apples had a diameter less than 75 mm compared with the NK, PK and NP treatments that had 20.9%, 32.8% and 44.1%, respectively. The largest average fruit weight was 267.1 g in NPKM treatment, which was significantly larger than that in any other treatment.

Table 4 Effects of different fertilization treatments on fruit grading after five years

Treatment	Fruit grading/%			High quality ratio/%	Average weights of apple/g
	＞80 mm	80-75 mm	＜75 mm		
PK	41.5	25.7	32.8	41.1	217.9 c
NK	58.2	21.2	20.9	79.4	225.5 bc
NP	37.2	18.7	44.1	37.2	206.9 c
NPK	68.5	24.3	7.1	68.5	242.9 b
M	69.3	22.8	7.9	69.3	237.5 b
NPKM	71.3	23.5	5.1	71.3	267.1 a

3.3.2 Intrinsic quality

The intrinsic quality included contents of soluble sugar, titratable acids, vitamin C, soluble solid, and the firmness value. Various apple intrinsic quality indicators during this 5-year study were shown in Figure 2. The rational fertilization increased apple quality. And over time, improper application of fertilizers led to a decline in quality. Figure 2 showed that the contents of soluble sugar, soluble solid, vitamin C and firmness value for NPK, M, and NPKM treatments increased over time and they were significantly higher than those in PK and NP treatments at the same year (Figures 2a, 2d, 2e, 2f). But the contents of titratable acids for all treatments showed a downward trend from 2008 to 2009 (Figure 2b), and the contents for PK and NP treatments were higher than those in other treatments in the same year.

The results from Figure 2 also showed that the contents of soluble sugar, soluble solid, vitamin C, sugar to acid (S:A) ratio and firmness were higher in NPK treatment compared with NPKM and M treatments at the beginning of the experiment (in 2005, 2006 even in 2007). But the NPKM and M treatments showed a steady uptrend, especially for NPKM treatment. The sugar to acid (S:A) ratio was greatest and amounted to 32.9 in 2009. The contents of soluble sugar and vitamin C in NPKM treatment were increased by 10.7% and 17.6%, respectively after five years.

The contents of soluble sugar, soluble solid, vitamin C and firmness in NP treatment were lower than other treatments after 2006, likely as potassium could promote the starch transform into sugars, so potassium deficiency treatment was not favorable to the improvement of fruit quality.

Firmness is an important index for apple shelf life. It was declined by NP and PK treatments. But with the NPKM, NPK and M treatments, it had a fluctuating change, increasing first and decreasing afterwards. Overall, it maintained at between 6.5 and 7.5 kg/cm^2 in the five-year study (Figure 2f).

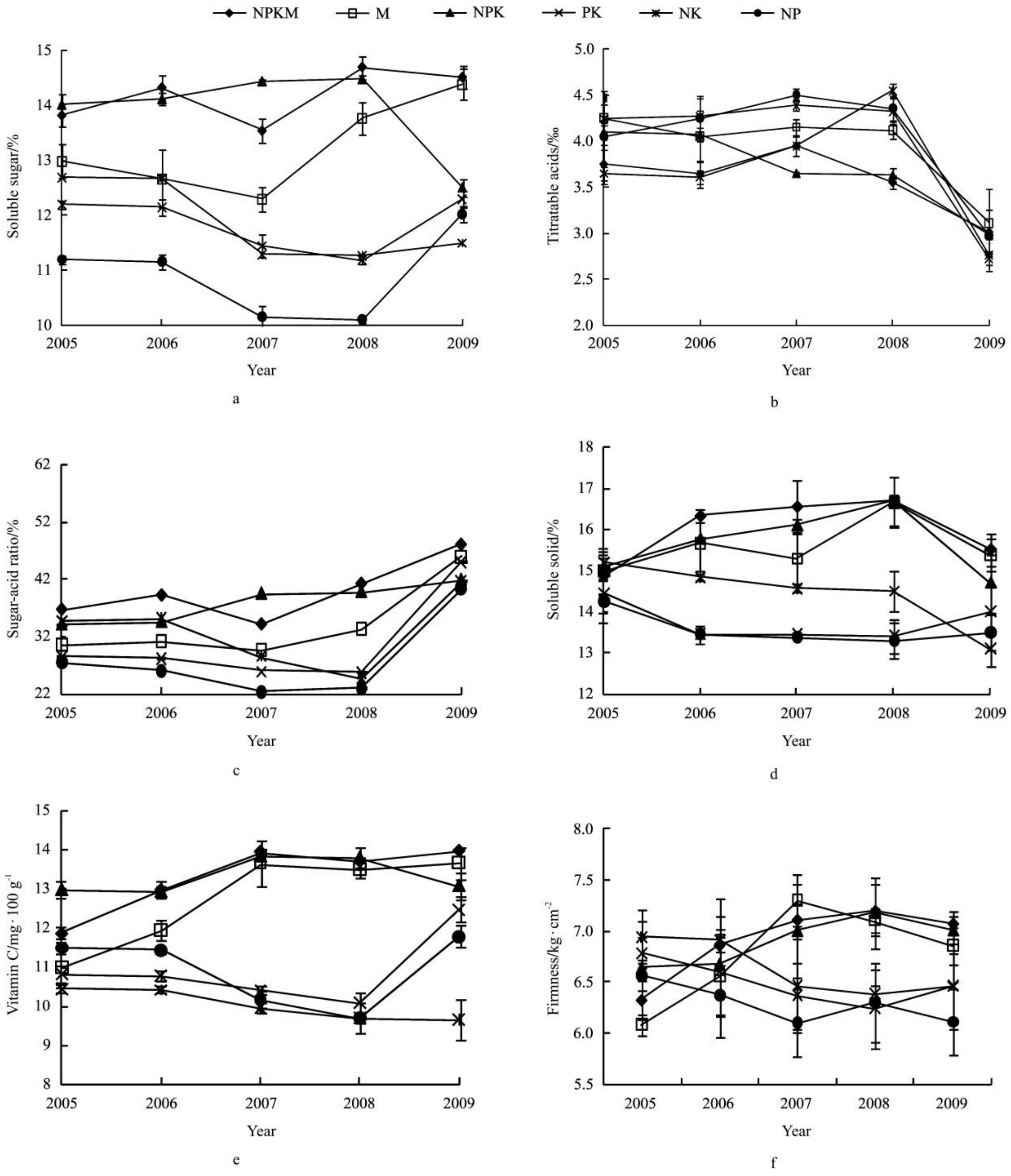


Figure 2 Effect of different fertilization treatments on fruit quality during the five years (Error bars represent standard deviation)

3.4 Soil fertility

3.4.1 Soil organic matter and total nitrogen

The concentration of SOC in the 0 to 20 cm depths was significantly affected by M fertilizer added (Figure

3a). Compared with the antecedent soil properties in 2004, the SOCS in the NPKM and M treatments were 28.8%, 29.4% more, and TN contents were 56.5%, 49.8% more for 0–20 cm in depth, respectively. The trend was attributed to more C being sequestered in the soil amended with M than only chemical fertilizer application treatment. However, consistent differences among treatments were not observed in the subsoil layers.

The results indicated no differences in the concentration of SOC and TN among PK, NK and NP treatments and the antecedent soil properties in 2004 throughout the 1 m depth (Figures 3a and 3b). The lack of significant differences in SOC concentration may be due to the low C input and the enhanced fertilizer-induced decomposition of SOC[28].

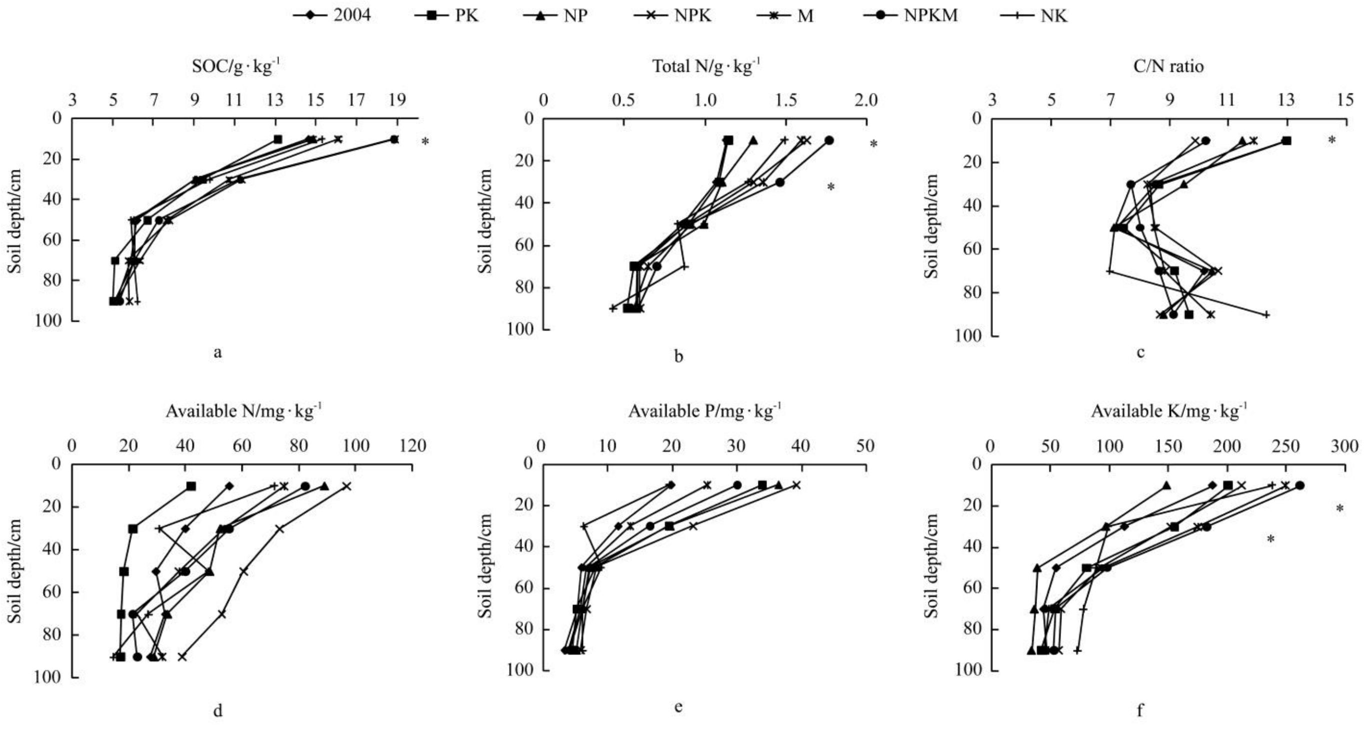
The NPK treatment also enhanced SOC sequestration (Figure 3a) which can be attributed to the regular addition of inorganic fertilizers for five years, creating a higher crop productivity and hence a return of more crop residues in the form of roots and stubbles.

3.4.2 Available nutrients

The major soil nutrients of N, P and K were significantly increased by M, NPK and NPKM treatments after five years (Figures 3d, 3e, 3f). Especially for NPK treatment, the available N was significantly increased compared to the antecedent soil properties in 2004, which was 75.1%, 83.6%, 105.1%, 61.1%, 40.9% more, for 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm in depth, respectively. The changes of available N content in subsoil layers indicate that leakage had taken place.

The available P was significantly increased by mineral fertilizer treatments (PK, NP and NPK) in surface soil compared with the antecedent soil. But in the subsoil layers, there was no difference among all treatments.

The content of available K in the 0 to 40 cm depths was significantly affected by K fertilizer added (PK, NPK, M and NPKM) for five years (Figure 3f). Compared with the antecedent soil properties, the available K contents in NPKM, M and NPK treatments were 39.7%, 33.1% and 13.1% more, for 0–20 cm depths, respectively. But for NP treatment it was decreased by 20.7% for 0–20 cm in depth. There was no difference among treatments for 60–100 cm in depth.



Note: *Significant differences between NPKM and M or PK at $P<0.05$.

Figure 3 Effects of different fertilization treatments on the distribution of soil nutrients after 5 years in 2009

Soil depths were 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm.

4 Discussion

The results indicated that application of chemical fertilizer combined with organic manure significantly increased apple yield, apple quality, soil organic C content, total N, and the available soil nutrients. Lu et al.[26] observed that manure application increased the sugar to acid (S:A) ratio by 30% compared with only chemical fertilizer application. However, we observed that the NPKM treatment increased the sugar to acid (S:A) ratio by 29% compared with NPK treatment. One explanation is that the original available soil nutrients in experiment fields of Lu et al.[29] were higher than that in our field. Another possibility is that the amounts of manure applied in these treatments of Lu et al.[29] were greater than those in our treatments. Certainly, organic manure application increased apple quality of both studies. We obtained the same trend in soluble solid and firmness, both of which values were greater in NPK, M and NPKM treatments than those in PK, NK and NP treatments and were the greatest in the NPKM treatment.

Zhong et al.[30] reported that crop yields could be increased to a very limited extent through only chemical fertilizer application. They found a significant regression relationship between grain yields plus straw and soil organic C content, and thus inferred that amendment with organic materials is essential for further improvement in soil fertility and increase in crop yield as well as increasing microbial biomass and community functional diversity. Our study showed that application of organic manure plus balanced fertilization with N, P and K could greatly increase apple yield. Compared with PK treatment, the yield in NPKM treatment was 42.4% more, and in M treatment 34.4%. In NPKM treatment in 2009, 71% of the collected apples had an apple diameter greater than 80 mm compared with 58.2%, 41.5% and 37.2% in NK, PK and NP treatments, respectively. In contrast, application of chemical NPK fertilizer only also increased apple yield by 36.7%, but the yield was increased by directly supplying plant nutrients required for crop growth. Fan T.L et al.[31] reported that FYM and NPK treatments increased crop yields significantly compared to no fertilizer control for a long-term application fertilizer management experiment in China’s Loess Plateau. Similar effects of the application of FYM and inorganic fertilizer (INF) on crop yields have also been reported for red soil of Southern China[32].

The results in our study also indicated that the concentrations of SOC and TN were significantly increased by the application of organic manure added (M and NPKM) compared with the initial SOC value and total N at the beginning of the experiment. The SOC value in NPKM and M treatments were 28.8%, 29.4% more, and TN contents were 56.5%, 49.8% more for 0–20 cm in depth, respectively. These results show that beneficial effects of manure added are primarily limited to the surface layer. Chen et al. found[33] that the concentration of SOC by conservation tillage management was primarily enhanced in the upper layer, and the concentration of SOC in the subsoil was unaffected for 11 years. Increase in SOC and TN concentrations with application of M could be attributed to the regular addition of organic manure for five years, and also to a higher crop productivity and hence to return of more crop residues in the forms of roots and stubbles. Blair et al. reported[34] that FYM increased concentrations of SOC by 165% and TN by 151% compared to those of the control treatment in the Broad balk Wheat Experiment at Rothamsted, UK. Banger et al. observed[35] that a sandy soil amended with FYM contained 36.1% more SOC and 24.4% more TN concentrations in the 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[36-41]. 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 fertilizer did not significantly increase the TN concentration in comparison with the antecedent soil. 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.[40]. Over and above the N contained in M, increase in TN concentration in the M and NPKM treatments may also be attributed to a slow release of N from manure and thus lower losses of N, and higher biological N-fixation stimulated by M added[41].

Simon reported[42] that the C:N ratio indicated the capacity of the soil to store and recycle nutrients. The soil C:N ratio decreased with the increase in depth irrespective of the treatments. Ranging from 12.9 in the 0–20 cm depth to 8.6 in the 80–100 cm depth in our study, the C:N ratio of SOM is usually around 10–12[43]. The C:N ratio showed that frequent tillage operations might accentuate decomposition of SOM[44,45]. As decomposition proceeds, C is released during respiration and some of the mineralized N is lost through leaching or gaseous emissions while some is reincorporated into the SOM pool[46]. There was no significant change in the C:N ratios by different treatments.

The stability of apple yield and apple quality under irrational fertilization (PK and NP) treatments was decreased and easily influenced by the change of climate. The middle and micro-elements such as Mg, S, and Zn would 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 system productivity[47]. Thus our study validated that the amendment with organic manure was essential for improving soil organic C content and soil fertility, and in particular enhancing the apple yields and quality.

5 Conclusions and suggestions

5.1 Conclusions

1) Continuous application of organic manure plus balanced fertilization with N, P and K for five years significantly increased apple yield and improved apple quality. The average annual yield reached 36.9 t/ha in NPKM treatment, which was 42.5% greater than that in PK treatment.

2) The sugar to acid (S:A) ratio, Vitamin C content, soluble solid concentration and apple firmness indicated that NPKM treatment had the highest values.

3) The concentrations of SOC, TN and the major soil nutrients N, P and K in surface soil were significantly increased relative to 2004's values by the application of organic manure (M and NPKM). Application of chemical fertilizer alone was not sufficient to increase SOC and soil nutrients N, P, K relative to the values of 2004.

5.2 Suggestions

For a production of 35-40 t/ha in an apple orchard on the Loess Plateau of China, the 25-30 t/ha organic manure, 160-200 kg/ha N, 100-150 kg/ha P_2O_5, 120-160 kg/ha K_2O were the most suitable fertilizer application. It will be helpful for harmonious development of apple production technology, economic income of farmers, and the apple orchard ecosystem.

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