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RESEARCH PAPER

Relationships of Shading-Induced Reductions in Yield and Morphological Traits with Mineral Nutrition of Apple Trees

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Abstract

Protective nets are commonly used in orchards to prevent hail damage and sunburns. However, these nets partially prevent sunlight exposure of the trees. Sunlight directly influences plant physiology. In present study, the effects of reduced sunlight on mineral nutrition of trees were investigated. Experimental orchard had protective nets with different shading ratios (0, 32, 42 and 56%) for 7 years. In 8, 9 and 10th year of the orchard, to reveal relationships of protective nets and mineral nutrition, apple trees were sampled from part of leaves, bud, and flower and subjected to mineral analyses. Leaf nutrients were all influenced by light intensity and increasing N, K, Fe, Cu, Mn and B levels were observed with increasing shading ratios. In fruit buds, shading treatments all had more Ca, Fe and Cu concentrations. In flower samples, only P and Mg were significant and the lowest values were obtained from the greatest shading ratio. Nutrient ratios were assessed for each sample group and only the leaf nutrient ratios were significant. It was observed when the common ratios (N:K and K:Mg) were assessed that the greatest N:K ratio was obtained from the control treatment and the other treatments were placed into the same group; the lowest K:Mg ratio was obtained from the control treatment and the other treatments were placed into the same group. It couldn't be detected relationships between decreasing yield, morphological traits and reduced sunlight with nutrient contents based on concentrations under experimental conditions.

1. Introduction

Plant productivity largely depends on the absorption of light energy by green tissues and the conversion of this energy into biomass through photosynthesis. Previous studies conducted with several plant species revealed that there was a linear relationship between light intake and dry matter production. For high yield and fruit quality, orchards should take sufficient quantity of light and the light should be well distributed within the tree canopy (Wünsche et al., 1996). Sunlight is composed of photons of different wavelengths and the solar energy they conveyed is dependent of their frequencies (Taiz and Zeiger, 2006). Majority of the energy supplied by the plants is within the visible spectrum (400-740 nm) (Raven and Johnson, 1999). In apple trees, since light directly or indirectly influence photosynthesis, flower bud formation and fruit quality, it is quite a significant parameter for fruit yield and quality. Limited light before or after flowering may reduce fruit set, size and quality (Rom, 1991).

Protective or shade nets are used in orchards to prevent hail damages and sunburns. Shade nets alter or reduce direct sunlight quantities through absorption or reflection of the light by the net. In this way, potential energy used by the plant is reduced, then probably plant energy balance is distorted and the type of growth is influenced (Stampar et al., 2001). In practice, various cover nets with different density and color are used in orchards. Previous research revealed that net color and density play a critical role in fruit quality and tree growth. Density of the cover system significantly influences solar radiation reaching to plant, thus play an important role in fruit quality traits like red coloration, fruit size, soluble solids content and starch conversion ratio (Stampar et al., 2001; Shahak et al., 2004). Better spur development is observed in trees receiving high sunlight as compared to low sunlight conditions and fruit quality increased in high sunlight conditions. Differences in size and quality of the fruits collected from different sections of the tree canopy are mostly related to total light ratio passing through the canopy. In practice, light is the most significant factor designating economic performance of the orchard (Tustin, 2005).

Shading may result in reductions in flower bud formation and fruit set. Leite et al. (2002) conducted a study for five years on apple trees and reported about 19% less flower bud formation in shade net-covered trees than in uncovered trees. Similarly, Middleton and McWaters (2002) indicated that there was no need for chemical thinning in ‘Hi Early’ and ‘Red Delicious’ apple cultivars under shade net, but there was a need for chemical treatments twice in adjacent uncovered trees (Smit, 2007). Shading is also effective in nutrition of trees. Light designates auxin synthesis. Auxin plays an important role in calcium (Ca) transfer. Montanaro et al. (2006) reported that light intensity increased Ca concentration of xylem sap in kiwi fruit. Rosati et al. (1999) reported that peach leaves in sun-exposed outer sections of the tree had greater N contents than the leaves in shaded sections and increased N contents were related to photosynthesis capacity. Zhao and Oosterhuis (1998) conducted a study on cotton and reported that shading increased NO_3-N, P, K, S, Ca and Mg concentrations of petioles and such a case was related to reduced carbohydrate accumulation.

In this study, the effects of protective nets with different shading ratios on nutrient uptake of ‘Granny Smith’ apple cultivars grafted on M9 rootstocks were investigated through leaf, fruit bud and flower analyses.

2. Material and Method

Experiments were conducted at experimental plots of Fruit Research Institute (Isparta-Türkiye) with ‘Granny Smith’ apple cultivar grafted on M9 rootstock in randomized blocks design with 6 replicates and 3 trees in each replicate. Shading treatments were initiated about 50 days after full bloom (10th of June) and continued until the end of October. 3 different net materials providing 32, 42 and 56% shading were used for 10 years (2003-2013) beginning from plantation of the trees. However, effects of shading on nutrient uptake were assessed with nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu) manganese (Mn), zinc (Zn) and boron (B) contents of fruit bud, flower and leaf samples collected during the last 3 years. Fruit buds were sampled at dormant season (in March) from the youngest shoots. Flowers together with pedicle were sampled from flower bouquet formed over the youngest shoots and from the flowers at balloon stage (in April). Leaf sampling with petiole was performed 85-90 days after full bloom (in July) from the mid-sections of the shoots of the same year within the tree canopy.

Samples were brought to laboratory and immediately washed through tap water, then washed through 0.1 N HCl and finally washed through deionized water and roughly dried out with drying papers. Samples were then placed into paper bags and dried in an oven at 65-70°C until a constant mass (for about 48 hours) (Kacar and İnal, 2010). Dried samples were ground and prepared for N, P, K, Ca, Mg, Fe, Cu, Mn, Zn and B analyses. Nitrogen concentration was determined through Kjeldahl method. Dry-ashing method was carried out for P, K, Ca, Mg, Fe, Cu, Mn, Zn and B (Ryan et al., 2001) and they detected in ICP-AES. NIST-brand reference apple leaf (1515) was used to check the accuracy of leaf analyses.

Experimental data were subjected to one-way ANOVA with the use of “JMP© 8.0” (SAS Institute, Inc.). Significant means were compared with the use of LSD (Least Square Difference) test at $P<0.05$ and $P<0.01$ significance levels.

3. Results and Discussion

In first 7 years of this study, it was revealed the “shade net systems or anti-hail nets” commonly used to prevent hail and sunlight damages generated on fruit peel affected yield and fruit quality traits. Present findings revealed that shading delayed harvest time and reduced yields. A linear decrease was observed in yield with increasing shading ratios. Such a decrease was not distinctive in the initial years of the study, but got more distinctive in subsequent years. Lower fruit weight, width and length values were observed in shading treatments. Shade nets are generally used in ‘Granny Smith’ apples to prevent sunburns and cheek redness and significant linear decreases were observed in these parameters with increasing shading ratios. Parallel to sunburns, soluble solids content values also decreased. In addition, fruit color parameters were influenced by shading treatments. While b* and L* values increased, a* values decreased with increasing shading ratios (unpublished data). When the leaf nutrient contents were assessed based on shading treatments, it was observed that the effects of shading on the mineral nutrition of the trees were found to be significant for all nutrients. The N, K, Fe, Cu, Mn and B nutrition of the trees linearly increased with increasing shading ratios and the greatest values were obtained from the greatest shading ratio. While the greatest Ca and the lowest Zn values were obtained from the 42% shading treatment, these nutrients were placed into the same statistical group. P and Mg nutrition of the trees were similar and the greatest values were obtained from the control treatment and the 56% shading treatment (Table 1). Nutrient accumulation in fruit buds was similar for some nutrients, but exhibited differences for some others. The greatest P values were obtained from 32% shading treatment and control treatment. As compared to control treatment without shading, significantly greater Ca, Fe and Cu values were obtained from the shading treatments. On the other hand, changes in the other nutrients were not found to be significant (Table 2). In flower tissues, changes only in P and Mg were found to be significant and the lowest values were obtained from the greatest shading ratios (Table 3).

Significant effects of sunlight intensity on sunburn (Piskolczi et al., 2004), redness (Reay, 1999), yield (Tustin, 2005; Robinson, 2007), flower bud formation (Dennis, 2000), soluble solid concentration (Amarante et al., 2011), fruit size and harvest time (Smit, 2007) were reported in previous studies. Decreased fruit bud formation and resultant decreasing yields in subsequent years were found to be remarkable. Therefore, it was thought that such negative effects of shade nets might directly or indirectly be related to mineral nutrition. In the experimental plot provided with shade nets with different shading ratios for long years, shading provided for additional 3 years and treatments were compared in terms of nutrient accumulation in fruit bud, flower and leaf tissues.

Zhao and Oosterhuis (1998) conducted a study on cotton and reported that shading treatments increased concentrations of some nutrients in petioles, but related such increases to carbohydrate accumulation. Cui et al. (2014) reported that shading reduced dry matter accumulation, N and P absorptions in maize. N and P absorptions increased to some extent with different treatments, but decrease in dry matter was greater than the increase in N and P absorption. Gao et al. (2020) conducted a study on maize and indicated that decreasing yields were resulted from the negative effects of shading on dry matter and N uptake and transport.

It was indicated in previous studies that even at sufficient level of a nutrient in leaf, there may be deficiency symptoms of that nutrient based on

Table 1. Effects of shading levels on leaf nutrient contents of apple trees grafted on M9 rootstock cv. 'Granny Smith' (average of three subsequent years).

Shading levels (%)	N (% DW)	P (% DW)	K (% DW)	Ca (% DW)	Mg (% DW)
0	2.32 ± 0.070 b	0.20 ± 0.006 a	1.27 ± 0.064 c	1.14 ± 0.041 b	0.37 ± 0.014 ab
32	2.37 ± 0.039 b	0.18 ± 0.005 b	1.44 ± 0.038b	1.12 ± 0.021 b	0.35 ± 0.008 b
42	2.39 ± 0.042 b	0.21 ± 0.014 b	1.47 ± 0.040 b	1.32 ± 0.041 a	0.35 ± 0.009 b
56	2.50 ± 0.042 a	0.18 ± 0.002 a	1.61 ± 0.038 a	1.18 ± 0.037 b	0.38 ± 0.011 a
P value	P<0.01	P<0.01	P<0.01	P<0.01	P<0.05
Shading levels (%)	Fe (mg kg^{-1} DW)	Cu (mg kg^{-1} DW)	Mn (mg kg^{-1} DW)	Zn (mg kg^{-1} DW)	B (mg kg^{-1} DW)
0	94 ± 3.98 b	8.8 ± 0.35 c	26.0 ± 1.37 b	21.5 ± 3.12 a	32.5 ± 0.72 c
32	98 ± 4.56 b	9.8 ± 0.38 b	25.6 ± 1.94 b	17.2 ± 1.48 b	34.2 ± 1.09 c
42	124 ± 6.32 a	11.0 ± 0.26 a	27.2 ± 1.22 ab	21.9 ± 2.99 a	37.4 ± 0.65 b
56	118 ± 5.91 a	11.2 ± 0.29 a	29.4 ± 1.47 a	22.4 ± 3.68 a	39.5 ± 0.89 a
P value	P<0.01	P<0.01	P<0.05	P<0.01	P<0.01

NS: non-significant. ±: standard error of mean. DW: dry weight

Table 2. Effects of shading levels on fruit bud nutrient contents of apple trees grafted on M9 rootstock cv. 'Granny Smith' (average of two years).

Shading levels (%)	N (% DW)	P (% DW)	K (% DW)	Ca (% DW)	Mg (% DW)
0	1.72 ± 0.090	0.30 ± 0.014 ab	0.55 ± 0.026	2.04 ± 0.102 b	0.13 ± 0.004
32	1.89 ± 0.053	0.31 ± 0.008 a	0.58 ± 0.013	2.46 ± 0.092 a	0.14 ± 0.005
42	1.82 ± 0.077	0.28 ± 0.005 c	0.55 ± 0.022	2.31 ± 0.065 a	0.13 ± 0.003
56	2.00 ± 0.070	0.29 ± 0.006 bc	0.59 ± 0.016	2.38 ± 0.083 a	0.14 ± 0.004
P value	NS	P<0.05	NS	P<0.01	NS
Shading levels (%)	Fe (mg kg^{-1} DW)	Cu (mg kg^{-1} DW)	Mn (mg kg^{-1} DW)	Zn (mg kg^{-1} DW)	B (mg kg^{-1} DW)
0	58 ± 4.19 b	77 ± 11.7 b	17.6 ± 1.26	63 ± 5.54	26.8 ± 1.93
32	76 ± 5.49 a	105 ± 9.05 ab	19.6 ± 0.93	75 ± 4.80	29.3 ± 1.13
42	72 ± 3.35 a	113 ± 10.56 a	19.4 ± 1.07	78 ± 6.21	28.7 ± 1.11
56	79 ± 4.40 a	130 ± 9.05 a	19.1 ± 0.93	73 ± 3.23	28.8 ± 1.21
P value	P<0.01	P<0.01	NS	NS	NS

NS: non-significant, ±: standard error of mean, DW: dry weight

Table 3. Effects of shading levels on flower nutrient contents of apple trees grafted on M9 rootstock cv. 'Granny Smith' (average of two years).

Shading levels (%)	N (% DW)	P (% DW)	K (% DW)	Ca (% DW)	Mg (% DW)
0	3.37 ± 0.16	0.43 ± 0.008 a	1.88 ± 0.022	0.44 ± 0.013	0.24 ± 0.005 a
32	3.54 ± 0.12	0.42 ± 0.004 ab	1.85 ± 0.021	0.42 ± 0.008	0.24 ± 0.003 a
42	3.26 ± 0.13	0.42 ± 0.005 ab	1.87 ± 0.043	0.43 ± 0.009	0.24 ± 0.003 a
56	3.44 ± 0.13	0.41 ± 0.006 b	1.81 ± 0.030	0.45 ± 0.010	0.23 ± 0.004 b
P value	NS	P<0.05	NS	NS	P<0.05
Shading levels (%)	Fe (mg kg^{-1} DW)	Cu (mg kg^{-1} DW)	Mn (mg kg^{-1} DW)	Zn (mg kg^{-1} DW)	B (mg kg^{-1} DW)
0	91 ± 5.67	52 ± 3.39	36 ± 6.69	45 ± 3.08	58 ± 2.80
32	83 ± 4.16	53 ± 3.99	38 ± 7.56	46 ± 3.09	56 ± 2.84
42	92 ± 5.67	57 ± 4.57	33 ± 5.71	44 ± 2.74	62 ± 2.81
56	86 ± 6.76	60 ± 8.00	35 ± 7.30	39 ± 3.38	56 ± 3.82
P value	NS	NS	NS	NS	NS

NS: non-significant, ±: standard error of mean, DW: dry weight

Table 4. Effects of shading levels on leaf nutrient ratios of apple trees grafted on M9 rootstock cv. 'Granny Smith' (average of three years).

Shading levels (%)	C:B	Ca:Fe	K:Mg	Mg:B	Mg:Fe	N:B
0	362 ± 16 a	128 ± 7 a	3.69 ± 0.16 b	114 ± 6.0 a	40 ± 2.0 a	731 ± 16 a
32	334 ± 11 a	119 ± 6 ab	4.22 ± 0.15 a	103 ± 3.9 b	36 ± 1.4 ab	703 ± 23 a
42	355 ± 14 a	110 ± 6 bc	4.23 ± 0.19 a	96 ± 3.8 c	30 ± 1.5 c	641 ± 14 b
56	305 ± 14 b	103 ± 4 c	4.32 ± 0.13 a	97 ± 4.2 bc	33 ± 1.4 bc	638 ± 17 b
P value	P<0.01	P<0.05	P<0.01	P<0.01	P<0.01	P<0.01
Shading levels (%)	N:Fe	N:K	P:B	P:Ca	P:Fe	P:Mn
0	262 ± 14 a	1.82 ± 0.08 a	62 ± 2.2 a	0.18 ± 0.007 a	22.2 ± 1.39 a	80 ± 3.5 a
32	251 ± 10 a	1.66 ± 0.06 b	55 ± 2.2 b	0.17 ± 0.004 ab	19.7 ± 1.12 ab	78 ± 5.5 a
42	202 ± 12 b	1.65 ± 0.06 b	57 ± 3.8 ab	0.16 ± 0.008 b	17.9 ± 1.56 bc	79 ± 4.9 a
56	220 ± 10 b	1.56 ± 0.04 b	46 ± 1.3 c	0.15 ± 0.004 b	15.8 ± 0.78 c	63 ± 2.6 b
P value	P<0.01	P<0.01	P<0.01	P<0.05	P<0.01	P<0.01

±: standard error of mean

relative quantities of the other elements (Bergmann, 1992; Stiles, 1994; Hoying et al., 2004; Uçgun et al., 2013; Rietra et al., 2017). Therefore, relative quantities of all nutrients in leaf, flower bud and flower were assessed based on treatments and significant outcomes were observed only for leaf nutrient concentrations. Explainable results, in other words, linear increase of decreases with increasing shading ratios, are provided in Table 4. In leaves, shading-dependent N:B, N:Fe and P:Ca ratios were similar. These ratios were similar and greater in control and 32% shading treatments and different and lower in 42 and 56% shading treatments. Ca:B and P:Mn ratios were also similar. These ratios were significant and lower only in the greatest shading treatments and the other treatments were placed into the same statistical group. K:Mg and N:K ratios were different only in the control treatments and similar in all shading treatments. The lowest K:Mg and the greatest N:K ratios were observed in control treatment. Ca:Fe, P:Fe and P:B ratios linearly decreased with increasing shading ratios. Mg:B and Mg:Fe ratios were similar and decreased with increasing shading ratios, but both ratios were greater in 56% shading treatment than in 42% shading treatment. In terms of nutrient ratios, all ratios, except for K:Mg, were found to be more favorable for tree nutrition.

4. Conclusions

The damage directly generated by sunlight on fruit peels could totally be prevented with increasing shading ratios of the protective nets used especially against sunburn in orchards. However, apart from yield and sunburn, there is an inverse relationship between the other quality traits and shading ratios of protective nets. Since plant physiology is directly related to light intensity, the decrease especially in bud formation and yield with decreasing light intensity was also thought to be related to mineral nutrition of the trees. In other words, nutritional disorders were expected through reduced nutrient uptake with increasing shading ratios or possible imbalances between the nutrients. Present data revealed that the case was different from the expectations since increases were observed in uptake of several nutrients with increasing shading ratios. The nutrient ratios also revealed that there was a more balanced nutrition in shading treatments. In plant analyses, identified values generally express as concentrations in dry matter. But there is a linear negative relationship between light intensity and dry matter accumulation. Therefore, when expression of nutrients based on concentration in dry matter, proportional increase realizes in nutrient concentrations with decreasing dry matter quantities. This case complicates the assessment of the on-going relationships between shading and nutrition of the trees. Such cases even may lead to erroneous outcomes. Therefore, in similar studies, it is thought that nutrient accumulations should be determined instead of nutrient concentrations or resultant values should be assessed based on different criteria like leaf area to get more reliable outcomes.

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