1 Fruit performance of kiwifruit in the loess area of **2 Northwest China**

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23 **Abstract**

24 Attempts had been made to provide evident insight into the performance of fruit
 25 quality and the status of soil property, and explicate the soil property factors that
 26 dominantly affect the fruit quality of kiwifruit. Currently, 8-year-old kiwifruit cultivar
 27 ‘Hayward’, which was grown in Zhouzhi County (108°37’ E, 33°42’N), Shanxi
 28 Province of China, was used as materials. The results of Pearson correlation
 29 coefficient illustrated that the soil organic matter (SOM) content was positively
 30 related to soil properties except the soil PH. Moreover, based on the canonical
 31 correlation analysis (CCA), canonical variables alkaline hydrolyzable-N (AN),
 32 available ferrum (AF_e), available boron (AB), PH in soil property index and the
 33 fresh weight of single fruit (FW), fruit shape index (FI), total soluble solids (TSS),
 34 titratable acidity (TA), total soluble sugar (SS) in fruit quality parameter were
 35 selected. And the ‘best’ regression equation (model) indicated that the effects of soil
 36 property somewhat varied among ‘Hayward’ fruit qualities in the loess area of
 37 Northwest China. Specifically, FW and SS could be mainly affected by soil AN, and

FI affected by soil AB and PH. Fruit SS mostly depended upon soil AFe, whereas TSS was affected by soil AN, AFe and PH. The effect of soil PH on fruit quality is probably achieved, however, affecting the absorption of soil nutrients.

Keywords: Actinidia Chinensis; Fruit quality; Soil property; Northwest China

Introduction

As an edible berry of several *Actinidia* species, kiwifruit is unequalled, compared with other commonly consumed fruit, for their rich antioxidant, health benefits, and consumer appeal [1]. The successful development of kiwifruit industry was first appeared in New Zealand, and then expanded rapidly in other countries. Over the past decade, large amount of kiwifruit had been planted in China due to the strongly economic incentive caused by the international kiwifruit trade [2]. Among many factors that affect economic benefit of fruit, fruit quality plays a pivotal role in consumption choice, agro-industrial processing, food technology, and production data.

Normally, the fruit quality was determined by both cultivar and growing environment, which was confirmed on many tree species, *e.g.* blueberry [3], citrus [4], apple [5]. Likewise, the difference on fruit quality of kiwifruit in terms of sensory

56 acceptance, sugar and nutritive factors as well as polyphenols among cultivars were
57 reported by previous studies [6,7], which was affected by tree canopy density [8],
58 ambient temperature [9], soil water potential as well [10]. Particularly, previous
59 surveys illustrated that soil nutrient is of utmost importance for fruit quality of
60 kiwifruit. For instance, Hasinurrahman et al. [11] provided a indirect evidence that
61 kiwifruit quality mostly depended upon the use of a biological farming system, which
62 linked with the soil properties. Lago et al. [12] found that the K: Mg ratio in soil was
63 closely related to the absorption of Ca^{2+} and Mg^{2+} by kiwifruit. The level of soil
64 nutrient, however, majorly depended on the environmental conditions,
65 *e.g.*, topography, climate and man- induced factors, *e.g.*, agricultural management
66 [13,14]. For instance, Khan et al. [4] reported that the orchard location and soil
67 nutrient status play a crucial role in fruit quality of citrus in Sargodha city of Pakistan.
68 Zhouzhi, a county of Guanzhong plain, Shanxi Province of China, where the soil type
69 are primarily composed of anthrosol, which is super common type in the loess area of
70 Northwest China. Researchers had previously applied the Pearson correlation
71 coefficient for predicting the relationship between fruit quality of kiwifruit and
72 anthrosol type soil in Northwest China. But in the present work, the canonical
73 correlation analysis (CCA) method was applied to select the main soil properties
74 factors affecting fruit quality. And then the method of stepwise multiple regression
75 was used for establishing the ‘best’ regression equation (model). Therefore, the
76 objectives of the work are: (a) assessing of the performance of fruit quality and the
77 status of soil nutrient, and exposing of the mutual relationship; (b) based on the

method of multivariate analysis, illustrating the soil nutrient factors that dominantly 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 was grown in Zhouzhi County (108°37'E, 33°42'N), Shanxi Province of China (Fig 1), were sampled as materials in 2018. The climate of the orchard belongs to a warm temperate continental monsoon climate, characterized by the average total annual precipitation of 850.52 mm and the mean annual sunshine hours of 1,774.6 h as well as average annual temperatures of 14.3 °C. The 8-year-old kiwifruit trees were planted in the row spacing of 4 m×5 m and grown to the height about 4.5 m. At the stage of fruit mature (from early August to end September), a sample of randomly obtained 12 fruits were harvested from East, South, West and North of each tree (three trees per replication), and quickly frozen in ice box with under -20 °C. Soil in this area is mainly a type of earth-cumuli-orthic anthrosols. The average soil bulk density in soil layer depth 0-40 cm is about 1.35-1.62 g·cm⁻³. To approach more representative data, soil was sampled randomly from three distantly separated plots, which was consisted of three replicates of nine trees, from June to August. Soil in 0-40 cm layer was collected with soil drilling method from East, South, West and North of each tree crown vertically inward 50 cm, and were air-dried naturally at room temperature and crushed, before been sieving through a 2-mm mesh sieve.

Fig 1. Geographical location of sampling sites in China

Determination the performance of fruit quality

Weight and shape index

The fresh weight of single fruit (FW, expressed in g) was determining on an analytical balance (Mettler-Toledo AL204). The fruit height and width (expressed in mm) were measuring by a Vernier caliper (Nscing Es, China) and calculating fruit shape index (FI) as height/width ratio. Three replications were conducted and averaged the value.

Soluble solids, titratable acidity, soluble sugar

These levels were assessed with juice obtained randomly from three fruits per replication. Juice was obtained from fruit center using the indelicate super automatic extractor (SamTech, Mannersdorf, Austria). The concentration of total soluble solids (TSS) were determined at 20 °C using a refractometer (SHGWYT-2, 0–32%, China) and reported as °Brix. Titratable acidity (TA) was 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. Total soluble sugar (SS) was measured through anthrone-H₂SO₄ colorimetry and expressed in °Brix.

Detection the property of soil

Total organic matter 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 [15]. The total nitrogen (TN) was measured by the Kjeldal method, while PH was determined using 1:2.5 CaCl₂ dilution method [16]. Alkaline hydrolyzable-N (AN) in soil was assessed with a micro-diffusion technique after samples went through alkaline hydrolysis. Soil available phosphorus (AP) was determined by the Olsen method [17]. Soil available potassium (AK) was measured in 1 mol L⁻¹ NH₄ OAc extracts by flame photometry. DTPA-extractable micronutrients, *i.e.*, available ferrum (AF_e), available Zinc (AZ_n), available boron (AB) contents in soil were measured on atomic absorption spectrophotometer (4530F China) from 1:2 soil-extractant ratio using DTPA-TEA buffer (0.005 M DTPA + 0.001 M CaCl₂ + 0.1 M TEA, pH 7.3) with method described by Lindsay & Norvell (1978) [18].

Statistical Analysis

Pearson's correlation analysis (PCA) was used to evaluate the Pearson correlation

coefficient between the fruit quality values and soil nutrient levels by SPSS 22.0 statistical software. And heatmap was drawn by R package function heatmap.2 (<http://cran.r-project.org/web/packages/gplots/index.tml>).

According to the modern regression theory, soil nutrients and fruit qualities belong to two different normal distributions, and each variable set consisting of more than two variables. To model the response variable as a function of one or more predictor variables. CCA completing by 'Syntax' macro program of SPSS, was employed for assessing the relationship between the soil nutrients, *i.e.*, OM(x_1), TN(x_2), AN(x_3), AP(x_4), AK(x_5), AFe(x_6), AZn(x_7), AB(x_8), PH(x_9) as independent set of variables and fruit qualities, *i.e.*, FW(y_1), FI(y_2), TSS(y_3), SS(y_4), TA(y_5) as dependent set. Then, the method of stepwise multiple linear regression (SMLR) was used alternatively to build linear regression prediction equations (models) by SPSS 22.0 software.

Results

Quality performance of fruit and property status of soil

Performance of fruit quality were presented in Table 1. The FW values ranged from 77.63 to 91.12 g with a mean of 84.49 g (STD=5.12, *C.V.* =6.00%), while FI levels varied from 1.09 to 1.30 with an average of 1.20 (STD=0.07, *C.V.* =6.00%). As for the internal qualities of kiwifruit fruit, *i.e.*, TSS, SS, and TA, which were used to calculate values of the TSS/TA and SS/TA. Contents of TSS and SS ranged from 12.99 to 14.29 °Brix with a mean of 13.62 °Brix (STD=0.58, *C.V.* =4.00%) and 8.57

to 10.00 °Brix with an average of 9.01 °Brix (STD=0.66, *C.V.*=7.00%), respectively. Whereas TA concentration varied from 1.12 to 1.33% with a mean of 1.23% (STD=0.08, *C.V.*=7.00%). The TSS/TA and SS/TA estimates varied from 9.77 to 11.95 with a mean of 11.16 (STD=0.89, *C.V.* =8.00%) and 6.11 to 8.93 (STD=0.98, *C.V.* =13.00%).

Table 1. Fruit quality of ‘Hayward’ kiwifruit

	FW	FI	TSS	SS	TA	TSS/TA	SS/TA
	(g)		(°Brix)	(°Brix)	(%)		
Maximum	77.63	1.30	14.29	10.00	1.33	11.95	8.93
Minimum	91.12	1.09	12.99	8.57	1.12	9.77	6.11
Mean	84.49	1.20	13.62	9.01	1.23	11.16	7.39
STD	5.12	0.07	0.58	0.66	0.08	0.89	0.98
<i>C.V.</i> (%)	6.00	6.00	4.00	7.00	7.00	8.00	13.00

Note: ‘STD’ and ‘C.V.’ stand for standard deviation and coefficient of variation respectively.

Status of the studied soil properties were shown in Table 2. The OM contents of the samples varied from 22.75 to 24.10 g·Kg⁻¹ with an average of 23.43 g·Kg⁻¹ (STD=0.53, *C.V.* =2.27%). TN and AN statues with different order of magnitude, ranged from 1.46 to 1.61 g·Kg⁻¹ with a mean of 1.55 g·Kg⁻¹ (STD=0.06, *C.V.* =3.81%) and 104.95 to 109.05 mg·Kg⁻¹ with an average of 107.17 mg·Kg⁻¹ (STD=1.76, *C.V.* =1.64%) respectively. Moreover, the estimates of AP, AK, AFe with an average of 94.45 mg·Kg⁻¹, 110.95 mg·Kg⁻¹, 9.11 mg·Kg⁻¹, varied from 89.86 to 106.73 mg·Kg⁻¹(STD=6.37, *C.V.* =6.74%), 107.32 to 114.01 mg·Kg⁻¹ (STD=2.83, *C.V.*

170 =2.55%) and 8.73 and 9.51 mg·Kg⁻¹ (STD=0.27, *C.V.* =2.91%), respectively.
 171 Furthermore, the AZn and AB values of sampled soils ranged from 0.92 to 1.08
 172 mg·Kg⁻¹ with a mean of 0.98 mg·Kg⁻¹ and 0.53 to 0.63 mg·Kg⁻¹ with an average of
 173 0.57 mg·Kg⁻¹. Afterwards, the levels of soils PH varied from 6.15 to 7.39 with an
 174 average of 6.95 (STD=0.42, *C.V.* =6.06%).

175 **Table 2 Nutrient status of the studied soil**

	OM	TN	AN	AP	AK	AF _e	AZn	AB	PH
	g·Kg ⁻¹	g·Kg ⁻¹	mg·g ⁻¹	mg·Kg ⁻¹	mg·Kg ⁻¹	mg·Kg ⁻¹	mg·Kg ⁻¹	mg·Kg ⁻¹	
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
<i>C.V.</i> (%)	2.27	3.81	1.64	6.74	2.55	2.91	6.19	7.61	6.06

176 Results of correlation analyses of fruit qualities and soil properties were shown in
 177 Fig 2. As for the soil properties, OM content showed a positive correlation with others
 178 measured parameters except for the soil PH, which showed significant negative
 179 correlation with AP level ($R=-0.860^*$). Moreover, obvious correlation among some
 180 fruit traits were found as well, such as FW was positively and significantly correlated
 181 with SS content ($R=0.813^*$) and TSS/TA ($R=0.885^*$); SS content was significantly
 182 positive correlated with TSS/TA ($R=0.889^*$) and SS/TA ($R=0.964^{**}$), whereas
 183 remarkably negative correlation with TA concentration ($R=-0.821^*$); TSS/TA showed
 184 significantly positive correlation with SS/TA ($R=0.898^*$) while obviously negative

correlation TA ($R=-0.862^*$), which showed significantly negative correlation with SS/TA ($R=-0.940^{**}$). Furthermore, statistically significant positive or negative correlation between fruit traits and soil properties were observed. Soil AN content was negatively and significantly correlated with fruit TA ($R=-.955^{**}$), however, positively and obviously correlated with TSS/TA ($R=0.863^*$) and SS/TA ($R=0.902^*$). Soil Fe content showed significantly positive correlation with fruit TSS concentration ($R=0.838^*$).

Fig 2. Pearson correlation heatmap of fruit qualities and soil nutrients.

Multivariate analysis of relationship between soil property and fruit quality

CCA of soil nutrient and fruit quality

Results of CCA were revealed in Table 3. According to Wilk's λ and Chi-square tests for canonical correlation coefficients, three pairs of canonical variables (U_1, V_1 ; U_2, V_2 ; U_3, V_3) of soil property and fruit quality, of which the canonical correlation coefficient and p -value for these canonical variables were 1.000 and 0.000, 1.000 and 0.000, 0.987 and 0.001 respectively, all reached a significant level. The three pairs of canonical variables for soil property and quality could be described as follows:

$$U_1 = -0.201x_1 + 0.274x_2 + 0.564x_3 + 0.435x_4 + 0.137x_5 - 0.662x_6 - 0.128x_7 - 0.322x_8 + 1.07x_9$$

$$V_1 = -0.199y_1 + 0.352y_2 - 0.807y_3 + 0.453y_4 - 0.187y_5$$

$$U_2 = -0.147x_1 + 0.247x_2 - 1.015x_3 + 0.035x_4 + 0.168x_5 - 0.523x_6 - 0.067x_7 - 0.205x_8 - 0.02x_9$$

$$V_2 = 0.262y_1 + 0.189y_2 - 0.568y_3 + 0.034y_4 + 1.115y_5$$

$$U_3 = -0.218x_1 - 0.283x_2 - 0.5x_3 + 0.295x_4 - 0.007x_5 - 0.666x_6 - 0.463x_7 + 0.8x_8 - 0.782x_9$$

$$V_3 = 1.394y_1 - 0.754y_2 - 0.705y_3 - 0.873y_4 + 0.169y_5$$

For the first pair of canonical variables, AN(x_3), AFe(x_6), PH(x_9) in soil nutrient index and TSS(y_3) in fruit quality index presented greater weight coefficient. It illustrated that the contents of soil AN, AFe and PH value played a crucial role in the levels of fruit TSS. The second pair of canonical variables (U_2, V_2) where the dominant factors are AN(x_3), AFe(x_6) in soil nutrient index, and TSS(y_3), TA(y_5) in fruit quality index. Similarly, the results indicated that the contents of AN, AF have dramatic impact not only on fruit TSS level, but also on TA concentration. Furthermore, AFe(x_6), AB(x_8), PH(x_9) in soil nutrient index and FW(y_1), FI(y_2), TSS(y_3), SS(y_4) in fruit quality index

of the third pair of canonical variables appeared a larger weight coefficient as well. It also showed that FW, FI, TSS, SS were obviously affected by the contents of soil AFe, AB, and PH value. Additionally, with canonical redundancy analysis, 9.1%, 12.9%, and 11.3% of the variance of 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 of fruit quality could be explained by the canonical variables U_1 , U_2 , and U_3 .

Table 3. Wilk's λ and Chi-square tests of canonical correlation coefficients

canonical vector No.	canonical correlation coefficients	Wilk's λ	χ^2	df	p
1	1.000	0.000	869.829	45	0.000**
2	1.000	0.000	463.298	32	0.000**
3	0.987	0.005	61.430	21	0.001**
4	0.894	0.188	19.246	12	0.083
5	0.253	0.936	0.763	5	0.979

Note: '**' indicated significance at $p < 0.01$ level

Stepwise regression analysis for the nutrient to fruit quality

By establishing SMLR equation between dependent and independent variable, and automatically eliminate from the selected equation the insignificant independent variables, and F -value were used to evaluate statistical significance of SMLR model. The results of SMLR analysis indicated that AN(x_3) were positively related to FW (y_1)

and $SS(y_4)$, whereas was negatively related to $TA(y_5)$. Moreover, $AFe(x_6)$ showed positive correlation with $TSS(y_3)$ while negative correlation with $TA(y_5)$. Furthermore, $AB(x_8)$ was negatively related to $FI(y_2)$. Additionally, $PH(x_9)$ was positively related to $FI(y_2)$, but negatively related to $TA(y_5)$.

Table 4. The stepwise regression equations and F -value for soil nutrient to 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***

Note: '*', '**' and '***' indicated significance at $p < 0.05$, < 0.01 , < 0.001 level, respectively.

Discussion

Currently, difference in status of soil property was observed when comparing with the same soil type and land using same patial distribution, same climate condition in other regions of China [19-21]. It was elucidated that the level of soil property was affected by many interacting factors. Moreover, fruit quality of 'Hayward' cultivar in the studied orchard also has discrepancy to other orchards [22,23]. It was likely indicate that orchard location had significant effect on fruit quality, which was in accordance with the study by Shiri et al. [24], who revealed the significant difference in

biochemical compounds of ‘Hayward’ kiwifruit fruit sampled from two different commercial “Hayward” orchards in the north of Iran . Furthermore, a growing tonnage of evidences have illustrated the closely relationship between soil property and fruit quality in many fruit species, *e.g.*, in citrus [25], blueberry [3], apple [5]. Also, our finding explicated correlated relationship between soil nutrient and fruit quality of kiwifruit, among which soil AN has significantly negative correlation with fruit TA ($R=-.955^{**}$) and AFe showed significant positive correlation with fruit TSS ($R=0.838^{*}$). SS has significantly positive correlation with FW ($R=0.813^{*}$). The level of SS in fruit closely correlated with photosynthetic capacity of tree, and the higher the ability can be conducive to the accumulation of dry matter and therefore enhancement of fruit mass, which was in accordance with the evidence from Bertin et al [26], who illustrated that the total photosynthetically active radiation (PAR) received during the production stage from flowering to harvest has obvious correlation with the fresh mass of tomato fruit . However, according to the report published by El-Gizawy et al. [27], increasing shading levels from 35% to 63% increased the TA in tomato fruit, it declared that the photosynthetic capacity has negative correlation with TA, which was consistent with our results that SS was remarkably and negatively correlated with TA ($R=-0.821^{*}$).

It is well known that the synergistic and antagonistic effects existing among soil nutrients, which will affect the availability of soil nutrient, and therefore has an great impact on its uptake by crops [28,29]. Based on the CCA and SMLR, our investigation indicated that soil AN content has positive correlation with FW, which

was in accordance with the evidence from Hipps et al [30], who explicated that the enhancement of nitrogen fertiliser application could enhance the FW of apple. Moreover, we found that soil AN and AFe content were positively related to the fruit SS and TSS concentration, respectively, which were in agreement with results of PCA. Lindsay [31] who previously reported that the activity of Fe in soil solution was highly PH-dependent. The significantly positive effect of soil AFe on fruit TA level was presented, in the current work, by a combination of CCA and SMLR. It is likely that soil AFe had an antagonistic effect against soil PH [32]. Soil PH, however, is one of the most important soil chemical properties in determining plant growth of nutrient uptake, and its effect on fruit quality was mainly achieved through the uptake of soil nutrients by plants [33,34].

Conclusion

Our study provided useful information on the status of soil property in Guangzhong plain of Northwest China, and its effect on the performance of fruit quality of ‘Hayward’ cultivar. The content of SOM was positively related to the measured soil nutrients except for the soil PH. It was indicated that the effects of soil properties somewhat varied among ‘Hayward’ fruit qualities. Among these fruit quality performance, FW and SS mainly affected by soil AN, and FI affected by soil AB and

288 PH. Fruit SS mostly depended upon soil AFe, whereas TSS was affected by soil AN,
289 AFe and PH. The effects of soil PH on fruit quality is probably achieved, however,
290 affecting the uptake of soil nutrients.

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