The effect of organic mulches and mycorrhizal substrate on growth, yield and quality of Gold Milenium apples on M.9 rootstock

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Sas-Paszt, L., Pruski, K., Żurawicz, E., Sumorok, B., Derkowska, E. and Głuszek, S. 2014. **The effect of organic mulches and mycorrhizal substrate on growth, yield and quality of Gold Milenium apples on M.9 rootstock**. Can. J. Plant Sci. **94**: 281–291. A 3-yr study was conducted to evaluate the effects of organic mulches and mycorrhizal substrate on growth and yield of apple cv. Gold Milenium grown on M.9 rootstock. Straw (rye), pine bark, conifer tree sawdust, compost (plant debris), cow manure, peat moss substrate (commercial), and mycorrhiza substrate (Mykoflor®, containing mycorrhizal fungi: *Glomus intraradices, G. mosseae, G. etunicatum*) were applied in spring of each year. All the applied treatments did not affect significantly the tree growth. Mulches did not have a positive effect on total soluble solids of the fruit and the number of fruits in different size categories. Only sawdust mulch significantly increased the number of fruit in size diameter class of 7.0–7.5 cm compared with the control. The use of mulches affected the concentration of macro- and microelements in leaves, particularly Cu, Fe, Mn and Zn. Mulches positively affected the pH and organic matter content of soil. The best results were observed with the use of the compost, cow manure and the mycorrhizal substrate, where the concentrations of P, K and Mg, most of microelements and soil organic matter were elevated.

Key words: *Malus × domestica*, apple variety, tree growth, fruit yield, apple fruit quality

Sas-Paszt, L., Pruski, K., Żurawicz, E., Sumorok, B., Derkowska, E. et Głuszek, S. 2014. **Effet des paillis organiques et d'un substrat à mycorhizes sur la croissance, le rendement et la qualité des pommes Gold Milenium cultivées sur le porte-greffe M.9**. Can. J. Plant Sci. **94**: 281–291. Les auteurs ont entrepris une étude de trois ans afin d'évaluer les effets des paillis organiques et d'un substrat à mycorhizes sur la croissance et le rendement du pommier Gold Milenium, cultivé sur le porte-greffe M.9. Dans cette optique, il ont appliqué chaque année, au printemps, de la paille de seigle, de l'écorce de pin, de la sciure de conifère, du compost (débris végétaux), du fumier de vache, un substrat commercial à base de mousse de sphaigne et un substrat de mycorhizes (Mykoflor®, contenant les champignons *Glomus intraradices, G. mosseae* et *G. etunicatum*). Aucun traitement n'a affecté significativement la croissance des arbres. Le paillis n'a pas eu d'incidence positive sur la concentration totale de solides solubles dans le fruit, ni sur le nombre de fruits de divers calibre. Seule la sciure a augmenté le nombre de fruits dans la catégorie 7,0–7,5 cm de diamètre, comparativement au témoin. Le paillage modifie la concentration de macroéléments et d'oligoéléments dans les feuilles, notamment celle de Cu, de Fe, de Mn et de Zn. Le paillis influe positivement sur le pH et la teneur en matière organique du sol. Les meilleurs résultats ont été obtenus avec le compost, le fumier de vache et le substrat à mycorhizes, qui ont entraîné une hausse de la concentration de P, de K et de Mg, de la plupart des oligoéléments et de la teneur en matière organique dans le sol.

Mots clés: *Malus × domestica*, variété de pommier, croissance des arbres, rendement fruitier, qualité des pommes

Apple trees can be cultivated using conventional methods (traditional, highly intensive), integrated (limited and controlled use of pesticides) and ecological also called organic. Due to reduced use or even a complete elimination of chemical pesticides and synthetic fertilizers, integrated/ecological methods have lower environmental impact than conventional cultivation. Many different types of mulches are used in the organic cultivation of apple. These include cow manure, peat moss substrate, straw, bark, sawdust, paper (Shribbs and Skroch 1986; Swezy 2000; Forge et al. 2003, 2008; Philips 2005), synthetic mulches (Haynes 1987), black plastic mulch, reflective plastic film (Blanke 2008; Grout et al. 2004; Mika et al. 2007a, b), agriculture fabric and intercropping mulches such as marigold plants, clover, facelia and a variety of grasses (Hartley and Rahman 1998; Deguchi et al. 2007). In some crops, municipal solid waste (Pinamonti et al. 1995; Forge et al. 2003; Neilsen et al. 2003) or spent mushroom compost (Saoir and Mansfield 2000) were used. Organic mulches are of benefit to soils by increasing their productivity and organic matter content, protecting them from excessive

Abbreviation: **TCSA**, trunk cross sectional area solar radiation, wind and moisture loss (Jalota and Prihar 1998;Niggli et al. 1990; Tamás and Bubán 2000; Rubauskis et al. 2004), temperature fluctuations (Larsson and Baringth 1996) and water erosion (Smets et al. 2008). Mulches also positively influence the development of beneficial microorganisms in soils (Hartley et al. 1996; Forge et al. 2003; Prokopy 2003; Yang et al. 2003; Yao et al. 2005, 2006; Hoagland et al. 2008), restrict the presence of nematodes affecting the root system of cultivated plants (Forge et al. 2003, 2008) and reduce the occurrence of fungal diseases and insect populations (Ścibisz and Sadowski 1996; Brown and Tworkoski 2004). Mulches also restrict the amount of light penetrating the soil surface, which reduces germination and growth of weeds (Niggli et al. 1990; Hogue and Peters 1994). The use of organic mulches increases soil productivity and can allow for reduced use of chemicals, having a positive effect on environment. In apple orchards, mulching facilitates the development of soil aggregate stability and reduces the severity of apple replant disease/disorder (Walsh et al. 1996; Yao et al. 2006; van Schoor and Stassen 2008; St. Laurent et al. 2008). Some mulches, such as bark, sawdust and cow manure, can also improve postharvest storage of apple fruit (Lang et al. 2001; Markuszewski and Kopytowski 2008b). In sustainable orchards, application of organic mulches allows the reduction in the use of mineral fertilizers and fulfills the nutrient requirements of trees (Szewczuk and Gudarowska 2004b; Sas Paszt et al. 2010).

Besides organic mulches, bio-stimulants and fungal/bacterial formulations are also used to promote the availability of nutrients in the rhizosphere and their subsequent uptake and acquisition by the plants. The use of mycorrhizal inoculum containing some species of arbuscular mycorrhizal fungi positively influences the absorption of nutrients by the fruit trees, enhancing their growth and yield (Sas Paszt and Głuszek 2007; Głuszek et al. 2008). Arbuscular mycorrhiza fungi colonize the roots of wild (*Malus communis* L.) and cultivated (*Malus sylvestris* Mill) apple (Harley and Harley 1987). Apple is the first tree fruit species successfully introduced to organic farming in cool climatic zones. The objective of this research was to evaluate the effects of the organic mulches including straw (rye), pine bark, conifer tree sawdust, compost (plant debris), cow manure, peat moss substrate (commercial), mycorrhiza substrate (Mykoflor®, containing mycorrhiza fungi: *Glomus intraradices, G. mosseae, G. etunicatum*) on the growth and yield of Gold Milenium apple trees. The results of the studies will be included in recommendations for organic commercial production and cultivation of apple.

MATERIALS AND METHODS

The study was conducted at the Pomological Orchard of the Research Institute of Horticulture (RIH) in Skierniewice, Poland, between 2008 and 2010. Apple trees cv. Gold Milenium grafted on M.9 dwarfing rootstock were used. Gold Milenium was released by Edward Żurawicz from the apple breeding program at the Research Institute of Horticulture in Skierniewice in 1986 (Żurawicz et al. 2004).

The research plots were situated on sandy loam soil with levels of N, P, K, Ca and Mg (as percent dry matter: total N, 2.37; P, 0.15; K, 1.35; Mg, 0.22; and Ca, 1.64) and microelements (milligrams per kilogram): B, 3.2; Cu, 13.5; Fe, 1084; Mn, 96.6; and Zn, 11.8 (extracted with 1 M HCl, Mercik 2002). The pH of soil was 6.0.

The following treatments were applied: (1) control – no mulch, no mycorrhiza, (2) straw (rye), (3) pine bark (chipped), (4) sawdust (from conifer trees), (5) compost (mixture of mineral soil, horse manure and peat substrate at the ratios of 1:1:1 by volume), (6) cow manure (solid beef cattle manure), (7) peat moss substrate (commercial), (8) commercial mycorrhizal substrate (Mykoflor®, manufactured by the Mykoflor, Końskowola, Poland), containing 10^6 "infective propagules" of arbuscular mycorrhizal fungi (*Glomus intraradices, G. mosseae, G. etunicatum*) per 100 g of the peat substrate carrier.

One-year-old whips grafted on M.9 were planted in the autumn of 2003. A randomized block experiment with four replications and three trees per plot was planted at 4.0-m × 1.5-m spacing, without any guard trees between the plots. The trees were irrigated using a computerized trickle irrigation system. The applied water amount was calculated and delivered every year according to the potential evapotranspiration (ETo) and plant coefficient (k), on average 60–150 mm. Pest management (insects, diseases, weeds) followed standard recommendations for apple orchards. Each year, standard winter pruning was applied to canopies of the trees. The first crop was harvested from the trees in 2005.

Treatments were applied every spring (end of April/beginning of May) each year between 2004 and 2010. Twenty-five liters of mulch per research plot was applied within a 60-cm-wide band placed along both sides of the planted trees (the bulk density of the applied mulches was not estimated). The chemical composition of the applied mulches and mycorrhizal substrate used in the experiment is presented in the Table 1a and 1b. Treatments were immediately incorporated into the soil to a depth of about 15 cm using forks. The mycorrhizal inoculum was applied at a rate of 20 mL per tree (2×10^7 infective propagules per tree) in a trench about 15 cm deep circling each tree and 20 cm from its trunk. In all of the treatment combinations, regular NPK fertilizers were applied, consisting of 60 kg N ha^{-1} (ammonium nitrate), 40 kg P ha^{-1} (granulated superphosphate) and 60 kg K_2O ha^{-1} (potassium sulfate fertilizer, containing 50% K_2O and 18% sulfur) prior to mulch application in the first year of the study. Mineral nutrients and the organic matter content of the mulches, including the mycorrhizal substrate, were analyzed at the accredited analytical laboratory of the Institute.

Table 1a. Macroelement and organic matter content of the organic mulches and mycorrhizal substrate (g kg^{-1} dry wt.) used in the experiment

Treatment	N	P	K	Mg	Ca	Organic matter (%)
Straw	1.17	0.13	0.22	0.12	0.55	65.9
Bark	0.41	0.04	0.14	0.07	0.94	77.8
Sawdust	0.16	0.05	0.21	0.10	0.19	25.3
Compost	1.20	0.06	0.13	0.07	0.30	15.7
Cow Manure	2.59	0.71	0.97	0.47	1.77	77.9
Peat Substrate	0.53	0.03	0.14	0.08	1.04	42.7
Mycorrhizal substrate	0.23	0.10	0.66	0.71	1.75	3.4

Measurements and Observations

The effects of different treatment combinations on the growth of Gold Milenium apple trees were evaluated in the years 2008–2010, whereas the yield and fruit characteristic were evaluated in 2008–2010, since, due to severe late spring frost in 2007, the yield of the trees in this year was drastically reduced. The macro- and microelement content in leaves and in soil were analyzed in 2008–2010. A standard of 40 leaves per sample were collected for analysis. Soil samples were taken from each treatment combination separately. The growth of the trees (the tree height in centimeters) was evaluated annually after completion of the growing season; trunk diameter (mm) was measured at 30 cm above soil level annually after completion of the growing season, Trunk cross sectional area (TCSA; m^2) was determined annually and the intensity of the green color of the leaves was measured three times during the growing season (mid-June, mid-July, mid-August) using SPAD/Minolta instrument (Minolta, Japan). Total yield (kg) was evaluated as the weight of all fruit picked from the trees at harvest, when fruits reached harvest maturity (°Brix, iodine test; refractometer Rudolph J-157, Rudolph Research Analytical, NJ); the total number of fruits was counted during harvest. The fruit size was evaluated as the fruit diameter. Fruits were divided into seven size categories separated by 0.5 cm, starting from 6.0 cm diameter up to 9.0+ cm. Fruit firmness (N kg^{-1}) was measured using a fruit pressure tester, type Instron 5542 (Instron Corp., Canton, MA), based on 10 fresh fruit samples collected from the middle and outer part of the canopy at the harvest time. Total soluble solids (%) was measured using a refractometer STEP Systems GmbH (Soil Equipment – Professional Systems, Germany) based on a fresh fruit sample of 10 apples, collected as described for fruit firmness measurement. Leaf samples were collected in late summer from each treatment combination separately from tree canopy at mid-height of the tree. Macro- and microelement content in leaf tissue and in soil was analyzed at the Chemical Pollution Research Laboratory of the Research Institute of Horticulture, Skierniewice, Poland. For the determination of available forms of phosphorus and potassium in a mineral soil, the Egner-Riehm (Domagała-Świątkiewicz 2005) method was used. The method consists in extracting phosphorus and potassium compounds from the soil by means of calcium lactate. For the determination of available forms of magnesium in a mineral soil, the Schachtschabel method was used (Domagała-Świątkiewicz 2005). For the determination of available forms of micro-elements in soil, the method of extraction in 1 M HCl was used (Gorlach et al. 1999). Determination of the mineral content in plant material was done using the process of mineralization (combustion). Wet combustion of vegetable matter consists of complete oxidation with liquid oxidants mixture: concentrated sulfuric acid (1 part), nitric acid (20 parts) and perchloric acid (5 parts) per 0.75 g of dry, milled plant material (Mercik 2002). For the determination of mineral content 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). Total nitrogen content in both soil and plant material was determined by the conductometric method using a TruSpec CNS analyzer. The same method was used to determine the amount of organic carbon in soil.

Table 1b. Microelement and dry matter content of the organic mulches and mycorrhizal substrate (mg kg^{-1} dry wt.) used in the experiment

Treatment	B	Cu	Fe	Mn	Zn	Dry weight (%)
Straw	15.2	10.5	3142	203	66.7	48.4
Bark	11.1	6.0	1998	180	18.8	61.3
Sawdust	17.5	19.5	6329	214	13.3	63.4
Compost	11.9	3.3	5286	168	<0.01	85.1
Cow Manure	21.9	22.5	2810	871	87.6	36.3
Peat Substrate	12.1	8.7	4429	109	<0.01	55.8
Mycorrhizal substrate	46.2	16.5	3818	207	31.6	98.6

Statistical Analysis

The collected data have a typical repeated-measures structure, in which multiple measurements were made on the same plot across time (3 yr). In simple notation, the basic linear mixed model (LMM) represents the trait value y_{ijk} for jth treatment T_J at kth year Y_k in the ith block as:

$$y_{ijk} = \beta_0 + \beta_1 T_j + \beta_2 Y_k + \beta_3 T_j \times Y_k + b_i + b_{ij} + \epsilon_{ijk}, \quad i = 1, \ldots, 4, j = 1, \ldots, 8, k = 1, \ldots, 3$$

The fixed intercept β_0 represents the expected value of trait y_{ijk}. The parameters β_1, β_2, β_3 represent the fixed effects of the T, Y and interaction $T \times Y$, respectively. The b_i denotes the block random effects, b_{ij} denotes the treatment within block random effects, and ϵ_{ijk} denotes errors. In the first step of parameters estimation (REML estimation method), the basic model has a compound symmetry structure: equal variances at all Y_k and equal covariance between measurements on the same plot at all pairs of Y_k. On the basis of information criteria (Akaike, Bayesian) and LRT test, first-order autoregressive covariance structure has been incorporated into the basic model. The model estimation was done by means of ‘‘nlme’’ package (v. 3.1-109) with function ‘‘lme’’ (Pinheiro and Bates 2000) in the R statistical environment (R Development Core Team 2013). The fixed parameter vectors and covariance matrix produced by ‘‘nlme’’ were used in ‘‘multcomp’’ package v. 1.2-17 (Bretz et al. 2011) with function ‘‘glht’’ (Tukey type procedure) to compare means for the significant effects of the model.

RESULTS

The mineral and organic contents of the mulches differed greatly, depending on the mulch. The cow manure was characterized as the richest mulch in terms of the N, P, K, Ca, Mg and organic matter content, while the straw mulch was poor. The microelement and dry matter content also differed depending on the mulch type. The mycorrhizal substrate contained high concentrations of B, Cu, Fe, Mn, Zn and the highest percentage of dry weight in comparison with the applied mulches.

The interactions of the tested factors with the years were not significant for most of the growth and yield characteristics studied. Therefore, the results obtained for each year of investigation are presented as mean values over the years (Table 2). Only tree height × year interaction was significant, with trees grown under sawdust mulch and bark being significantly shorter compared with trees from other treatments (Tables 2 and 3).

The cumulative effects of different mulches on growth and yield parameters were evaluated starting from 2004 and continued until 2010. Data collected from 2008 until 2010 are included here. The effect of different mulches on (i) growth vigor of trees is compiled in Table 3 and (ii) leaf tissue and soil analyses in Tables 5–8. Overall, tree height and trunk diameter were significantly different between applied mulches; however, no positive effects were observed compared with the control and, as mentioned earlier, trees mulched with sawdust and bark were shorter. No significant differences were observed in TCSA between mulches. Similarly, the overall yield, total number of fruits, fruit firmness and total soluble solids content were not significantly affected by the use of different mulches and/or mycorrhiza. For the above reasons these data are not presented. Independently of applied type of mulch, the total yield ranged from 26.3 kg to 32.1 kg per tree, the total number of fruits from 150 to 211 per tree, fruit firmness ranged from 5.26 to 5.76 N kg^{-1} and total soluble solids from 14.0 to 14.5%.

Collected fruits were grouped into seven different size categories (Table 4). No statistically significant differences were observed between sizes (diameter) among the fruit collected from trees grown under various mulches, with exception of slight significance in medium-sized fruits, categories 6.51–7 cm and 7.01–7.5 cm diameter, where sawdust contributed to the significant increase of the fruit diameter (Tables 2 and 4).

The type of mulch significantly affected the macroelement content (N, P, K, Mg, Ca) of Gold Milenium apple leaves (Table 5). Compared with the control treatment, all the applied mulches contributed to the significant increase in N content in the leaves. The highest N content was observed in leaves from trees grown on plots mulched with straw (2.58% dry wt.). It was followed by trees mulched with saw dust (2.56% dry wt.) and bark (2.54% dry wt.). Leaves of control trees (2.37% dry wt.) and trees grown on plots mulched with mycorrhizal substrate and peat moss substrate had the lowest N content, 2.44 and 2.45% dry wt., respectively (Table 5).

Leaves of trees grown on plots with sawdust and cow manure showed the highest P concentration (0.16% dry wt.), but not significant in comparison with the control. The lowest was observed in trees grown with mycorrhizal substrate (Table 5). All applied mulches significantly increased the K content in apple leaves, with the exception of peat substrate. In comparison with the control, mulching with cow manure increased K concentration in leaves to 1.73% dry wt., followed by straw, 1.57% dry wt., bark, saw dust and mycorrhizal substrate, 1.45% dry wt. (Table 5). No significant positive effects of any mulch were observed with regard to Mg and Ca concentration in leaves of trees as compared with the control. In fact, the leaves from trees grown on control plots had the highest concentration of these two elements, Mg at 0.22% and Ca at 1.64% dry wt., significantly higher than any other treatment combination with exception of peat substrate mulch (Table 5).

Table 6 shows the microelement content (B, Cu, Fe, Mn and Zn) in Gold Milenium leaves grown under different mulches. Mulches did not have a positive effect on B concentration in leaves, and the control trees

Table 2. Probability of *F* statistic from the linear mixed model for fixed effects

Trait	Treatment	Year	Treatment × Year
Yield	0.007	0.310	0.088
Total number of fruits	0.000	0.000	0.768
Number of fruits in size category: Fruit diameter (cm)			
>9.00	0.125	0.624	0.839
8.51–9.00	0.000	0.888	0.240
8.01–8.50	0.268	0.036	0.611
7.51–8.00	0.021	0.458	0.990
7.01–7.50	0.000	0.004	0.840
6.51–7.00	0.000	0.000	0.457
<6.50	0.245	0.726	0.924
Fruit/flesh firmness	0.211	0.000	0.511
Tree height[z]	0.003	0.000	0.002
Trunk diameter[z]	0.108	0.000	0.169
Fruit size category[z]	0.847	0.000	0.070
Green colour intensity[z]	0.425	0.000	0.361

[z]Traits analyzed in 2008–2010.

showed significantly higher amount of B in their leaves, 42.5 mg kg^{-1} dry wt. Compared with the control, straw mulch, compost, sawdust and cow manure significantly increased and improved the Cu concentration in leaves (Table 6). Similarly, straw mulch, sawdust, compost, peat substrate, cow manure and mycorrhizal substrate positively influenced Fe concentration in leaves. All mulches significantly increased Mn concentration and the Zn concentration was significantly higher in leaves of trees grown under the bark mulch and compost (Table 6). In comparison with the control, all other mulches lowered the Zn concentration in the leaves. Overall, sawdust could be considered as having a positive influence on microelement concentration in leaves, with the exception of Zn (Table 6).

The mulch treatment combinations had various effects on soil pH and N, P, K and Mg levels in soil, as well as on soil organic matter content (Table 7). Only straw, cow manure, compost and mycorrhizal substrate caused a significant increase in soil pH compared with the control, particularly compost (pH 6.1) and mycorrhizal substrate (pH 6.0). The bark mulch, peat substrate and sawdust decreased the soil pH below that of the control, to 4.3, 4.5, 4.7, respectively; the control pH was 5.0 (Table 7).

Table 3. The effects of different treatments on tree height, trunk diameter and trunk cross sectional area (TCSA) of Gold Milenium apple (Pomological Orchard, average 2008–2010)

Treatment	Tree height (cm)	Trunk diameter (mm)	TCSA (m^2)
Control	267*a*	50.1*ab*	0.0020*a*
Straw	266*a*	51.2*a*	0.0021*a*
Bark	247*b*	47.5*c*	0.0018*a*
Sawdust	253*b*	48.6*bc*	0.0019*a*
Compost	274*a*	50.0*ab*	0.0020*a*
Cow manure	275*a*	51.2*a*	0.0021*a*
Peat substrate	267*a*	51.1*a*	0.0020*a*
Mycorrhizal substrate	266*a*	48.3*bc*	0.0018*a*

a–c Means in columns with the same letter do not differ significantly according to Tukey's test (5%).

In comparison with the control, application of compost, cow manure and mycorrhizal substrate significantly increased soil N content to 15.3, 14.0 and 12 mg 100 g^{-1} soil, respectively. The highest P concentration was detected in the control soil (15.3 mg 100 g^{-1} soil). All applied treatments contributed to a significant decrease in P concentration in the soil, particularly mycorrhizal substrate and compost (5.0l and 6.3 mg 100 g^{-1} soil, respectively). Potassium and magnesium contents in the soil were significantly increased on plots mulched with straw, compost, cow manure and mycorrhizal substrate, as compared with the control. Organic matter content of soil in control plots was at a medium level of 2.7% and only compost, cow manure and mycorrhizal substrate caused its content to increase significantly above the control (Table 7).

The use of different mulches also had an effect on the microelement content of the soil (Table 8). The soil mulched with compost had significantly higher level of B, while the other mulches had no effect on this element. Only the mycorrhizal substrate caused a significant increase in Cu content, while the other mulches, i.e., sawdust, compost, cow manure and peat substrate, had no effect or even lowered its level (Table 8). Overall, the Fe content of soil in the research plots was high, and only sawdust and compost increased Fe levels compared with the control (Table 8); other mulches lowered the Fe levels in the soil. Mulching with sawdust, compost, cow manure and mycorrhizal substrate significantly increased Mn levels compared with the control. Similarly, the soil Zn content was high in the research plots, though mulching with compost increased it, while the other mulches reduced the Zn levels, particularly the peat substrate (Table 8).

Table 4. The effects of different treatments on the number and size of harvested Gold Milenium fruits (a number of fruits in different size categories) (Pomological Orchard, average 2008–2010)

	Number of fruit in size category (fruit diameter, cm)						
Treatment	>9.0	8.51–9.0	8.01–8.5	7.51–8.0	7.01–7.5	6.51–7.0	6.0–6.5
Control	4.7*a*	19.0*a*	43.8*a*	42.3*a*	31.4*bc*	10.5*a–c*	1.2*a*
Straw	3.6*a–c*	19.8*a*	56.3*a*	57.4*a*	32.3*bc*	8.7*bc*	2.3*a*
Bark	2.1*cd*	13.5*a*	43.4*a*	62.6*a*	44.0*ab*	14.1*ab*	2.4*a*
Sawdust	1.1*d*	12.4*a*	48.2*a*	62.8*a*	56.6*a*	16.2*a*	1.8*a*
Compost	4.2*ab*	17.0*a*	47.8*a*	50.8*a*	35.9*bc*	13.9*ab*	2.2*a*
Cow manure	4.7*a*	23.2*a*	55.2*a*	46.1*a*	19.6*c*	7.1*c*	1.7*a*
Peat substrate	5.4*a*	18.2*a*	42.3*a*	49.2*a*	33.2*bc*	8.1*bc*	2.1*a*
Mycorrhizal substrate	2.7*b–d*	17.3*a*	46.2*a*	51.3*a*	31.0*bc*	7.7*bc*	1.6*a*

a–d Means in columns with the same letter do not differ significantly according to Tukey's test (5%).

DISCUSSION

The data generated in this study are not fully consistent with previous findings concerning the beneficial effects of organic mulches on overall growth, yield and fruit quality parameters (Hogue and Neilsen 1987; Neilsen and Hogue 1992; Merwin et al. 1994; Linczar et al. 1997; Rubauskis et al. 2002, 2004; Nielsen et al. 2003). The mulches protect topsoil from moisture loss and overheating, control weeds, and positively modify soil pH, macro- and micro-element content and organic matter content. Yao et al. (2005) reported the highest N content in leaves of Empire apple cultivar (on M.9/MM.11 rootstock) from trees grown under deciduous tree bark mulch (maple, oak, walnut, European ash, linden) compared with grass mulch (*Festuca rubra*). The organic mulches used in our research, such as straw, sawdust and bark, also enhanced the N and K content of Gold Milenium leaves, as well as Cu, Fe (except sawdust) and Mn. Peat moss mulching had a positive effect only on Ca content in leaves, although it did not differ significantly from the control. Contrary to our findings, Hartley and Rahman (1998) observed that the use of compost positively affected the amount of B when mulches were used. None of the mulches used in our studies had a positive effect on B content in leaves. Lang et al. (2001) reported elevated amounts of Ca and K in leaves when trees were mulched with sawdust. Our studies did not confirm these results with Ca; compared with the control, the use of sawdust mulch significantly lowered Ca levels in leaves of Gold Milenium.

In our studies, the use of mycorrhizal substrate positively affected the amount of N, K, Fe, and Mn in Gold Milenium leaves, but did not affect P content, which is contradictory to the results published by Gnekow and Marschner (1989). In their studies increased amounts of P, Zn and Cu in leaves of *Malus pumila* var. *domestica* on M.26 rootstock were obtained when trees were inoculated with fungus species *Glomus macrocarpum*. Our results with Gold Milenium did not confirm their observations, which can be related to the differences in nutrient uptake and acquisition between apple genotypes. In the studies of Cavallazzi et al. (2007), mycorrhizal substrates with a number of different fungi (*Glomus etunicatum* SCT110, *Scutellospora pellucida* SCT111, *Acaulospora scrobiculata* SCT112, *Scutellospora heterogamia* SCT113) positively affected vegetative growth of *Malus prunifolia* trees grown on soil with low pH and high aluminum and magnesium contents. The absorption of nutrients: N, P, K, Ca, Zn, Cu, S, Na, Fe and Al was significantly higher in mycorrhizae-treated trees. With regards to N, K and Fe, the leaves of our trees mulched with micorrhizal substrate also contained significantly higher amounts of these three elements compared with the control. Levels

Table 5. The effects of different treatments on macroelement content in leaves of Gold Milenium apple (Pomological Orchard, average 2008–2010)

	Macroelements (% dry matter)				
Treatment	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium
Control	2.37*a*	0.15*ab*	1.35*b*	0.22*d*	1.64*f*
Straw	2.58*f*	0.15*ab*	1.57*e*	0.18*ab*	1.33*b*
Bark	2.54*d*	0.15*ab*	1.45*d*	0.20*c*	1.39*c*
Sawdust	2.56*e*	0.16*b*	1.45*d*	0.19*bc*	1.41*d*
Compost	2.50*c*	0.15*ab*	1.41*c*	0.18*ab*	1.28*a*
Cow manure	2.49*c*	0.16*b*	1.73*f*	0.17*a*	1.33*b*
Peat substrate	2.45*b*	0.15*ab*	1.30*a*	0.20*c*	1.65*f*
Mycorrhizal substrate	2.44*b*	0.14*a*	1.45*d*	0.20*c*	1.55*e*

a–f Means in columns with the same letter do not differ significantly according to Tukey's test (5%).

Table 6. The effects of different treatments on microelement content in leaves of Gold Milenium apple (Pomological Orchard, average 2008–2010)

	Microelements (mg kg^{-1} dry wt.)				
Treatment	Boron	Copper	Iron	Manganese	Zinc
Control	42.5*h*	5.2*b*	123.0*b*	47.5*a*	24.9*e*
Straw	37.1*a*	5.9*g*	152.0*g*	68.0*f*	22.7*b*
Bark	39.1*d*	5.2*b*	121.0*a*	73.0*g*	28.7*g*
Sawdust	40.8*f*	5.8*f*	143.0*f*	57.0*e*	24.9*e*
Compost	39.5*e*	5.6*e*	142.0*ef*	54.0*cd*	26.2*f*
Cow manure	41.2*g*	5.5*d*	140.0*cd*	55.0*d*	24.1*c*
Peat substrate	37.8*b*	4.9*a*	141.0*de*	53.0*c*	20.7*a*
Mycorrhizal substrate	38.1*c*	5.2*b*	139.0*c*	51.0*b*	24.6*d*

a–h Means in columns with the same letter do not differ significantly according to Tukey's test (5%).

of P, Ca, Cu and Zn, however, were lower than in leaves of the control trees. Also, in tissue-cultured MM.106 *Malus pumila* L. rootstocks, an increase in phosphorus uptake was observed when mulching with peat moss inoculated with *Glomus mosseae* (isolate BEG 12) was performed on field-planted trees (Schubert and Lubraco 2000).

Neilsen et al. (2003) studied the effects of mulching and the use of municipal solid waste on growth and yield of Spartan apples grown on M.9 (T337) rootstock. Both mulching and the use of municipal solid waste stimulated growth and fruiting of this variety compared with conventional fertilizers. Macro- and microelement contents of leaves were also elevated when the municipal solid waste was used. The amounts of Cu, Mn and Zn in leaves of trees mulched with solid waste are comparable with our results with trees mulched with cow manure and compost. Szwedo and Maszczyk (2000) reported higher phosphorus and potassium contents in soils mulched with straw. According to data from our studies, the most valuable mulches were compost, cow manure and mycorrhizal substrate, which influenced pH increase, phosphorus, potassium and magnesium content as well as organic matter content in topsoil.

The above results are in contrast to those of Linczar et al. (1997), who did not observe any influence of different mulches on the content of mineral components in apple orchard soil, or on their uptake by the plants. This might have been caused by the high fertility of soil on which the above studies were carried out. However, not all of the studied mulches have had a positive effect on soil characteristics and/or its mineral content. Compared with the control plots, a significant drop in soil pH was observed when peat moss and sawdust were used as mulches.

Although organic mulches positively influence the environment and improve the physical properties of soils, they are always associated with a higher cost, especially when used in cultivation of apples. A commercial apple grower must consider whether the use of organic mulches will provide a better crop and a higher income. Yao et al. (2009) showed that mulching increased vegetative growth and yield of apple trees *Malus* × *domestica* grown on M.9/MM.111. Our studies, however, did not show an improvement in parameters of Gold Milenium grown on dwarfing rootstock M.9. Tree height, trunk diameter and TCSA were not positively affected by the use of mulches. Although negative, significance was only visible for tree height (sawdust and compost) and trunk diameter (for sawdust, compost and micorrhizal substrate). Similar observations were made by Czynczyk et al. (2009), who tested linen fabric mulch and sawdust. These results also confirm the observations of Markuszewski and Kopytowski (2008a). Other authors, conversely, report

Table 7. The effects of different treatments on soil pH, content of P, K, Mg and organic matter in orchard soil with Gold Milenium apple trees (Pomological Orchard, average 2008–2010)

		Macroelements (mg 100 g^{-1} soil)				
Treatment	pH [KCl]	Nitrogen	Phosphorus	Potassium	Magnesium	Organic matter (%)
Control	5.0*d*	8.9*b*	15.3*f*	17.9*c*	6.3*d*	2.7*bc*
Straw	5.1*e*	8.1*a*	8.2*c–e*	20.4*d*	6.9*e*	2.6*ab*
Bark	4.3*a*	8.4*ab*	9.9*e*	16.4*ab*	4.8*b*	2.5*a*
Sawdust	4.7*c*	8.7*ab*	7.6*bc*	17.1*bc*	5.5*c*	2.6*ab*
Compost	6.1*h*	15.3*e*	6.3*ab*	32.0*e*	10.1*h*	3.6*e*
Cow manure	5.2*f*	14.0*d*	9.5*de*	45.7*f*	9.8*g*	3.0*d*
Peat substrate	4.5*b*	8.9*b*	7.8*b–d*	15.8*a*	4.6*a*	2.8*c*
Mycorrhizal substrate	6.0*g*	12.0*c*	5.0*a*	21.0*d*	7.9*f*	3.0*d*

a–h Means in columns with the same letter do not differ significantly according to Tukey's test (5%).

Table 8. The effects of different treatments on boron, copper, iron manganese and zinc content of orchard soil with Gold Milenium apple trees (Pomological Orchard, average 2008–2010)

	Microelements (mg kg^{-1} of soil)				
Kombinacja	Boron	Copper	Iron	Manganese	Zinc
Control	3.2*f*	13.5*de*	1084*f*	96.6*d*	11.8*f*
Straw	3.2*d*	13.6*e*	1031*c*	95.6*c*	11.3*d*
Bark	2.9*b*	13.4*d*	1069*e*	90.9*b*	8.1*b*
Sawdust	3.2*f*	12.2*a*	1144*g*	103.9*f*	8.1*b*
Compost	4.4*g*	12.6*b*	1190*h*	108.9*h*	20.8*g*
Cow manure	3.0*c*	12.5*b*	906*b*	102.8*e*	10.6*c*
Peat substrate	2.7*a*	13.0*c*	1055*d*	87.7*a*	7.1*a*
Mycorrhizal substrate	3.2*e*	14.2*f*	840*a*	105.0*g*	11.5*e*

a–h Means in columns with the same letter do not differ significantly according to Tukey's test (5%).

the highest TCSA under bark mulch from deciduous trees (Yao et al. 2005). Treder et al. (2004) observed the highest trunk diameter in trees that were irrigated and mulched with organic mulches. Mika and Krzewińska (1992), when studying the effects of mulches on the growth of apple trees, showed better tree vigor under bark and sawdust mulches than under plastic and fabric coverings. The better tree vigor under the above mulches was observed in new orchards with young trees (Lipecki and Szwedo 1994; Mika et al. 1998; Szewczuk and Gudarowska 2004b). Treder et al. (2004) reported that soils under organic mulches retained a higher humidity compared with controls without mulching. Temperature fluctuations were reduced and significantly fewer weeds were observed. Similar observations were made by Kawecki et al. (1999). The best growth in 12-yr old apple trees cvs. Szampion and Gloster grown on rootstocks M.26, MM.106 and Antonowka seedling with B9 insert was observed on plots mulched with black fabric compared with a number of different mulches used (Markuszewski and Kopytowski 2008a, b). The above data were collected over a 3-yr period. However, there were no significant effects in yield of these trees, probably due to the overall age of trees and well-established/developed root system.

The results of our research confirm that organic mulches do not necessarily positively affect growth and yield of apple trees. Only slight differences were observed in the number of fruits per tree, which contradicts the findings of Rubauskis et al. (2002), that mulching increases the number of fruits. Szewczuk and Gudarowska (2004b) found that the highest fruit yield was observed from trees mulched with pine bark, and the lowest from trees with no ground cover. The pine bark mulch also increased the number of fruit per tree, and these fruits were more firm compared with other treatment combinations. Generally, our data do not show significant effects of any of the mulches on fruit firmness. Mulches did not have significant effects on total soluble solids content in fruits of Gold Milenium.

A number of reports state that mulching increases the number and the size of the fruit (Szewczuk and Sosna 2001; Rubauskis et al. 2002). Hartley and Rahman (1998) reported the highest yield from apple trees cv. Fiesta grown without ground cover (herbicide); the lowest from trees mulched with *Triforium repens* and *Festuca longifolia*. Trees mulched with grass and compost produced the lowest number of fruits. Overall, we did not observe significant effects of mulching on the number and the size of fruits in class categories. In the category with fruit diameter of 7.01–7.5 cm, trees mulched with sawdust produced significantly more fruits compared with the control. Although the majority of fruits 7.51–8.0 cm in size were collected from trees mulched with bark and sawdust, the differences were not significant.

Bielińska et al. (2004) did not observe significant differences in yield of fruit from trees mulched with various materials and controls (either herbicide or mechanical cultivation). Our studies did not provide clear evidence that mulching of Gold Milenium trees with various substrates grown under experimental conditions would positively influence the yield and number of fruit per tree, or the mineral content of soil and leaf tissues. The lack of strong, positive effects of the organic mulches on growth and yield of Gold Milenium apple, does not eliminate them from possible use in commercial production of apples. This might be attributed to the soil in our research plots, which was already rich in mineral nutrients. The mulches would definitely have a significant, positive effect on sandy soils, poor in nutrients, affected by replant disorder or on non-irrigated plots. Moreover, prior to establishment of the research plots, N, P, K fertilizer program was applied to the whole field.

CONCLUSIONS

1. Organic mulches differed in their effects on soil pH, macro- and micro-element content in soil and effects on leaf tissue nutrient levels.
2. In the studies reported here, mulches did not affect yield, fruit firmness, fruit size, total soluble solids content, tree growth and leaf color of Gold Milenium apple.

3. Lack of strong, positive effects of the organic mulches on the above traits of Gold Milenium apple in our studies does not eliminate them from possible use in commercial production of apples. The mulches could have significantly positive effects if the orchard(s) is situated on sandy soils, poor in nutrients or soils affected by replant disorder. Non-irrigated orchards would definitely benefit from mulching applications.

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