Original article

The effects of soil nutrient on fruit quality of ‘Hayward’ kiwifruit (*Actinidia chinensis*) in Northwest China

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Summary

Attempts had been made to provide clear insight on the performance of fruit quality and the status of soil nutrient and to explain the soil nutrient factors that predominantly affect the fruit quality of kiwifruit. The 8-year-old kiwifruit cultivar ‘Hayward’, which is grown in Zhouzhi County (33°42’N, 108°37’E), Shanxi Province, China, was used as the material in the study. The results of the Pearson correlation coefficient illustrated that the soil organic matter (OM) content was positively related to the soil property except the soil pH. Moreover, based on the canonical correlation analysis (CCA), the canonical variables alkaline hydrolyzable-N (AN), available iron (AF_e), available boron (AB), and pH of the soil property index and the fruit quality parameters fresh weight of single fruit (FW), fruit shape index (FI), total soluble solids (TSS), titratable acidity (TA), and total soluble sugar (SS) were selected. The best regression equation (model) indicated that the effects of the soil nutrient somewhat varied among ‘Hayward’ fruit quality in Northwest of China. Specifically, the FW and SS were positively related to soil AN, while FI was negatively related to soil AB and PH; TSS showed a positive correlation with soil AF_e, whereas TA was positively related to soil AN(x₃), AF_e(x₆) and PH(x₉). Soil pH is an important factor affecting the availability of soil nutrient, and its effect on fruit quality is probably affected the absorption of soil nutrient.

Keywords

Actinidia chinensis, CCA, fruit quality, Northwest China, PCA, soil nutrient

Introduction

In comparison to other commonly consumed fruit, as an edible berry of several *Actinidia* species, kiwifruit is unequaled for its rich antioxidants, health benefits, and consumer appeal (Collins et al., 2013). The successful development of the kiwifruit industry first appeared in New Zealand, and then expanded rapidly in other countries. Over the past decade, a large amount of kiwifruit has been planted in China due to the strong economic incentive of the international kiwifruit trade (Huang and Ferguson, 2001). Among many factors that affect the economic benefits of fruit, fruit quality plays a pivotal role in consumption choice, agroindustrial processing, food technology, and production data.

Significance of this study

What is already known on this subject?

- Fruit quality is determined by both cultivar and growing environment. In particular, soil nutrient are of utmost importance for kiwifruit quality.

What are the new findings?

- The effects of soil nutrient somewhat varied among the ‘Hayward’ fruit qualities.

What is the expected impact on horticulture?

- Soil nutrient have multi-faceted impact on kiwifruit fruit quality, which should be taken comprehensive consideration in improving fruit quality.

Typically, fruit quality is determined by both cultivar and growing environment, which has been confirmed for many tree species, e.g., blueberry (Saftner et al., 2008), citrus (Khan et al., 2011) and apple (Holb et al., 2012). Similarly, the difference in fruit quality of kiwifruit in terms of sensory acceptance, sugar and nutritive factors as well as polyphenols among cultivars has been reported by previous studies (Park et al., 2011), and is affected by tree canopy density (Snelgar et al., 1998), ambient temperature (Hopkirk and Snelgar, 1989) and soil water potential (Biazar et al., 2013). In particular, previous studies have illustrated that soil nutrient are of utmost importance for kiwifruit quality. For instance, Rahman et al. (2011) provided indirect evidence that kiwifruit quality mostly depended upon the use of a biological farming system linked with the property. Lago et al., (2015) found that the K:Mg ratio in soil was closely related to the absorption of Ca²⁺ and Mg²⁺ by kiwifruit. The level of soil nutrient, however, depends primarily on environmental conditions, e.g., topography and climate as well as human-induced factors such as agricultural management (Wang et al., 2015). For instance, Khan et al. (2011) reported that orchard location and soil nutrient played a crucial role in fruit quality of citrus in Sargodha city of Pakistan. Zhouzhi, a county on Guanzhong Plain, Shanxi Province, China, has a soil type that primarily contains anthrosol, a super common type in the loess area of Northwest China, and researchers have applied the Pearson correlation coefficient for predicting the relationship between the fruit quality of kiwifruit and this anthrosol type soil in Northwest China. However, in the present work, the CCA method was applied to select the main soil nutrient affecting fruit quality. Then, the stepwise multiple

regression method was used to establish the best regression equation (model). Therefore, the objectives of the work are as follows: (a) assess the performance of fruit quality and status of soil nutrient, and expose their relationship, and (b) based on multivariate analysis, illustrate the soil nutrient factors that predominantly affect the fruit quality of kiwifruit in Northwest China.

Materials and methods

Plant material and soil sample

Currently, a well-known kiwifruit cultivar 'Hayward', which is grown in Zhouzhi County (33°42'N, 108°37'E), Shanxi Province, China, was used as sample materials in 2017 and 2018. The orchard has a warm temperate continental monsoon climate, characterized by an average total annual precipitation of 850.52 mm and mean annual sunshine hours of 1,774.6 h as well as an average annual temperature of 14.3°C. The 8-year-old kiwifruit trees were planted in a row with a spacing of 4 m × 5 m and grown to a height of approximately 4.5 m. At the stage of fruit maturation (from early August to the end of September), a sample of 12 randomly obtained fruits was harvested from the east, south, west and north of each tree (three trees per replication) and quickly frozen in an ice box at -20°C. Soil in this area is mainly an earth-cumuli-orthic anthrosol. The average soil bulk density at a soil layer depth of 0–40 cm is approximately 1.35–1.62 g cm⁻³. To provide more representative data, soil was sampled randomly from three distantly separated plots, which consisted of three replicates of nine trees, from June to August. Soil in the 0–40 cm layer was collected with a soil drilling method from the east, south, west and north of each tree crown vertically inward 50 cm and was air-dried naturally at room temperature and crushed before being sieved through a 2-mm mesh sieve.

Evaluation of the performance of fruit quality

The FW (expressed in g) was determined using an analytical balance (Mettler-Toledo AL204, China). The fruit height and width (expressed in mm) were measured by a Vernier caliper (Nscing Es, China) and the FI was calculated as the height/width ratio. Three replications were conducted and the values were averaged. The levels of TSS, TA and SS were assessed using the juice obtained randomly from three fruits per replication. The juice was obtained from the fruit center using the delicate automatic extractor (SamTech, Mannersdorf, Austria). The concentration of TSS was determined at 20°C using a refractometer (SHGWYT-2, 0–32%, China) and reported as °Brix. The levels of TA were determined by titration with 0.05 mol L⁻¹ NaOH to pH 8.2 and reported as g citric acid per 100 g fresh weight. The contents of SS was measured through anthrone-H₂SO₄ colorimetry and expressed in °Brix.

Detection of the status of soil property

The total OM content was gravimetrically determined by loss on ignition (OM_{LOI}). Briefly, 10-g samples were oven-dried at 105°C overnight, weighed, ignited to equilibrium in a muffle furnace set at 350°C for 18 h and reweighed. The lower ignition temperature was chosen to prevent errors from high loss of structural water from kaolinite clays, which is generally greatest between 450 and 600°C (Moebiusclune, 2011). The TN was measured by the Kjeldahl method, while pH was determined using a 1:2.5 CaCl₂ dilution method (Gupta and Gajbhiye, 2000). AN in the soil was assessed with a microdiffusion technique after samples underwent alkaline hydrolysis. Soil AP was determined by the Olsen method. Soil AK was measured in 1 mol L⁻¹ NH₄ OAc extracts by flame photometry. DTPA-extractable micronutrients, i.e., AFe, AZn, and AB contents, in soil were measured on an atomic absorption spectrophotometer (4530F, China) from a 1:2 soil-extractant ratio using DTPA-TEA buffer (0.005 M DTPA + 0.001 M CaCl₂ + 0.1 M TEA, pH 7.3) based on the method described by Lindsay and Norvell (1978).

Statistical analysis

PCA was used to evaluate the Pearson correlation coefficient between the fruit quality values and soil nutrient levels using SPSS 22.0 statistical software. A heatmap was drawn using the R package function heatmap.2. According to modern regression theory, soil nutrients and fruit qualities belong to two different normal distributions, and each variable set consists of more than two variables. To model the response variable as a function of one or more predictor variables, a CCA was completed using the 'Syntax' macro program of SPSS and employed to assess the relationship between the soil nutrients, i.e., OM(x₁), TN(x₂), AN(x₃), AP(x₄), AK(x₅), AFe(x₆), AZn(x₇), AB(x₈), and PH(x₉), as an independent set of variables and fruit qualities, i.e., FW(y₁), FI(y₂), TSS(y₃), SS(y₄), and TA(y₅), as a dependent set of variables. Then, SMLR was used alternatively to build linear regression prediction equations (models) with SPSS 22.0 software.

Results

The performance of fruit quality

The performance of fruit quality is presented in Table 1. The average value of FW was 84.49 g, while the FI level was 1.20. The average contents of TSS and SS were 13.62 °Brix and 9.01 °Brix, respectively, and the TA concentration was 1.23%. The internal qualities of kiwifruit fruit, i.e., TSS, SS, and TA, were used to calculate the TSS/TA and SS/TA values, which were 11.16 and 7.52, respectively.

The status of the soil property

The status of the studied soil property are shown in Table 2.

TABLE 1. Fruit quality of 'Hayward' kiwifruit.

	FW (g)	FI	TSS (°Brix)	SS (°Brix)	TA (%)	TSS/TA	SS/TA
Minimum	77.63	1.09	12.99	8.57	1.12	9.77	6.11
Maximum	91.12	1.30	14.29	10.00	1.33	11.95	8.93
Mean	84.49	1.20	13.62	9.01	1.23	11.16	7.52
STD	5.12	0.07	0.58	0.66	0.08	0.89	0.89
C.V. (%)	6.00	6.00	4.00	7.00	7.00	8.00	12.00

'STD' and 'C.V.' stand for standard deviation and coefficient of variation, respectively.

TABLE 2. Nutrient status of the studied soil.

	OM (g kg ⁻¹)	TN (g kg ⁻¹)	AN (mg g ⁻¹)	AP (mg kg ⁻¹)	AK (mg kg ⁻¹)	AF _e (mg kg ⁻¹)	AZn (mg kg ⁻¹)	AB (mg kg ⁻¹)	PH
Maximum	24.10	1.61	109.05	106.73	114.01	9.51	1.08	0.63	7.39
Minimum	22.75	1.46	104.95	89.86	107.32	8.73	0.92	0.53	6.15
Mean	23.43	1.55	107.17	94.45	110.95	9.11	0.98	0.57	6.95
STD	0.53	0.06	1.76	6.37	2.83	0.27	0.06	0.04	0.42
C.V. (%)	2.27	3.81	1.64	6.74	2.55	2.91	6.19	7.61	6.06

FIGURE 1. Pearson correlation heatmap of fruit qualities and soil nutrients.

The average content of the OM samples was 23.43 g kg⁻¹. The averages of TN and AN statuses with different orders of magnitude were 1.55 g kg⁻¹ and 107.17 mg kg⁻¹, respectively. Moreover, the estimates of AP, AK, and AFe were 94.45 mg kg⁻¹, 110.95 mg kg⁻¹, and 9.11 mg kg⁻¹, respectively. Furthermore, the AZn and AB values of the sampled soils were 0.98 mg kg⁻¹ and 0.57 mg kg⁻¹, respectively. In addition, the average level of soil pH was 6.95.

PCA of fruit qualities and soil nutrients

The results of the correlation analyses of fruit quality and soil property are shown in Figure 1. Regarding the soil property, the OM content showed a positive correlation with the other measured parameters except for soil pH, which showed a significant negative correlation with soil AP level ($R = -0.860^*$). Moreover, obvious correlations among some fruit trait were also found, such as FW, which was positively and significantly correlated with SS content ($R = 0.813^*$) and TSS/TA ($R = 0.885^*$); SS content was significantly positively correlated with TSS/TA ($R = 0.889^*$) and SS/TA ($R = 0.964^{**}$),

whereas it had a remarkably negative correlation with TA concentration ($R = -0.821^*$). TSS/TA showed a significantly positive correlation with SS/TA ($R = 0.898^*$), while it showed a clear negative with correlation TA ($R = -0.862^*$), which showed a significantly negative correlation with SS/TA ($R = -0.940^{**}$). Furthermore, statistically significant positive or negative correlations between fruit trait and soil property were observed. Soil AN content was significantly negative correlated with fruit TA ($R = -0.955^{**}$); however, it was obviously positive correlated with TSS/TA ($R = 0.863^*$) and SS/TA ($R = 0.902^*$). The soil AFe content showed a significantly positive correlation with the fruit TSS concentration ($R = 0.838^*$).

Selection of soil nutrient factors and establishment of regression equation affecting kiwifruit qualities

The results of the CCA are shown in Table 3. Three pairs of canonical variables (U_1V_1 ; U_2V_2 ; U_3V_3) for soil property and fruit quality reached a significant level and therefore were selected, among which the soil AN, AFe and pH played a crucial role in the levels of fruit TSS, and the contents of

TABLE 4. Stepwise regression equations and F -value for the relationship among soil nutrients and fruit quality.

Fruit qualities	Soil nutrients	Regression equations	R^2	F -value
FW(y_1)	OM(x_1), TN(x_2)	$y_1 = 1.18x_3 - 41.878$	0.191	5.496*
FI(y_2)	AN(x_3), AP(x_4)	$y_2 = -1.377x_8 + 0.09x_9 + 1.731$	0.366	6.475**
TSS(y_3)	AK(x_5), AFe(x_6)	$y_3 = 0.884x_6 + 5.541$	0.525	21.999***
SS(y_4)	AZn(x_7), AB(x_8)	$y_4 = 0.188x_3 - 11.124$	0.258	7.610*
TA(y_5)	PH(x_9)	$y_5 = -0.045x_3 - 0.028x_6 - 0.072x_9 + 6.771$	0.971	215.303***

*, **, and *** indicate significance at the $p < 0.05$, < 0.01 , and < 0.001 levels, respectively.

TABLE 3. Canonical correlation analysis of soil property and fruit quality.

Canonical vector no.	Canonical variables for soil property and fruit quality	Canonical correlation coefficients	Wilk's λ	χ^2	df	p
1	$U_1 = -0.201x_1 + 0.274x_2 + 0.564x_3 + 0.435x_4 + 0.137x_5 - 0.662x_6 - 0.128x_7 - 0.322x_8 + 1.07x_9$ $V_1 = -0.199y_1 + 0.352y_2 - 0.807y_3 + 0.453y_4 - 0.187y_5$	1.000	0.000	869.829	45	0.000**
2	$U_2 = -0.147x_1 + 0.247x_2 - 1.015x_3 + 0.035x_4 + 0.168x_5 - 0.523x_6 - 0.067x_7 - 0.205x_8 - 0.02x_9$ $V_2 = 0.262y_1 + 0.189y_2 - 0.568y_3 + 0.034y_4 + 1.115y_5$	1.000	0.000	463.298	32	0.000**
3	$U_3 = -0.218x_1 - 0.283x_2 - 0.5x_3 + 0.295x_4 - 0.007x_5 - 0.666x_6 - 0.463x_7 + 0.8x_8 - 0.782x_9$ $V_3 = 1.394y_1 - 0.754y_2 - 0.705y_3 - 0.873y_4 + 0.169y_5$	0.987	0.005	61.430	21	0.001**

*** indicates significance at the $p < 0.01$ level.

AN and AFe have a dramatic impact not only on fruit TSS level but also on TA concentration, as well as the values of FW, FI, TSS, and SS were obviously affected by the contents of soil AFe, AB, and pH. Moreover, with the canonical redundancy analysis, 9.1%, 12.9%, and 11.3% of the variance in soil nutrient could be explained by the canonical variables V_1 , V_2 , and V_3 , respectively, and 21.9%, 27.6%, and 14.8% of the variance in fruit quality could be explained by the canonical variables U_1 , U_2 , and U_3 , respectively. Furthermore, the results of SMLR analysis (Table 4) indicated that FW(y_1) and SS(y_4) were positively related to soil AN(x_3), and FI(y_2) was negatively related to soil AB(x_8) and PH(x_9); TSS(y_3) showed a positive correlation with soil AFe(x_6), and TA(y_5) was positively related to soil AN(x_3), AFe(x_6) and PH(x_9).

Discussion

Currently, differences in soil property status have been observed when comparing the same soil type and land using the same spatial distribution and the same climate conditions in other regions of China (Jiao et al., 2013; Zhang et al., 2011). The fruit quality of the 'Hayward' cultivar in the studied orchard also differed from that of the 'Hayward' cultivar in other orchards (Famiani et al., 2012; Bostan and Günay, 2014). It was likely that orchard location had a significant effect on fruit quality, which was in accordance with the results of Shiri et al. (2016), who revealed a significant difference in biochemical compounds of 'Hayward' kiwifruit fruit sampled from two different commercial 'Hayward' orchards in northern Iran.

A growing body of evidence has illustrated the close relationship between soil nutrient and fruit quality in many fruit species, e.g., blueberry (Saftner et al., 2008), apple (Amiri et al., 2009), pummelo (Li et al., 2015). In the current work, we also illustrated the correlated relationship between soil nutrient and fruit quality of kiwifruit, among which soil AN level had a significantly negative correlation with fruit TA ($R = -0.955^{**}$) and soil AFe content showed a significant positive correlation with fruit TSS ($R = 0.838^{*}$), which was similar with the results of Srivastava et al. (2002), who revealed that soil AN showed a negative correlation with TA and soil AZn showed a significant positive correlation with TSS of citrus.

According to the report published by Yeboah et al. (2016), increasing application of nitrogen fertilizer enhanced the photosynthetic capacity of plant, and the higher the photosynthetic capacity, the greater the accumulation of dry matter is, and therefore the enhancement of fruit mass (Nava et al., 2007). Based on the CCA and SMLR, our investigation indicated that soil AN content had a positive correlation with SS and FW, which was in accordance with the results of Hipps et al. (2010), who demonstrated that enhancing nitrogen fertilizer applications could enhance the FW of apple. Previous study indicated that synergistic and antagonistic effects exist among soil nutrients, which will affect the availability of soil nutrient, and therefore have a great impact on soil nutrient uptake by crops (Abbasi et al., 2012). In the current work, the significantly negative effect of soil AFe and pH on fruit TA level was presented by a combination of CCA and SMLR. It is likely that soil pH had an interaction with soil AFe, whose activity in soil solution was highly pH-dependent (Graf, 1980). However, soil pH is one of the most important soil chemical properties in determining plant growth and nutrient uptake, and its effect on fruit quality was mainly achieved through the uptake of soil nutrient by plants (Fageria and Zimmermann, 1998; Ruijter and Haverkort, 1999).

Conclusion

Our study provided useful information on the status of soil nutrient on the Guangzhong plain of Northwest China, and its effect on the fruit quality of the 'Hayward' cultivar. The effect of soil nutrient somewhat varied among the 'Hayward' fruit quality. Among the performance of the fruit quality, FW and SS were positively related to soil AN, and FI was negatively related to soil AB and PH; TSS showed a positive correlation with soil AFe, and TA was positively related to soil AN, AFe and PH. The effect of soil pH on fruit quality most likely occurred due to the uptake of soil nutrient. Further study is needed to declare the effect of soil nutrient on other years-old fruit trees, and reveal the relationship between fruit quality and other soil property, which has important practical value and guiding significance for the development of kiwifruit industry in Northwest of China.

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