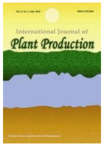

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Effect of living mulches and conventional methods of weed control on weed occurrence and nutrient uptake in potato

M. Kołodziejczyk[a,*], J. Antonkiewicz[b], B. Kulig[a]

[a]*Institute of Plant Production, University of Agriculture in Krakow, Poland.*
[b]*Department of Agricultural and Environmental Chemistry, University of Agriculture in Krakow, Poland.*
*Corresponding author. E-mail: m.kolodziejczyk@ur.krakow.pl

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Abstract

The aim of the study was to determine the biomass, abundance and species composition of weeds, as well as macroelement uptake in potato weeded using mechanical, mechanical–chemical and mechanical control combined with the sowing of living mulches of white mustard, common vetch, Persian clover and tansy phacelia. Abundance and biomass of the weeds was the most effectively limited by the mechanical treatments. The effectiveness of mechanical treatments in weed biomass reduction was 2.5–fold lower. The mechanical treatments more effectively limited the number of monocotyledonous than dicotyledonous weeds. Living mulches increased the efficiency of mechanical weeding by affecting both weed biomass development and weeds abundance. The living mulch that most effectively limited the growth of weed biomass was white mustard, while vetch was effective to reduce of the number of monocotyledonous weed and Persian clover for dicotyledonous weeds. The most frequently occurring weed species were *Galinsoga parviflora*, *Chenopodium album* and *Echinochloa crus-galli*. The share of N accumulated in the biomass of neighboring plants constituted from 5% to 34%, P from 6% to 38%, K from 5% to 36%, Ca from 27% to 190% and Mg from 12% to 55% of the amount of these nutrients absorbed by potato plants. Mechanical treatments plus living mulches, especially Persian clover, may be useful in organic cropping systems due to their effectiveness at reducing weed abundance and biomass and relatively low nutrient uptake compared with weeds.

Keywords: Weed biomass and abundance; Floristic composition; N, P, K, Ca and Mg uptake.

Introduction

Weed control is an important factor determining the profitability of potato, as well as any other crop production, since among all plant pests, weeds result in the highest reduction in potential yield (Fernandez-Quintanilla et al., 2008). Tuber crop losses in potato cultivation caused by weed infestation are estimated at 20-80% (Jaiswal and Lal, 1996; Hashim, 2003). The effect of weed infestation on crops plants yield depends on the abundance and biomass of weeds and their species composition. The most abundant weed species observed on potato fields in Poland include: *Chenopodium album*, *Stellaria media*, *Echinochloa crus-galli*, *Veronica persica*, *Amaranthus retroflexus*, *Matricaria inodora*, *Capsella bursa-pastoris*, *Poa annua* and *Viola tricolor* (Sawicka et al., 2005). These species include nitrophilous weeds, which grow rapidly and accumulate significant amounts of nutrients from the soil. The studies by Andreasen et al. (2006) shows that the amount of macroelements taken up weeds may be similar, or even higher, than the amounts absorbed by cultivated plants. Control of weed infestation in potato is usually carried out using mechanical and chemical treatments. Despite the use of herbicides to effectively control a broad spectrum of weeds for more than seventy years, new problems have arisen. These include for example the occurrence of new weed species and biotypes resistant to herbicides in the crops (Heap, 2015). Activities aimed at sustainable development favor the introduction of alternative methods of weed control. One of them is cultivation of ground-cover plants, including living mulches, that have an ability to suppress weeds and positively affect a range of soil properties (Hartwig and Ammon, 2002). Living mulches grow in association with the crop and can compete with it for light, water and nutrients, like weeds, which results in yield reduction (Jędrszczyk and Poniedziałek, 2007). It seems, however, to be generally possible to obtain similar or even higher crop yields are possible with such systems than in conventional cultivation (Adamczewska-Sowińska et al., 2009).

The aim of this study was to determine the effects of living mulches and mechanical and mechanical–chemical weed control on the abundance, species composition and fresh weight of weeds, as well as macroelement uptake by potato and accompanying it plants.

Material and Methods

Field experimental design

Field research was carried out in 2009-2011 at the Experimental Station of the Agricultural University in Krakow (50º 07′ N and 20º 05′ E). A two-factor field experiment was established in a randomized block design with 4 replications. The experimental factors were cultivar and method of weed control. Two potato cultivars were assessed: early ‘Vineta’ and medium early ‘Tajfun’. The methods of weed control included: the control – without weeding (C), mechanical treatments (M), mechanical –chemical treatments (MCH) and mechanical treatments combined with sowing living mulches of white mustard (*Sinapis alba*), (MSA), common vetch (*Vicia sativa*), – (MVS), Persian clover (*Trifolium resupinatum*), (MTR) and tansy phacelia (*Phacelia tanacetifolia*), (MPT). A detailed description of treatments limiting potato weed infestation is presented in Table 1. The seeds of living mulches were sown manually in potato inter-rows (in BBCH 31-32 phase) in the following amounts: phacelia and clover 15 kg ha^{-1}, mustard 20 kg ha^{-1}, vetch 120 kg ha^{-1}. The forecrops for potato were winter wheat and peas. Only mineral fertilization in amount of 150 kg N, 60 kg P_2O_5 and 180 kg K_2O ha^{-1} was used in potato cultivation. A detailed description of other agrotechnical elements are presented in the publication by Kołodziejczyk (2015).

Table 1. Description of treatments limiting potato weed infestation.

Weed control system		Treatments	
		from planting to emergence	after emergence
C	control - without weeding	–	–
M	mechanical treatments	3 times hilling combined with harrowing	2 times hilling
MCH	mechanical-chemical treatments	3 times hilling combined with harrowing, just before emergence the spraying a mixture of clomazon (96 g a.i. ha^{-1}) and linuron (500 g a.i. ha^{-1})	–
	mechanical treatments + living mulch:	3 times hilling combined with harrowing	hilling, undersowing of living mulches, hilling
MSA	white mustard		
MVS	common vetch		
MTR	Persian clover		
MPT	tansy phacelia		

Soil and meteorological conditions

The experiment was located on Luvic Chernozem developed from loess. The arable soil layer (0-35 cm) was characterized by the following granulometric composition: sand 120-130 g kg^{-1}; silt 533-540 g kg^{-1}; clay 337-345 g kg^{-1} and chemical properties: slightly acidic reaction (pH_{KCl} 5.8-6.1); total nitrogen content 1.40-1.68 g kg^{-1}; C/N 7.8-9.0; content of P 54.1-60.5 mg kg^{-1}; K 128.5-153.8 mg kg^{-1}; Mg 116.0-122.0 mg kg^{-1}; Ca 950.8-988.5 mg kg^{-1}.

The characteristics of the precipitation–thermal conditions during potato vegetation are based on data obtained from automatic meteorological station Hardi Metpole located within the experimental field (Table 2). In 2009 and 2011, the total precipitation from April to September was approximate to the multi–year average. However, the effect of uneven distribution in particular periods on vegetation was noted. Rainfall deficiency occurred in April 2009 and June 2011. Excessive rainfall amounts were noted in May and June 2009 and in April and July 2011. Different moisture conditions were observed in 2010, that was characterized by precipitation considerably higher than the multi–year average throughout the whole period of potato cultivation.

Table 2. Meteorological conditions during potato vegetation in the years 2009-2011.

Year	Month						Mean/Sum
	IV	V	VI	VII	VIII	IX	
	temperature (°C)						
2009	11.4	13.6	16.2	20.2	18.8	15.4	15.9
2010	9.1	13.1	17.6	20.8	18.7	12.2	15.3
2011	10.2	13.7	17.8	17.6	19.2	15.8	15.6
Long–term period 1981-2010	8.6	13.7	16.5	18.4	18.0	13.3	14.8
	rainfalls (mm)						
2009	0 (-57)	100 (+46)	163 (+95)	72 (-5)	67	40	442
2010	40 (-8)	303 (+251)	135 (+60)	105 (+25)	128	132	843
2011	78 (+26)	61 (+7)	44 (-31)	195 (+128)	70	8	456
Long–term period 1981-2010	48	79	89	85	77	65	443

(+) excess and (–) deficit of rainfall compared to the water needs of potato by Klatt (citation for Nyc. 2006).

Assessment of weed infestation and uptake of macronutrients

Weed density and biomass at potato maturity (BBCH 91-93) were determined to evaluate weed infestation. All non-crop species (weeds and living mulches) was taken from an area of 1 m^2 in two randomly selected sites in each. These samples were used to determine the fresh mass of weeds and living mulches, number of mono- and dicotyledonous weeds, as well as their botanical composition. N content was determined in the dry mass of weeds, living mulches and potato plants using the Kjeldahl method, P using colorimetric method, while K, Ca and Mg using atomic spectrophotometry on ICP-OES spectrometer (Inductively Coupled Plasma – Optical Emission Spectrometers) after prior digestion of dry plant material. The range of macroelements uptake was determined based on the content of individual macroelements and the amount of dry mass produced by potato and neighboring plants. At the plots where legume living mulch were sown (Persian clover, common vetch), the amount of N uptake by plants was presented based on that component uptake only on uptake by the weeds.

Statistical evaluation

The results were subjected to statistical evaluation using analysis of variance (ANOVA) in Statistica 10.0 software. Tukey's Honestly Significant Difference (HSD) test was used for mean separation at a significance level of $P<0.05$.

Results and Discussion

Fresh biomass of weeds and living mulches

Biomass of weeds and living mulches significantly dependent on the method of weeding, potato cultivar, weather conditions during the growing season and the interaction of these factors (Table 3). Fresh mass of the weeds in the control (C), was 488 g m^{-2} (Figure 1). Mechanical–chemical treatments (MCH) reduced by 81% the biomass of weeds, while mechanical treatments (M) only by 33%. The effectiveness of the methods combining mechanical weeding with living mulches (MSA, MVS, MTR, MPT) ranged from 46% to 57%. The living mulch that was most effective at limiting weed growth was white mustard, while the least competitive against weeds was tansy phacelia. In the study conducted by Jędrszczyk et al. (2005), the most effective at reducing weed biomass in white cabbage was living mulch composed of white clover (96%) and the least effective was common vetch (37%). High potential possibilities of weed biomass reduction by living mulches plants were also confirmed by Hessler (2013). According to these authors, the amount of weeds biomass is reduced in proportion to the increase in living mulches biomass. Such a relationship was not observed in the current study, probably because of differences in growth habit and density of living mulches. The mean biomass of common vetch and tansy phacelia plants was lower by 42% than weed biomass, Persian clover higher by 28%, while white mustard biomass was equal to weed biomass (Figures 1 and 2).

Table 3. Analysis of variance results for the biomass and density of weeds and living mulches, nutrient uptake by potato and accompanying plants.

Variance source	Fresh biomass		Density			Nutrients uptake									
			weeds		living mulch	potato					weeds and living mulches				
	weeds	living mulch	monocotyledonous	dicotyledonous		N	P	K	Ca	Mg	N	P	K	Ca	Mg
Year (Y)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Cultivar (C)	***	***	***	***	***	***	***	***	***		***	***	***	***	***
Weeding (W)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Y×C	***	***			***	***	***		*	***	***	***	***	***	***
Y×W	***	***	***		***	***	***	***	***	***	***	***	***	***	***
C×W	***	***	**	*	***	*		**			***	***	***	***	***
Y×C×W	***	**		*	**		***	***	***	***	***	***	***	***	***

Significant effects at *P*<0.05 (*), *P*<0.01 (**) and *P*<0.001 (***). Blank values indicate no significant (P>0.05).

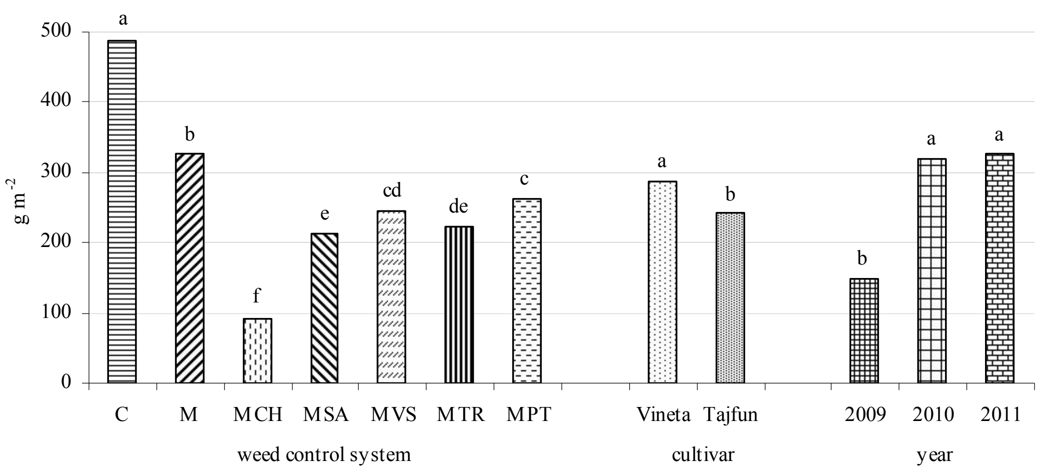

Figure 1. Fresh biomass of weeds depending on the method of weeding, potato cultivar and year of the study. The means that share the same letters are not significantly different at *P*<0.05.

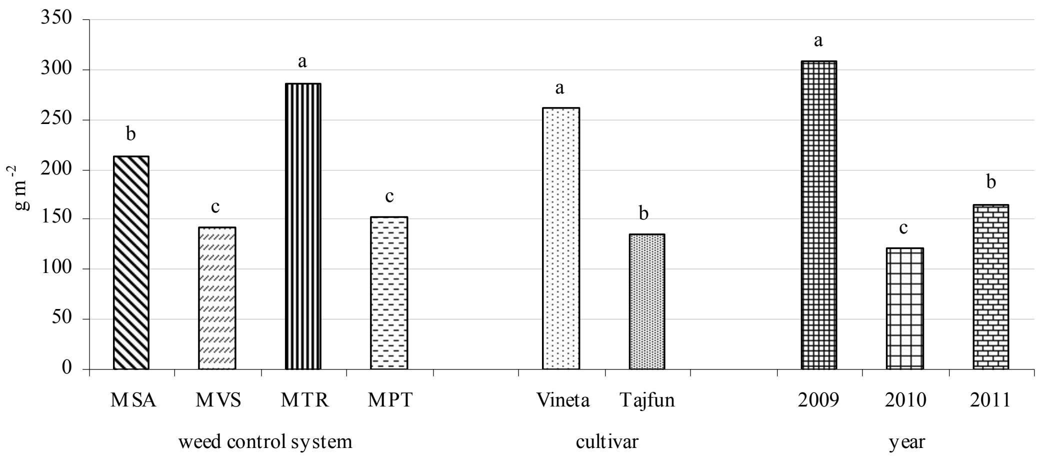

Figure 2. Fresh biomass of living mulches depending on the method of weeding, potato cultivar and year of the study. The means that share the same letters are not significantly different at *P*<0.05.

Morphological and physiological features of the plants of the examined potato cultivars significantly affected the fresh mass and number of weeds and living mulches (Table 4). Monocotyledonous and dicotyledonous weeds and living mulches found better conditions for development in the canopy of early–ripening ‘Vineta’ cultivar with foliar habit, susceptible to *Phytophthora infestans* and early terminating the vegetation, than in the canopy of medium early ripening ‘Tajfun’ cultivar with stem habit of the plants and resistant to late blight. Higher weed infestation in the early–ripening cultivar could also result from a secondary infestation, which is determined by the length of vegetation season and above–ground mass of potato plants (Sawicka et al., 2005).

Table 4. Density of weeds and living mulch plants (number per m^2) depending on the method of weeding, potato cultivar and year of the study.

Experimental factors	Density of weeds						Density of living mulches	
	monocotyledonous		dicotyledonous		*Equisetum arvense*			
Weed control system								
C[*]	13.6	a[**]	54.5	a	0.7	ab		
M	6.9	b	33.2	b	1.1	a		
MCH	1.9	d	8.3	e	0.0	b		
MSA	5.6	bc	24.5	cd	0.0	b	28.5	a
MVS	4.6	c	26.1	cd	1.0	ab	20.8	b
MTR	4.8	c	22.7	d	0.0	b	34.8	a
MPT	4.9	c	27.5	c	0.8	ab	16.9	b
Cultivar								
Vineta	6.6	a	30.1	a	0.4	a	33.4	a
Tajfun	5.4	b	26.1	b	0.6	a	17.1	b
Year								
2009	3.5	c	21.3	b	0.4	b	39.0	a
2010	8.1	a	31.9	a	0.0	b	15.6	c
2011	6.5	b	31.1	a	1.1	a	21.2	b

[*] see Table 1. [**] values followed by the same letter within columns are not significantly different at $P = 0.05$.

Number and species composition of the weeds

The presence of five monocotyledonous weed species, 21 dicotyledonous weeds species and *Equisetum arvense* was documented in this study within the potato canopy (Table 5). The group of monocotyledonous species was dominated by *Echinochloa crus-galli* and *Agropyron repens* and the others occurred sporadically. Among the dicotyledonous weed species, the most abundant were *Galinsoga parviflora*, *Chenopodium album*, *Polygonum nodosum*, *Galium aparine*, *Stellaria media*, *Viola arvensis*, *Capsella bursa-pastoris*, *Amaranthus retroflexus*, *Matricaria inodora* and *Veronica persica*. The density of other dicotyledonous weed species was lower and was below 1 plant per m^2. The greatest diversity of weeds species was found in the control treatment (C) and where mechanical treatments of weeds control were applied (M).

Weed density was significantly affected by the method of weed infestation control. Mechanical–chemical treatments (MCH) reduced the population density of monocotyledonous weeds by 86% and dicotyledonous weeds by 85% (Table 4). The mechanical method (M) more effectively reduced the density of monocotyledonous weeds (49%) compared to dicotyledonous ones (39%). Similar relationship was found in the combination of mechanical treatments with living mulches. The number of monocotyledonous weeds was most effectively limited by common vetch (MVS), while dicotyledonous weeds were mainly reduces by Persian clover (MTR), 66% and 58%, respectively. The lowest biomass and number of weeds was found in 2009, which was probably due to the lack of rainfall in April and high effectiveness of mechanical treatments limiting weeds growth (Figure 1 and Table 4). Lack of competition from weeds and adequate moisture conditions (from May to September 2009) probably favored the development of living mulches such that living mulch biomass was 87 to 152% higher than in the other years of research (Figure 2). High precipitation in spring 2010, as well as in 2011 hampered mechanical weed management activities and reduced its effectiveness. As a result, in 2010 and 2011 was greater biomass and abundance of weeds than in 2009. According to Sawicka et al. (2005), weather conditions affect both the efficacy of weed management and thus the number and biomass of weeds, as well as their species composition.

Table 5. Species composition of weeds in potato (number per m^2) depending on the method of weeding (mean for potato cultivar and year of the study).

Species composition	Weed control system							Mean
	C*	M	MCH	MSA	MVS	MTR	MPT	
Agropyron repens	1.8	1.9	1.0	1.2	1.3	1.0	1.3	1,3
Amaranthus retroflexus	3.5	1.5	0.6	1.0	1.1	0.6	1.1	1,3
Apera spica-venti	-	-	-	-	-	-	0.1	0,0
Capsella bursa-pastoris	2.8	1.8	0.5	1.1	1.1	1.7	1.8	1,5
Chenopodium album	8.1	5.2	1.5	3.6	4.5	3.8	4.2	4,4
Cirsium arvense	0.4	0.4	0.4	0.2	0.5	0.2	1.4	0,5
Echinochloa crus-galli	9.4	4.0	0.8	3.9	2.7	3.5	2.7	3,9
Equisetum arvense	0.7	1.1	-	-	1.0	-	0.8	0,5
Fallopia convolvulus	3.0	1.9	0.2	1.4	1.8	1.6	1.1	1,6
Galinsoga parviflora	9.3	5.5	1.6	5.0	4.4	4.2	5.1	5,0
Galium aparine	4.2	2.3	-	1.9	1.8	1.8	2.2	2,0
Geranium pusillum	1.6	0.9	-	0.9	0.3	0.8	0.6	0,7
Lamium purpureum	1.7	1.1	-	0.8	0.2	0.3	1.2	0,7
Matricaria inodora	1.8	1.0	0.5	1.4	0.9	1.1	1.8	1,2
Plantago lanceolata	0.7	0.2	-	0.3	-	-	-	0,2
Poa annua	1.3	0.2	0.2	0.3	0.3	0.3	0.2	0,4
Polygonum nodosum	3.9	3.1	0.6	1.9	2.3	2.0	1.9	2,3
Senecio vulgaris	1.2	1.1	0.4	0.5	0.7	0.6	0.3	0,7
Setaria glauca	1.1	0.8	-	0.2	0.3	-	0.6	0,4
Sisymbrium officinale	0.8	-	-	0.2	0.2	-	-	0,2
Sonchus oleraceus	0.7	0.3	-	0.1	0.5	0.4	0.2	0,3
Stachys palustris	1.4	1.5	0.6	0.1	0.8	0.3	0.4	0,7
Stellaria media	4.1	1.9	0.2	1.6	1.4	1.5	1.8	1,8
Thlaspi arvense	-	0.8	-	-	-	-	-	0,1
Tussilago farfara	0.4	0.2	-	-	-	-	-	0,1
Veronica persica	2.3	0.6	1.1	1.2	1.9	0.9	0.7	1,2
Viola arvensis	2.9	2.0	0.3	1.3	1.8	1.0	1.8	1,6
Number of weeds (m^2)	68.8	41.3	10.5	30.1	31.8	27.5	33.1	
Number of species	25	25	16	23	23	20	23	27

* see Table 1.

Macroelement uptake

Potato plants accumulated the most nitrogen when weeds were controlled using MCH and the least with the control treatment (Table 6). The amount of nitrogen taken up by weeds and living mulches (mustard and phacelia) ranged from 8 to 33 kg N ha^{-1}. A N–uptake ranging from 10.9 to 21.3 kg N ha^{-1}, on plots treated with herbicides and 80.6 kg N ha^{-1} on the control was demonstrated by Singh and Lal (1994). The superior ability of weeds to compete for nitrogen with potato plants was also evidenced by the results of the study conducted by Pramanick et al. (2012). The methods of weed control evaluated in the study also influenced the quantity of other macroelements taken up by potato plants, weeds and living mulches. The highest amounts of P, K, Ca and Mg were absorbed by potato plants witch MCH and the lowest on the control (C). The positive effect of weed control on the size of macroelements uptake by potato plants was also reported by Banga et al. (2002) as well Zarzecka and Gugała (2010). Our results demonstrated that the amount of phosphorus accumulated in biomass of weeds and living mulches accounted for 6% to 38% of the amount of that component absorbed by potato plants, for potassium it was from 5% to 36%, calcium from 27% to 190% and magnesium from 12% to 55%. The highest uptake of these macroelements by the weeds was found on the control (C) and the lowest after an application of mechanical–chemical weed control treatments (MCH). Large amounts of P and K were also absorbed by weeds and living mulch composed of Persian clover (MTR), while Ca and Mg by weeds in the treatments where weed control was performed using only mechanical treatments (M). Pramanick et al. (2012) demonstrated that the share of phosphorus accumulated in weeds biomass, depending on the method of weeds control, constitutes from 38% to 147% and potassium from 67% to 370% of these components amount absorbed by potato plants. The amount of macroelements uptake by the weeds seems to depend on their biomass and species composition. To the most relevant competitors in nutrient uptake include *Chenopodium album* and *Echinochloa crus–galli* (Gruczek, 2004). These species, as well as *Galinsoga parviflora,* dominated quantitatively also in our study, especially with the control (C) and the mechanical weed control treatments were applied (M).

The range of the macroelements uptake by potatoes significantly depended also on their cultivar characteristics (Table 6). 'Tajfun' potato plants accumulated more N, P, K and Ca than 'Vineta' plants. The shorter vegetative growth period of 'Vineta' and susceptibility to *Phytophthora infestans* favored in turn the development of weeds and living mulches and consequently higher macroelements uptake by these plants.

Weather conditions in 2009 and 2011, characterized by significantly lower precipitation compared to 2010, favored macroelements accumulation in potato plant biomass. A different relationship was found in the case of macroelements uptake by weeds and living mulches. These plants growing in association with the potato crop accumulated the highest amounts of macroelements in 2010 and 2011, when weather conditions favored the development of weeds and were concurrently less favorable for living mulches development. The lowest macroelements uptake by the neighboring plants was found in 2009, when living mulches were more dominant than. This provides evidence that the weeds may be more competitive for nutrients than both the potato plants and living mulches.

Table 6. Range of macroelements uptake with biomass of potato and neighboring plants (kg ha^{-1}) depending on the method of weeding, potato cultivar and year of the study.

Experimental factors	N		P		K		Ca		Mg	
	p**	w+lm***	p	w+lm	p	w+lm	p	w+lm	p	w+lm
Weed control system										
C*	97^{e}	33^{a}	21^{d}	8^{a}	140^{e}	50^{a}	20^{c}	38^{a}	11^{c}	6^{a}
M	132^{bcd}	21^{c}	29^{bc}	4^{c}	197^{bc}	29^{c}	27^{b}	28^{b}	15^{b}	5^{b}
MCH	146^{a}	8^{e}	35^{a}	2^{d}	226^{a}	11^{e}	30^{a}	8^{e}	17^{a}	2^{e}
MSA	127^{d}	30^{ab}	27^{c}	5^{bc}	179^{d}	25^{d}	26^{b}	19^{d}	14^{b}	3^{d}
MVS	135^{bc}	17^{d}	29^{bc}	5^{bc}	194^{bc}	32^{bc}	27^{b}	23^{c}	15^{b}	4^{c}
MTR	139^{b}	16^{d}	30^{b}	6^{b}	204^{b}	35^{b}	27^{b}	23^{c}	15^{b}	4^{c}
MPT	131^{cd}	27^{b}	27^{c}	4^{c}	187^{c}	25^{d}	25^{b}	20^{cd}	14^{b}	3^{d}
Cultivar										
Vineta	122^{b}	25^{a}	26^{b}	6^{a}	178^{b}	34^{a}	24^{b}	24^{a}	14^{a}	4^{a}
Tajfun	137^{a}	18^{b}	31^{a}	4^{b}	201^{a}	25^{b}	27^{a}	21^{b}	15^{a}	3^{b}
Year										
2009	148^{b}	18^{b}	32^{a}	3^{b}	230^{a}	18^{c}	29^{a}	13^{b}	16^{a}	2^{c}
2010	88^{c}	24^{a}	20^{b}	6^{a}	133^{c}	32^{b}	22^{c}	27^{a}	11^{b}	5^{a}
2011	153^{a}	23^{a}	33^{a}	6^{a}	206^{b}	38^{a}	26^{b}	28^{a}	17^{a}	4^{b}

* see Table 1, ** potatoes, *** weeds and living mulches.

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