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MACROELEMENTS CONCENTRATION IN PLUM TREE LEAVES AND SOIL IN RESPONSE TO ORCHARD FLOOR MANAGEMENT

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ABSTRACT

The aim of the study was to determine the influence of various methods of orchard floor management on extractable mactronutrients concentration in plum leaves and orchard soil. Study carried out between 2013 and 2015. Standard mineral fertilization on experimental plots was applied. Trees of 'Valjevka' plum (*Prunus domestica* L.), grafted onto Myrobalan seedlings (*Prunus cerasifera* Ehrh. var. *divaricata* Ledeb.), were planted in the spring of 2008. From 2009 to 2015, the following methods of soil cultivation under tree canopies were introduced: control with limited weeding around tree trunks; spraying with foliar herbicides; mulching with organic waste, i.e. straw with compost; mechanical soil cultivation with the use of rotary cultivators and hoe; weed mowing. The method of soil cultivation had influence on leaf concentration of phosphorus, potassium, magnesium and calcium, as well as soil concentration content of phosphorus, potassium, and magnesium in particular years of the study or as three-year mean. Orchard floor management did not affect leaf nitrogen concentration in any way. The results showed that regular weed control in the evaluated type of orchard is not necessary for properly supplying plum trees with macronutrients.

Key words: *Prunus domestica* L., plant nutrition, soil maintenance, weeds

INTRODUCTION

Fertilizer recommendations are based on the analyses of mineral composition of soil and leaves. Nutrient concentration in fruit tree leaves depends on a multitude of factors, of which the most important are: type and mineral content of the soil [Zydlik et al. 2011], fertilizing form [Komosa and Szewczuk 2002], rootstock [Mestre et al. 2017], tree species and variety [Tagliavini et al. 1992], weather conditions [Sosna 2010], age of trees [Treder and Olszewski 2004], yield [Sadowski et al. 1995, Treder and Olszewski 2004], density of tree planting [Olszewski and Mika 1986, Singh-Sidhu and Kaundal 2005], agricultural practices [Olszewski and Mika 1986, Robbins et al. 1986, Olszewski et al. 1995], pruning [Rutkowski et al. 2018] and the growth phase [Sánchez-Alonso and Lachica 1987, Tagliavini et al. 1992, Szwedo and Maszczyk 2000]. Leaf nitrogen (N) concentration is correlated with one-year-old shoot length, fruit weight and yield of plum cultivars [Milošević et al. 2012].

An important factor that modifies the concentration of mineral components in orchard soil and tree leaves is the method of orchard soil maintenance [Neilsen and Hogue 1985, Merwin and Stiles 1994, Lipecki and Berbeć 1997, Szwedo and Maszczyk 2000, Neilsen et al. 2003, Bielińska and Głowacka 2004, Stefanelli et al. 2009]. Orchard floor management treatments which include the use of cover crops, tillage, mulching, the use of herbicides and flaming, are also important for soil pH, organic carbon (C) concentration and C:N ratio [Zoppolo et al. 2011, Granatstein et al. 2014, Sas Paszt et al. 2014]. Increasingly, the authors point out that the soil maintenance method affects the avail-

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ability of nutrients, also by stimulating the microbial activity of the soil, hence the growing role of ground cover plants and organic mulches as a source of organic matter [Yao et al. 2005, Hoagland et al. 2008].

Taking into account the number of factors and varying conditions, identification of fertilizing needs of fruit plants is a difficult task. It is arguable especially in the case of mineral N, for which, due to high runoff and leaching, there are no official recommendations regarding its optimal soil content in the Polish orchards. Plants mowed in orchard interrows [Jadczuk 1990], mulches of plant origin such as alfalfa hay [Neilsen et al. 2003, Stefanelli et al. 2009, Zoppolo et al. 2011] and cover crops, especially from Fabaceae family [Marsh et al. 1996], may all serve as sources of N.

Nutritional status of yielding fruit trees is assessed by comparing concentration of particular components, obtained through chemical analyses of leaves, with the so-called compositional standards. Compositional standards that indicate optimal concentration of macronutrients are determined for particular tree species while taking into account the following aspects: soil and climatic conditions in a given country (region), cultivation, methodology of sampling and making analyses [Kłossowski 1972, Leece 1975, Sadowski et al. 1990]. Plant nutritional status may be alternatively assessed with deviation from optimum percentage – DOP of macro- and micronutrients [Montañés et al. 1993]. The sum of DOP indexes (ΣDOP_{macro-} and $\Sigma DOP_{micronutrients}$) allows to assess general nutritional status of all macro- and micronutrients. So far, the mentioned indexes were used to assess tree nutritional status depending on various factors: fertilizer, cultivar [Milošević et al. 2013] and rootstock [Milošević and Milošević 2016, Mestre et al. 2017].

Majority of studies on fertilizers and orchard floor management in orchards is dedicated to apple trees, with particular attention turned recently to organic orchards [Stefanelli et al. 2009, Zoppolo et al. 2011, Granatstein et al. 2014]. Literature regarding *Prunus domestica* is rather scarce. The aim of the study was to determine the influence of orchard floor management on mactronutrients concentration in plum leaves and orchard soil as well as on soil pH, organic C concentration and C:N ratio in the soil of plum orchard. Such findings are interesting in the context of the effect of weeds on the nutritional status of plants and soil nutrient concentration and the potential differentiation of fertilizer recommendations depending on the soil maintenance method in the future.

MATERIAL AND METHODS

Experiment conditions and design. The field experiment was conducted in the Experimental Orchard of the Research Institute of Horticulture in Dąbrowice, Central Poland (51°55'N, 20°06'E), Central Europe. Orchard soil type was classified as luvisol, according the international soil classification system [IUSS Working Group 2015]. Floatable parts (silt and clay), with diameter less than 0.02 mm, marked according to Casagrande's method of aerometry, modified by Prószyński [Shepard 1954], constituted 15% of soil granulometric composition. The temperate climate of Central Poland, intermediate between maritime and continental, is characterized by cold winters and hot summers, and relatively low and changeable precipitation. In the years 2013–2015, average air temperature was −1.5°C in January (coldest month) and 19.7°C in July (warmest month). Annual precipitation in particular years during this period was 423, 390 and 314 mm respectively. The research was conducted in the years 2013–2015 on plum trees. One-year-old trees of the cultivar 'Valjevka' (*Prunus domestica* L.), grafted on Myrobalan seedlings (*Prunus cerasifera* Ehrh. var. *divaricata* Ledeb.), were planted in spring of 2008. The trees were spaced at 2 m in rows and 4 m between rows. Perennial grass *Festuca rubra* subsp. *rubra* was sowed in the interrows in September after the establishment of the orchard. From 2009 to 2015, the following methods of soil cultivation were introduced: control with limited weeding; spraying with foliar herbicides (glufosinate ammonium, one treatment, 0.6 kg a.i. ha^{-1} per year; glyphosate, 2.88 kg a.i. ha^{-1} per year) – 3 treatments between May and August; mulching with organic waste – cereal straw with 2-yers-old compost from plant wastes in a volume ratio of 2:1 (layer of about 10 cm, filled in every 2 years, which was enough to effectively reduce the emergence of weeds); mechanical soil cultivation (tillage) with the use of rotary cultivators and hoe – three times from May to September; weed mowing – 3 times between May and September. The concentration of macronutrients (g kg^{-1} DW) and organic matter (%) in the mulch used in the experiment at a dose of about 5 kg m^{-1}, was as follows: N – 1.19; P – 0.11; K – 0.18; Mg – 0.1; Ca – 0.43; organic matter – 42.3. On control plots with limited weeding, the weeds growing around tree trunks were pulled several times (3–4 times during a season, within 0.5 m from trunk). Treatments were applied in completely randomized blocks with 4 replications and 5 trees on the plots (20 trees per treatment). Plot width was 2 m. Trees trained to a central leader spindle system were drip-irrigated. Soil water potential was kept between 0 and –0.02 MPa at a depth of 20 cm, according to the readings on tensiometers, which were checked with a frequency depending on weather conditions, but at least twice a week. In 2009, the initial soil nutrient concentration (mg 100 g^{-1} soil) was as follows; at a depth of 0–20 cm: N_{Tot} – 105; P – 8.1; K – 15.4; Mg – 5.7, at a pH (KCl) of 6.8; organic matter – 1.95 (% DW), and at a depth of 20–40 cm: N_{Tot} – 73.5; P – 6.1; K – 8,9; Mg – 5.3, at a pH (KCl) of 5.9. Mineral fertilization – N: 50 kg ha^{-1} in 2008 and 2009, 30 kg ha^{-1} in 2010–2014, 15 kg ha^{-1} in 2015 (as ammonium nitrate); phosphorus (P): 50 kg ha^{-1} in 2008 (triple superphosphate); potassium (K): 75 kg ha^{-1} in 2008, 50 kg ha^{-1} in 2010, 50 kg ha^{-1} in 2012 (potassium chloride); calcium (Ca): 500 kg ha^{-1} in 2009, 150 kg ha^{-1} in 2012 (lime fertilizer); magnesium (Mg): 100 kg ha^{-1} in 2012 (lime fertilizer) and plant protection were carried out according to current recommendations for commercial orchards. Leaf and soil samples were taken annually, chemical analyses determining macronutrient concentration and soil pH performed from 2013 to 2015. In accordance with Polish recommendations, N, P, K, Ca and Mg concentration in leaves and P, K and Mg concentration in soil was analyzed. Samples of soil and leaves were taken at the beginning of August. Leaves with petioles were picked from the middle part of non-bearing one-year-old shoots, from various parts of tree canopies, at the height of 1.5–2 m. Soil samples were taken at a depth of 0–20 cm, assuming that soil maintenance will primarily affect its surface layer. The validity of this assumption was confirmed by soil analysis from a depth of 20–40 cm, where no significant differences were found between the initial and final macronutrient values. In 2015, total N, organic C concentration in soil were measured. Based on these data, organic matter concentration and C:N ratio were calculated.

Measurements and analyses. Macroelement concentration in leaf tissue and soil was analyzed at the accredited Chemical Pollution Research Laboratory of the Research Institute of Horticulture, Skierniewice, Poland. For the determination of available forms of P and K in a mineral soil, the Egner-Riehm method was used [Domagała-Świątkiewicz 2005]. The method consists in extracting P and K compounds from the soil by means of calcium lactate. For the determination of available forms of Mg in a mineral soil, the Schachtschabel method was used [Domagała-Świątkiewicz 2005]. The Schachtschabel method involves shaking soil with 0.025 M calcium chloride. Mineral content in plant material was determined through the process of mineralization (combustion) (VELP DK 42, VELP Scientifica Srl, Usmate, Italy). Wet combustion of dry, milled plant material consists of complete oxidation with liquid oxidants mixture: concentrated sulfuric acid (15%), nitric acid (75%) and perchloric acid (10%). For the determination of mineral concentration in the solutions obtained by the analytical methods mentioned above, measurements were carried out using the technique of atomic emission spectrometry with excitation in inductively coupled plasma (ICP-OES) (Spectrometer iCAP 6500 duo, Thermo Fisher Scientific, Waltham, Massachusetts, USA). Dry matter (DW) was determined with the use of the weight method. Total N concentration in both soil and plant material was determined by the Dumas method (conductometric technique) using a TruSpec CNS analyzer (LECO Corporation, Saint Joseph, Michigan, USA). The same method was used to determine the amount of soil organic matter (on the basis of organic C concentration). To calculate organic matter concentration, the organic C concentration was multiplied by 1.724 with the asumption that on average it contains 58% of C. Soil pH was determined in 1 M KCl, using the electrochemical method (pH meter ACCUMET 50, Fisher Scentific, Waltham, Massachusetts, USA). For this purpose, 10 g of air-dry soil was flooded with 25 ml KCl and the measurement was carried out after 24 hours.

Nutritional status of bearing fruit trees was assessed by comparing N, P, K and Mg leaf concentration obtained through chemical analyses with Polish compositional standards [Kłossowski 1972, Sadowski et al. 1990]. Polish guidelines do not provide for compositional standard of leaf Ca since its deficiency is rarely reported. Australian standards were used to assess the concentration of this macronutrient [Leece 1975]. Nutritional status of fruit trees was additionally determined using the deviation from optimum percentage – DOP index of macronutrients. The DOP index was calculated on the basis of the leaf analysis by the algorithm:

$$DOP = \frac{C_n \times 100}{C_{ref}} - 100$$

where C_n is foliar concentration of the tested nutrient, and C_{ref} is optimum macronutrient concentration which was estimated according to the guidelines of interpretation for plum nutrition [Montañés et al. 1993]. Mean optimum concentration of N, P, K and Mg was taken from Polish guidelines [Kłossowski 1972, Sadowski et al. 1990], and mean optimum concentration of Ca from Australian guidelines [Leece 1975]. DOP indexes provide general nutritional status of nutrients through the ΣDOP index, which was obtained by adding absolute values of DOP of each element. The lower the ΣDOP, means the better balance among nutrients.

Results were analyzed statistically using analysis of variance. The significance of the means was evaluated using Duncan's test at 5% level. Data concerning DOP and ΣDOP indexes were transformed according to the Bliss function.

RESULTS

Orchard floor management had no influence on N concentration in plum leaves in the course of the study (Tab. 1). P concentration in leaves in 2013 did not vary between treatments; in 2014, P content in leaves of trees growing in herbicide fallow was considerably lower than on control plots; in 2015, it was lower than on control plots and mowed plots (Tab. 1). Mean leaf P concentration in 2013–2015 was significantly lower on herbicide plots and tilled plots than on other plots. Leaf K concentration remained at the same level during subsequent years of the study, but its mean three-year concentration was considerably higher in trees growing on control plots than in trees growing on herbicide-treated, tilled and mowed plots (Tab. 1). Leaf Mg and Ca concentration was not affected by orchard floor management during the course of the study (Tab. 2). However, between 2013 and 2015 the mean content of those macronutrients was significantly lower on mechanically tilled plots compared with all other treatments, and Mg was significantly higher under the mowing treatment.

DOPN, DOPMg, DOPCa indexes indicated deficiency of those macronutrients; DOPP and DOPK showed nutrient excess in plum leaves, regardless of orchard floor management strategy (Tab. 3). Mean DOPN deficiency in herbicide fallow was considerably lower than on control plots. Leaf P excess showed by DOP index was significantly higher on control plots,

Table 1. Macronutrients – N, P, K concentration in leaf of plum trees during early-August, 2013–2015

Treatment	Macronutrients (% DW)											
	N				P				K			
	2013	2014	2015	2013–2015	2013	2014	2015	2013–2015	2013	2014	2015	2013–2015
Control	2.58 a	2.70 a	2.32 a	2.53 a	0.48 a	0.58 b	0.55 b	0.54 b	3.38 a	3.37 a	4.20 a	3.64 b
Herbicides	2.65 a	2.79 a	2.35 a	2.59 a	0.43 a	0.49 a	0.50 a	0.47 a	3.30 a	3.21 a	4.05 a	3.51 a
Mulching	2.58 a	2.69 a	2.35 a	2.54 a	0.47 a	0.56 ab	0.51 ab	0.51 b	3.35 a	3.29 a	4.09 a	3.57 ab
Tillage	2.61 a	2.67 a	2.40 a	2.56 a	0.45 a	0.50 ab	0.48 a	0.48 a	3.31 a	3.14 a	4.12 a	3.51 a
Mowing	2.59 a	2.68 a	2.34 a	2.53 a	0.46 a	0.54 ab	0.56 b	0.52 b	3.28 a	3.22 a	4.03 a	3.50 a
Optimal range[1]	2.01–3,6, mean 2.8				0.2–0.6, mean 0.4				1.65–3.25, mean 2.45			

Averages in column marked by the same letter do not differ significantly at P = 0.05 according to Duncan test
[1] Nutrient ranges recommended for plum in Poland [Kłossowski 1972, Sadowski et al. 1990]

Table 2. Macronutrients – Mg, Ca concentration in leaf of plum trees during early-August, 2013–2015

Treatment	Macronutrients (% DW)							
	Mg				Ca			
	2013	2014	2015	2013–2015	2013	2014	2015	2013–2015
Control	0.38 a	0.40 a	0.49 a	0.42 b	1.95 a	1.48 a	2.06 a	1.82 b
Herbicides	0.37 a	0.39 a	0.48 a	0.41 b	1.95 a	1.51 a	2.07 a	1.84 b
Mulching	0.38 a	0.39 a	0.50 a	0.42 b	2.04 a	1.42 a	1.95 a	1.79 b
Tillage	0.34 a	0.37 a	0.46 a	0.39 a	1.74 a	1.35 a	1.78 a	1.62 a
Mowing	0.39 a	0.43 a	0.50 a	0.44 c	1.90 a	1.48 a	2.05 a	1.80 b
Optimal range	0.31–0.7, mean 0.5[1]				1.5–3.0, mean 2.25[2]			

Averages in column marked by the same letter do not differ significantly at P = 0.05 according to Duncan test
[1] Nutrient ranges recommended for plum in Poland [Kłossowski 1972, Sadowski et al. 1990]
[2] Nutrient ranges recommended for plum in Australia [Leece 1975]

Table 3. Deviation from optimum percent (DOP) index, ΣDOP determined from plum leaf macronutrients – N, P, K, Mg, Ca, 2013–2015

Treatment	N	P	K	Mg	Ca	ΣDOP
Control	–9.61 b	+34.2 b	+49.0 b	–15.3 b	–18.6 a	126.7 b
Herbicides	–7.27 a	+18.3 a	+43.7 a	–17.3 b	–18.1 a	104.7 a
Mulching	–9.30 ab	+28.3 b	+46.0 ab	–15.3 b	–19.8 a	118.8 b
Tillage	–8.57 ab	+19.2 a	+43.8 a	–22.0 c	–27.9 b	121.4 b
Mowing	–9.40 ab	+30.0 b	+43.2 a	–12.0 a	–19.6 a	114.2 ab

Averages in column marked by the same letter do not differ significantly at P = 0.05 according to Duncan test

Table 4. Soil pH of orchard soil with plum trees, 2013–2015

Treatment	pH			
	2013	2014	2015	2013–2015
Control	6.35 a	6.38 a	6.55 a	6.43 a
Herbicides	6.43 a	6.53 a	6.45 a	6.47 ab
Mulching	6.58 a	6.60 a	6.63 a	6.60 c
Tillage	6.33 a	6.40 a	6.43 a	6.39 a
Mowing	6.45 a	6.55 a	6.65 a	6.55 bc

Averages in column marked by the same letter do not differ significantly at P = 0.05 according to Duncan test

mulched and mowed plots than on herbicide fallows and tilled plots. Leaf K excess was significantly higher on control plots than on plots treated with herbicides, mechanically tilled and mowed plots. Tillage resulted in significantly higher deficiency of leaf Mg and Ca than other kinds of treatment (according to DOP index). Based on the sum of DOP indexes, trees growing on herbicide-treated fallow had best balanced leaf macronutrient concentration.

Soil pH did not differ between treatments in particular years of the study, but its mean value for the three-year period was significantly higher on mulched and

Table 5. Macronutrients – P, K, Mg content in orchard soil with plum trees, 2013–2015

Treatment	Macronutrients (mg 100 g $^{-1}$ soil)											
	P				K				Mg			
	2013	2014	2015	2013–2015	2013	2014	2015	2013–2015	2013	2014	2015	2013–2015
Control	9.66 a	9.01 a	13.3 a	10.7 a	22.1 b	19.9 a	22.5 a	21.5 b	6.07 ab	5.71 b	7.98 b	6.59 c
Herbicides	8.40 a	7.82 a	10.8 a	9.01 a	17.6 b	17.5 a	17.2 a	17.4 ab	5.21 ab	4.96 ab	6.21 ab	5.46 b
Mulching	19.5 b	16.1 b	22.7 b	19.4 b	21.0 b	18.2 a	18.5 a	19.2 ab	5.54 ab	5.22 ab	7.05 ab	5.94 bc
Tillage	8.44 a	8.26 a	11.1 a	9.27 a	19.9 b	21.5 a	15.6 a	19.0 ab	4.72 a	3.79 a	5.28 a	4.60 a
Mowing	10.8 a	9.22 a	13.6 a	11.2 a	10.3 a	20.1 a	16.1 a	15.5 a	6.50 b	5.85 b	6.47 ab	6.27 bc
Optimal range[1]	2–4				5–8				2.5–4			
High range[1]	>4				>8				>4			

Averages in column marked by the same letter do not differ significantly at P = 0.05 according to Duncan test
[1] Nutrient ranges recommended for plum in Poland [Kłossowski 1972, Sadowski et al. 1990]

Table 6. Total nitrogen (N_{Tot}), organic carbon (C), organic matter content in soil and C:N ratio, 2015

	Content (% dry matter)			C:N ratio
	N_{Tot}	C	Organic matter	
Control	0.112 b	1.33 b	2.29 b	11.9 a
Herbicides	0.090 a	1.10 a	1.89 a	12.3 a
Mulching	0.140 c	1.74 c	2.99 c	12.4 a
Tillage	0.095 ab	1.15 ab	1.97 ab	12.2 a
Mowing	0.097 ab	1.15 ab	1.99 ab	11.9 a

Averages in column marked by the same letter do not differ significantly

mowed plots than on other kinds of plots (Tab. 4). Soil P in particular years and its mean three-year content were highest on mulched plots (Tab. 5). Soil K level in 2014 and 2015 did not differ between treatments (Tab. 5). In 2013 soil K concentration on mowed plots was significantly lower than on all other plots including the control when expressed as a mean of a three-year period. Lowest soil Mg concentration was obtained on mechanically tilled plots; as a mean of three years it was significantly lower than in other treatments, in 2013 and 2014 lower than on mowed plots, in 2014 and 2015 – lower than on control plots (Tab. 5). In 2015, total N, organic C and organic matter concentration in the soil of mulched plots was significantly higher than in other treatments (Tab. 6). N in soil did not relate with leaf N. C:N ratio did not differ substantially among treatments.

DISCUSSION

In order to determine the practical usefulness of orchard floor management, the results on mineral nutrition of trees need to be evaluated together with data on orchard floor management influence on growth and yield of trees. Results on yield and growth of trees being subject of this study have been described in another article [Lisek and Buler 2018]. There was no significant influence of orchard floor management strategy on the following tree characteristics: total number of annual shoots per tree and total length of shoots, TCSA (trunk cross-sectional area) and productivity index. It is worth mentioning that, the largest cumulative yield from experimental trees was collected from herbicide-treated plots [Lisek and Buler 2018] – treatment with best balanced leaf macronutrient concentration, which had the lowest $\Sigma DOP_{macronutrients}$ index. In the case of the orchard under study, with strongly growing trees grafted on Myrobalan, it can be concluded that regular weeding is not necessary for good nutrition, growth and yield, similar to apple trees [Merwin 2004].

In the studied model of plum orchard with strong-growing 'Valjevka' trees grafted on Myrobalan seedlings, leaf concentration of N, P and Mg fell within limits considered optimal in Polish conditions [Kłossowski 1972, Sadowski et al. 1990]. According to Polish guidelines, leaf K concentration was on optimal or high level, depending on treatment. Leaf Ca concentration, according to Australian guidelines [Leece 1975] was optimal. As there were no differences in nutritional status based on compositional standards, DOP indexes were helpful in assessing the status. Soil concentration of P and K fell within limits considered high in Polish conditions, and soil Mg concentration remained at optimal or high level [Kłossowski 1972, Sadowski et al. 1990].

Present results confirm a relationship between the nutrition of fruit trees and orchard floor management. Detailed comparison of the effectiveness of particular methods confirms some findings already described in literature of the subject but contradicts others. The difficulty in comparing our results with results of others lies in differences between plant genotypes used for the study, dissimilar natural conditions as well as varied type and chemical composition of mulches. A mixture of compost and straw used in the present study differed from mulches used by other researchers who usually used single component mulches (compost or straw).

Grass hay and wheat straw mulches did not change significantly leaf N, P, Ca and Mg concentration of 'Italian' plum grafted on Myro 29-C; wheat straw increased K content in comparison with herbicide-treated control [Robbins et al. 1986]. Similar relationships between mulching and using herbicides regarding leaf N, Ca and Mg concentration were discovered in present study but, unlike in Robbins et al. [1986], the mulch significantly increased the level of leaf P and did not change leaf K. Robbins et al. [1986] also report that mushroom compost mulch increased N and K and reduced Mg concentration in plum leaves compared to control. Present study, where the mixture of compost and straw was used, did not confirm this. The differences in the K content in the leaves could not be measured due to the high content of this macronutrient in the soil. Results of research on the role of orchard floor management in mineral nutrition of plum trees are rare and should be supplemented with publications describing other species of fruit trees growing in temperate climate zone.

In contrast to Szwedo and Maszczyk [2000], who examined macroelement concentration in 'English Morello' cherry grafted on *Prunus mahaleb*, present analyses did not show differences in leaf N and K concentration between mulches and herbicide fallow. They did, however, indicate that on mulched plots, plum leaves contained more P than on herbicide fallow. Similar to Szwedo and Maszczyk [2000], no differences were found in leaf Mg and Ca concentration between studied treatments.

Present results contradict results obtained in the study of apple trees 'Gold Milenium'/M.9, where straw and compost increased N and K content, did not change P content and reduced Mg and Ca content in leaves compared to herbicide fallow [Sas-Paszt et al. 2014]. Our results, are consistent with those achieved by Merwin and Stiles [1994] who showed lack of significant differences in N concentration between mown sod-grass, straw mulch, tillage and foliar-applied herbicides (glyphosate) in leaves of apple trees 'Empire' and 'Jonagold' grafted on MM 111. In case of plum trees, mean leaf P concentration on mowed and mulched plots was higher than on tilled plots and plots treated with herbicides, similiar to apple orchard [Merwin and Stiles 1994].

Present study confirmed results obtained by Neilsen and Hogue [1985] who observed that herbicide fallow and shallow tillage in orchard with 'Red Delicious'/M26 apple trees reduce leaf K, but contradicted their reports that mentioned treatments increase leaf Mg and leaf N compared to full ground cover with vegetation and have no significant influence on leaf P and tillage on leaf Ca also. Present results are consistent with Neilsen et al. [2003] who observed that leaf P in 'Spartan' apple trees on M.9 rootstock, was more affected by mulch and organic amendment treatment than leaf N.

Present study found that the use of foliar herbicides did not reduce soil pH, which is consistent with reports made by Merwin and Stiles [1994] and Bielińska and Głowacka [2004]. On the other hand, it contradicts data on the use of soil-applied herbicides which indicates that long-term use of herbicides in the orchard acidified the soil and reduced the concentration of organic matter in comparison with the soil under grass [Lipecki and Berbeć 1997].

Present study showed that the mulch used did not change soil K content compared to control, similar to straw in cherry orchard [Szwedo and Maszczyk 2000]. However, unlike in Szwedo and Maszczyk's research [2000], mulch used in our study increased soil P and organic C concentration significantly.

In present study mulch increased soil pH, similar to straw and compost in apple tree orchard [Sas-Paszt et al. 2014]. Similar to compost in apple trees, mulch used in plum trees composed of straw and compost increased total N concentration in soil whereas straw alone reduced total N concentration [Sas-Paszt et al. 2014] or did not have a significant effect on total N level [Lipecki et al. 2004]. In this study, total N concentration in soil, after herbicide treatment, tillage and mowing was similar at the end of the experiment, to which recirculation of N from eliminated weeds contributed greatly. As opposed to results presented by Sas-Paszt et al. [2014] concerning straw and compost, mulch used in plum trees increased soil P concentration and did not increase soil K and Mg content compared to herbicide fallow, though it did increase mean Mg concentration compared to tilled plots. Present results are consistent with results obtained by Merwin and Stiles [1994] in apple tree orchard, where soil P concentration was considerably higher after mulching with straw than on herbicide-treated, cultivated and mowed plots, and soil Mg concentration was lowest on tilled plots. High concentration of available soil P on mulched plots may have resulted not only from its presence in organic mulch, but also from relatively higher soil organic matter concentration as compared with other treatments [Peterson and Stevens 1994]. In present study, K:Mg ratio in soil was correct, i.e. less than 3.5 in all treatments with the exception of soil tillage where the ratio reached 4.1 (mean value from 2013–2015). Present study found that the vegetation (weeds) maintained mean extractable soil Mg high level compared to vegetation control treatments (herbicides and tillage) which is consistent with results obtained by Neilsen and Hogue [1992].

The mixture of straw and compost used in the experiment on plum trees increased soil organic matter, similar to compost [Sas-Paszt et al. 2014]. Present study showed that mulching increased soil organic matter concentration compared to both herbicide treatment and tillage, contrary to results presented by Bielińska and Głowacka [2004] where organic matter concentration on plots mulched with straw and tilled plots was higher than on herbicide-treated plots.

Present study confirmed that soil organic matter concentration in the orchard increases under cover plant and organic mulch [Merwin 2004] but, unlike in this author's study, expected decrease in organic matter concentration on tilled plots compared to untreated control was not observed. Granatstein et al. [2014] provide conclusions similar to ours; in their study, a three-year tillage in apple tree and pear tree orchards – shorter than in this study – did not reduce soil organic matter concentration.

CONCLUSIONS

The deviation from optimum percentage indexes of macronutrients and the sum of those indexes may be an additional information on the mineral nutrition of fruit trees depending on orchard floor management. According to the sum of DOP indexes, trees growing on herbicide-treated fallow had best balanced leaf macronutrient concentration. In the orchard with 'Valjevka' plum trees grafted on Myrobalan seedlings with standard NPK mineral fertilization, the method of soil cultivation affected leaf concentration of P, K, Mg and Ca, as well as soil concentration of P, K, Mg in particular years of the study or as a mean of three years. Orchard floor management did not affect N concentration in plum leaves. Total N, organic C and organic matter concentration in soil was significantly lower in herbicide fallow than on control plots with limited weeding around tree trunks and on mulched plots, where it was highest of all studied treatments. At standard mineral fertilization of strong-growing plum trees, leaf concentration of macronutrients – N, P, Mg and Ca – remained at optimal level; K concentration remained at optimal or high level regardless of orchard floor management method, also on control plots with limited weeding. This indicates that regular weed control in the evaluated type of orchard is not necessary for properly supplying plum trees with macronutrients.

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