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Variation in nutrient absorption tendency of Thompson Seedless grape on own root and Dog Ridge rootstock

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ABSTRACT

A Study of the variation in the absorption of major nutrients on Thompson Seedless on its own roots and Dog Ridge rootstock, showed no correlation between soil and petiole nutrients, indicating strong interference of other nutrients. Path coefficient analysis was employed to assess the direct and indirect effects of nutrients on other nutrients in Thompson Seedless on its own roots and Dog Ridge rootstock. Correlation observed between any two nutrients is the outcome of direct effect modified by the indirect effects *via* other nutrients. The direct and indirect effects of nutrients on the absorption of a particular nutrient were different in Thompson Seedless vines on Dog Ridge rootstock compared to vines on their own root. Variation in the indirect effect of a pair of nutrients on the absorption of different nutrients was attributable to the complexity of the interrelationship among nutrients, relative abundance of nutrients, preferential absorption of roots, mobility of nutrients and ionic balance in foliar tissues. The direct and indirect effects indicated that restricting the application of P and K can limit the absorption of N in vines on their own root; whereas restricting the input of P and application of sulphur on Dog Ridge rootstock. Phosphorus absorption could possibly be increased by limiting the application of potash to vines on their own roots and foliar application of Mg to those on Dog Ridge in soils with high levels of available K and Na. Absorption of soil K by Thompson Seedless on own roots can be increased by higher rates of application of N, S and Mg, and reducing the application of P; and growing in soils with low levels of Na. Higher petiole N and P levels and soil S levels were found to restrict Na absorption.

Key words: *Vitis vinifera*, path coefficient analysis, phosphorus absorption, soil and petiole nutrients.

INTRODUCTION

Any nutrient in the medium does not alone get absorbed by the plant, but in a secondary fashion it either suppresses or increases the uptake of other nutrients (Emmert, 9). Effect of an available soil nutrient on the composition of other nutrients in grape petioles has been amply demonstrated (Shikhamany *et al.*, 17). A soil nutrient may have a direct positive effect on its content in vine petiole but its effect could have been suppressed or deviated by its interaction with other nutrients. A nutrient in the soil directly or indirectly in association with particular nutrient/ nutrients, may influence other nutrient differently on different rootstocks because of difference in affinity of roots towards a nutrient (Downton, 8). Correlation between two nutrients is the outcome of the complex interrelationship with other nutrients. It is the summation of the direct effect of the independently varying nutrient and the indirect effects through other nutrients. Hence the direct and indirect effects of nutrients on different nutrients in Thompson Seedless on its own roots and Dog Ridge rootstock were assessed using path coefficient analysis. Path analysis is a process of splitting correlation coefficients into its component parts, namely direct and indirect effects. Knowledge of direct and indirect effects will help in the management of nutrients by limiting the application of the nutrients that are exerting indirect negative effect or increasing the application of those which have indirect positive effects, instead of increasing the application of the nutrients, the absorption of which is hampered in spite of its adequate levels in the soil.

MATERIALS AND METHODS

The present investigation was carried out in growers' vineyards of Thompson Seedless raised on their own roots and Dog Ridge rootstock in Nashik and Sangli districts of Maharashtra during 2015-16 cropping season. Twenty five vineyards each on own roots and rootstock were selected for the study. All the vineyards were in the age group of 4-6 years, raised on montmorillionite type of clay soil with varying physic-chemical characteristics (Table 1) and varying levels of available nutrients and petiole nutrient contents (Table 2). All the vines selected for the study were planted at 2.7 × 1.8 m, trained to extended Y trellis and pruned to have 30±2 canes/

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Table 1. Phsico-chemical characteristics of vineyard soils.

Character	Own root		Dog Ridge	
	Range	Mean	Range	Mean
Organic carbon (%)	1.76 – 3.34	2.57	1.48 – 4.01	2.55
pH	6.98 – 8.54	7.76	6.72 – 8.36	7.65
EC (dSm^{-1})	0.56 – 1.92	1.21	0.42 – 2.34	1.17
$CaCO_3$ (%)	9.7 – 22.6	16.2	8.2 – 18.8	14.6
ESP (%)	5.82 – 9.71	7.77	5.04 – 12.04	8.42

vine. One hundred petioles of leaves opposite to flower clusters were collected at full bloom from each vineyard. Soil samples were collected at back pruning before the application of fertilizers from 15-30 cm depth at 60 cm away from the vine stem, where maximum feeder roots are located. N, P, K, Ca, Mg, S and Na contents in petiole and soil samples were estimated following the standard analytical methods suggested by the AOAC.

The direct and indirect effects of soil and petiole nutrient contents on a selected nutrient content in the petioles were assessed by the path coefficient analysis. Path coefficients were determined by the computer based method, evolved by Akintude (2) using the Microsoft Office Excel. The residual effects on account of other factors, those were not included in the present study were also worked out.

RESULTS AND DISCUSSION

No correlation was observed between the nutrient content in soil and petiole in both the cases i.e. plants with own root and on rootstocks, except N on own root and Mg on Dog Ridge rootstock had positive correlation. On the other hand soil S correlated negatively with petiole S on own root (Table 3). Lack of correlation between soil and petiole nutrient contents, differential degree of correlation of N and Mg on different root systems and the negative relationship of soil S with petiole S were indicating interference of other nutrients in the absorption of a nutrient and the preferential absorption of different nutrients on different roots. Interaction among the nutrients (Shikhamany *et al.*, 18) and the rootstock (Kalbhor *et al.*, 12) were found to influence the nutrient status of vines.

Petiole content of a nutrient is termed as its absorption in the presentation of results and discussion. The relationships among nutrients which correlated significantly and in which the direct effects were more than the significant correlation coefficient value, are only presented and discussed. The direct effect higher than the significant level of correlation coefficient was considered significant.

Lack of correlation of soil N and its non-significant direct effect on petiole N on Dog Ridge were indicative of less preference of its roots for N. Since N is absorbed in NO_3^- form by grape roots, Dog Ridge roots appeared to have less affinity for monovalent anions in light of their Cl^- exclusion (Sharma and Upadyay, 16). Nitrogen absorption was positively influenced by petiole P levels on both root systems and soil N on own root, but negatively by petiole Ca and Na contents on Dog Ridge. Positive relationship between N and P in the foliar tissues was observed in many crop plants including grapes (Shikhamany and Satyanarayana, 20). Relative abundance of nutrients, root affinity, isomorphic ion substitution in the adsorption by clay particles and the ease with which the ions are released in to soil solution determine the interaction among nutrients, while by the physiological need for nutrients, their mobility and ionic equilibrium in the foliar tissues. N is more mobile than Ca and Na; and accumulates more in leaf lamina as compared to other nutrients (Shikhamany and Satyanarayana, 19). When N was absorbed as NH_4^+

Table 2. Soil and petiole nutrient contents in vineyards surveyed.

Nutrient	Available soil nutrient contents (mg/kg)				Petiole nutrient contents (g/100g)			
	Own root		Dog Ridge		Own root		Dog Ridge	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
N	95 - 384	199.2	89 - 412	218.8	0.95 - 2.24	1.59	1.01 - 2.18	1.489
P	10 - 177	63.6	20 - 675	152.7	0.23 - 0.82	0.501	0.25 - 0.64	0.446
K	115 - 900	521.3	70 - 2000	917.5	1.05 - 3.5	2.17	1.0 - 3.65	1.927
Ca	2931 - 9075	5948	2475 - 9950	5788	0.69 - 3.0	1.45	0.64 - 2.85	1.397
Mg	690 - 2088	1295	698 - 1725	1189.5	0.25 - 0.92	0.582	0.20 - 1.15	0.562
S	8 - 781	91.4	18 - 1060	212.7	0.06 - 0.29	0.157	0.06 - 0.29	0.159
Na	95 - 900	551.1	130 - 945	577.5	0.15 - 1.5	0.658	0.19 - 1.8	0.726

Table 3. Relationship of soil and petiole nutrient contents in Thompson Seedless grape.

Nutrient contents	Correlation coefficients with petiole nutrients													
	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sulphur		Sodium	
	OR	DR	OR	DR	OR	DR	OR	DR	OR	DR	OR	DR	OR	DR
Petiole N	1.000	1.000	0.5661**	0.6537**	-0.0870	-0.1176	-0.3832	-0.4232*	-0.2106	-0.0264	0.0204	-0.2795	-0.3772	-0.5137**
Petiole P	0.5661**	0.6537**	1.000	1.000	0.1638	0.0224	-0.2164	-0.2163	0.0215	0.2836	0.2935	0.2716	-0.2713	-0.4583*
Petiole K	-0.087	-0.1176	0.1638	0.0224	1.000	1.000	0.1956	0.2022	0.1560	0.0223	0.3646	0.3193	0.3916	0.4613*
Petiole Ca	-0.3832	-0.4232*	-0.2164	-0.2163	0.1956	0.2022	1.000	1.000	0.6292**	0.6731**	0.3136	0.3403	0.6591**	0.5549**
Petiole Mg	-0.2106	-0.0264	0.0215	0.2836	0.1560	0.0223	0.6292**	0.6731**	1.000	1.000	0.5132**	0.4095*	0.3954	0.1176
Petiole S	0.0204	-0.2795	0.2935	0.2716	0.3646	0.3193	0.3136	0.3403	0.5132	0.4095*	1.000	1.000	0.2292	0.0338
Petiole Na	-0.3772	-0.5137**	-0.2713	-0.4583*	0.3916	0.4613*	0.6591**	0.5549**	0.3954	0.1176	0.2292	0.0338	1.000	1.000
Soil N	0.4139*	0.2645	0.0272	0.2468	0.0853	-0.3320	-0.1368	-0.2336	-0.2311	-0.0465	-0.2127	-0.2540	0.0078	-0.2789
Soil P	0.319	0.1263	0.0478	0.2002	-0.3204	-0.2678	-0.3278	-0.0924	-0.2316	0.0390	-0.3442	-0.1716	-0.1715	-0.1145
Soil K	0.3156	0.2826	-0.0096	0.2823	-0.2648	-0.3041	-0.3396	-0.3426	-0.4532*	-0.2194	-0.4089*	-0.3119	-0.1481	-0.0771
Soil Ca	0.3497	-0.0417	0.0367	0.0783	0.1085	0.1848	-0.1250	0.0323	0.0661	0.1487	-0.0232	0.3061	0.0108	0.0475
Soil Mg	0.3605	0.0520	0.1966	-0.0791	0.1023	-0.0654	-0.1161	0.3465	0.1627	0.4996*	-0.0391	0.0064	0.0864	0.0929
Soil S	0.1485	-0.1367	0.1232	-0.0667	-0.2859	-0.4299*	-0.2852	0.1481	-0.4024*	0.1657	-0.5412**	0.0547	-0.2137	0.0579
Soil Na	0.3604	0.0977	0.3832	0.2189	-0.1431	-0.0803	-0.0083	-0.2618	-0.0462	-0.1464	-0.0247	-0.0114	0.0396	-0.0230

OR = Own rooted vines; DR= vines on Dog Ridge

ion form it might have moved into lamina and younger tissues, Ca^{2+} and Na^{+} seemed to move into petioles to maintain the cations concentration resulting in negative correlation. The relationship between soil N and petiole N in Thompson Seedless vines on their own root was a true relationship, because the direct effect of soil N on petiole N was almost equal to its correlation coefficient.

Correlation observed between any two nutrients was the modified direct effect as a result of indirect effects of other nutrients. The positive direct effect of petiole P on N absorption was enhanced by the indirect effect *via* petiole Na resulting in the significant correlation of petiole P with petiole N on own root, but it was reduced by its negative indirect effect *via* petiole S on Dog Ridge (Table 5). Although the positive direct effect of soil K on N absorption was significant, it was reduced to non significant level of correlation, predominantly due to the negative indirect effects of soil K via soil P and Soil S on own root. On the other hand, the non significant negative direct effects of Ca and Na were enhanced to their negative correlations with petiole Na due to indirect negative effects of Ca *via* petiole P, petiole S and petiole Mg and of Na *via* petiole P on Dog Ridge (Table 5).

All petiole and soil nutrients together could determine N absorption by 62 per cent on own root and by 44.1 per cent on Dog Ridge. Residual effect was 0.380 and 0.559, respectively on own root and Dog Ridge, accountable for the other factors influencing its absorption.

Phosphorus absorption was influenced positively by petiole N levels on both root systems, positively by soil N on own root, but negatively by petiole Na on Dog Ridge. While the direct effect of soil K was negative on P absorption on own root, it was positive on Dog Ridge. Petiole Mg and soil Na contents had direct positive effect, but the soil S had negative effect on P absorption on Dog Ridge. Generally P has positive interaction with N in promoting growth (Sumner and Farina, 24). Root proliferation and root density were shown to be basically responsible for the synergic effect of soil K on P absorption (Schenk and Barber, 15) and Dog Ridge was found to have highly prolific root system (Somkuwar *et al.*, 23). Positive relationship between P and Mg is natural, because Mg is an activator of Kinase enzyme involved in phosphate metabolism. Positive correlation between P and Mg contents in the petioles of Anab-e-Shahi grape also was observed Shikhamany and Satyanarayana, 20). This finding coupled with non significant direct effect of Mg on P on own root, is suggestive of a higher phosphate metabolism in Thompson Seedless on Dog Ridge. Positive effect of soil Na on petiole P could be attributed increased P availability in saline-sodic soils due to the formation of soluble sodium phosphate compounds (Qadir *et al*., 14). Further, increasing levels of sodium chloride in the root medium were found to increase the phosphorus content in foliar tissues in Thompson Seedless on different rootstocks (Fisarakis *et al*., 10). Soil S exerted direct negative effect on petiole P on Dog Ridge but not on own root (Tables 4 & 5). Kalbhor *et al*. (12) observed preferential uptake of S by Dog Ridge roots and their less preference for N was observed in the present study. SO_4^{2-} and NO_3^- both being anions, absorption of the former would have resulted in reduced absorption of the latter, and vice-versa.

Positive direct effect of petiole N on P absorption was reduced by its indirect negative effect via petiole Ca resulting in the reduced degree of correlation of petiole N with petiole P on own root. But in case of Dog Ridge, it was enhanced by its positive indirect effects on P absorption via petiole Na and soil K. The negative effect of soil K was reduced by its positive indirect effect via petiole N in vines on their own root. Whereas, its positive effect in vines on Dog Ridge was reduced by its indirect negative effects via petiole Mg and soil S. The direct positive effect of petiole Mg was reduced by its indirect negative effects via soil K and soil Mg. While the negative direct effect of petiole Na was enhanced by its indirect negative effect via petiole N, the direct positive effect of soil Na was reduced by the indirect negative effect via soil S. The negative direct effect of soil S was reduced by the positive effects via soil Na and soil K (Table 5).

All other nutrient contents in soil and petiole including soil P content could account for only 18.0 and 69.4 per cent of the variation in petiole P content respectively on own root and Dog Ridge; the rest being accounted for by other factors influencing P absorption.

Lack of correlation between soil K and petiole K on any root system could be attributed to the antagonistic effects other cations, namely Ca and Na, their relative abundance in the soil, isomorphism of Na^+ and K^+ ions and the comparative ease at which Na^+ is released in to soil solution. Potassium absorption was not influenced by any nutrient on own root but influenced positively by petiole Na and negatively by soil S on Dog Ridge (Table 5). Difference in the affinity for K and Na by the roots of Thompson Seedless and Dog Ridge (Shikhamany and Sharma, 21) was the basic reason for negative effect of soil Na on petiole K on own root and positive effect of petiole Na on Dog Ridge.

Petiole S had direct positive effect on K absorption on both root systems, but the direct effect of soil S was positive in vines on own root, while was negative on Dog Ridge. The direct effects of soil contents of N, and Mg were positive on K absorption, but of soil P and soil Na were negative in vines on own root. Direct effect of petiole Na was positive on Dog Ridge (Table 5). Simultaneous increase in the uptake of S and K with higher rates of S application was observed in a variety of field crops (Balpande *et al*., 3; Singh and Chaudhari, 22). This was attributed to the reduction in soil pH favourable for K uptake. While this also explains the positive relationship of soil S petiole K on own root, the preferential absorption of S by Dog Ridge (Kalbhor *et al*., 12) explains their negative relationship. Positive relationship between soil N and petiole K could be attributed to co-transportation of K^+ with NO_3^- as accompanying cation from roots to aerial parts (Blevins, 4). Such relationship was not observed on Dog Ridge, since its roots had less affinity for N compared to Thompson Seedless. Interaction among the major cations is a complex phenomenon. In a multiple regression analysis, increasing levels of soil Na was found to reduce simultaneously the petiole contents of K and Mg in Thompson Seedless on own root as a result of preferential absorption of Na (Kalbhor *et al*., 12). Under such simultaneous antagonism K and Mg could have positive relationship. Soil P exerted negative effect on petiole K on own root, but not on Dog Ridge. It could be attributed to root affinity. Thompson Seedless roots had less affinity for K^+ but more for HPO_4^{3-} ions compared to Dog Ridge (Kalbhor *et al*., 12). The positive effect of petiole Na on K absorption could be due to high demand for cations for balancing the anions on Dog Ridge and its preference for Na^+ ions over K^+ ions (Kalbhor *et al*., 12). Synergism between Na and K contents in the petioles of Thompson Seedless on Dog Ridge was also reported by Shikhamany and Sharma (21).

The direct positive effect of petiole S was reduced by the negative indirect effect of soil S and soil N in own rooted vines, while by that of petiole N and soil Ca in vines on Dog Ridge. The direct effect of soil S was positive in vines on own root, but negative in vines on Dog Ridge. The direct positive effect of soil S was reduced by the indirect negative effect via soil P and petiole S in own rooted vines, while its direct negative effect was reduced by the indirect positive effect via soil Na in vines on Dog Ridge. Direct positive effect of soil N on K absorption was reduced by its indirect negative effect via soil P and petiole N. The direct negative effect of soil P was reduced by its indirect positive effect via soil S and soil N. The direct positive effect of soil Mg was reduced by its indirect negative effect via N contents of petiole and soil. The direct negative effect of soil Na in own rooted vines was reduced by its indirect positive effect via soil S and petiole P, whereas the direct positive effect of petiole Na was reduced by its indirect negative effect via petiole N (Table 4).

All petiole and soil nutrients together could determine K absorption by 7.2 and 29.0 per cent, residual effect being 0.928 and 0.710 respectively on own root and Dog Ridge accounted for other factors influencing its absorption.

Increasing levels of soil calcium were not associated with corresponding increase in petiole calcium as indicated by the non significant correlations of soil Ca with petiole Ca on own roots as well as Dog Ridge rootstock. Neither any direct effect nor indirect effect of soil Ca on petiole Ca was significant on either of the root types (Tables 4& 5). It clearly indicates the stronger antagonism of other soil cat-ions on the absorption of available Ca in spite of high levels of free calcium content of the vineyard soils. Calcium absorption was influenced positively by the Mg and Na contents of petioles on both root systems, but negatively by petiole N on Dog Ridge. Positive relationship between Ca and Mg contents was also observed in Anab-e-Shahi grape petioles (Shikhamany and Satyanarayana, 24). Suppression of K, the antagonising ion of Ca, by Na in soils with high levels of Na (Shikhamany and Sharma, 21) could be attributed to the positive correlation between petiole Ca and Na.

The direct positive effect of petiole Mg was enhanced by its indirect positive effect via petiole Na on own root but via soil K on Dog Ridge. The direct positive effect of petiole Na was supplemented by its indirect positive effect via petiole Mg on both root systems. The non-significant level of direct negative effect of petiole N on Ca absorption was elevated to significant correlation by the indirect negative effect of petiole N via petiole Na (Table 5).

All other nutrient contents in soil and petiole including soil Ca content could account for 36.3 per cent of the variation in petiole Ca content on own root but 55.9 per cent on Dog Ridge. The rest being accounted for by other factors influencing Ca absorption

Petiole Mg correlated positively with soil Mg on Dog Ridge rootstock but not on own root (Table 3). It hints at the higher affinity of Dog Ridge roots for Mg compared to own roots and other cat-ions; and a stronger antagonism of other soil cat-ions on the absorption of available Mg by own roots than Dog Ridge roots. Neither direct effect nor the indirect effect of soil Mg via any soil or petiole nutrient on petiole Mg was significant. Petiole Mg was associated positively with petiole contents of Ca and S on both root systems, but negatively with soil contents of K and S on own root (Table 4). The direct effects of petiole Ca, petiole S and soil P on own root and of petiole P on Dog Ridge were positive on Mg absorption, while that of soil K was negative on own root. Higher levels of P in the nutrient medium were associated with increased Mg contents in celery (Li *et al*., 13) and tomato (Cole *et al*., 7). Positive relationship between petiole P and Mg contents was also observed in Anab-e-Shahi grape (Shikhamany and Satyanarayana, 20). Positive relationship of petiole P and petiole S with petiole Mg could be attributed to neutralization of ionic charges. Differential direct effects of petiole P on Dog Ridge and petiole S on own root could be due to their preferential absorption. Higher levels of soil K were found to reduce the Mg contents in foliar tissues in a variety of crops including grapes (Shikhamany *et al*., 17).

Direct effect of petiole Ca was enhanced by its indirect effect via soil K on both root systems, and also by soil Mg on Dog Ridge. The direct effect of petiole S on Mg absorption was positive on own root, but negative on Dog Ridge. The direct positive effect of petiole S was enhanced by its indirect positive effects via soil K and petiole Ca on own root. The direct negative effect of petiole S on Mg absorption on Dog Ridge was nullified and its correlation was elevated to significant positive level by its indirect positive effects via petiole P, petiole Ca and soil K. The direct positive effect of soil P was changed to negative, though not significant, correlation by its strong indirect negative effect via soil K, petiole Ca and petiole S on own root. The direct positive effect of petiole P was reduced to non-significant correlation by its indirect negative effects via many nutrients but predominantly via petiole N and soil K on Dog Ridge. The direct negative effect of soil K was reduced by its indirect positive effect via soil P on own root. The negative correlation of soil S with petiole Mg was the resultant of its indirect negative effect via soil K on own root (Table 4).

All other nutrient contents in soil and petiole including soil Mg content could account for 31.0 per cent of the variation in petiole Mg content on own root but 58.0 per cent on Dog Ridge; the rest being accounted for by other factors influencing Mg absorption.

Increasing levels of S in soil were associated with its reduced contents in petioles on own roots as indicated by their significant negative correlation. This could be due to inhibition of absorption of available S from soil and/or its translocation in the aerial tissues. The correlation was not significant on

Table 4. Path co-efficient analysis of petiole nutrient content in Thompson Seedless on own root.

Dependent Variable (X)	Independent Variable (Y)	Direct Effect (P)	Indirect Effect *via* (p x r)														Correlation Coefficient (r)
			Petiole N	Petiole P	Petiole K	Petiole Ca	Petiole Mg	Petiole S	Petiole Na	Soil N	Soil P	Soil K	Soil Ca	Soil Mg	Soil S	Soil Na	
Petiole N	Petiole P	0.3361	--	-	-0.0228	-0.0343	-0.0026	0.0664	**0.1036**	0.0109	-0.0099	-0.0050	0.0079	0.0744	-0.0223	0.0637	0.5661**
	Soil N	0.4004*	--	0.0091	-0.0119	-0.0217	0.0277	-0.0481	-0.003	-	-0.1034	**0.2724**	-0.0150	-0.0686	-0.0358	0.0118	0.4139*
	Soil K	0.5234**	--	-0.0032	0.0368	-0.0538	0.0543	-0.0925	0.0565	0.2084	**-0.1733**	-	-0.0539	-0.0625	**-0.1339**	0.0092	0.3156
	Residual Effect = 0.3804																
Petiole P	Petiole N	0.7243**	--	--	-0.0229	0.0677	-0.0290	0.0041	0.0172	-0.0714	0.0144	**-0.1258**	-0.0730	-0.0286	0.0578	0.0311	0.5661**
	Soil K	-0.3981*	**0.2286**	--	-0.0697	0.0600	-0.0624	-0.0812	0.0068	-0.0898	0.0380	-	0.0520	0.0131	0.2883	0.0048	-0.0096
	Residual Effect = 0.820																
Petiole K	petiole S	0.5092**	-0.0069	0.0875	--	-0.0181	**-0.1079**	-	0.0729	**-0.1363**	0.1851	0.0812	-0.0007	-0.0167	**-0.2950**	0.0103	0.3646
	Soil N	0.6410**	**-0.1404**	0.0081	--	0.0079	0.0486	**-0.1083**	0.0025	-	**-0.2700**	-0.1034	-0.0021	-0.0773	0.1081	-0.0295	0.0853
	Soil P	-0.5379**	-0.1082	0.0143	--	0.0189	0.0487	-0.1753	-0.0546	**0.3218**	-	-0.1671	-0.0080	0.0185	**0.3516**	-0.0432	-0.3204
	Soil Mg	0.4262*	**-0.1222**	0.0586	--	0.0067	-0.0342	-0.0199	0.0275	**-0.1163**	-0.0233	0.0328	0.0169	-	-0.0606	-0.0899	0.1023
	Soil S	0.5450**	-0.0504	0.0367	--	0.0165	0.0846	**-0.2756**	-0.0679	0.1272	**-0.3471**	-0.1473	-0.0093	-0.0474	-	**-0.1509**	-0.2859
	Soil Na	-0.4155*	-0.1222	**0.1143**	--	0.0005	0.0097	-0.0126	0.0126	0.0454	-0.0559	-0.0110	0.0012	0.0924	**0.1979**	-	-0.1431
	Residual Effect = 0.928																
Petiole Ca	Petiole Mg	0.5211**	-0.0559	-0.0029	-0.0062	--	-	-0.0639	**0.2146**	0.0111	0.0621	0.0300	-0.0134	-0.0327	-0.0348	0.0001	0.6292**
	Petiole Na	0.5427**	-0.1002	0.0372	-0.0155	--	**0.2060**	-0.0285	-	-0.0004	0.0461	0.0098	-0.0022	-0.0174	-0.0185	-0.0001	0.6591**
	Residual Effect = 0.637																
Petiole Mg	Petiole Ca	0.5648**	0.0834	-0.0251	-0.0306	-	--	**0.1391**	-0.0266	-0.0174	-0.1548	**0.2011**	-0.0249	-0.0201	-0.0611	0.0014	0.6292**
	petiole S	0.4434*	-0.0044	0.0340	-0.0571	**0.1771**	--	-	-0.0092	-0.0270	-0.1625	**0.2422**	-0.0046	-0.0068	-0.1159	0.0041	0.5132**
	Soil P	0.4721*	-0.0694	0.0055	0.0501	**-0.1851**	--	**-0.1526**	0.0069	0.0637	-	**-0.4982**	-0.0531	0.0075	0.1382	-0.0173	-0.2316
	Soil K	-0.5922**	-0.0687	-0.0011	0.0414	-0.1918	--	-0.1813	0.0060	0.0661	**0.3971**	-	-0.0497	-0.0286	**0.1588**	-0.0092	-0.4532*
	Soil S	0.2142	-0.0324	0.0143	0.0447	-0.1611	--	**-0.2400**	0.0086	0.0252	0.3046	**-0.4391**	-0.0619	-0.0192	-	-0.0605	-0.4024*
	Residual Effect = 0.690																
Petiole S	Petiole Mg	0.3846	-0.0750	0.0031	0.0513	-0.0737	-	--	0.0550	**0.1180**	-0.0405	-0.1344	-0.0109	-0.0672	**0.3135**	-0.0107	0.5132**
	Soil K	0.2966	0.1124	-0.0014	-0.0870	0.0398	**-0.1743**	--	-0.0206	**-0.2658**	0.1470	-	0.0410	0.0682	**-0.5776**	0.0128	-0.4089*
	Soil Mg	-0.4129*	**0.1284**	0.0285	0.0336	0.0136	0.0626	--	0.0120	**0.0926**	0.0076	-0.0490	-0.0928	-	0.0866	0.0500	-0.0391
	Soil S	-0.779**	0.0529	0.0179	-0.0940	0.0334	-0.1548	--	-0.0297	-0.1013	**0.1127**	**0.2199**	0.0510	0.0459	-	0.0838	-0.5412**
	Residual Effect = 0.599																
Petiole Na	Petiole N	-0.6086**	-	-0.0192	-0.0181	-0.1980	0.0075	0.0029	--	0.0808	-0.0535	**0.2023**	0.0322	**0.1300**	-0.0441	0.1087	-0.3772
	Petiole Ca	0.5166**	**0.2332**	0.0074	0.0407	-	-0.0223	0.0442	--	-0.0267	0.0549	-0.2177	-0.0115	-0.0419	0.0847	-0.0025	0.6591**
	Soil K	0.6411**	**-0.1921**	0.0003	-0.0551	**-0.1754**	0.0160	-0.0576	--	0.1016	-0.1410	-	-0.0230	-0.0596	**-0.2203**	0.0167	-0.1481
	Residual Effect = 0.607																

Table 5. Path co-efficient analysis of petiole nutrient content in Thompson Seedless on Dog Ridge rootstock.

Dependent Variable (X)	Independent Variable (Y)	Direct Effect (P)	Indirect Effect *via* (p × r)														Correlation Coefficient (r)
			Petiole N	Petiole P	Petiole K	Petiole Ca	Petiole Mg	Petiole S	Petiole Na	**Soil N**	Soil P	Soil K	Soil Ca	Soil Mg	Soil S	Soil Na	
Petiole N	Petiole P	0.8516**	--	-	0.0052	0.0154	-0.0618	**-0.1361**	0.0863	0.0171	-0.0141	-0.0210	-0.0004	-0.0207	-0.0188	-0.0491	0.6537**
	Petiole Ca	-0.0710	--	**-0.1842**	0.0469	-	**-0.1466**	**-0.1705**	-0.1045	-0.0161	0.0065	0.0255	-0.0001	0.0906	0.0417	0.0588	-0.4232*
	Petiole Na	-0.1884	--	**-0.3903**	0.1069	-0.0394	-0.0256	-0.0169	-	-0.0193	0.0080	0.0057	-0.0002	0.0243	0.0163	0.0052	-0.5137**
	Residual effect= 0.559																
Petiole P	Petiole N	0.4664*	-	--	0.0028	-0.0243	-0.0135	-0.0872	**0.1348**	-0.0262	-0.0183	**0.1316**	-0.0010	-0.0122	0.0593	0.0407	0.6537**
	Petiole Mg	0.5132**	-0.0123	--	-0.0005	0.0386	-	0.1277	-0.0309	0.0046	-0.0056	**-0.1022**	0.0011	**-0.1173**	-0.0719	-0.0609	0.2836
	Petiole Na	-0.2625	**-0.2396**	--	-0.0111	0.0319	0.0604	0.0105	-	0.0276	0.0166	-0.0359	0.0003	-0.0218	-0.0251	-0.0096	0.4583*
	Soil K	0.4658*	0.1318	--	0.0073	-0.0197	**-0.1126**	-0.0973	0.0202	-0.0603	-0.1018	-	-0.0022	0.0646	**-0.1346**	0.1210	0.2823
	Soil S	-0.4339*	-0.0638	--	0.0104	0.0085	0.0850	0.0171	-0.0152	-0.0200	-0.0447	**0.1444**	-0.0027	0.0238	-	**0.2245**	-0.0667
	Soil Na	0.4161*	0.0456	--	0.0019	-0.0150	-0.0751	-0.0036	0.0060	-0.0399	-0.0527	0.1355	-0.0007	0.0348	**-0.2341**	-	0.2189
	Residual effect= 0.306																
Petiole K	Petiole S	0.4358*	**-0.0823**	-0.0152	--	-0.0228	0.0069	-	0.0211	0.0442	-0.0265	0.0571	**-0.0600**	-0.0007	-0.0351	-0.0033	0.3193
	Petiole Na	0.6257**	**-0.1512**	0.0256	--	-0.0372	0.0020	0.0147	-	0.0485	-0.0177	0.0141	-0.0093	-0.0102	-0.0372	-0.0066	0.4613*
	Soil S	-0.6417**	-0.0402	0.0037	--	-0.0099	0.0028	0.0238	0.0362	-0.0351	0.0477	-0.0568	0.0743	0.0111	-	**0.1542**	-0.4299*
	Residual effect= 0.710																
Petiole Ca	Petiole N	-0.0560	-	0.0540	0.0049	--	-0.0095	-0.0292	**-0.2735**	0.0217	0.0241	**-0.1085**	0.0049	0.0035	-0.0285	-0.0309	-0.4232*
	Petiole Mg	0.3592	0.0015	0.0234	-0.0009	--	-	0.0428	0.0626	-0.0038	0.0074	**0.0843**	-0.0174	0.0332	0.0346	**0.0463**	0.6731**
	Petiole Na	0.5325**	0.0288	-0.0379	-0.0192	--	**0.0422**	0.0035	-	-0.0229	-0.0218	0.0296	-0.0056	0.0062	0.0121	0.0073	0.5549**
	Residual effect= 0.441																
Petiole Mg	Petiole P	0.7039**	**-0.1069**	-	0.0002	-0.0740	--	-0.0102	-0.0515	0.0153	0.0404	**-0.1025**	-0.0010	-0.0279	-0.0263	-0.0759	0.2836
	Petiole Ca	0.3423	0.0692	-0.1523	0.0020	-	--	-0.0128	0.0624	-0.0145	-0.0187	**0.1244**	-0.0004	**0.1222**	0.0585	0.0908	0.6731**
	Petiole S	-0.0375	0.0457	**0.1912**	0.0032	**0.1165**	--	-	-0.0038	-0.0158	-0.0347	**0.1132**	-0.0039	0.0023	0.0216	0.0040	0.4095*
	Soil Mg	0.3526	-0.0085	-0.0557	-0.0006	**0.1186**	--	-0.0002	0.0104	-0.0027	-0.0198	0.0998	-0.0056	-	-0.0401	0.0514	0.4996*
	Residual effect= 0.420																
Petiole S	Petiole N	-0.6082**	-	**0.4518**	-0.0490	-0.0681	0.0016	--	**0.1461**	0.0172	-0.0081	-0.0543	-0.0127	-0.0029	-0.0693	-0.0237	-0.2795
	Petiole P	0.6912**	**-0.3976**	-	0.0093	-0.0348	-0.0172	--	0.1304	0.0160	-0.0128	-0.0543	0.0239	0.0044	-0.0338	-0.0531	0.2716
	Petiole K	0.4165*	0.0715	0.0155	-	0.0326	-0.0014	--	**-0.1312**	-0.0215	0.0171	0.0584	0.0564	0.0036	**-0.2178**	0.0195	0.3193
	Petiole Mg	-0.0607	0.0161	**0.1960**	0.0093	**0.1084**	-	--	-0.0335	-0.0030	-0.0025	0.0422	0.0454	-0.0276	0.0839	0.0355	0.4095*
	Soil S	0.5066**	0.0831	-0.0461	**-0.1791**	0.0238	-0.0101	--	-0.0165	0.0131	-0.0198	-0.0596	**-0.1155**	0.0056	-	**-0.1310**	0.0547
	Residual effect= 0.679																
Petiole Na	Petiole N	-0.1562	-	**-0.2598**	-0.0481	**-0.2370**	-0.0033	0.0543	--	-0.0474	-0.0303	0.1712	-0.0046	-0.0019	0.0171	0.0323	-0.5137**
	Petiole P	-0.3975*	**-0.1021**	-	0.0092	**-0.1211**	0.0352	-0.0528	--	-0.0442	-0.0480	0.1710	0.0086	0.0028	0.0083	0.0723	-0.4583*
	Petiole K	0.4086*	0.0184	-0.0089	-	**0.1133**	0.0028	-0.0620	--	0.0595	0.0642	-0.1842	0.0203	0.0023	0.0537	-0.0265	0.4613*
	Petiole Ca	0.5601**	0.0661	0.0860	0.0826	-	0.0835	-0.0661	--	0.0419	0.0221	**-0.2075**	0.0036	-0.0124	-0.0185	-0.0865	0.5549**
	Soil K	0.6057**	-0.0441	**-0.1122**	-0.1243	**-0.1919**	-0.0272	0.0606	--	-0.1091	**-0.1684**	-	-0.0334	0.0098	-0.0388	0.0961	-0.0771
	Residual effect= 0.464																

Dog Ridge. Direct effect of soil S on petiole S was negative on own roots but positive on Dog Ridge (Table 5). This indicates that many nutrients together inhibited the absorption of soil S by the rootstock and the low affinity of Thompson Seedless roots for SO_4^{--} ions as observed by (Kalbhor *et al.*, 12). Petiole P and K contents influenced the S absorption positively on Dog Ridge, while soil Mg on own root and petiole N on Dog Ridge did negatively. Antagonism observed between N and S in petioles on Dog Ridge could be due to similar charge of both ions and their differential mobility in plant tissues. When Mg is applied as $MgSO_4$ to soil, it can exert negative effect on petiole S as an associate ion with SO_4^{2-} since soil S had negative effect on petiole S on own root. Both P and S being absorbed as anions, the positive effect of petiole P on petiole S could be due to simultaneous demand by cations in the petioles for ionic balance. This assumption suggests the study of variation in the root CEC and base equilibrium as influenced by different rootstocks. The positive effect of petiole K on petiole S can be explained by their positive relationship in foliar tissues as a result of higher rates of sulphur application as explained in the absorption of potassium.

The direct negative effect of soil Mg on S absorption on own root was reduced by its indirect positive effects via petiole and soil N contents. While the direct effect of petiole N on S absorption was negative, petiole P and K effects were positive on Dog Ridge. The direct negative effect of petiole N was reduced by its indirect positive effect via petiole P, while the direct positive effect of petiole P was reduced by its indirect negative effect via petiole N and that of petiole K by its indirect negative effects via petiole Na and soil S on Dog Ridge (Table 5). The residual effect on S absorption was 0.599 and 0.679 respectively on own root and Dog Ridge, indicating the determination of S absorption by all soil and petiole nutrients including soil S was 40.1 and 32.1 per cent, respectively.

Neither the correlation nor the direct effect of soil Na was significant on petiole Na either on own roots or on Dog Ridge rootstock (Table 3). It could be due to less affinity of Dog Ridge roots (Kalbhor *et al.*, 12) and in case of own roots, the domination of other nutrients effect-direct or indirect- on the absorption of Na. Sodium absorption correlated positively with petiole Ca on both root systems and also with petiole K on Dog Ridge, but negatively with petiole N and petiole P on Dog Ridge. The direct effects of petiole Ca and soil K on both root systems and petiole K on Dog Ridge were positive, while those of petiole N on own root and petiole P on Dog Ridge were negative (Table 5). Negative effect of petiole N on own root and that of petiole P on Dog Ridge could be explained by the positive correlation between N and P contents of petiole on own root as well as Dog Ridge and the preferential absorption of NO_3^- by Thompson Seedless roots but PO_4^{3-} by Dog Ridge. While mobility of N and its preferential accumulation in leaf lamina were implicated in the negative effect of N (see nitrogen absorption above), reduced Na contents in the leaves as a result of higher rates of P application (Gibson, 11) for the negative effect of P. Regardless to root affinity, Na^+ is released with greater ease than K^+ in to soil solution. Both being monovalent cations, Na^+ is absorbed more, when available, leaving more K^+ in the soil. Thus soil K correlates positively with petiole Na. The positive relationship between petiole K and petiole Na is the consequence of ionic balance as explained earlier under pathways of potassium absorption.

The Direct positive effect of petiole Ca on Na absorption was enhanced by its indirect positive effect via petiole N on own root but not influenced by indirect effect of any nutrient on Dog Ridge. The direct positive effect of soil K was reduced by its indirect negative effects via soil S, petiole N and petiole Ca on own root, while via petiole Ca and soil P on Dog Ridge. The direct positive effect of petiole K was enhanced by its indirect positive effect via petiole Ca on Dog Ridge. The direct negative effect of petiole N on Na absorption was reduced by its indirect positive effects via soil K and soil Mg on own root, but enhanced by the indirect negative effects via petiole P and petiole Ca on Dog Ridge. The direct negative effect of petiole P was enhanced by its indirect negative effects via petiole Ca and petiole N on Dog Ridge (Table 5). All the soil and petiole nutrient contents including soil Na content accounted for 39.3 and 53.6 per cent variation in Na absorption respectively on own root and Dog ridge, as indicated by the residual effects (Table 5). The rest was accounted for by other factors influencing Na absorption.

Indirect effect of a pair of nutrients on the absorption different nutrients was different on different roots. It was because of the complexity of the interrelationship among nutrients resulting from relative abundance of nutrients, preferential absorption of roots, antagonism among the similarly charged ions at absorption level, and synthesis of anionic organic compounds, mobility of nutrients and ionic balance in foliar tissues.

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