

Potato plant growth and macronutrient uptake as affected by soil tillage and irrigation systems

Julio Cezar Silveira Nunes⁽¹⁾, Paulo Cezar Rezende Fontes⁽¹⁾, Eduardo Fontes Araújo⁽¹⁾ e Carlos Sedyama⁽¹⁾

⁽¹⁾Universidade Federal de Viçosa, Dep. de Fitotecnia, Av. P.H. Rolfs, CEP 36570-000 Viçosa, MG, Brazil. E-mail: ds06024@correio.ufv.br, pacerefo@ufv.br, efaraujo@ufv.br, csedyama@ufv.br

Abstract – The objective of this study was to evaluate potato plant growth and macronutrient uptake, as affected by soil tillage methods, in sprinkle and drip irrigated experiments. Eight treatments were set: T1, no tillage, except for furrowing before planting; T2, one subsoiling (SS); T3, twice rotary hoeing (RH); T4, one disc plowing (DP) + twice disc harrow leveling (DL); T5, 1DP + 2DL + 1RH; T6, 1DP + 2DL + 2RH; T7, 1SS + T6; T8, one moldboard plowing (MP) + 2DL. Treatments were arranged in a randomized block design with four replications. In both irrigation systems, plants presented higher emergence velocity index (EVI), when the soil was not tilled, and the EVI was inversely related to the maximum tuber dry mass production. In both experiments, a functional direct relationship was found between the leaf area index and maximum tuber dry mass yield. The growth of plant organs (tuber, leaf, stem and root) and the macronutrient (N, P, K, Ca and Mg) contents in potato plant responded positively to a deeper soil revolving caused by plowing, especially with moldboard plow.

Index terms: *Solanum tuberosum*, moldboard plow, minimum tillage.

Crescimento da batateira e absorção de macronutrientes influenciados pelos sistemas de preparo de solo e de irrigação

Resumo – O objetivo deste trabalho foi avaliar o crescimento da batateira e seu acúmulo de macronutrientes, influenciados por métodos de preparo de solo, em experimentos irrigados por aspersão e gotejamento. Em cada experimento, foram estudados oito tratamentos: T1, nenhum preparo do solo, exceto abertura do sulco de plantio; T2, uma subsolagem (SS); T3, duas passadas de enxada rotativa (RH); T4, uma aração com disco (DP) + duas gradagens niveladoras (DL); T5, 1DP + 2DL + 1RH; T6, 1DP + 2DL + 2RH; T7, 1SS + T6; T8, uma aração com aiveca (MP) + 2DL. Os tratamentos foram distribuídos em blocos ao acaso, com quatro repetições. Em ambos os experimentos, nos tratamentos em que o solo não foi arado, as plantas apresentaram alto índice de velocidade de emergência (EVI). A EVI foi inversamente relacionada com a produção de matéria seca de tubérculos. Também, em ambos os experimentos, foi encontrada uma relação funcional direta entre o índice de área foliar e a máxima produção de matéria seca dos tubérculos. O crescimento dos órgãos (tubérculo, folha, caule e raiz) e o conteúdo de macronutrientes (N, P, K, Ca e Mg) na planta responderam positivamente à maior profundidade de revolvimento do solo, causada pela aração, especialmente com o arado de aiveca.

Termos para indexação: *Solanum tuberosum*, arado de aiveca, preparo mínimo de solo.

Introduction

Sequential measurement of dry matter accumulation in both tubers and other plant organs, complemented by leaf area determination, are the essence of growth analysis (Taiz & Zeiger, 2002). This technique is an integrative, holistic, and explicative approach used to describe and interpret the performance of a given species (Hunt et al., 2002). Plant phenology quantification is an important step in modeling potato plant development, which influence tuber yield (Oliveira, 2000).

The indices determined in the growth analysis indicate the capacity of the plant assimilatory system to synthesize (source) and allocate organic matter into several organs (sink). Such capacity depends on photosynthesis, respiration, and translocation of photoassimilates from the carbon fixation sites to the utilization and storage places, where organ growth and differentiation occur. Thus, growth analysis expresses plant morphophysiological conditions and quantifies the net yield derived from the photosynthetic process, which is influenced by biotic and abiotic factors, as soil preparation methods (Fontes, 2005).

In Brazil, conventional soil tillage for potato crop normally involves disc plowing, disc leveling and sometimes, rotary hoe at various intensity levels according to soil type (Fontes, 1997). This intensive soil tillage reduces the diameter of the soil aggregates by mechanical effect, produces low quantity of organic residue (Carter & Sanderson, 2001), and promotes a rapid soil organic matter oxidation and CO₂ flow to the atmosphere (Balota et al., 2004).

Recently, changes are occurring regarding environmental care and natural resources conservation. Questions have been made on soil losses due to erosion related to intense soil mobilization. Concern with the excesses verified in soil tillage has led researchers to look for alternative soil tillage systems, such as plowing by zone (Pierce & Burpee, 1995), reduced plowing (Alva et al., 2002), chisel plow instead of moldboard plow (Carter et al., 1998), and lower number of machinery operations. However, soil tillage must be economically viable, socially accepted, and yield constant results, mainly in relation to disease effects (Sturz et al., 1997).

In this view, no-tillage system, may be a possibility for potato crop. Minimum cultivation and direct planting were developed to save energy, provide soil stability, reduce erosion and make agriculture sustainable. Viability of conventional or reduced tillage for mechanically planted potato has been shown (Ekeberg & Riley, 1996; Alva et al., 2002; Oliveira, 2003).

The objective of this study was to evaluate the growth and macronutrients accumulation by potato plant, as affected by soil tillage methods in sprinkle and drip irrigated experiments.

Material and Methods

Two experiments were set up in a Typic Hapludult whose characteristics are in Table 1. One of the experiments was sprinkler-irrigated and the other, drip-irrigated in adjacent areas of Universidade Federal de Viçosa. The experimental field has a history of conventional tillage (chisel plowing and disking), was previously planted with vegetables, and for the last three years was planted with *Stylozobium aterrimum*. The area was two times sprayed with glyphosate, at the 75th and 20th days before potato sowing, on May 13, 2003.

In both experiments, eight treatments were evaluated, involving different soil preparation methods, arranged in a randomized block design, with four replications. The

useful plot was constituted of four 6-m long rows. The treatments were: T1, no soil tillage, except for furrowing before planting, also carried out in the other treatments; T2, one subsoiling (SS); T3, twice rotary hoeing (RH); T4, one disc plowing (DP) + twice disc leveling (DL); T5, 1DP + 2DL + 1RH; T6, 1DP + 2DL + 2RH; T7, 1SS + treatment 6 sequence; T8, one moldboard plowing (MP) + 2 DL. Subsoiling was performed at 45 cm depth, in the places prepared for two central plant rows. All the operations were carried out six days after field irrigation to field capacity and immediately before planting.

After soil tillage and furrowing, 4,000 kg ha⁻¹ of fertilizer 4-14-8, 10 kg ha⁻¹ of borax, 200 kg ha⁻¹ of magnesium sulphate, and systemic organophosphorated insecticide were applied in the furrows and mixed with the soil. Certified sprouted seed tubers of 'Monalisa' potato were hand-planted in furrows 0.10 m deep. Seed spacing was 0.31 m in the row, with rows 0.75 m apart. The plots consisted of four 6-m long rows. At the 37th day after planting (dap), before the hilling up, sidedress fertilizer application was carried out using 810 kg ha⁻¹ of ammonium sulphate. During the cycle, fungicides and insecticides were sprayed as necessary.

In the sprinkler-irrigated experiment, the water was applied every seven days. The volume applied was 386 mm and restored the water evapotranspired during the period. During the experimental phase, rainfall was not significant.

In the drip-irrigated experiment, a low-pressure drip tube was used with a 0.20-m emitter spacing and flow rate

Table 1. Some soil physical and chemical properties in 0–20 cm deep, before treatment application.

Soil properties	Unit	Average value
pH (water suspension 1:2.5)	-	5.2
P (Mehlich 1)	mg dm ⁻³	165
K (Mehlich 1)	mg dm ⁻³	313
Ca ²⁺ (KCl 1 mol L ⁻¹)	cmol _c dm ⁻³	7.9
Mg ²⁺ (KCl 1 mol L ⁻¹)	cmol _c dm ⁻³	1.3
Al ³⁺ (KCl 1 mol L ⁻¹)	cmol _c dm ⁻³	-
Cation exchange capacity	cmol _c dm ⁻³	10.0
Organic matter	g kg ⁻¹	26.9
Sand	g kg ⁻¹	380
Silt	g kg ⁻¹	200
Clay	g kg ⁻¹	420
Texture class	-	Clayey
Geometric mean diameter	mm	1.15
Bulk density	kg dm ⁻³	1.26
Particle density	kg dm ⁻³	2.61
Macroporosity	m ³ m ⁻³	0.17
Microporosity	m ³ m ⁻³	0.38
Soil humidity at field capacity	m ³ m ⁻³	0.394
Soil humidity at wilting point	m ³ m ⁻³	0.341
Resistance to penetration	MPa	1.46

of 4 L h⁻¹ m⁻¹. The tube was placed along each row, following planting. Before the hilling up, the tube was displaced from the original position to avoid being damaged. Over the cycle, 266 mm of irrigation water were utilized in applications every four days, partly following procedures adopted by Fabeiro et al. (2001).

Up to 25 days after planting, the number of emerged plants was daily quantified. The data obtained were used to calculate the emergence velocity index (EVI), according to Maguire (1962).

In the drip-irrigated experiment, three days after the hilling up, the depth of the soil layer revolved was measured from the hill top. In the minimally cultivated systems, there was no soil layer revolved. In plants collected at 43, 58, 73, 88 and 103 dap, the foliar area and leaf, stem, root and tuber dry weights were determined. The first derivative of the equation adjusted to the dry matter mass of the plant was used to calculate the absolute growth rate of the culture (G).

In the dry matter of the leaf, stem, root, and tubers from treatments T1, T6 and T8 in the sprinkler-irrigated experiment, the nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg) contents were determined; the same procedure was performed in T6 of the drip-irrigated experiment.

In each experiment, the dependent variables were analyzed by variance and regression analyses. In the regression analysis, time (plant age) was considered the independent variable, expressed in days after planting, with the linear, quadratic and cubic effects being tested. The model was selected based on: F test at 5% probability, biological significance, and the highest R² value.

Results and Discussion

In the drip-irrigated experiment, plant emergence started at 10 dap and completed at 17 dap. In the sprinkle-irrigated experiment these values were 12 and 23 dap, half the time observed by Fabeiro et al. (2001), under other experimental conditions. In both experiments, there was effect of treatments on EVI, which was higher in T1 (Table 2). This indicates that the most rapid emergence occurred in the treatments with no soil plowing. Before emerging, the potato plant emits a profuse root system, which has its growth limited in compacted soil (Lesczynski & Tanner, 1976). In the treatments, where the soil was not plowed, the

mother-tuber might have directed its reserves to a more rapid stem emission, due to the greater resistance to root growth.

EVI was lower in the sprinkle-irrigated experiment than in the drip-irrigated one, probably due to the formation of a superficial soil layer compacted by the impact of water drops applied. Lower EVI was verified in sprinkle-irrigated soybean plants than in drip-irrigated ones (Wang et al., 2000), due to the higher temperature of the drip-irrigated soil, as well as due to the maintenance of the soil surface physical structure, which did not favor the formation of a compacted layer.

EVI (plant per day) presented inverse functional relationship with the maximum tuber dry weight (g per plant) in both experiments: drip-irrigated ($Y = 156.81 - 13.67X$, $r = 0.79^*$); and for sprinkler-irrigated experiment ($Y = 126.60 - 9.78X$, $r = 0.83^*$).

In both experiments, the treatments did not influence the dry matter partition in the plant, with 68% of the maximum dry matter produced by the plant being allocated in the tubers, 22% in the leaves, 7% in the stems and 3% in the roots. Dry matter partitioning pattern in potato plant is greatly influenced by the presence of the tubers, which are very strong sinks for assimilates. Any factor influencing the partitioning pattern of tubers would be of considerable significance for yield formation (Jenkins & Mahmood, 2003).

The treatments resulted in similar forms of mathematical equations representatives of plant organ growth in function of time, but with different maximum values (Table 3). The values were higher in T8, where the soil was moldboard plowed, lower in T1 where minimal cultivation was performed without soil revolving, and intermediary in treatments T2 through T7. The soil

Table 2. Maximum potato leaf area index (LAI) and plant emergence velocity index (EVI) in the treatments, in drip and sprinkler-irrigated experiments⁽¹⁾.

Treatment	Drip		Sprinkler	
	LAI (cm ² cm ⁻²)	EVI (plants per day)	LAI (cm ² cm ⁻²)	EVI (plants per day)
T1. No-tillage	1.83C	7.0A	1.75D	5.5A
T2. ISS	1.68C	6.3AB	1.78D	5.0A
T3. 2RH	2.45AB	6.5AB	2.23C	4.8A
T4. 1DP + 2DL	1.98C	6.5AB	2.50BC	3.4B
T5. 1DP + 2DL + 1RH	2.43AB	6.0AB	2.39C	4.0AB
T6. 1DP + 2DL + 2RH	2.08B	5.8B	2.46BC	5.2A
T7. 1SS + 1DP + 2DL + 2RH	2.52A	5.6B	2.78AB	3.8AB
T8. 1MP + 2DL	2.81A	5.5B	3.06A	3.8AB

⁽¹⁾Within columns, means followed by equal letters are not significantly different at $p < 0.05$ (Newman-Keuls test).

tillage and management systems interfered directly in plant development and productivity due to effects on density, porosity and water storage in the soil profile, according to Pereira et al. (2004).

The lowest root dry weight was verified in T1, no-tillaged soil (Table 3). Root, shoot and tuber had difficulty in developing in no revolved soil, under the minimum tillage (T1 and T2), and grew less than under the systems where the soil was revolved. For a wide range of soil type, lower growth occurred, when plants were cultivated in direct planting compared to planting in prepared soil (Schmidt & Belford, 1994). Poor wheat root growth found in direct-drilled soils, which was significantly related to poor shoot growth, was not caused by soil higher bulk density, but by biological factors involved, as soil fumigation completely eliminated poor shoot growth (Chan & Mead, 1992). Also, in no-tillaged soils, an inhibitory root signal may occur, which has been shown under controlled conditions, to reduce shoot growth in hard soil, even when leaves are well supplied with water and nutrients (Stirzaker et al., 1993).

The depth of soil plow layer in T1, T6 and T8 was 0, 24 and 30 cm, respectively (Table 4), and tends to follow the order: disc harrow plow + moldboard plow > moldboard plow > disc harrow leveling + disc plow > disc plow > disk harrow plow (Radosevich et al., 1996). No-tillage reduces soil mechanic revolving and preserves the cultural residues on the soil surface. A beneficial effect of deep preparation on the potato roots and tubers development is reported (Bishop & Grimes, 1978), although deep preparation may not always be advantageous (Pierce & Burpee, 1995).

In both experiments, the effects of the treatments on the leaf area index (LAI) were similar to those verified on the plant dry weight, being LAI higher in T8 (Table 2). Young et al. (1993) found the highest LAI, and stem, stolon and potato tuber dry weight, in soil where resistance to penetration was lower, due to lower

machinery traffic in the area. Maximum LAI was obtained at 61 dap, on treatment average, similarly to the findings of Melo et al. (2003) for an early-maturing potato variety. In early-maturing potato cultivars, new leaf production ceases at a relatively early stage, and dry matter partition for the tubers occurs at a relatively low total plant dry weight (Jenkins & Mahmood, 2003). Higher LAI value indicates higher foliar area for the solar radiation interception and, within determined limits, also indicates greater potato tuber growth and production (Midmore, 1988). LAI ($\text{cm}^2 \text{cm}^{-2}$) presented a direct and positive functional relationship with maximum tuber dry weight (g per plant) in both experiments: drip-irrigated ($Y = 28.48 + 19.90X$, $r = 0.86^*$); and sprinkler-irrigated ($Y = 35.22 + 20.26X$, $r = 0.98^{**}$).

The highest and the lowest nutrient uptake were verified in T8 and T1, respectively (Table 4). Under no-tillage, the soil tends to accumulate lower moisture and presents greater soil strength than soil in a conventional tillage system (Cannell, 1985). High density reduces the soil capacity for retaining water, restricting nutrient absorption by the root (Carter et al., 1998). Soil conditions may alter root growth and affect shoot growth and nutrient uptake indirectly (Qin et al., 2005). In maize and sorghum cultures, Canalli & Roloff (1997) observed a greater exploration of the soil by the roots, when the soil was revolved with moldboard plow, compared with disc plow and rotary hoe. Under no-tillage system, soil solution pH was lower than under conventional tillage, and was inversely related to total organic carbon concentration in soil solution and precipitation (Lilienfein et al., 2000). Such conditions may alter nutrient availability in the soil. Ekeberg & Riley (1996) found no significant difference in N uptake by potato tuber between no-tillage and conventional tillage systems.

In the sprinkler-irrigated experiment, the maximum nutrient uptake in plants in T6, expressed in kg ha^{-1} , were: N, 109; P, 14; K, 195; Ca, 30; and Mg, 19 (Table 4).

Table 3. Maximum estimated values of leaf, stem, root, and potato tuber dry weight (DW), plant growth rate (G) and tuber growth rate (G_T) in T1, T6, and T8 treatments, in drip and sprinkler irrigated experiments⁽¹⁾.

Characteristic	Drip			Sprinkler		
	T1	T6	T8	T1	T6	T8
Leaf DW (g per plant)	20.9B	23.7AB	28.3A	22.6B	28.8AB	31.4A
Stem DW	6.9B	6.5B	9.2A	7.3B	8.6AB	10.1A
Root DW	1.80B	2.41A	3.00A	2.40B	3.31A	3.80A
Tuber DW	61.5B	72.2AB	86.9A	70.6B	84.1AB	96.6A
Plant DW	91.1B	104.8AB	127.4A	102.9B	124.8AB	141.9A
G (g per plant per day)	1.10B	2.50A	2.85A	1.90C	2.97B	4.08A
G_T (g per plant per day)	0.79B	1.68A	1.90A	0.99B	2.01A	2.74A

⁽¹⁾Within rows, in each experiment, means followed by equal letters are not significantly different at $p < 0.05$ (Newman-Keuls test).

In the drip-irrigated experiment T6, the corresponding values (kg ha^{-1}) were: N, 77 ; P, 10; K, 106; Ca, 24; and Mg, 13. These values are within the range cited as normal (Perrenoud, 1993). Plant nutrient uptake is the result of three processes, namely, absorption, translocation, and incorporation, and correlates well with plant growth and dry matter production (Fontes, 2001). Nitrogen and potassium accumulation curves along the plant cycle in T6 presented higher values in the sprinkler-irrigated experiment (Figure 1). The same occurred for calcium, phosphorus and magnesium (Figure 2). For all nutrients, the uptake efficiency, considered as plant maximum estimated dry weight, divided by the maximum nutrient uptake, was higher in the drip-irrigated experiment (Table 5).

Table 4. Soil plow layer depth (SPD) and maximum nutrient uptake (kg ha^{-1}) by potato plant in T1, T6, and T8 treatments, in sprinkler-irrigated experiment⁽¹⁾.

Characteristic	Treatments		
	T1	T6	T8
SPD (cm)	0	23.9B	29.6A
Nitrogen	85B	109A	110A
Phosphorus	18A	14B	19A
Potassium	170B	195A	194A
Calcium	25C	30B	34A
Magnesium	14B	19A	15AB

⁽¹⁾Within rows, means followed by equal letters are not significantly different at $p < 0.05$ (Newman-Keuls test).

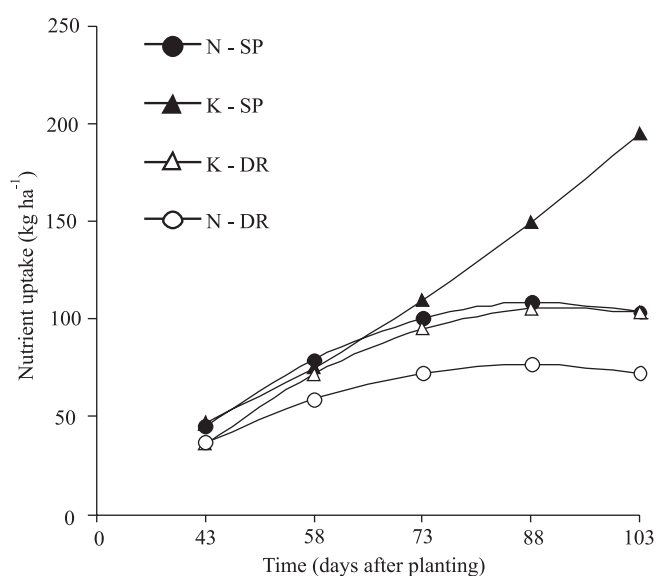


Figure 1. Relationships between harvest time and nitrogen (N) and potassium (K) uptake by potato plant in T6, in sprinkler (SP) and drip-irrigated (DR) experiments.

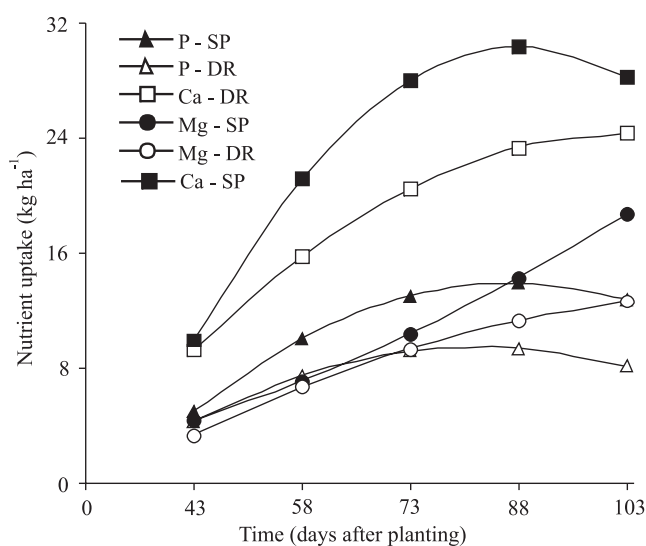


Figure 2. Relationship between harvest time and calcium (Ca), phosphorus (P), and magnesium (Mg) uptake by potato plant in T6, in sprinkler (SP) and drip-irrigated (DR) experiments.

Table 5. Nutrient uptake efficiency⁽¹⁾ in potato plant in T6, in drip and sprinkler-irrigated experiments⁽²⁾.

Nutrient	Drip	Sprinkler
Nitrogen	59A	49B
Phosphorus	479A	386B
Potassium	42A	28B
Calcium	189A	175A
Magnesium	366A	289B

⁽¹⁾Maximum plant dry weight (kg ha^{-1})/maximum nutrient uptake (kg ha^{-1}). ⁽²⁾Within rows, means followed by equal letters are not significantly different at $p < 0.05$ (Newman-Keuls test).

Conclusion

The growth of plant organs and the macronutrient uptake in potato plant respond positively to a deeper soil revolving caused by plowing, especially with moldboard plow, for both sprinkler and drip-irrigated experiments.

Acknowledgements

To Fapemig and to CNPq, for scholarships granted.

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Recebido em 16 de fevereiro de 2006 e aprovado em 30 de agosto de 2006