INFLUENCE OF THERMAL REGIME OF SOIL ON THE SULFUR (S) AND SELENIUM (Se) CONCENTRATION IN POTATO PLANTS

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ABSTRACT

Three consecutive years of field experiments were carried out to investigate the effect of different root temperatures, induced by the application of mulches on the concentration of sulfur (S) forms (organic-S, total-S and $SO^2{}_4$) and Se in different organs of potato plants (roots, tubers, stems and leaves). Four different plastic covers were used (T1: transparent polyethylene; T2: white polyethylene; T3: white and black coextruded polyethylene, and T4: black polyethylene), using uncovered soil as control (T0). The different treatments had a significant effect on mean root temperatures (T0=16°C, T1=20°C, T2=23°C, T3=27°C and T4=30°C) and induced a significantly different response in the S forms and Se concentration, showing the T3 treatment (27°C) the greatest concentration of total S and organic S in the stems and leaflets. The Se reached higher levels in the roots and tubers in T3. With regard to possibilities in phytoremediation, it is necessary to control the thermal regime of the soil to optimize the accumulation of elements.

INTRODUCTION

Root zone temperature strongly influences the growth and uptake of nutrients.[1] The potato plants require optimal temperatures in the root zone for maximum growth and yield[2] and one of the techniques used to increase root zone temperature is the application of polyethylene covers (mulch) of different colours and characteristics, which generate a favourable microenvironment (higher temperatures) in the root zone.[3]

In its reduced form, sulfur (S) has an important function in growth and regulation of plant development,[4] because of its essential role in the synthesis of amino acids, proteins and some secondary metabolites.[5]

While selenium (Se) is not an essential plant nutrient,[6] and exerts toxic effects in plants principally by interfering with sulfur (S) metabolism,[7] this elements is essential for maintaining mammalian health. Benefits attributed to proper Se nutrition range from immune system enhancement to cancer suppression.[8] However, when consumed in high quantities, Se can accumulate in tissues and become toxic.[9]

The current problem of the pollution of agricultural soils and waters causes problems for human health which can be partially solved with the application of technology of phytoremediation.[10] The objective of this technology is to eliminate contaminants for the environment by using plants.[11]

The aim of the present work was to evaluate the effect of the different root zone temperatures generated by the application of mulches on S status and Se concentrations using field grown potato plants. The aim of the present work was to evaluate the effect of the different root zone temperatures generated by the application of mulches on S status and Se concentrations using field grown potato plants.

MATERIALS AND METHODS

Crop Design

The experiment was conducted for three consecutive years (1993–1995) in the field (Granada, Spain), using Solanum tuberosum L. var. Spunta, planted at the beginning of March and the crop cycle was about 4 months. The climate was semiarid and the area intensively used for agriculture. The soil used showed the following characteristics: sand 45.3%, silt 43.2%, and clay 11.2%, pH (H_2O 1:2.5) 8.6; electrical conductivity 1.10dSm^{-1}, $CaCO_3$ 11.2%; total N (0.1%); P_2O_5 (58μgg^{-1}); K_2O (115μgg^{-1}); DTPA+TEA+$CaCl_2$ (pH 7.3) extractable Se 24μgkg^{-1}. The characteristics of the irrigation water were: pH 7.6; E.C. 1.05dSm^{-1}; Cl 58mgL^{-1}; Na^+ 25mgL^{-1}; K^+ 4mgL^{-1}; H_2CO_3 369mgL^{-1}, Se 1μgL^{-1}, $SO^{-2}{}_4$ 90mgL^{-1}.

The experimental design was a factorial arrangement in a randomized complete block with 5 treatments replicated 4 times (20 plots). Each plot occupied an area of 78.4m^{-2}, with a planting density of 4.2 plants m^{-2}. Plants were spaced 30cm apart, with 80cm between rows. The soil temperature was measured at the 15-cm in depth, using probes (107 type) from Campbell Scientific TM. Root zone temperature was measured (6 measurements at 4-h intervals) every 3 days of the crop cycle.

The different treatments consisted of covering the soil surface of each plot with plastic mulches (polyethylene sheets), making a tight seal with the soil: transparent polyethylene (25mm in thickness, T1), white polyethylene (25mm in thickness, T2), coextruded black and white polyethylene (50mm in thickness, T3), and black polyethylene (25mm in thickness, T4). Finally, no plastic was applied in the control treatment (T0).

The fertilization used was the same as is habitually applied by farmers in the zone. In the month of February in all three years, N (NH_4NO_3) and P and K (K_2HPO_4) were applied (27gm^{-2}). Afterwards, at the end of the month of April, 25gm^{-2} of NH_4NO_3 were applied. Fertigation was complemented with the following micronutrients: Fe: 0.5mgL^{-1}; B: 0.1mgL^{-1}; Mn: 0.1mgL^{-1}; Zn: 0.075mgL^{-1}; Cu: 0.075mgL^{-1} and Mo: 0.05mgL^{-1}. Iron was applied as FeEDDHA, B as H_3BO_3 and the remaining micronutrients as sulphates.

Plant Sampling

The plant material (stems, leaves, roots and tubers) were sampled 6 times every two weeks, throughout the plant development for the three years of experiments. For each sampling, 10 plants were collected from each replicate per treatment. Leaf samples were taken only from plants with fully expanded leaves of the same size. Leaves were picked at about one third of the plant height from the plant apex. Roots, leaves, stems and tubers were rinsed three times in distilled water after decontamination with non-ionic detergent at 1%, then blotted on filter paper. Then a sample was dried in a forced air oven at 70°C for 24h, ground in a wiley mill and then placed in plastic bags for the further analyses.

Plant Analysis

Se Determination:

For the assay of total Se concentration, oven-dried and pulverized plant material was digested with concentrated nitric acid and measurements were made using an atomic absorption spectrophotometer equipped with a graphite furnace.[12] Reagent blanks for analysis were also prepared performing the entire extraction procedure but in the absence of the samples.

Sulfate Determination:

Sulfate (SO^{2-}_4) was determined in aqueous extraction of 0.2g of dried ground material in 10mL of MILLIPORE-filtered water, shaking 120min at room temperature and then filtered with Whatman-n1 filter paper. SO^{2-}_4 was determined from the aqueous extract obtained and measured by turbidimetry of the $BaSO_4$ maintained in suspension by means of tensioactive agent (gum arabic) according to Novozamsky and Van Eck.[13]

Organic-S and Total-S Determination:

A 0.1g dry weight sub-sample was digested with nitric acid mineralization and H_2O_2.[14] After dilution with deionized water, in the product, organic S was measured as described previously for the sulphate,[13] against a pattern curve. Total S were recalculated from the sum of organic S and sulphate.

Statistical Analyses

Analysis of variance was used to assess the significance of treatment means. Significant differences according to the Duncan's Multiple Range Test (DMRT) are indicated with different letters in the tables. Level of significance are represented by * at $p<0.05$, ** at $p<0.01$, *** at $p<0.001$, and ns: not significant.

RESULTS AND DISCUSSION

Table 1 shows the mean root zone temperatures (RZT) generated under the different treatments with the highest value in T4 (30°C), and the lowest in T0 (16°C). The effect of the different mulches on root-zone temperatures were similar to those of Ham et al.,[15] who reported that black polyethylene (our T4), absorbs roughly 96% of the incoming radiation while reflecting very little, thus warms the soil.[16] The white polyethylene covers (T2) induced a cooler soil temperature than did black covers (T4) because the former reflected most wavelengths than transparent mulches (T1) do not cause soil warming, presenting mean temperatures of 18–20C whereas the whiteþ black coextruded covers generated higher mean RZT (27°C in T3).

Table 1 also presents the results of the biomass (in a dry-weight basis) for the different organs of the potato plants. The dry mass was significantly affected by the RZT and showing for the roots, leaves and tubers, the highest values in T3 (27°C), and the lowest in T1 (20°C), the latter being lower than in T0 (16°C). On the contrary, in the stems, T1 reached the highest dry weight while T3 showed the lowest. Similarly to the results of Klock et al.,[17] with tomato plants, the increase in total biomass was obtained in plants within the root-zone temperature ranging of 23–27°C in roots, tubers and leaflets, while outside this range (T0, T1 and T4), the dry weight fell with a lower dry weight accumulation (Table 1).

In relation to the effect of the different root-zone temperatures on Se in roots, T3 reached the highest concentration surpassing T0 by 51%, while the lowest value was found in T1 (Table 2). In tubers, the Se concentrations were below the limit of the detection of the employed technique, whereas in stems T4 presented the highest Se concentration (9% higher than in T0), and the lowest in T2. Finally, the highest and the lowest Se concentrations in leaflets were recorded in T3 (60% higher than in T0) and T1 (22% lower than T0), respectively.

Root-zone temperature strongly influences the uptake of elements.[1,18] In our experiments, the RZT treatments significantly increased the Se in the roots and leaflets in T3 and T4 with higher root temperatures (Table 2) increasing the root absorption and its transport to the aerial part. The failure to detect Se in the tubers was possibly due to the minor translocation of this element via the phloem,[19] since edible plant parts (tubers) contain much less Se than do the inedible parts.[20]

Non-significant differences were found between the treatments for $SO^{2-}{}_4$ concentration in roots (Table 3), whereas in tubers, the highest concentration was found in T1 (exceeding T0 by 56%) and the lowest in T2 and T3 (33% and 35% lower than T0, respectively). In stems, higher $SO^{2-}{}_4$ concentration were found in T0 and T1 whereas T2, T3 and T4 were significantly lower. Finally, T1 gave highest leaflets $SO^{2-}{}_4$ concentration (15% higher than in T0), and the lowest in T3 (10% less than in T0).

Since $SO^{2-}{}_4$ is absorbed in low quantities,[5] the different root zone temperatures did not significantly affect the $SO^{2-}{}_4$ concentration in the roots (Table 3). However, in tubers, the RZT in T1 induced higher redistribution of this elements and the temperatures generated by T2 and T3 reduced the $SO^{2-}{}_4$ concentration significantly, possibly due to a high reduction and assimilation in the aerial part in organic compounds, giving the low concentration in the tubers. With regard to the aerial part (Table 3), both in stems and leaflets, the $SO^{2-}{}_4$ concentrations in T2 and T3 were the lowest. The reduction of $SO^{2-}{}_4$ under this conditions was higher and the $SO^{2-}{}_4$ which are highly mobile in the xylem would be assimilated in the leaflets, while in T0 and T1, occured high levels of $SO^{2-}{}_4$ possibly for a decrease in assimilation.[4]

The organic-S concentrations reflects S fraction in organic structures and represents its assimilation, varying similarly to the total-S.[21] In roots, the highest organic-S concentration was also recorded in T3 (26% higher than T0; Table 4) and the lowest values were recorded in T0 and T1. In tubers, except T1, which gave the lowest concentration (18% lower than T0), the rest of treatments did not statistically differ from each other. In stems, non-significant differences were found between treatments. Finally, in leaflets, T3 also gave the highest concentration (23% higher than T0), and no significant differences were found between the rest of treatments.

With respect to this organic form of the S in the roots (Table 4), the temperatures induced by T2, T3 and T4 favoured a higher assimilation of $SO^{2-}{}_4$, in comparison with the lower root temperatures of T0 and T1.[22] In the tubers, except for the T1 treatment, with low concentrations of organic S, the temperatures generated by other treatments did not influence its redistribution. For the aerial part (Table 4), we observed that the concentration of organic-S in the stems was not significantly affected by the root zone temperatures, while in the leaflets T3 induced maximum concentration of this S forms, implying a higher SO^{2-}_4 reduction and a high transport rate of SO^{2-}_4 from the roots,[5] while the lower temperatures induced by T0 and T1, and the too high temperatures of the T4 had a negative influence on these processes.

The total-S in roots (Table 5), presented in T3 the highest concentration surpassing T0 by 22% and the lower values were found in T0 and T1, while in tubers, non-significant differences were found between treatments. For stems, the highest total-S concentrations were found in T0 and T4 and the lowest in intermediate treatments. In leaflets, T3 gave an increase of 19% with respect to T0.

Therefore, the different root-zone temperatures significantly influenced the total-S concentration (Table 5), with lower concentrations of total-S in the roots in T0 and T1 as a result of the lower root-zone temperatures,[23] affecting significantly the S uptake and assimilation as well as growth, in comparison with the treatments of high temperatures, mainly the T3 that favoured a higher assimilation and concentration of this macronutrient. In the tubers, the root-zone temperature did not affect the total-S concentrations and for the stems, the highest levels were given in the treatments with the highest (T4) and the lowest root temperatures (T0), since the root-zone temperature directly affect the total-S concentration, because the effect was exerted on the concentrations of SO^{2-}_4 and organic-S, while the range of more appropriate temperatures, T2 and T3, reduced the concentration of total S in the stems. In the leaflets (Table 5), in order to favour the synthesis of amino acids as tolerance mechanism to toxic elements, would interest a higher growth and S concentrations,[24] since a high level of organic-S was observed in T3 (treatment with a high concentration of Se), a higher SO^{2-}_4 assimilation was favoured in the leaflets.

For plants, Se toxicity results primarily from the interference with the sulfur metabolism,[7] and most agricultural crops have low Se tolerance (<50mgSekg^{-1} d.w.). In relation to such phytotoxicity, according to Pais and Jones,[24] the normal Se content is 0.02mgkg^{-1} leaf d.w., while in our experiments the plants accumulated quantities exceeding 0.4–0.5mgkg^{-1} without any toxicity symptoms. Ulrich,[25] suggested that the normal concentrations of S and SO^{2-}_4 are between 0.8–3.0mgg^{-1} leaf d.w., and between 0.25–1mgg^{-1} leaf d.w., respectively. Our potato plants presented higher concentrations in leaflets (25–30mg g^{-1}S d.w.; 3–4mgg^{-1} SO^{2-}_4 d.w.) probably as a tolerance mechanism of these plants to the high S status.

According to Salt and Krämer,[26] a plant is a hyperaccumulator if the ratio (concentration of the metal in the aerial part):(concentration of metal in the root part) exceeds 1. According to this, for Se, the ratio exceeded 1 and implies a potential for hyperaccumulation.[27] Although the Se levels is below 0.1% d.w. in the aerial part, these potato plants provides an advantage in phytoremediation against the techniques based on engineering, which are costly and also cause pollution.[11] Therefore, there is a need to improve the possibilities of accumulation of elements in potato crops and/or in other species, using the mulch technique to ensure phytoextraction by manipulation of the root-zone temperatures.

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Table 1.Effect of Mulch Treatments on Root-Zone Temperature (RZT) and on Biomass (Dry Weight) of Potato Organs

	RZT	Roots	Tubers	Stems	Leaflets
		Biomass g Plant^1			
Treatments	°C				
T0	16 e[a]	1.75 bc	19.94 c	1.82 b	2.48 b
T1	20 d	1.04 c	10.89 d	2.19 a	1.93 c
T2	23 c	1.97 b	22.42 b	1.85 b	2.59 b
T3	27 b	2.34 a	26.93 a	1.70 c	2.84 a
T4	30 a	1.63 bc	20.70 c	2.09 ab	2.51 b

[a] Mean values followed by the same letter within a column were not significantly different at $p<0.05$ according to Duncan’s Multiple Range Test.

Table 2. Effect of Root-Zone Temperatures on Total Se Concentration in Potato Organs

Treatments	Roots	Tubers	Stems	Leaflets
	Mgg^{-1} d.w.			
T0	209 cd[a]	-[y]	448 b	263 c
T1	115 d	-	465 ab	206 d
T2	225 c	-	154 d	322 b
T3	315 a	-	195 c	423 a
T4	260 b	-	489 a	307 bc

[a] Mean values followed by the same letter within a column were not significantly different at $p<0.05$ according to Duncan's Multiple Range Test. [y] Concentration below detection limits.

Table 3. Effect of Root-Zone Temperatures on SO^2_4 Concentration in Potato Organs

Treatments	Roots	Tubers	Stems	Leaflets
	Mgg^{-1} d.w.			
T0	3.61 a[a]	2.45 b	4.05 a	3.38 ab
T1	3.73 a	3.84 a	4.31 a	3.89 a
T2	3.72 a	1.66 c	3.14 b	3.18 b
T3	3.65 a	1.61 c	3 b	3.07 b
T4	3.60 a	2.49 b	3.01 b	3.41 ab

[a] Mean values followed by the same letter within a column were not significantly different at $p<0.05$ according to Duncan's Multiple Range Test.

Table 4. Effect of Root-Zone Temperatures on Organic-S Concentration in Potato Organs

Treatments	Roots	Tubers	Stems	Leaflets
	mgg^{1} d.w.			
T0	20.98 b[a]	13.24 a	25.47 a	22.76 b
T1	20.49 b	10.82 b	22.11 a	21.28 b
T2	23.57 ab	13.96 a	23.11 a	23.53 b
T3	26.48 a	14.28 a	23.67 a	28.11 a
T4	23.47 ab	13.56 a	26.46 a	22.67 b

[a] Mean values followed by the same letter within a column were not significantly different at $p<0.05$ according to Duncan's Multiple Range Test.

Table 5. Effect of Root-Zone Temperatures on Total-S Concentration in Potato Organs

Treatments	Roots	Tubers	Stems	Leaflets
	mgg^{1} d.w.			
T0	24.6 c[a]	15.7 a	29.5 a	26.1 b
T1	24.2 c	14.7 a	26.4 b	25.2 b
T2	27.2 b	15.6 a	26.3 b	26.7 b
T3	30.1 a	15.9 a	26.7 b	31.2 a
T4	27.1 b	16.1 a	29.5 a	26.1 b

[a] Mean values followed by the same letter within a column were not significantly different at $p<0.05$ according to Duncan’s Multiple Range Test.