Asian Journal of Chemistry Vol. 21, No. 2 (2009), 1302-1308

Analysis of VNIR Reflectance for Prediction of Macro and Micro Nutrient and Chlorophyll Contents in Apple Trees (*Malus communis*)

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Studies have demonostrated the value of spectral vegetation reflectance's based on visible near infrared spectra in agriculture. The aim of this study was to determine the relationships between nitrogen, phosphorus, potassium, magnesium, calcium, iron, copper, manganese, zinc and chlorophyll content of leaves of three apple trees and spectral reflectance. Blue, green, red and near-infrared bands were used to predict the nitrogen, phosphorus, potassium, magnesium, calcium, iron, copper, manganese, zinc and chlorophyll content of apple trees (Granny smith, Starkrimson delicious and Golden delicious). In Granny smith, it was determined that the highest r^2 values were N, Mg, Fe, Zn and chlorophyll contents in degree of 10 angle (0.99, 0.68, 0.94, 0.92 and 0.98, respectively). In contrary, P, K, Ca, Cu and Mn had higher r^2 values in plant probe (0.97, 0.99, 0.71, 0.92 and 0.99, respectively). While the highest r^2 values were determined from Ca, Cu, Mn and chlorophyll (0.50, 0.87, 0.99 and 0.93, respectively) in degree of 10 angle, N, P, K, Mg, Fe and Zn had highest r^2 values in plant probe in Starkrimson delicious. In golden delicious, the highest r^2 values was achieved from P, K, Mg, Fe and chlorophyll (0.83, 0.99, 0,99, 0.94 and 0.99, respectively) in degree of 10 angle, N, Ca, Cu, Mn and Zn had highest r^2 values in plant probe (0.89, 0.99, 0.99, 0.97 and 0.99, respectively). Present results suggest that spectral reflectance can be used for non-destructive prediction of macro and micro nutrient contents in leaves of apple trees.

Key Words: Apple tree, Spectroradiometer, Reflectance, Near-infrared.

INTRODUCTION

Macro and micro nutrients are mainly responsible for plant development and health[1]. The traditional methods available for detecting plant quality require detailed sampling and expensive laboratory analysis. Remote sensing offers potential to predict foliar biochemical concentration in plants, thereby reducing the tedious process of intensive sampling and laboratory analysis[2].

A relationship between spectral reflectance, particularly visible absorption and macronutrients such as phosphorous, potassium, magnesium and calcium is expected due to their effect on the photosynthetic process in plants[2,3].

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A variety of spectral measures that relate to nitrogen and chlorophyll content or other plant stress have been developed. As leaves become more chlorotic, reflectance increases[4]. Energy absorption with chlorophyll of leaf has been found positively proportional at blue and red band of wavelength and negatively proportional at green and near infrared band of wavelength of light spectrum[5,6]. It was observed that strong relationships exist between remotely sensed data and many biochemical substances of crop canopies and plant physiology[7,8].

The aim of this study was to determine the relationships between nitrogen, phosphorus, potassium, magnesium, calcium, iron, copper, manganese, zinc and chlorophyll content of leaves of apple trees and spectral reflectance.

EXPERIMENTAL

This research was conducted at Egirdir (37° 45' N, 30° 31' E, elevation 1030 m) located on the Mediterranean region of Turkey in 2007. Three apple trees (Granny smith, Starkrimson delicious and Golden delicious) were chosen randomly from the plots, which had similar soil types.

A portable ASD Hend Held spectroradiometer was used to collect the spectral reflectance data. Reflectances were measured on 10 May, 24 May, 7 June, 21 June, 5 July and 21 July 2007. The ASD measures spectral reflectance in the 325-1150 nm wavelength range with a 1 nm sampling interval. The radiometer had 10° field of view, producing a view area with a 0.35 m diameter. A Spectralon reference panel (white reference) was used to optimize the ASD instruments for taking canopy reflectance measurements at each sampling plot. The canopy reflectance data were expressed as relative values by dividing them by the white reference panel reflectance readings[9]. In addition, plant probe was also used to collect the spectral reflectance data in apple tress leaves. Leaves samples were immediately dried, weighed and ground for determinations of N, P, K, Mg, Ca, Fe, Cu, Mn, Zn and chlorophyll content according to standard laboratory producers.

The reflectance values measured by VNIR spectroradiometer and plant probe were recorded *via* ASD ViewSpect® software. Wavelength bands of the spectroradiomer and plant probe were follows: 400-500 nm (blue band), 500-600 nm (green band), 600-700 nm (red band) and 700-900 nm (near infrared band). Reflectance values at this wavelength were separately recorded for each apple trees. Then stepwise regression analysis applied to leaf to measure the N, P, K, Mg, Ca, Fe, Cu, Mn, Zn and chlorophyll content among reflectance values (%) and laboratory analysis. Predicted values for N, P, K, Mg, Ca, Fe, Cu, Mn, Zn and chlorophyll content were obtained by using stepwise regression equations. The r^2 values were estimated as a result of the stepwise regression analysis between measured and predicted values.

RESULTS AND DISCUSSION

Nitrogen content ranged between 2.09 and 2.90 %, P was between 0.01 and 0.10 %, K was 1.15 and 2.79 %, Mg was 0.20 and 0.64 %, Ca was 0.33 and 3.50 %, Fe was 219.80 and 335.40 ppm, Cu was 8.60 and 12.87 ppm, Mn was 29.70 and 40.82 ppm, Zn was 1.90 and 11.32 ppm and chlorophyll was 0.37 and 2.96 in Granny smith (Table-1). In Starkrimson delicious, N content ranged between 0.54 and 2.54 %, P was between 0.03 and 0.09 %, K was 1.24 and 2.42 %, Mg was 0.19 and 0.76 %, Ca was 0.28 and 3.65 %, Fe was 155.80 and 228.80 ppm, Cu was 4.00 and 12.09 ppm, Mn was 16.00 and 41.87 ppm, Zn was 0.70 and 10.12 ppm and chlorophyll was 0.45 and 3.21 (Table-2). N content ranged between 1.92 and 3.24 %, P was between 0.01 and 0.10 %, K was 1.29 and 2.58 %, Mg was 0.22 and 0.69 %, Ca was 0.29 and 3.38 %, Fe was 211.80 and 302.20 ppm, Cu was 3.80 and 12.41 ppm, Mn was 24.60 and 41.52 ppm, Zn was 0.80 and 9.30 ppm and chlorophyll was 0.48 and 2.93 in golden delicious (Table-3).

TABLE-1
DESCRIPTIVE STATISTICS OF MACRO AND MICRO NUTRITION CONTENTS OF GRANNY SMITH

	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Chlorophyll (Chl)
Max.	2.90	0.01	2.79	0.64	3.50	335.40	12.87	40.82	11.32	2.96
Min.	2.09	0.10	1.15	0.20	0.33	219.80	8.60	29.70	1.90	0.37
Mean	2.45	0.04	2.16	0.37	1.09	269.80	10.84	37.61	6.72	1.37

TABLE-2
DESCRIPTIVE STATISTICS OF MACRO AND MICRO NUTRITION CONTENTS OF STARKRIMSON DELICIOUS

	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Chlorophyll (Chl)
Max.	2.54	0.09	2.42	0.76	3.65	228.80	12.09	41.87	10.12	3.21
Min.	0.54	0.03	1.24	0.19	0.28	155.80	4.00	16.00	0.70	0.45
Mean	1.58	0.04	1.80	0.42	1.15	192.82	8.58	30.51	6.12	1.67

TABLE-3
DESCRIPTIVE STATISTICS OF MACRO AND MICRO NUTRITION CONTENTS OF GOLDEN DELICIOUS

	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Fe (ppm)	Cu (ppm)	Mn (ppm)	Zn (ppm)	Chlorophyll (Chl)
Max.	3.24	0.10	2.58	0.69	3.38	302.20	12.41	41.52	9.30	2.93
Min.	1.92	0.01	1.29	0.22	0.29	211.80	3.80	24.60	0.80	0.48
Mean	2.22	0.04	1.80	0.37	1.19	248.08	8.27	33.40	5.85	1.67

Granny smith, Starkrimson delicious and golden delicious macro and micro nutrition contents in the test data set were predicted by the degree of 10 angle and plant probe corresponding equations of the blue (400-500 nm), green (500-600 nm), red (600-700 nm) and NIR (700-900 nm) wavelengths reflectance in Tables 4-9. These macro and micro nutrition contents variables were also predicted by the models of the stepwise regression in Tables 4-9 on the basis of the reflectance data. Stepwise regression equations developed from the test data set were applied to the test data set for all spectral reflectance. The 4 most important wavebands for each measured quality variable and the corresponding multivariable equations and r^2 values, obtained by stepwise regression, are given in Tables 4-9.

TABLE-4
FOUR WAVE BANDS (± 5) SELECTED FROM STEPWISE REGRESSION FOR DETERMINING RELATIONSHIPS BETWEEN REFLECTANCE AND MACRO AND MICRO NUTRITION'S ON THE BASIS OF CALIBRATION DATA SET IN GRANNY SMITH (10º ANGLE)

Parameters	Equations	SE	r^2
N	-0.27+100.8(R430)-678.8(R510)+397.8(R640)+17.6(R770)	0.04	0.99
P	-0.09+15.21(R410)-4.45(R500)-0.14(620)+0.02(R730)	0.05	0.59
K	4.07+156.63(R460)-31.00(R580)+5.24(R630)-59.41(R700)	0.24	0.97
Mg	0.24-0.97(R480)-31.7(R540)+29.74(R690)+1.99(R750)	0.24	0.68
Ca	-4.14+162.02(R400)-179.16(R530)+117.36(R660)+19.17(790)	2.02	0.44
Fe	375.31+21298(R450)+26719(R570)-36086(R610)-1337.66(R780)	23.17	0.94
Cu	6.93+1091.15(R420)+662.15(R550)-920.00(R600)-47.59(R740)	1.23	0.90
Mn	54.12-1053.15(R440)+1850(R520)-643.01(R680)-227.49(R720)	2.42	0.93
Zn	8.05+286.69(R470)-555.07(R590)+501.68(R650)-4.40(R760)	2.03	0.92
Chl	-3.09-31.43(R490)-489.23(R560)+221.45(R670)+217.82(R710)	0.31	0.98

TABLE-5
FOUR WAVE BANDS (±5) SELECTED FROM STEPWISE REGRESSION FOR DETERMINING RELATIONSHIPS BETWEEN REFLECTANCE AND MACRO AND MICRO NUTRITION'S ON THE BASIS OF CALIBRATION DATA SET IN STARKRIMSON DELICIOUS (10º ANGLE)

Parameters	Equations	SE	r^2
N	2.15+0.68(R410)-116.33(R530)+135.82(R640)+1.70(R740)	0.61	0.92
P	0.03+8.36(R470)+3.75(R550)-6.77(R670)-0.58(R820)	0.02	0.88
K	1.36+146.50(R490)-214.10(R510)+104.35(R650)-1.11(R780)	0.29	0.94
Mg	0.82+29.52(R440)+5.95(R520)-16.66(R680)-1.89(R750)	0.39	0.55
Ca	1.96-71.28(R450)-8.39(R540)-86.65(R630)+12.90(R790)	2.02	0.50
Fe	256.74+45847(R430)-64103(R500)+18305(R610)-192.30(R770)	12.40	0.97
Cu	15.68-363.55(R400)-1636.51(R570)+766.45(R620)+455.24(R710)	2.48	0.87
Mn	37.25+1183(R420)-1634.39(R580)+1164.47(R690)+10.63(R870)	3.18	0.99
Zn	-1.82-223.68(R460)-1042.1(R560)+1043.66(R600)+84.62((R810)	4.71	0.70
Chl	1.31+289.85(R480)+206.16(R590)-383.60(R660)-9.35(R850)	0.56	0.93

TABLE-6
FOUR WAVE BANDS (±5) SELECTED FROM STEPWISE REGRESSION FOR DETERMINING RELATIONSHIPS BETWEEN REFLECTANCE AND MACRO AND MICRO NUTRITION'S ON THE BASIS OF CALIBRATION DATA SET IN GOLDEN DELICIOUS (10º ANGLE)

Parameters	Equations	SE	r^2
N	2.24+96.93(R430)+84.19(R550)-78.59(R610)-11.37(R740)	0.73	0.74
P	-0.03-12.15(R460)+2.95(R500)+1.98(R630)+0.47(R780)	0.03	0.83
K	1.32+50.41(R450)-83.47(R590)+80.06(R670)+2.07(R850)	0.03	0.99
Mg	-0.03+36.33(R490)-27.59(R570)+7.65(R690)+1.78(R880)	0.00	0.99
Ca	4.41-27.18(R440)+195.18(R560)-126.50(R600)-21.80(R870)	1.94	0.44
Fe	211.59+6472(R480)-1979.76(R530)-644.18(R680)-16.47(R790)	17.71	0.94
Cu	15.26-1070.95(R400)-83.87(R580)+430.97(R640)-3.56(R770)	1.75	0.95
Mn	38.43+2074.52(R420)+722.63(R510)-905.45(R620)-65.71(R810)	4.18	0.92
Zn	2.74+691.03(R410)-140.14(R540)-40.68(R660)+0.37(R830)	5.86	0.44
Chl	-15.21-824.37(R470)-2472(R520)+1640.83(R650)+178.84(R820)	0.23	0.99

TABLE-7
FOUR WAVE BANDS (±5) SELECTED FROM STEPWISE REGRESSION FOR DETERMINING RELATIONSHIPS BETWEEN REFLECTANCE AND MACRO AND MICRO NUTRITION'S ON THE BASIS OF CALIBRATION DATA SET IN GRANNY SMITH (PLANT PROBE)

Parameters	Equations	SE	r^2
N	8.89+44.93(R470)+13.71(R530)-14.11(R650)-10.18(R790)	0.15	0.95
P	1.25-2.07(R440)+3.79(R560)-10.82(R640)-1.20(R740)	0.01	0.97
K	-5.62-101.67(R460)-48.86(R590)+131.33(R680)+10.35(R830)	0.16	0.99
Mg	5.23-75.87(R400)-61.67(R510)+68.57(R670)-1.94(R760)	0.25	0.67
Ca	4.94+91.37(R420)+120.30(R570)-311.36(R620)-1.86(R710)	1.46	0.71
Fe	-394.3+9691.7(R490)+8228.4(R580)-11279.9(R610)+299.4(R880)	32.93	0.88
Cu	253.87+55.78(R430)-1329.49(R500)+525.21(R630)-231.51(R820)	2.20	0.92
Mn	-221.11+695.09(R480)-225.6(R540)+713.05(R690)+228.98(R770)	0.88	0.99
Zn	-58.30-1069.12(R410)-247.96(R550)+520.7(R600)+107.16(R840)	2.14	0.91
Chl	-4.72+1488.06(R450)+310.64(R520)-1343.16(R660)-23.05(R870)	1.36	0.55

TABLE-8
FOUR WAVE BANDS (±5) SELECTED FROM STEPWISE REGRESSION FOR DETERMINING RELATIONSHIPS BETWEEN REFLECTANCE AND MACRO AND MICRO NUTRITION'S ON THE BASIS OF CALIBRATION DATA SET IN STARKRIMSON DELICIOUS (PLANT PROBE)

Parameters	Equations	SE	r^2
N	1.46+77.32(R440)-6.27(R530)-201.48(R670)+9.52(R740)	0.310	0.98
P	1.52+70.89(R430)-71.72(R500)+22.68(R640)-2.66(R850)	0.001	0.99
K	12.70-101.72(R480)-5.05(R560)-8.81(R680)-5.27(R760)	0.140	0.99
Mg	16.74-41.94(R410)+43.14(R550)-92.29(R610)-15.52(R750)	0.050	0.99
Ca	-100.64-66.01(R470)-96.49(R590)+521.35(R660)+95.04(R770)	2.060	0.49
Fe	53.60+3583.9(R460)+3774.02(R510)-2043.59(R690)-119.4(R870)	5.260	0.99
Cu	605.12+207.18(R420)+1488.9(R570)-3156.99(R620)-618.6(R810)	4.630	0.55
Mn	82.94-290.12(R490)+213.96(R540)-876.06(R630)-47.28(R700)	9.200	0.87
Zn	-114.88-378.55(R400)-167.18(R520)+134.4(R600)+155.73(R780)	2.420	0.92
Chl	10.71+154.10(R450)+2.89(R580)+22.82(R650)-19.66(R820)	0.740	0.89

TABLE-9
FOUR WAVE BANDS (±5) SELECTED FROM STEPWISE REGRESSION FOR DETERMINING RELATIONSHIPS BETWEEN REFLECTANCE AND MACRO AND MICRO NUTRITION'S ON THE BASIS OF CALIBRATION DATA SET IN GOLDEN DELICIOUS (PLANT PROBE)

Parameters	Equations	SE	r^2
N	22.6+90.88(R470)+27.2(R540)-86.7(R670)-25.7(R820)	0.18	0.89
P	10.82+24.24(R440)+13.74(R520)-8.76(R690)-13.40(R780)	0.03	0.73
K	-26.73-107.27(R430)-65.71(R580)+143.61(R620)+32.73(R880)	0.62	0.67
Mg	-28.21-177.35(R460)-41.63(R570)+148.41(R640)+35.93(R770)	0.12	0.91
Ca	-17.46-363.57(R420)-295.08(R500)+395.53(R630)+30.82(R740)	0.26	0.99
Fe	-7708-14645.8(R450)-2319.9(R560)-6005.3(R610)+10079(R790)	25.44	0.88
Cu	107.24+3513.59(R480)+1019.9(R510)-5169.29(R660)-80.2(R870)	0.21	0.99
Mn	-16.36-785.42(R410)-533.46(R590)+2460.40(R650)+4.94(R730)	2.69	0.97
Zn	-737.27-1604.4(R400)-471.95(R530)+319.56(R600)+918.9(R760)	0.53	0.99
Chl	-13.64-335.94(R490)+19.36(R550)+196.94(R680)+18.14(R840)	1.29	0.51

In Granny smith, it was determined that the highest r^2 values were N, Mg, Fe, Zn and chlorophyll contents in degree of 10 angle (0.99, 0.68, 0.94, 0.92 and 0.98, respectively). In contrary, P, K, Ca, Cu and Mn had higher r^2 values in plant probe (0.97, 0.99, 0.71, 0.92 and 0.99, respectively) (Tables 4 and 6).

While the highest r^2 values were determined from Ca, Cu, Mn and chlorophyll (0.50, 0.87, 0.99 and 0.93, respectively) in degree of 10 angle, N, P, K, Mg, Fe and Zn had highest r^2 values in plant probe in Starkrimson delicious (Tables 5 and 7).

In golden delicious, the highest r^2 values was achieved from P, K, Mg, Fe and chlorophyll (0.83, 0.99, 0,99, 0.94 and 0.99, respectively) in degree of 10 angle, N, Ca, Cu, Mn and Zn had highest r^2 values in plant probe (0.89, 0.99, 0.99, 0.97 and 0.99, respectively) (Tables 6 and 8).

Several studies on different plant species have indicated that reflectance of plant leaves correlated with leaf chlorophyll and leaf N concentration[10-13]. Light reflectance in the visible wavelengths (400-700 nm) increases with N deficiency because of chlorophyll reduction[14,15]. N and Mg are essential in the formation of chlorophyll. Deficiency of Ca, K and P resulted in only slight chlorosis[16]. Mutanga *et al.*[2] found that r^2 values of 0.70, 0.80, 0.64, 0.50 and 0.68 for nitrogen, phosphorus, potassium, calcium and magnesium, respectively. Reflectane values were measured duirng six different periods. In general, macro and micro nutrient elements of all three varieties of apple were increased up to the certain period but later they were decreased. It was found that there was very strong relationship between chlorophyll content and the macro and micro nutrient elements of apple leaves measured by both lens with 10º angle and plant probe.

Nutrient elements exist in different organic forms in the leaves of different apple varieties. This affects not only affect morphology of leaves but also its determination by spectroradiometer. Thus, Starkrimson Delicious has darker colour, thicker, more woolly leaves than golden delicious and Granny smith. While its chlorophyl content is high but N content is low. This may be the reason for differences in r^2 values between nutrient elements and both plant probe and lens with 10º angle.

Present results suggest that spectral reflectance can be used for non-destructive prediction of macro and micro nutrient contents in leaves of apple trees. Specially hiperspectral data provide more alternative VNIR bands among their spectra as compared to multispectral data and therefore could provide greater accuracy use plant probe. We anticipate that the future development of VNIR reflectance and spectroradiometer technique will support the asessment of plant nutrition in field study.

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(*Received*: 29 January 2008; *Accepted*: 1 October 2008) AJC-6907