

## The Effect of Weed Competition on Apple Fruit Quality

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### Abstract

Orchard performance is influenced by weed competition. In this study, the effects of weed competition on nutrient contents, chemical and physical fruit quality properties were sought. The study was carried out in a high-density apple orchard ('Golden Delicious'/M.9) over two consecutive growing seasons. The effect of weed competition was studied at three different levels: weak, moderate and strong. Fruit firmness, soluble solids content, macronutrients (such as nitrogen, potassium and calcium) and potassium+magnesium/calcium ratio in fruit were significantly affected by weed competition. Strong weed competition negatively affected soluble solids content and potassium+magnesium/calcium ratio. In both trial years, soluble solids content was significantly higher in weak weed competition. In the first year of the study, soluble solids content ranged between  $13.77 \pm 0.06\%$  (strong weed competition) and  $15.20 \pm 0.10\%$  (weak weed competition). In the following year, soluble solids content values were determined as  $13.13 \pm 0.23\%$  in strong weed competition and  $13.83 \pm 0.21\%$  in weak weed competition. Weak weed competition showed superiority for fruit weight and potassium+magnesium/calcium ratio. As a whole, this study indicates that insufficient weed control in tree rows might be a limiting factor for fruit quality in high-density apple orchards.

**Keywords:** bitter pit, ground cover, *Malus × domestica*, micronutrient, weed suppression

### Introduction

The techniques (e.g. mechanical, chemical and cultural) and strategies for managing orchard-floor (both tree rows and alleyways) and soil resources in fruit growing are referred to as orchard-floor management (OFM) systems (Houge and Neilsen, 1987; Singh *et al.*, 2016). The OFM systems used to manage competition between weeds and fruit trees are crucial for root development, tree performance, fruit set, storage life, soil and leaf nutrients, soil structure, soil temperature, tree water status, soil water retention, soil organic matter, enzyme and microbial activity, mycorrhizal fungi and soil microbial community composition, water and nutrient availability, insects, small mammals, root and replant diseases, and erosion and pollution (Merwin and Stiles, 1994; Merwin, 2003; Yao *et al.*, 2005; St Laurent *et al.*, 2008; Potter *et al.*, 2012; Meyers *et al.*, 2014; Neilsen *et al.*, 2014; Slatnar *et al.*, 2014; Fisk *et al.*, 2015; Meyer *et al.*, 2015; Tahir *et al.*, 2015; Singh *et al.*, 2016). Weed competition for resources with fruit trees stunt the tree's growth in young orchards and often reduce the quantity and quality of yields in mature trees (Merwin and Stiles, 1994;

Merwin, 2003; Sharifi *et al.*, 2016). Practical knowledge about the effects of weed competition on fruit quality in the orchard is highly crucial for fruit growers. Fruit quality is poorly considered by solely fruit size and skin colour (Crisosto and Costa, 2008). In fact, fruit quality determined by genetic, cultural and environmental factors is a concept including a large number of criteria such as sensory properties (e.g. appearance, taste and aroma), health benefits (e.g. antioxidants), nutritional properties (e.g. nutrients), pesticide residues and defects (e.g. bitter pit) (Crisosto and Costa, 2008; Atay *et al.*, 2010). The complete elimination of weed competition in orchards is possible with residual herbicides, but it may not be desirable for economic and environmental reasons (Merwin, 2003). Existing knowledge is not satisfactory enough to explicitly indicate the effect of weed competition on fruit quality properties such as nutrient contents. From this viewpoint, this study shows the effects of weak, moderate and strong weed competition on fruit nutrient contents, chemical (i.e. SSC and pH) and physical (i.e. weight, firmness and skin colour) fruit quality properties in a high-density apple orchard over two subsequent years.

## Materials and Methods

### Experimental site and plant materials

This study was conducted at Fruit Research Institute (MAREM), Isparta, Turkey (<http://arastirma.tarim.gov.tr/marem>). 'Golden Delicious' cultivar on M.9 rootstock was used as plant material. The orchard was planted in spring 2005 at an in-row spacing of 1 m with 3.5 m between rows. Trees were trained to a vertical axis and supported by a trellis system. 'Red Delicious' was planted as pollinator cultivar in the orchard. There was no pollination problem during the trial considered, and any blossom thinning was not performed over two trial years. Hand-thinning after the physiological drop was managed according to local crop husbandry practices when crop load exceeded 4.5 fruit per cm<sup>2</sup> of branch cross-sectional area. There was a relatively high yield in 2012 compared to 2011. Thus, 'Golden Delicious' is susceptible to the biennial bearing (Atay *et al.*, 2013a). Trees were fertilized according to soil analyses with drip irrigation water at regular intervals. All other agricultural practices were provided according to commercial procedures in the region.

### Weed competition level

Mowing in the alleyways between tree rows was maintained with a tractor-mounted mower when needed, which was standard in all weed competition levels. Mowing in tree rows was carried out with a grass cutter mower of 0.5 m on either side of the trees. Details for weed species of the study area have been described elsewhere (Atay *et al.*, 2013b). Mowing to 1-5 cm, to eliminate existing weed competition in tree rows, was carried out at the following intervals: April through October – hereafter referred to as 'Weak Weed Competition (WWC)', April+May+June - hereafter referred to as 'Moderate Weed Competition (MWC)'. Mowing in May was done one month later from first bloom in April, and the next mowing was applied at an interval of 1-month. In 'Strong Weed Competition (SWC)', weeds were not treated throughout the trial. The mowing applications were practiced over three subsequent years, 2010-2012, using the same methodology and trees, and the data were collected in last couple years of the trial (2011 and 2012).

### Data collection

On a set of 30 fruit taken from randomly for each weed competition level, fruit weight (g), fruit firmness (kg cm<sup>-2</sup>), soluble solids content - SSC (%), pH and fruit skin colour were measured as described by Atay (2015). In summary, fruit weight was measured by a digital scale sensitive to 0.01 g. Fruit firmness was measured on opposing sides of peeled fruit by a hand-held penetrometer (Effegi, Italy) with an 11.1 - mm probe. SSC by a digital refractometer (Hanna, HI 96801, USA) and pH by a digital pH meter (Hanna, HI 2211 pH/ORP meter, USA) were measured in fruit juice. Fruit skin colour values (b\* here) were measured with a colorimeter (Minolta CR-400, Japan). The values of b\* can be positive ('+' = yellow) or negative ('-' = blue) (Alcobendas *et al.*, 2012). On a sample of 30 fruit taken from the 75-80 mm size class for each weed competition level, fruit nutrient contents were determined. The fruit, initially, were decontaminated and rinsed with tap water, 2 N HCl, and distilled water. Then, samples were dried at 70 °C until constant weight and then ground for sieving. The total nitrogen (N) was determined using the Kjeldahl method with a distillation unit

(Gerhardt, Königswinter, Germany). Contents of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu) and boron (B) were determined with an inductively coupled plasma spectrometer (Perkin-Elmer, Optima 2100 DV Optical Emission Spectrometer, Shelton, CT 06 484, USA). K+Mg/Ca ratio was calculated. The contents of macro- (N, P, K, Ca and Mg) and micronutrients (Fe, Mn, Cu, B and Zn) in fruit tissues were expressed on a dry-mass basis.

### Data analysis

The experiment was conducted in three tree rows. Weed competition levels were employed with the factorial randomised block design. Each weed competition level had three replications of 4 experimental trees (i.e. 4 × 3 = 12 trees in total per weed competition level), and those on either side acted as guard trees between the different weed competition levels. Data were subjected to analysis of variance (ANOVA) procedures. When the *F*-test statistics were significant in ANOVA, means were separated using Least Significant Difference (LSD) multiple comparison test. In all analyses threshold for statistical significance was set at *P* ≤ 0.05. Associated *P*-values were figured in the paper. Data were analyzed using SAS-JMP software version 7.0 (<http://www.jmp.com/software/>).

## Results and Discussion

The interactions between weed competition level and year were significant for fruit weight (Fig. 1A), SSC (Fig. 1C) and pH (Fig. 1D). In this manner, results suggest that year effect, determined by many internal and external factors, has a considerable impact on these properties.

Weed competition level showed a significant effect on fruit firmness in 2012, and it was lower (7.79 ± 0.52 kg) in SWC than others (Fig. 1B). It can be speculated that this situation is likely a result of a not enough N content in fruit from SWC. The firmness is mainly determined by the number and size of cells in fruit cortex (Faust, 1989). The fruit with a large number of small cells are more likely to be firmer than those having sizeable fewer cells (Westwood, 1995). The practices increasing cell number in fruit may promote firmness. During the cell division period, the most notably determining factor is the N content of trees accumulated in the previous year (Millard, 1996; Neilsen *et al.*, 2001).

SSC was lower in SWC than others in both trial years (Fig. 1C). The dry-matter transport into fruit from leaves is relatively efficient after the time when the vegetative growth is ceased that generally coincide with the first half of July in the northern hemisphere (Faust, 1989; Westwood, 1995). The SWC after July might be hindered the accumulation of nutrients in the leaf that limits photosynthesis. In such situations, the leaves with a low dry-matter accumulation have a limited capacity to transport dry-matter into fruit.

Weed competition level did not significantly impact on fruit skin colour in both trial years (Fig. 1E). Fruit in 2011 had a higher b\* values than 2012 in all weed competition levels, which indicates that fruit in 2011 had a deeper yellow colour on 2012.

There was a significant interaction between weed competition level and year for N (Fig. 2A) and K (Fig. 2C) in fruit, which confers a year-to-year effect. Effect of weed competition level was significant for Ca in 2011 (Fig. 2D) and

for P in 2012 (Fig. 2B). Ca content was higher in WWC than in the other two weed competition levels (Fig. 2D). Ca uptake into fruit occurs in the first several weeks of the growing season, and there are complex relationships between shoot growth, crop load, fruit size, dilution, and seed number for Ca (Lakso, 2003; Saure, 2005; Atay *et al.*, 2013c).

Concerning K+Mg/Ca ratio, relatively higher values in both trial years were calculated in SWC without being significantly different from the other weed competition levels (Fig. 2F). The values for K+Mg/Ca ratio were higher in 2011 than in 2012 in all weed competition levels. The reason for this distinct differences between years for K+Mg/Ca ratio probably lies in the associated differences in the crop load of trees. As mentioned in material and methods, 'Golden Delicious' has a strong tendency to the biennial bearing (Atay *et al.*, 2013a), and yield was lower in 2011 than in 2012 in the trial orchard. In

2011, relatively low Ca content in fruit was recorded. In contrary, in 2012, a higher crop load resulted in an increase in Ca content in fruit. A low crop load promotes vegetative growth, leading to an increase in shoot growth (Tromp, 2005). Regarding the vigorously growing trees in low-crop years, Ca taken from soil is used to the growth of newly developing shoots, which may reduce Ca content in fruit. Thus, Ca taken from soil is firstly transported to newly developing shoot-tip leaves (Shear and Faust, 1970; Ford and Quinlan, 1979). In 2012, the total vegetative growth of trees might be reduced by a relatively high crop load, which may lead to an increase in the transport of Ca from roots to fruit. With referenced to Saure (2005), vigorous shoot growth accompanied by low crop load leads a decrease of Ca in fruit. A low Ca content in fruit tissues may result in a higher bitter pit incidence, a calcium-related physiological disorder (Watkins, 2003). It is well known that in

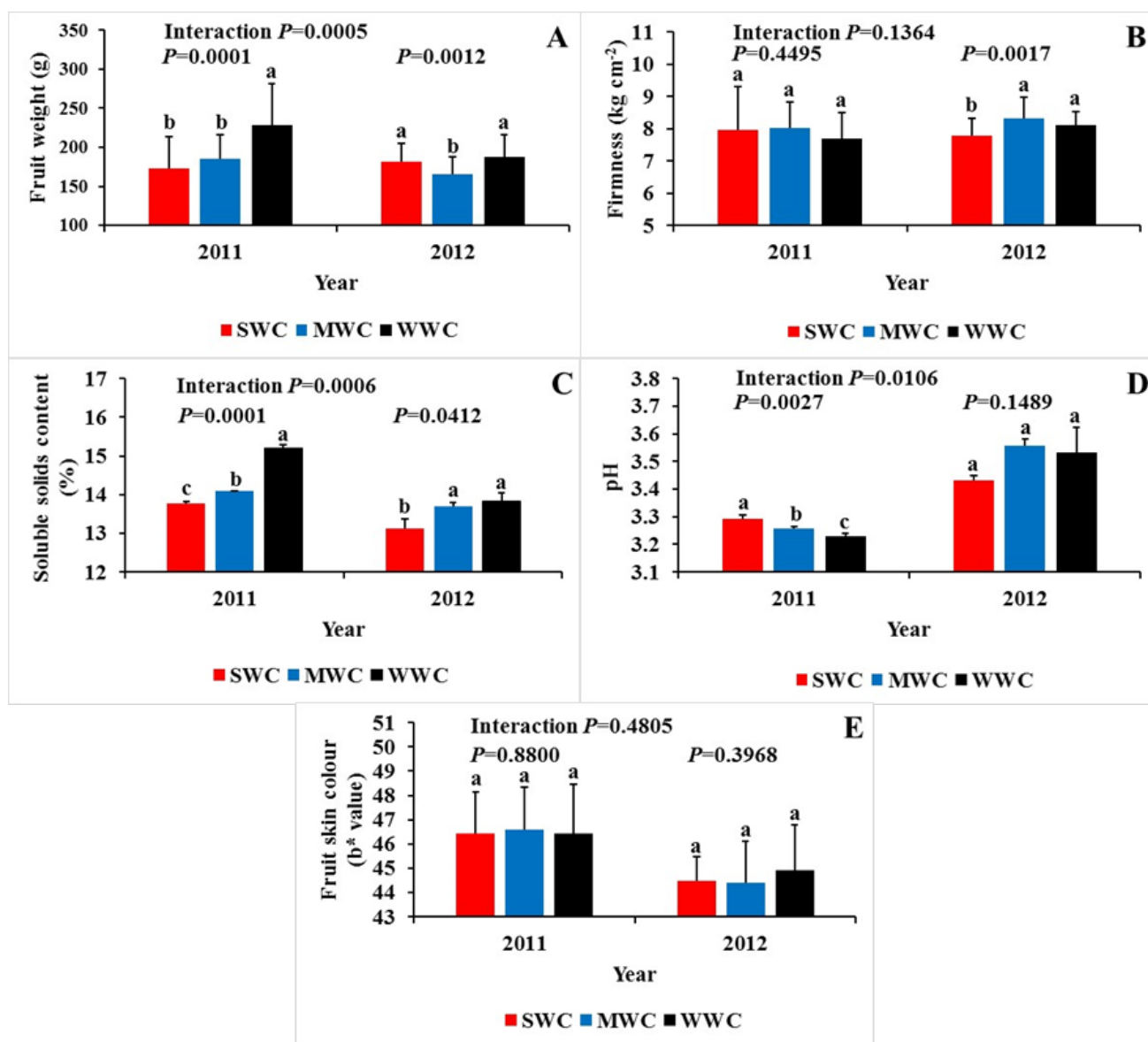


Fig. 1. Effect of weed competition on physical and chemical fruit quality properties (A) fruit weight ( $n=30$ ), (B) firmness ( $n=30$ ), (C) soluble solids content (SSC) ( $n=3$ ), (D) pH ( $n=3$ ), and (E) fruit skin colour ( $b^*$  value; '+' = yellow, '-' = blue) ( $n=30$ ). SWC: Strong Weed Competition, MWC: Moderate Weed Competition, WWC: Weak Weed Competition. Interaction  $P$ :  $P$ -value of the interaction between weed competition level  $\times$  year (2011 and 2012). Within each year, different letters indicate significant differences at  $P \leq 0.05$ . The values shown are means  $\pm$  standard deviation (SD)

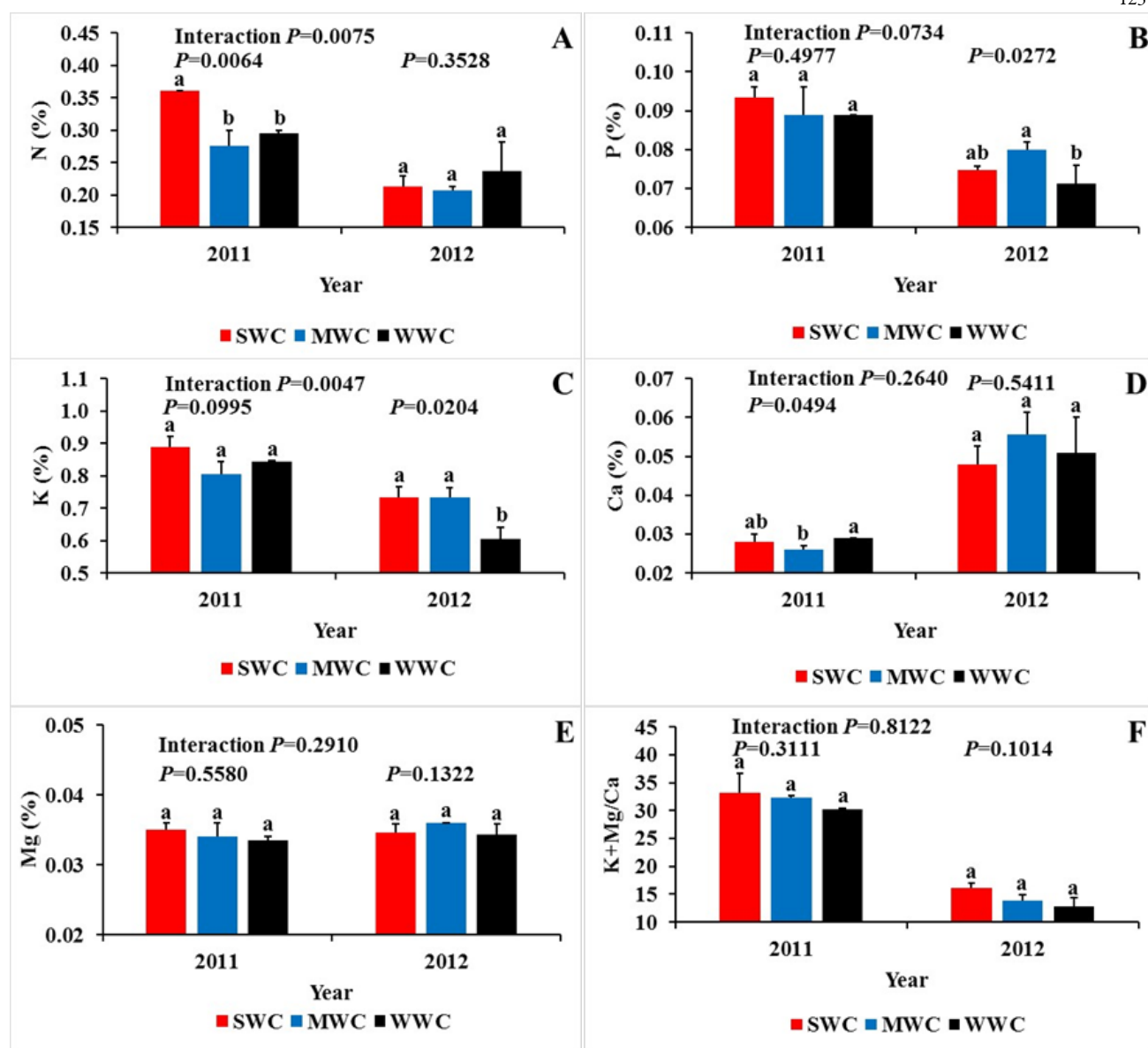


Fig. 2. Effect of weed competition on macronutrient contents in fruit (A) N: nitrogen ( $n=3$ ), (B) P: phosphorus ( $n=3$ ), (C) K: potassium ( $n=3$ ), (D) Ca: calcium ( $n=3$ ), (E) Mg: magnesium ( $n=3$ ), and K+Mg/Ca ( $n=3$ ). SWC: Strong Weed Competition, MWC: Moderate Weed Competition, WWC: Weak Weed Competition. Interaction  $P$ :  $P$ -value of the interaction between weed competition level  $\times$  year (2011 and 2012). Within each year, different letters indicate significant differences at  $P \leq 0.05$ . The values shown are means  $\pm$  SD

addition to Ca in fruit, K and Mg contents are related to bitter pit incidence in apple. Therefore, K+Mg/Ca ratio in the apple fruit has great importance for bitter pit incidence. A low ratio of K+Mg/Ca reduce bitter pit incidence following storage (Faust, 1989). Weed-crop competition for soil nutrients may not favorable for fruit trees, because the root density of fruit trees is lower than that of the weeds. In the orchards with a permanent ground cover all year round, competition between weeds and trees may negatively influence tree performance on nutrition uptake (Merwin, 2003; Webster, 2005). As a result of intense weed competition, the fruit contain relatively less calcium, which leads to a higher ratio of K+Mg/Ca. Moreover, large fruit are more prone to bitter pit than small ones. However, in the current study, WWC had higher values for average fruit weight in both trial years (Fig. 1A), and additionally, the nutrients in fruit were determined in the same

size class (75-80 mm) in all weed competition levels. Therefore, the eliminating of weed competition during the growth season seems to be advisable to apple growers because WWC provided lower K+Mg/Ca ratios in both trial years in this study.

The interactions between weed competition level and year were significant for Zn (Fig. 3D) and B (Fig. 3E) in fruit. Weed competition did not significantly affect other micronutrients – Fe (Fig. 3A), Cu (Fig. 3B) and Mn (Fig. 3C) in both trial years.

## Conclusions

To conclude, the findings showed that year-to-year effect had a significant impact on some fruit quality properties (fruit weight, SSC, pH, N, K, Zn and B). SSC and K+Mg/Ca ratio,

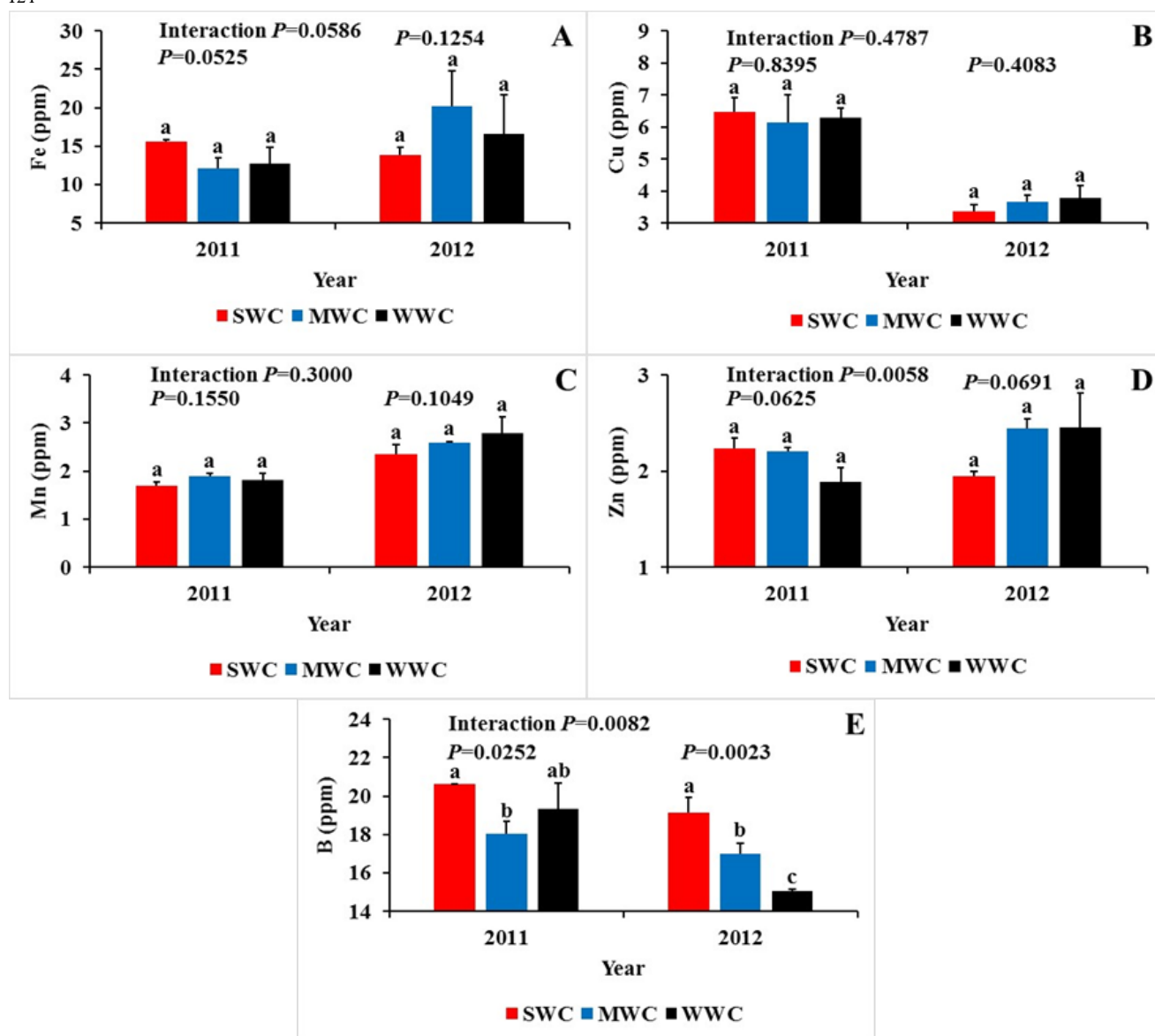


Fig. 3. Effect of weed competition on micronutrient contents in fruit (A) Fe: iron ( $n=3$ ), (B) Cu: copper ( $n=3$ ), (C) Mn: manganese ( $n=3$ ), (D) Zn: zinc ( $n=3$ ), and (E) B: boron ( $n=3$ ). SWC: Strong Weed Competition, MWC: Moderate Weed Competition, WWC: Weak Weed Competition. Interaction  $P$ :  $P$ -value of the interaction between weed competition level  $\times$  year (2011 and 2012). Within each year, different letters indicate significant differences at  $P \leq 0.05$ . The values shown are means  $\pm$  SD

commercially important fruit quality properties in the apple industry, were negatively influenced by SWC. The weed competition, in general, did not effect on micronutrient concentrations. WWC has provided superior results for fruit weight, SSC and  $K+Mg/Ca$  ratio.

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