ACTA SCIENTIARUM POLONORUM

Acta Sci. Pol. Hortorum Cultus, 20(1) 2021, 49–59

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2021.1.5

ORIGINAL PAPER

Accepted: 28.01.2020

# COMPARISON OF NUTRIENT UPTAKE BY STRAWBERRY (*Fragaria* × *ananassa* Duch.) VARIETIES ACCORDING TO PHENOLOGICAL STAGES

Seda Erdoğan Bayram✉, Ömer L. Elmacı

University of Ege, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, 35100, Izmir, Turkey

## ABSTRACT

The purpose of this study was to determine the amounts of nutrient elements taken up from the soil to the roots, stems and leaves, in five different growing periods and to the fruits in the harvesting period, in two different strawberry cultivars. For this purpose, ten plantations were selected for each cultivar. The roots, stems and leaves were separated and the amounts of nutrient elements taken up by each part was determined according to the development period. In this study, which was conducted over two years, the physico-chemical characteristics of the soils of the plantations from which the samples taken were determined. In both cultivars, the largest amounts of the macronutrients nitrogen, phosphorus, calcium and magnesium and of the micronutrient manganese were taken up at all phenological stages by the leaves, followed by the roots and stems. The amounts of potassium that taken up were as follows in the order of most to least: at the beginning and in the harvest period, leaves, stems and roots; in other periods, leaves, roots and stems. For the nutrient elements iron, copper and zinc, this comparison showed variation between parts of the plants according to year, variety and period. In general, statistically significant correlations were found between the nutrient elements taken up at different periods by different parts of the plant of different varieties in both years. Significant differences were shown among the years in the amounts of N, P, K, Ca and Mg taken up by the fruits of the Camarosa variety, and of Fe only by the Festival variety.

**Key words:** strawberry, plant parts, phenological stage, nutrient elements

## INTRODUCTION

Rapid industrialization and increasing population in the world, particularly in the second half of the twentieth century, has brought serious environmental problems and directed the growers to yield-focused production. This mode of production carries with it problems, like the unconsidered use of fertilizer, water and agricultural chemicals, mistaken soil cultivation practices, the disruption of the soil nutrient balance, and the risk of wastes [Atasay and Türemiş 2008]. Thus, the most important aim in sustainable agriculture is the reduction to a minimum of inputs, especially fertilizer, in the production of many horticultural crops [Tagliavini et al. 1996].

Strawberries are grown around the world and are the most important berry crop [Adak 2019], but in terms of growing they are more similar to vegetables, and need more nutrients than other plant species. For this reason, fertilizer application is of particular importance in strawberry growing. Not replacing nutrients taken up from the soil by the crop or removed from the soil in other ways has an adverse effect on yield and quality. Knowing the amount of nutrients taken up by plants

✉ seda.erdogan@ege.edu.tr

from the soil at different phenological stages and creating fertilization programs in accordance with this will directly affect yield and quality [Baldi et al. 2003].

Basically, plant needs for nutrient elements are under the control of soil, environment and plant factors. Plant factors are the most important ones, in setting the degree of effect of these factors. The plant species, genotype, age, stage of development and root system structure affect in different degrees the amounts of nutrients taken up by the plants from the soil [Mengel and Kirkby 1982, Bulduk and Erdal 2012]. For this reason, it is of great importance to take account of variety and development stage differences in applying nutrients which the plants need to increase yield and quality. Thus, Baldi et al. [2003] reported that the main indicators of the amount of nutrients taken up by a strawberry plant at different stages of development were variety and yield. At the same time, stage of development affects the accumulation of nutrients in the plant. In a study on this topic, it was reported that the highest accumulation of nutrients in plants and fruits during the vegetation period of three different strawberry cultivars was in the development stage between the formation of fruit and harvest [Albregts and Howard 1978, 1980]. Studies of the amounts of nutrients taken up by different parts of the strawberry plant at different stages of development are limited [Fattahi and Gholami 2009].

Growers in the study area, where intensive strawberry production is practiced, apply fertilizer according to their regular practices, without regard to the plant development stages. For this reason, the main purpose of the study was to determine the amounts of plant nutrients taken up by the roots, stems, leaves and fruits of two different strawberry cultivars at five different developmental stages throughout the vegetation period, and to show the differences at different stages.

## MATERIAL AND METHOD

This research was conducted over the two vegetation years in 2011–2013, in Emiralem, in the district of Menemen in Izmir province, Turkey (N: 38.622, E: 27.138). Climatic data for the years when the study was conducted; 2011, 2012 and 2013 (from July 2011 to September 2013) were calculated as 16.22, 17.52, 17.37°C, for mean temparatures; 49.3, 49.58, 60.6 mm for total precipitations and 63.56, 64.24, 65.13% for mean relative humidities respectively. Strawberries were grown intensively in the open, using a drip irrigation system. Ten plantations of the cultivar 'Camarosa' and ten of 'Festival', a total of 20, were selected. Soil and plant samples taken from these plantations constituted the research material. Soil samples were taken each year in August at a depth of 0–30 cm; plant samples were taken five times in each season according to the stages of growth as shown in Table 1. The strawberry plants were planted with the density of 5500–6000 plants/daa, at spacing of 25 × 30 cm in beds preapared to 60–70 cm width, 15–20 cm height, and 30–40 cm spacings. Fruit samples were taken once in each season in the harvesting period. The plant samples were taken whole, and later separated into roots, stems and leaves, and the amounts of plant nutrients in each part were determined. Before planting, 2–3 tons daa$^{-1}$ of well-matured farmyard manure and 35–40 kg daa$^{-1}$ 15–15–15 (N–P–K) were applied to the whole fields examined in the study. After planting, from the initial to the harvest stages; 5, 7, 0, 5, 3 kg daa$^{-1}$ (total 20 kg) N; 3, 2, 0, 5, 2 kg daa$^{-1}$ (total 12 kg) $P_2O_5$ and 3, 4, 0, 8, 10 kg daa$^{-1}$ (total 25 kg) $K_2O$ were applied.

Soil sand, clay and silt contents were determined by the hydrometric method [Bouyoucos 1962]; pH and

**Table 1.** Stages of growth when plant samples were taken, and number of samples

| Plant growth stages | Sampling months | Number of whole plant samplings (time/season) | Number of fruit samplings (time/season) |
|---|---|---|---|
| Initial (planting + 1 month) | end of October | 1 | – |
| Growing (100 days) | November–January | 1 | – |
| Dormant (35 days) | February–March | 1 | – |
| Blooming (30 days) | March–April | 1 | – |
| Harvest (35 days) | May–June | 1 | 1 |

total water-soluble salt were determined in a paste of soil saturated with water with a pH meter with a glass electrode and a conductometer [US Soil Survey Staff 1951]; lime contents were determined with a Scheibler calcimeter, and the amounts of organic matter were determined by wet digestion with $K_2Cr_2O_7$ and $H_2SO_4$ [Reuterberg and Kremkurs 1951].

With regard to plant nutrient elements in the soil, total nitrogen was determined by the modified Kjeldahl method [Bremner 1965], and available phosphorus was determined colorimetrically after extraction with sodium bicarbonate [Olsen et al. 1954]. Available $K^+$, $Ca^{++}$, $Na^+$, $Mg^{++}$ contents were determined by ICP-OES after extraction with 1 N $NH_4OAc$. As for Fe, Mn, Zn, Cu, after extraction with 0.05 M DTPA + TEA were also predicted by ICP-OES [Isaac and Johnson 1992]. The plant samples were separated into roots, stems and leaves, and also fruit samples that were taken in the harvest stage, dried in a drying oven at 65 ±5°C until a stable weight was reached. The amount of dry material was determined and prepared for analysis by grinding. The plant samples were reduced to ash at a temperature of 550°C and dissolved in 3 N HCl, and the amounts of nutrient elements in the extract obtained were determined by ICP-OES [Vandecasteele et al. 2018].

Statistical assessment of the data obtained was performed according to the two factorial (plant parts*vegetation periods) randomized block design. The strawberry varieties were evaluated separately for each year of the study. Analysis of variance (ANOVA) using the IBM SPSS 25.0 statistical software was applied to the various parts of the plants and the amounts of nutrient elements taken up at different developmental stages. Differences between groups were determined by the Duncan's multiple range test.

## RESULTS AND DISCUSSION

Table 2 shows various physical and chemical characteristics of the soils of the research area. Soil reactions were found to be between 6.84 and 8.20 in the plantations of the Festival cultivar, and between 7.08 and 7.91 in the Camarosa plantations, which is suitable for strawberry cultivation [Rieger 2006].

In a similar study conducted in strawberry growing areas in the province of Aydın, where the ecological conditions were similar, it was found that the pH values of 41% of the soils sampled were suitable for strawberry growing [Seferoğlu and Kılıç 2002]. The total content of water-soluble salt in the soils of both

**Table 2.** Various physical and chemical characteristics of the soils in the research area

| Year | Parameter | 'Festival' | | 'Camarosa' | |
|---|---|---|---|---|---|
| | | variation | mean | variation | mean |
| First | pH | 6.84–8.20 | 7.53 | 7.10–7.63 | 7.40 |
| | total water-soluble salt (%) | 0.010–0.110 | 0.050 | 0.026–0.078 | 0.042 |
| | $CaCO_3$ (%) | 1.66–5.65 | 3.59 | 0.51–5.30 | 3.74 |
| | organic matter (%) | 0.16–3.41 | 1.30 | 0.57–2.38 | 1.59 |
| | sand (%) | 55.28–94.56 | 79.74 | 55.28–91.28 | 79.48 |
| | clay (%) | 5.08–31.08 | 13.78 | 6.08–31.08 | 14.58 |
| | silt (%) | 0.36–17.64 | 6.48 | 1.64–13.64 | 5.94 |
| | texture | sandy/sandy-loam | | sandy/sandy-loam | |
| Second | pH | 7.18–8.18 | 7.79 | 7.08-7.91 | 7.51 |
| | total water-soluble salt (%) | 0.02–0.08 | 0.05 | 0.02–0.06 | 0.05 |
| | $CaCO_3$ (%) | 1.97–6.33 | 4.26 | 1.07–5.32 | 3.84 |
| | organic matter (%) | 2.43–5.69 | 3.97 | 1.81–4.40 | 3.00 |
| | sand (%) | 55.28–94.56 | 79.54 | 55.28–91.28 | 79.68 |
| | clay (%) | 5.08–31.08 | 14.58 | 6.08–31.08 | 13.78 |
| | silt (%) | 0.36–13.64 | 5.88 | 1.64–17.64 | 6.54 |
| | texture | sandy/sandy-loam | | sandy/sandy-loam | |

cultivars posed no problem in either year (<0.015%) [Soil Survey Manual, Soil Survey Division Staff 1993]. According to the mean lime content determined for the soils (Tab. 2), the soils of the area are calcareous (2–5–5.0%). A high lime content causes $Ca^{++}$ ions to change into a dominant state, forming insoluble compounds with available micronutrient elements in the soil, especially phosphorus and iron, and thus preventing them from being taken up by plants. This leads to a yellowing of strawberry leaves connected with deficiencies in these nutrients, which is known as chlorosis [Özden and Ayanoğlu 2002, Çakıcı and Aydın 2005, Rieger 2006]. Therefore, it is of great importance in the soils of the region that the application of fertilizer should be supported by application to the leaves, paying attention to choosing fertilizers containing phosphorus and micro-elements.

The mean organic matter contents of the soils were generally at a medium level, and because strawberries are known to grow better in soils rich in organic matter, organic matter needs to be added to the soils of the area.

Table 3 shows the total nitrogen and available nutrient contents of the soils of the research area.

Total mean nitrogen content of the soils of the Festival cultivar were found to be generally adequate in the first year of the study (0.09–0.17%) and low in the second year (0.045–0.09%), while the equivalent figures for the 'Camarosa' cultivar were 0.15% and 0.09% for the two years respectively (Tab. 3). According to this, the soils of the 'Camarosa' cultivar were adequate in total nitrogen in both years of the research (0.09–0.17%) [Zengin 2012]. The reductions in total nitrogen content in the soils of the second year show that the amount of nitrogen used by the plants in the first year was not made up by the application of fertilizer in the second year.

The mean available phosphorus contents of the soils (Tab. 3) in each year were found to be low (2.5–8 mg $kg^{-1}$) or very low (<2.5 mg $kg^{-1}$) in all the soils of both cultivars. This inadequacy of phosphorus in both years in the soils of the region where it was monitored can be explained by the high lime content of the soil.

All the soils in both years of the study and for both strawberry cultivars examined were found to be adequate in available potassium (150–200 mg $kg^{-1}$) [Fawzi and El-Fouly 1980].

**Table 3.** Variations between available soil contents of various plant nutrients

| Year | Parameter mg $kg^{-1}$ | 'Festival' | | 'Camarosa' | |
|---|---|---|---|---|---|
| | | variation | mean | variation | mean |
| First | N (%) | 0.03–0.25 | 0.13 | 0.11–0.22 | 0.15 |
| | P | 1.03–2.56 | 1.83 | 0.96–4.24 | 2.27 |
| | K | 193–423 | 297 | 189–452 | 334 |
| | Ca | 2728–5647 | 4289 | 2987–6421 | 4896 |
| | Mg | 259–401 | 323 | 246–451 | 354 |
| | Fe | 4.20–21.0 | 10.18 | 5.80–19.0 | 11.23 |
| | Cu | 1.00–16.0 | 5.30 | 1.20–7.20 | 3.21 |
| | Zn | 0.60–9.80 | 3.46 | 0.90–8.10 | 23 |
| | Mn | 7.00–42.0 | 23.1 | 12–38 | 3.50 |
| Second | N (%) | 0.03–0.12 | 0.08 | 0.05–0.13 | 0.09 |
| | P | 1.26–3.23 | 2.42 | 0.96–3.18 | 1.75 |
| | K | 189–301 | 219 | 176–312 | 236 |
| | Ca | 2156–5768 | 4312 | 4122–7021 | 5488 |
| | Mg | 174–382 | 258 | 198–401 | 290 |
| | Fe | 4.60–30.0 | 10.71 | 6.20–21.0 | 11.02 |
| | Cu | 0.70–13.1 | 4.72 | 0.90–6.80 | 3.08 |
| | Zn | 0.40–10.6 | 3.57 | 0.48–7.60 | 3.35 |
| | Mn | 10.0–40.0 | 22.47 | 10.0–36.0 | 20.8 |

The mean available calcium content of the soils was found to be excessive (3 500–10 000 mg kg$^{-1}$) for both years and both cultivars [Zengin 2012]. It is thought that the high available calcium content of all of the soils derives from their high lime content. The available magnesium content of all of the soils examined (162–488 mg kg$^{-1}$), was determined to be at an adequate level [Zengin 2012].

As for the evaluation of the mean amounts of plant micronutrient elements, all of the soils of the area had adequate levels: available iron (>4.5 mg kg$^{-1}$), copper (0.2 mg kg$^{-1}$), zinc (0.7 mg kg$^{-1}$–2.4 mg kg$^{-1}$) and manganese (14–50 mg kg$^{-1}$) – Table 3.

## Nutrients uptake by the various parts of the plant at the different growth stages

Table 4 shows the mean amounts of nutrient elements taken up by the roots, stems and leaves of the Festival strawberry cultivar at different stages of growth, in the first and second year of the study.

**Table 4.** Mean amounts[1] of plant nutrients taken up over two years by different parts of the 'Festival' strawberry cultivar

| | | First year | | | | | | Second year | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | initial | growing | dormant | blooming | harvest | sig.[2] | initial | growing | dormant | blooming | harvest | sig. |
| Root | N | 0.118 **c** | 0.155 **c** | 0.234 **b** | 0.244 **b** | 0.369 **a** | *** | 0.229 **c** | 0.275 **bc** | 0.372 **b** | 0.620 **a** | 0.622 **a** | *** |
| | P | 0.014 **c** | 0.031 **b** | 0.029 **b** | 0.036 **b** | 0.064 **a** | *** | 0.001 **c** | 0.052 **b** | 0.044 **b** | 0.051 **b** | 0.082 **a** | *** |
| | K | 0.096 **d** | 0.170 **cd** | 0.212 **c** | 0.505 **a** | 0.362 **b** | *** | 0.248 **c** | 0.270 **c** | 0.395 **bc** | 0.784 **a** | 0.501 **b** | *** |
| | Ca | 0.137 **c** | 0.134 **c** | 0.153 **c** | 0.320 **b** | 0.435 **a** | *** | 0.335 **bc** | 0.194 **c** | 0.279 **c** | 0.468 **ab** | 0.598 **a** | *** |
| | Mg | 0.065 **b** | 0.047 **b** | 0.061 **b** | 0.107 **a** | 0.122 **a** | *** | 0.141 **abc** | 0.098 **c** | 0.117 **bc** | 0.164 **ab** | 0.182 **a** | * |
| | Fe | 4.210 **b** | 4.719 **b** | 4.283 **b** | 6.616 **b** | 11.04 **a** | *** | 4.711 **b** | 5.204 **b** | 8.531 **ab** | 6.825 **ab** | 10.12 **a** | * |
| | Cu | 0.193 **b** | 0.224 **b** | 0.196 **b** | 0.613 **a** | 0.676 **a** | *** | 0.466 **bc** | 0.243 **c** | 0.340 **c** | 0.957 **a** | 0.676 **b** | *** |
| | Zn | 0.519 **c** | 0.820 **c** | 0.759 **c** | 1.480 **b** | 2.107 **a** | *** | 1.101 **cd** | 0.679 **d** | 1.462 **bc** | 2.388 **a** | 2.010 **ab** | *** |
| | Mn | 0.639 **c** | 0.899 **c** | 1.061 **bc** | 1.779 **a** | 1.301 **b** | *** | 1.432 **b** | 1.461 **b** | 2.025 **b** | 2.926 **a** | 1.313 **b** | *** |
| Stem | N | 0.064 **b** | 0.073 **b** | 0.066 **b** | 0.110 **b** | 0.180 **a** | *** | 0.160 **bc** | 0.115 **c** | 0.168 **bc** | 0.290 **b** | 0.539 **a** | *** |
| | P | 0.007 **b** | 0.012 **b** | 0.007 **b** | 0.001 **b** | 0.021 **a** | *** | 0.001 **c** | 0.016 **bc** | 0.022 **b** | 0.016 **bc** | 0.052 **a** | *** |
| | K | 0.106 **b** | 0.160 **b** | 0.188 **b** | 0.378 **a** | 0.500 **a** | *** | 0.216 **c** | 0.213 **c** | 0.352 **bc** | 0.482 **b** | 1.441 **a** | *** |
| | Ca | 0.051 **c** | 0.075 **bc** | 0.072 **bc** | 0.120 **b** | 0.204 **a** | *** | 0.095 **b** | 0.086 **b** | 0.137 **b** | 0.167 **b** | 0.426 **a** | *** |
| | Mg | 0.025 **b** | 0.031 **b** | 0.035 **b** | 0.038 **b** | 0.086 **a** | *** | 0.076 **b** | 0.042 **b** | 0.067 **b** | 0.064 **b** | 0.149 **a** | *** |
| | Fe | 0.369 **b** | 0.480 **b** | 0.559 **b** | 0.577 **b** | 1.242 **a** | ** | 1.370 **ab** | 0.673 **c** | 1.017 **bc** | 0.822 **bc** | 1.843 **a** | * |
| | Cu | 0.054 | 0.047 | 0.081 | 0.052 | 0.104 | n.s | 0.142 **ab** | 0.076 **c** | 0.102 **bc** | 0.092 **bc** | 0.169 **a** | * |
| | Zn | 0.089 | 0.136 | 0.182 | 0.156 | 0.153 | n.s | 0.257 | 0.218 | 0.364 | 0.238 | 0.238 | n.s |
| | Mn | 0.225 | 0.438 | 0.343 | 0.352 | 0.259 | n.s | 0.459 | 0.468 | 0.735 | 0.538 | 0.414 | n.s |
| Leaf | N | 0.353 **d** | 0.728 **c** | 0.654 **b** | 0.965 **ab** | 1.006 **a** | *** | 0.735 **b** | 0.714 **b** | 1.016 **b** | 1.545 **a** | 1.681 **a** | *** |
| | P | 0.017 **b** | 0.052 **b** | 0.063 **b** | 0.114 **a** | 0.021 **a** | *** | 0.001 **d** | 0.057 **c** | 0.090 **bc** | 0.128 **b** | 0.184 **a** | *** |
| | K | 0.235 **b** | 0.405 **b** | 0.395 **b** | 0.892 **a** | 0.977 **a** | *** | 0.547 **b** | 0.534 **b** | 0.559 **b** | 1.441 **a** | 1.689 **a** | *** |
| | Mg | 0.092 **c** | 0.120 **c** | 0.086 **c** | 0.211 **b** | 0.278 **a** | *** | 0.221 **bc** | 0.158 **c** | 0.158 **c** | 0.319 **b** | 0.492 **a** | *** |
| | Fe | 1.918 **c** | 2.941 **bc** | 2.517 **bc** | 4.485 **b** | 9.013 **a** | *** | 4.087 **c** | 3.315 **c** | 4.972 **bc** | 6.672 **b** | 9.995 **a** | *** |
| | Cu | 0.131 **b** | 0.207 **b** | 0.158 **b** | 0.302 **a** | 0.384 **a** | *** | 0.317 **b** | 0.297 **b** | 0.351 **b** | 0.484 **ab** | 0.554 **a** | * |
| | Zn | 0.357 **c** | 0.566 **bc** | 0.593 **bc** | 1.255 **a** | 0.832 **b** | *** | 0.739 **b** | 0.725 **b** | 1.078 **b** | 2.171 **a** | 0.998 **b** | *** |
| | Mn | 1.169 | 3.533 | 1.858 | 2.603 | 2.130 | n.s | 2.130 **b** | 2.898 **ab** | 3.317 **ab** | 4.117 **a** | 3.314 **ab** | * |

Means followed by a different letter in the same line indicate significant differences

[1] For N, P, K, Ca, Mg in kg daa$^{-1}$; for Fe, Cu, Zn, Mn in g daa$^{-1}$

[2] Significance: *** – $p < 0.001$; ** – $p < 0.01$; * – $p < 0.05$; n.s. – non-significant difference

In the first year of the research, the amounts taken up of the macro-elements examined (N, P, K, Ca and Mg) were generally at a minimum at the initial stage and at a maximum at the harvesting stage. In the second year, minimum amounts taken up were generally seen at the vegetation stage, and only phosphorus taken up by all parts of the plant was found to be at a minimum at the initial stage. Maximum amounts were seen at the harvest stage for the elements Fe and Cu. Amounts of zinc were at a maximum in the roots at the harvest stage, in the stems at the dormant stage, and in the leaves at the blooming stage. Amounts of manganese were found to be at a maximum in the stems and leaves at the growing stage and in the roots at the blooming stage.

The amounts of micro-nutrient elements taken up in the second year were generally found to be at a minimum at the growing stage. Only the amounts of Mn taken up by the roots and stems were found to be at a minimum at the harvesting stage. The amounts of the nutrient elements Fe and Cu were found to be at a maximum at the harvesting stage, while Zn and Mn showed variations which were similar to the first year. The maximum amounts of these elements were found to be taken up by the roots and leaves at the blooming stage and by the stems at the dormant stage (Tab. 4).

Table 5 shows the mean amounts of plant nutrients taken up by the roots, stems and leaves of the 'Camarosa' strawberry at different stages of development over two years. In the first year, all of the macro elements investigated (N, P, K, Ca and Mg) were found to be taken up at a minimum by the different parts of the plant at the initial stage, and at a maximum at the harvest stage. In the second year, minimum amounts of nutrients were found to be generally taken up at the growing stage.

Only the minimum amounts of nitrogen taken up by the roots and leaves and of potassium taken up by the roots were at a minimum at the initial stage. Amounts of macro elements taken up by all parts of the plant were found to be at a maximum level at the harvest stage.

Similar results were also reported by Tagliavini et al. [1996], that the lowest amounts of the elements N, P, K, Ca and Mg were taken up by different parts of strawberry plants in mid-autumn, equivalent to one month after planting, and the greatest amounts were taken up at the harvesting stage. Fattahi and Gholami [2009] researched the nutrient contents taken up by different parts of the plant of 'Camarosa' strawberries at the beginning of blooming, fruit formation and harvesting development stages, and it was reported that the highest amounts of Ca and Mg were taken up by the roots, leaves and stems at the harvesting stage. The figures reported for the macro elements examined are similar to the results of our study. On the other hand, Martin and Roson [1980], examined the variations in nutrients taken up by different parts of the plant at different stages of development in strawberries grown under greenhouse conditions, and reported that the concentrations of N, P and K in the roots, leaves, flowers and fruiting organs decreased from the blooming stage to the ripening (harvest) stage. The same researchers reported that the total maximum amounts of nutrient elements taken up were at the stage of fruit development.

It was found that the maximum amounts of Zn and Mn were taken up by the various plant parts in the first year, in the initial stage. The minimum amounts of Fe and Cu were taken up by the roots at the growing stage, by the stems at the blooming stage and by the leaves at the initial stage. The maximum amounts of Fe and Cu were taken up by all parts of the plants at the harvesting stage. The maximum amounts of zinc taken up by the stems and leaves were at the growing and blooming stages respectively, and the maximum amounts of Mn were taken up by the stems and leaves at the growing stage. The minimum amounts of micro elements taken up by the various parts of the plants in the second year were observed to be generally in the growing season, as in the first year.

The minimum amounts of Fe taken up by the roots and of Mn taken up by the leaves were found to be at the initial stage, and the minimum amounts of Mn taken up by the stems were found to be at the harvesting stage. The maximum amounts of Fe and Cu taken up by all parts were observed to be at the harvesting stage, and the elements Zn and Mn showed variations by stage as with the 'Festival' cultivar. The maximum amounts of these elements (Zn and Mn) taken up by the roots and leaves were at the blooming stage, and by the stems at the dormant stage (Tab. 5).

Fattahi and Gholami [2009] stated that the highest amounts of Fe, Mn and Zn taken up by the stems of the

**Table 5.** Mean amounts[1] of plant nutrients taken up over two years by different parts of the 'Camarosa' strawberry cultivar

| | | Firts year | | | | | | Second year | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | initial | growing | dormant | blooming | harvest | sig.[2] | initial | growing | dormant | blooming | harvest | sig. |
| Root | N | 0.106 **e** | 0.184 **d** | 0.270 **c** | 0.346 **b** | 0.437 **a** | *** | 0.259 **d** | 0.336 **cd** | 0.426 **bc** | 0.558 **ab** | 0.573 **a** | *** |
| | P | 0.015 **c** | 0.027 **bc** | 0.031 **b** | 0.024 **bc** | 0.059 **a** | *** | 0.001 **c** | 0.047 **b** | 0.037 **b** | 0.050 **b** | 0.099 **a** | *** |
| | K | 0.113 **c** | 0.131 **c** | 0.217 **b** | 0.323 **a** | 0.297 **ab** | *** | 0.208 **c** | 0.247 **c** | 0.284 **c** | 0.717 **a** | 0.583 **b** | *** |
| | Ca | 0.107 **c** | 0.105 **c** | 0.137 **bc** | 0.189 **b** | 0.389 **a** | *** | 0.250 **c** | 0.191 **c** | 0.234 **c** | 0.457 **b** | 0.664 **a** | *** |
| | Mg | 0.052 **b** | 0.048 **b** | 0.060 **b** | 0.065 **b** | 0.135 **a** | *** | 0.111 **bc** | 0.075 **c** | 0.109 **bc** | 0.135 **b** | 0.212 **a** | *** |
| | Fe | 3.812 **b** | 3.469 **b** | 5.429 **b** | 4.265 **b** | 9.988 **a** | *** | 3.954 **b** | 5.220 **b** | 5.776 **b** | 6.643 **b** | 10.628 **a** | *** |
| | Cu | 0.166 **b** | 0.160 **b** | 0.200 **b** | 0.361 **b** | 0.759 **a** | *** | 0.333 **b** | 0.205 **b** | 0.291 **b** | 0.678 **a** | 0.839 **a** | *** |
| | Zn | 0.319 **c** | 0.639 **bc** | 0.688 **bc** | 1.067 **b** | 2.072 **a** | *** | 0.894 **bc** | 0.678 **c** | 1.359 **b** | 2.443 **a** | 2.283 **a** | *** |
| | Mn | 0.483 **c** | 0.785 **bc** | 0.933 **bc** | 1.126 **ab** | 1.473 **a** | *** | 1.223 **c** | 1.187 **c** | 1.673 **bc** | 2.584 **a** | 2.096 **ab** | *** |
| Stem | N | 0.062 **b** | 0.085 **b** | 0.118 **b** | 0.151 **b** | 0.255 **a** | ** | 0.348 **c** | 0.610 **b** | 0.576 **b** | 0.900 **a** | 0.832 **a** | *** |
| | P | 0.006 **b** | 0.010 **b** | 0.006 **b** | 0.007 **b** | 0.018 **a** | *** | 0.001 **c** | 0.047 **b** | 0.037 **b** | 0.050 **b** | 0.099 **a** | *** |
| | K | 0.093 **c** | 0.145 **c** | 0.122 **c** | 0.256 **b** | 0.406 **a** | *** | 0.243 **cd** | 0.164 **d** | 0.368 **c** | 0.682 **b** | 1.016 **a** | *** |
| | Ca | 0.051 **b** | 0.064 **b** | 0.062 **b** | 0.081 **b** | 0.165 **a** | *** | 0.111 **bc** | 0.068 **c** | 0.156 **bc** | 0.212 **b** | 0.527 **a** | *** |
| | Mg | 0.022 **b** | 0.031 **b** | 0.030 **b** | 0.030 **b** | 0.058 **a** | *** | 0.075 **bc** | 0.040 **c** | 0.084 **b** | 0.079 **b** | 0.164 **a** | *** |
| | Fe | 0.516 **b** | 0.469 **b** | 0.481 **b** | 0.377 **b** | 0.871 **a** | * | 1.264 **ab** | 0.491 **c** | 1.457 **ab** | 0.954 **bc** | 1.835 **a** | * |
| | Cu | 0.049 | 0.040 | 0.066 | 0.033 | 0.077 | n.s | 0.146 **a** | 0.056 **c** | 0.099 **b** | 0.096 **b** | 0.153 **a** | *** |
| | Zn | 0.080 | 0.152 | 0.149 | 0.105 | 0.131 | n.s | 0.245 | 0.176 | 0.531 | 0.279 | 0.240 | *** |
| | Mn | 0.174 **b** | 0.435 **a** | 0.355 **ab** | 0.293 **ab** | 0.189 **c** | * | 0.463 **b** | 0.461 **b** | 0.870 **a** | 0.861 **a** | 0.360 **b** | *** |
| Leaf | N | 0.348 **c** | 0.610 **b** | 0.576 **b** | 0.900 **a** | 0.832 **a** | *** | 0.765 **c** | 0.846 **c** | 1.022 **bc** | 1.408 **ab** | 1.800 **a** | *** |
| | P | 0.014 **c** | 0.056 **b** | 0.069 **b** | 0.125 **a** | 0.143 **a** | *** | 0.001 **d** | 0.048 **c** | 0.106 **b** | 0.154 **a** | 0.179 **a** | *** |
| | K | 0.255 **c** | 0.436 **c** | 0.441 **c** | 0.888 **b** | 1.171 **a** | *** | 0.513 **c** | 0.435 **c** | 0.594 **c** | 1.425 **b** | 1.843 **a** | *** |
| | Ca | 0.172 **c** | 0.236 **c** | 0.286 **c** | 0.533 **b** | 0.931 **a** | *** | 0.337 **c** | 0.285 **c** | 0.401 **c** | 0.799 **b** | 1.488 **a** | *** |
| | Mg | 0.098 **c** | 0.127 **c** | 0.116 **c** | 0.228 **b** | 0.334 **a** | *** | 0.218 **bc** | 0.146 **c** | 0.179 **c** | 0.314 **b** | 0.460 **a** | *** |
| | Fe | 1.994 **c** | 3.195 **bc** | 3.919 **bc** | 5.254 **b** | 10.624 **a** | *** | 3.295 **c** | 3.029 **c** | 4.989 **bc** | 6.465 **b** | 10.447 **a** | *** |
| | Cu | 0.114 **c** | 0.235 **bc** | 0.247 **bc** | 0.370 **ab** | 0.424 **a** | *** | 0.281 | 0.211 | 0.321 | 0.431 | 0.428 | n.s |
| | Zn | 0.311 **c** | 0.820 **bc** | 0.790 **bc** | 1.452 **a** | 1.234 **ab** | * | 0.739 **cd** | 0.616 **d** | 1.384 **ab** | 1.865 **a** | 1.217 **bc** | *** |
| | Mn | 1.120 **b** | 3.311 **a** | 2.410 **ab** | 2.906 **a** | 2.784 **a** | * | 1.761 **b** | 2.386 **b** | 3.155 **ab** | 4.244 **a** | 2.962 **ab** | ** |

Means followed by a different letter in the same line indicate significant differences
[1] For N, P, K, Ca, Mg in kg daa$^{-1}$; for Fe, Cu, Zn, Mn in g daa$^{-1}$
[2] Significance: *** – $p < 0.001$; ** – $p < 0.01$; * – $p < 0.05$; n.s. – non-significant difference

'Camarosa' strawberry cultivar were at the harvesting stage. The values reported for micro elements were also in parallel with our findings.

## Plant nutrient elements taken up by the fruit

Figures 1 and 2 show the mean amounts of macro and micro nutrients taken up by the fruits of the 'Festival' and 'Camarosa' cultivars.

As can be seen in Figure 1, the macro nutrient elements taken up by each cultivar in each year were very similar to each other. Our findings are similar to the results of studies on the topic by different researchers in different ecologies.

The nitrogen content of the dry matter of the fruits of the 'Festival' cultivar were 1.3% (359 g 100 kg fresh weight$^{-1}$) in the first year and 1.2% (340 g

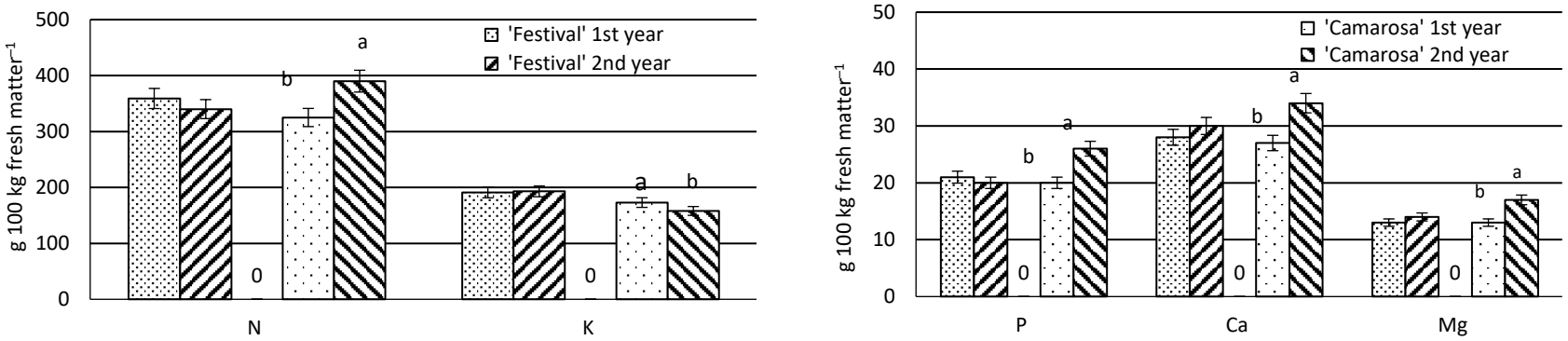


**Fig. 1.** Mean amounts of macro nutrient elements taken up by the fruits of two different cultivars in two consecutive years

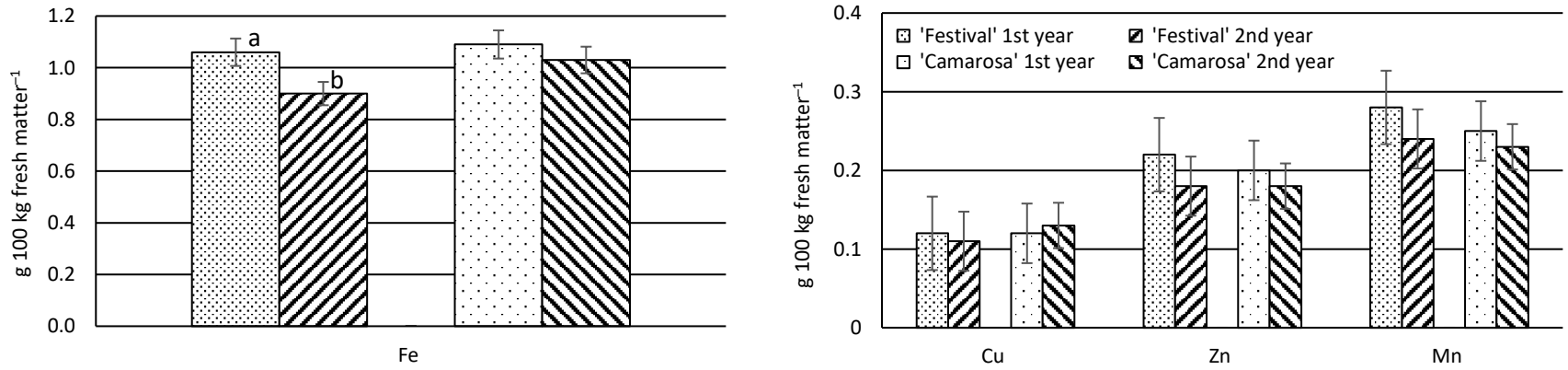


**Fig. 2.** Mean amounts of micro nutrient elements taken up by the fruits of two different cultivars in two consecutive years

100 kg fresh weight$^{-1}$) in the second year. The equivalent figure for fruits of the 'Camarosa' cultivar were 1.1% (325 g 100 kg fresh weight$^{-1}$) and 1.5% (390 g 100 kg fresh weight$^{-1}$). Atasay and Türemiş [2008] reported that the nitrogen content of the dry matter of fruit was 1.07–1.39% in the first year and 0.93–1.39% in the second year. Bottoms et al. [2013] reported that amounts of nitrogen in the dry material of fruits ranged between 1.2% and 1.5%, while Tagliavini et al. [1996] reported the amount of nitrogen taken up by the fruits of the 'Bounty' cultivar as 414g 100 kg fresh fruit$^{-1}$. Amounts of phosphorus taken up by strawberry fruits have been reported as 19 g 100 kg fresh weight$^{-1}$ [Hemphill and Martin 1992] and 21 g 100 kg fresh weight$^{-1}$ [Erenoğlu et al. 1999]. In a two-year study on the feasibility of organic strawberry production in the conditions of Eğridir, Turkey, the fruits took up 17–21 g 100 kg fresh weight$^{-1}$ of phosphorus in the first year and 15–19 g 100 kg fresh weight$^{-1}$ in the second year [Atasay and Türemiş 2008]. Different researchers have reported the amounts of potassium taken up by strawberry fruits as 140 g 100 kg fresh weight$^{-1}$ [Atasay and Türemiş 2008], 164 g 100 kg fresh weight$^{-1}$ [Erenoğlu et al. 1999] and 166 g 100 kg fresh weight$^{-1}$ [Hemphill and Martin 1992]. In the Jonsok strawberry cultivar, 157–188 g 100 kg fresh weight$^{-1}$ of potassium was taken up under organic conditions, and 164–218 g 100 kg fresh weight$^{-1}$ under conventional conditions [Hakala et al. 2003]. Amounts of calcium taken up by the fruits are reported as 22–32 g Ca 100 kg fresh weight$^{-1}$ [Atasay and Türemiş 2008], 21 g Ca 100 kg fresh weight$^{-1}$ [Erenoğlu et al. 1999], 19–22 g Ca 100 kg fresh weight$^{-1}$ in the 'Jonsok' cultivar [Hakala et al. 2003], and 17–26 g Ca 100 kg fresh weight$^{-1}$ in the 'Camarosa' cultivar [Polat 2005]. Atasay and Türemiş [2008] reported the amounts of Mg taken up by fruits in organic and conventional growing conditions as 10–12 g 100 kg fresh weight$^{-1}$, and Hempill and Martin reported that 10 g 100 kg$^{-1}$ of magnesium was taken up by fresh strawberry fruits. Hakala et al. [2003] found that the magnesium value of the 'Jonsok' strawberry cultivar was the same in organic and conventional growing, and that the distributions by years of mean values over two-year vegetation were 11–15 g 100 kg fresh weight$^{-1}$.

The micro nutrient elements taken up by the fruits of both cultivars in both years, like the macro elements, were also very similar to each other (Fig. 2). The findings of our study appear to be lower than the values reported by other researchers. As a matter of fact, Polat [2005] reported that strawberry fruits took up 2.87–5.84 g 100 kg fresh weight$^{-1}$ of iron, and Erenoğlu et al. [1999] reported 1 g iron in 100 kg of fresh strawberries. A study conducted under organic and conventional growing conditions reported amounts of Zn as 0.39–0.49 g Zn 100 kg fresh weight$^{-1}$ in the first year and 0.35–0.47 g Zn 100 kg fresh weight$^{-1}$ in the second year [Atasay and Türemiş 2008]. Polat [2005] reported that the fruit of the 'Camarosa' strawberry cultivar took up a mean of 1.07 g 100 kg fresh weight$^{-1}$ of zinc. Atasay and Türemiş [2008] reported that the Mn take-up by fruit varied between 0.96 and 1.24g 100 kg fruit$^{-1}$. Polat [2005] reported a mean of 2.30 g 100 kg$^{-1}$ of manganese in the fruits of 'Camarosa' strawberries.

According to examining the yearly changes in nutrient elements taken up by the fruits, statistically significant differences were found between years in the amounts of Fe taken up by the 'Festival' variety and of N, P, K, Ca and Mg in the 'Camarosa' variety (Figs 1, 2). The reason for this is thought to arise from differences in climatic factors in the research years and the genetic characteristics of the varieties. Moreover, growing period differences in the 'Festival' variety belonging to the first year, in the amounts of Cu taken up by the stems and of Mn taken up by the leaves, also in both years of the study in the amounts of Zn and Mn taken up by the stems were found statiscally non-significant. Apart from these relationships, the growing period differences in all of the nutrient elements taken up by the various parts of the 'Festival' variety were found to be statistically significant (Tab. 4). As for 'Camarosa' variety, apart from the amounts of Cu an Zn taken up by the stems in the first year and the amounts of Cu taken up by the leaves in the second year, the differences between growing periods of all the nutrient elements taken up by the various parts of the plants were found to be statistically significant in both years (Tab. 5).

## CONCLUSION

In the 'Festival' and 'Camarosa' varieties, the macro-nutrient elements N, P, Ca and Mg and the micro-nutrient Mn were taken up in all growing periods

mostly by the leaves, followed by the roots and the stems. Both varieties took up approximately half of the total amount of nutrient elements, until the end of dormant period. For this reason, half of the nutrient elements needed by the plants, should be given up to the end of dormant period. In both year of the research, the amount of nutrient elements taken up by the fruits of both varieties were found to be very close to each other. On average, 100 kg of fresh fruit of each cultivar took up 354 g N, 22 g P, 179 g K, 30 g Ca, 15 g Mg, 1.02 g Fe, 0.13 g Cu, 0.20 g Zn and 0.25 g Mn respectively.

## ACKNOWLEDGEMENTS

This research was financially supported by the Ege University Scientific Research Project Commission, Turkey (Project No: 2011-ZRF-064).

## REFERENCES

Adak, N. (2019). Effect of different $K^{+}/Ca^{(2+)}$ ratios on yield, quality and physiological disorder in soilless strawberry cultivation. Acta Sci. Pol. Hortorum Cultus, 18(2), 229–236. DOI: 10.24326/asphc.2019.2.20

Albregts, E.E., Howard, C.M. (1978). Elemental composition of fresh strawberry fruit. J. Amer. Soc. Hort. Sci., 103(3), 293–296.

Albregts, E.E., Howard, C.M. (1980). Accumulation of nutrients by strawberry plants and fruit grown in annual hill culture. J. Amer. Soc. Hort. Sci., 105(3), 386–388.

Atasay, A., Türemiş, N. (2008). Eğirdir (Isparta) Koşullarında Organik Çilek Yetiştiriciliğinin Uygulanabilirliği Üzerine Bir Araştırma. [An Investigation on the Application of Organic Strawberry Production in Eğirdir Isparta Conditions]. Çukurova Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 18(3), 72–81.

Baldi, E., Nestby, R., Raynal-Lacroix, C., Lieten, P., Salo, T., Pivot, D., Lucchi, P.L., Baruzzi, G., Faedi, W., Tagliavini, M. (2003). Uptake and partitioning of major nutrients by strawberry plants. In: Euro Berry Symposium-COST-Action 836 Final Workshop, Acta Hortic., 649, 197–200. DOI: 10.17660/ActaHortic.2004.649.36

Bottoms, T.G., Hartz, T.K., Cahn, M.D., Farrara, B.F. (2013). Crop and soil nitrogen dynamics in annual strawberry production in California. HortScience, 48(8), 1034–1039. DOI: 10.21273/HORTSCI.48.8.1034

Bouyoucos, G.J. (1962). Hydrometer Method Improved for Making Particle Size Analysis of Soil. Agron. J., 54(5), 464–465. DOI: 10.2134/agronj1962.00021962005400050028x

Bremner, J.M. (1965). Total Nitrogen. In: Methods of Soil Analysis, Part 2, Black, C.A. (ed). Amer. Soc. Agr. Inc., Publisher, Madison, Wisconsin, USA, 1149–1178.

Bulduk, E., Erdal, İ. (2012). Genotipsel farklılığın çileğin mineral beslenmesi üzerine etkisi [Effect of genotypic differences on mineral nutritions of strawberry]. Derim, 29(1), 59–70.

Çakıcı, H., Aydın, Ş. (2005). Emiralem-İzmir Yöresi Çilek Plantasyonlarının Beslenme Durumu [Nutritional Status of Strawberry Plantations in Emiralem-İzmir]. Ege Univ. Ziraat Fak. Derg., 42(1),155–166.

Erenoğlu, B., Baş, B., Ufuk, U., Erbil, Y. (1999). Marmara Bölgesine Uygun Yeni Çilek Çeşitlerinin Seçimi [Selection of New Strawberry Varieties Suitable for Marmara Region]. Atatürk Bahçe Kültürleri Merkez Araştırma Enstitüsü Bilimsel Araştırmalar ve İncelemeler, Yayın, 128: 26 s.

Fattahi, M., Gholami, M. (2009). Nutrient content changes in strawberry plant parts at different development stages. J. Appl. Hortic. (Lucknow), 11(2), 150–152.

Fawzi, A.F.A., El-Fouly, M.M. (1980). Soil and leaf analysis of potassium in different areas in Egypt. In: Role of potassium crop production, Sourat, A., El-Fouly, M.M. (eds.). IPI, Bern, 73–80.

Hakala, M., Lapveteläinen, A., Huopalahti, R., Kallio, H., Tahvonen, R. (2003). Effect of Varieties and Cultivation Conditions on the Composition of Strawberries. J. Food Comp. Anal., 16, 67–80. DOI: 10.1016/S0889-1575(02)00165-5

Hemphill, R., Martin L.W. (1992). Microwave oven-drying method for determining total solids of strawberries. HortScience, 27(12), 1326.

Isaac, R.A., Johnson, W.C. (1992). Determination of P, K, Ca, Mg, Mn, Fe, Al, B, Cu, and Zn in plant by emission spectroscopy. In: Plant Analysis Reference Procedures for Southern Region of the United States College of Agricultural and Environmental Sciences, Plank, C.O. (ed.). North Carolina Depart. Agr. Agron. Div. NC, 41–44.

Martin, M., Roson, R. (1980). Mineral composition of strawberry plants at different stages in the growth cycle. An. Edafol. Agrobiol., 39(5/6), 1019–1031.

Mengel, K., Kirkby, E.A. (1982). Principles of plant nutrition, Intern. Potash Inst., Bern.

Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Dep. Agric. Circ. 939, 1–19.

Özden, A., Ayanoğlu, H. (2002). Nutritional status of strawberry plantings near Silifke in Turkey. In: IV. International Strawberry Symposium, Acta Hortic., 567, 443–446. DOI: 10.17660/ActaHortic.2002.567.92

Polat, M. (2005). Ankara (Ayaş) Koşullarında Organik Çilek Yetiştiriciliği Olanaklarının Araştırılması [Investigation of Organic Strawberry Growing Opportunities in Ankara (Ayaş) Conditions]. Ankara Üniv. Fen Bilimleri Enstitüsü, Doktora Tezi, pp. 116.

Reuterberg, E., Kremkus, F. (1951). Bestimmung von Gesamthumus und Alkalischen Humusstoffen im Boden [Determination of the Total Humus and the Alkaline Humus Substances in the Soil]. J. Plant Nutr. Soil Sci., 54(3). DOI: 10.1002/jpln.19510540305

Rieger, M. (2006). Introduction to fruit crops. Haworth Press, USA, pp. 462.

Seferoğlu, S., Kılıç, I. (2002). Determining the soil nutrition level of strawberry fields in Aydın province. 13th Int. Fertilizer Symp., Tokat, 342–349.

Soil Survey Manual, Soil Survey Division Staff (1993). United States Department of Agriculture, Handbook No: 18, U.S. Government Printing Office, Washington, D.C, USA. pp. 410.

Tagliavini, M., Scudellazi, D., Marangoni, B., Toselli, M. (1996). Nitrogen fertilization management in orchards to reconcile productivity and environmental aspects. In: Fertilizers and environment, Rodriguez-Barrueco, C. (ed.). Springer, Dordrecht, 161–170.

U.S Soil Survey Staff (1951). Soil Survey Manual. U.S. Dept. Agr. Handbook 18. U.S Govt. Printing Office. Washington DC. USA.

Vandecasteele, B., Debode, J., Willekens, K., Van Delm, T. (2018). Recycling of P and K in circular horticulture through compost application in sustainable growing media for fertigated strawberry cultivation. Eur. J. Agron., 96, 131–145. DOI: 10.1016/j.eja.2017.12.002

Zengin, M. (2012). Toprak ve Bitki Analiz Sonuçlarının Yorumlanmasında Temel İlkeler [Basic Principles in Interpreting Soil and Plant Analysis Results In: Plant Nutrition]. In: Bitki Besleme, Karaman, M.R. (ed.). Gübretaş Rehber Kitaplar Dizisi, 2, 37–961.