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Tuber yield and economic result of 'Atlantic' potato in response to NPK fertilizer formulas

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ABSTRACT

The usual application of high 4-14-8 NPK fertilizer rates in the potato planting furrows, independently of the soil fertility or nutritional cultivar requirements, has become a paradigm in Brazil. However, the 4-14-8 NPK formula does not always meet the crop needs, and can unbalance the availability of nutrients in the soil. The objective of this study was to evaluate the tuber yield and economic results of 'Atlantic' potato as affected by rates of 4-14-8 and 6-30-6 NPK formulas applied in the planting furrows. The rates of both NPK formulas were calculated to reach P_2O_5 rates of 210, 420, and 630 kg ha^{-1}. At each P_2O_5 rate, the 6-30-6 formula resulted in less 30% N and 65% K_2O in the planting furrow compared to 4-14-8 formula. A randomized complete block design in a factorial scheme (2×3)+1, including an unfertilized furrow control, with three replications was used. Only the use of 6-30-6 formula increased the total tuber yield of 'Atlantic' potato. The marketable tuber yield reached higher levels (29.8 t ha^{-1}) with higher P_2O_5 rate (440 kg ha^{-1}) using the 6-30-6 than 4-14-8 formula. The fertilizer rates and formulas NPK did not affect specific gravity of marketable tubers. Therefore, the use of a fertilizer more concentrated in P_2O_5 that favors smaller contributions of N and K (as the 6-30-6 formula studied in this work) provides lower costs, and greater operational efficiency and profits in relation to the 4-14-8 formula traditionally used for the potato crop.

Keywords*:* *Solanum tuberosum*, mineral fertilization, fertilizer source, profitability.

RESUMO

Produtividade de tubérculos e resultado econômico da batata 'Atlantic' em resposta a fertilizantes NPK

A aplicação usual de altas doses do fertilizante NPK 4-14-8 nos sulcos de plantio da cultura da batata, independentemente da fertilidade do solo ou das necessidades nutricionais da cultivar, tornou-se um paradigma no Brasil. Contudo, a fórmula 4-14-8 nem sempre atende as necessidades da cultura e pode desequilibrar a disponibilidade de nutrientes no solo. O objetivo deste trabalho foi avaliar as produtividades de tubérculos e os resultados econômicos da batata cultivar Atlantic afetada por doses das fórmulas NPK 4-14-8 e 6-30-6 aplicadas no sulco de plantio. As doses de ambas as fórmulas NPK foram calculadas para atingirem doses de 210, 420 e 630 kg ha^{-1} de P_2O_5. Em cada uma das doses de P_2O_5, a fórmula 6-30-6 resultou em 30% menos N e 65% menos K_2O no sulco de plantio do que a fórmula 4-14-8. Foi utilizado um delineamento em blocos casualizados, em esquema fatorial (2×3)+1, que incluiu um controle sem adubação no sulco, com três repetições. Apenas a utilização da fórmula 6-30-6 aumentou a produtividade total de tubérculos da cultivar Atlantic. A produtividade de tubérculos comercializáveis atingiu maior nível (29,8 t ha^{-1}) com maior dose de P_2O_5 (440 kg ha^{-1}) utilizando-se a fórmula 6-30-6 comparada com a fórmula 4-14-8. As doses e fórmulas de fertilizantes NPK não afetaram o peso específico dos tubérculos comercializáveis. Portanto, o uso de um fertilizante mais concentrado em P_2O_5 que favorece aportes menores de N e K (como a fórmula 6-30-6 estudada neste trabalho) proporciona menores custos, e maiores eficiência operacional e lucros em relação à fórmula 4-14-8 tradicionalmente usada na cultura da batata.

Palavras-chave: *Solanum tuberosum,* adubação mineral, fonte de fertilizante, lucratividade.

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Brazilian growers have traditionally used high rates of 4-14-8 NPK fertilizer (N-P_2O_5-K_2O formula) in the potato planting furrows, regardless of soil fertility and nutritional requirements of cultivar (Sangoi & Kruse, 1994; Soratto *et al.*, 2017). That's why potato crop response to rates of 4-14-8 fertilizer have been historically studied for the estimation of maximum technical efficiency of this formula when applied in the planting furrows (Crisostomo *et al.*, 1983; Queiroz *et al.*, 2013; Silva *et al.*, 2017; Santos *et al.*, 2018). However, there are differences in the amounts of each nutrient required during the crop cycle, as well as among the nutritional requirements of different cultivars, which indicate the need for differential management of fertilization (Fernandes *et al.*, 2011).

'Atlantic' is the most planted potato cultivar for chip processing industries in Brazil (Evangelista *et al.*, 2011).

This cultivar has low P-use efficiency (Soratto *et al.*, 2015) and can respond to high P fertilizer rates in the planting furrows, especially in soils with low and medium P availability (Fernandes & Soratto, 2016). N and K are the nutrients taken up in greater amounts by 'Atlantic' potato plants, but this cultivar uptakes maximum only 26% N and 35% K of total required until 40 days after planting (DAP) (Fernandes *et al.*, 2011), which is inconsistent with 4-14-8 rates traditionally applied in the planting furrows.

Furrow-applied N and K can be lost by leaching and run-off, depending on the soil type, rainfall, additional and existent contents of these nutrients in the soil, presence of plant root system, and removed amounts by potato plants (Mesquita *et al.*, 2012). Furthermore, excessive N and K application in the planting furrows increases the saline soil concentration and alter ionic interactions that interfere in water and ions uptake by plants (James *et al.*, 1994; Mesquita *et al.*, 2012). It can also result in lower plant population and excessive vegetative growth, with lower tuber yield and dry matter (Westermann *et al.*, 1994; Reis Junior & Fontes, 1996; Cardoso *et al.*, 2007). N and K increase the water content of the cells to maintain their turgidity, making the solute potential more negative and reducing the specific gravity of tubers as well (Kumar *et al.*, 2012). High N and inadequate K supply also increase the content of the acrylamide precursors, a potentially carcinogenic substance that can accumulates in the fried potato products (Gerendás *et al.*, 2007).

The use of 4-14-8 formula does not always meet the soil and crop needs, as well as unbalance the Mg:K, Ca:K, and Ca+Mg:K ratios in the soil (Crisostomo *et al.*, 1983). Usual responses of potato crop to NPK fertilization makes it difficult to understand the cause-and-effect relationship between soil fertility, crop nutrition, and tuber yield. It was hypothesized that a NPK formula more concentrated in P, that promotes less input of N and K in the planting furrow may increase potato tuber yield and quality. The objective of this study was to evaluate the tuber yield and economic results of 'Atlantic' potato as affected by rates of two NPK fertilizer formulas applied in the planting furrows.

MATERIAL AND METHODS

The experiment was carried out in rainy season (October 2014 to February 2015) in commercial area of potato production in Lapa, south-central region of Paraná, Brazil (25°46'15"S, 49°43'8''W; 942 m altitude). The region climate is Cfb, according to the Köppen's classification system. Rainfall and temperatures measured during the experiment were regular, with 644 mm and 21.0^{o}C average temperature during the potato cycle. After 40 DAP, rainfall was 442 mm (69% of the total) and minimum and maximum temperatures registered were 16.7 and 25.9^{o}C, respectively. The soil, classified as a medium-textured Haplic Cambisol (Santos *et al.*, 2013), was sampled (0-0.2 m) prior to planting and analyzed chemically (Pavan *et al.*, 1992) and texturally (Claessen, 1997). The results were: pH($CaCl_2$)= 5.6; organic C (Walkley & Black)= 20.3 g dm^{-3}; P (Mehlich-1)= 20.7 mg dm^{-3}; K (Mehlich-1)= 0.50 cmol$_c$ dm^{-3}; Ca (KCl)= 7.05 cmol$_c$ dm^{-3}; Mg (KCl)= 1.31 cmol$_c$ dm^{-3}; H+Al= 4.27 cmol$_c$ dm^{-3}; V= 68%; sand = 450 g kg^{-1}; clay = 142 g kg^{-1} and silt = 408 g kg^{-1}. Soil characteristics indicated a very high pH, very high Ca, high Mg, very high organic C, high P, very high K, and high V%, according to the Paraná State's handbook for fertilization and liming (NEPAR-SBCS, 2017).

The experimental design was randomized complete blocks with (3×2)+1 factorial scheme and three replications. Treatments consisted of three NPK fertilizer rates (equivalent to 210, 420, and 630 kg ha^{-1} P_2O_5), applied in the planting furrows as the 4-14-8 and 6-30-6 N-P_2O_5-K_2O (NPK) formulas, and an unfertilized control. Keeping fixed the P_2O_5 rates, different rates of 4-14-8 and 6-30-6 formulas were obtained (Table 1). Each plot was composed of four 5-m long rows with 0.80-m row spacing. Only the two center most rows were used for measurements and 0.5 m at each end of each plot were discarded.

The soil was tilled with chiseling, plowing, and light harrowing one day before planting. After slight fertilizer incorporation into the soil, the uncut seed tubers of 'Atlantic' potato (type III, 35 g average mass) were planted on October 28, 2014. Phytosanitary management followed the technical recommendations for the potato crop and the criteria adopted by the growers. Irrigation was not necessary due to appropriate rainfall distribution. At 35 DAP, 60 kg ha^{-1} N (ammonium sulfate) were side dressed in all plots (including control treatment) followed by hilling, also according to the traditionally use of potato growers. A standard basic procedure used by Brazilian potato growers was adopted and any other fertilizer was added by soil or foliar application.

At 100 DAP plants were harvested after desiccation, using herbicide Diquat (330 g a.i. ha^{-1}) a week before. Tubers were weighed and classified into marketable (>45 mm diameter) and non-marketable (<45 mm diameter). Tuber yield of both classes was summed to obtain the total tuber yield. From each plot, ten marketable tubers were randomly sampled to estimate the specific gravity (specific gravity = tuber weight in air/tuber weight in air - tuber weight in water) (Fong & Redshaw, 1973).

Obtained data were subjected to analysis of variance by F test ($p<0.05$). The effect of fertilizer (P_2O_5) rates was evaluated by regression analysis and, for this purpose, the control (unfertilized treatment) was considered as zero fertilizer rate. Means of sources (NPK fertilizer formulas), in each NPK rate in the interactions ($p<0.05$), were compared by Tukey test ($p<0.05$). Maximum technical efficiency rates were calculated by the first derivative of the quadratic equation. Economic calculations for marketable tuber yield were made based on updated budget (2018) of cost prices for 4-14-8 (R$ 1,360.00 t^{-1}) and 6-30-6 (R$ 1,800.00 t^{-1}) NPK formulas and price of tubers paid by industry to the potato farmer (R$ 1,560.00 t^{-1}).

RESULTS AND DISCUSSION

Total tuber yield varied only with rates of formula 6-30-6, presenting maximum value of 34.9 t ha^{-1} with 414 kg ha^{-1} P_2O_5 as 1.4 t ha^{-1} of 6-30-6 formula (Figure 1a). In turn at the rate 420 kg ha^{-1} P_2O_5, the potato crop yielded 6.7 t ha^{-1} (22.9%; $p<0.05$) more tubers with 6-30-6 than with 4-14-8 formula.

Marketable tuber yield increased with the application of both formulas, reaching maximum of 27.6 t ha^{-1} with 294 kg ha^{-1} P_2O_5 as 4-14-8 formula (2.1 t ha^{-1}) and 29.8 t ha^{-1} with 440 kg ha^{-1} P_2O_5 as 6-30-6 formula (1.4 t ha^{-1}) (Figure 1b). The high soil fertility of the experimental area probably diminished the response of potato tuber yield, since the optimum 4-14-8 formula rate found in this study was lower than observed by Crisostomo *et al*. (1983) and Santos *et al*. (2018), respectively 4.2 and 6.0 t ha^{-1} 4-14-8 fertilizer. Studying three potato cultivars planted in the same plots that received 0 to 8 t ha^{-1} 4-14-8 formula, Crisostomo *et al*. (1983) observed that NPK rates reapplication in the same plots decreased about by half the maximum technical efficiency rate and respective marketable tuber yield. The lower total and marketable tuber yields obtained with higher rates of 4-14-8, compared to 6-30-6 formula, may be related to excessive N, K, or imbalance among K, Ca, and Mg, since the K content and Ca:Mg ratio in the soil were usually high.

Maximum technical efficiency rate (i.e., the optimum rate for maximum marketable tuber yield) for 4-14-8 formula cost was R$ 2,856.00, while for 6-30-6 formula cost was R$ 2,640.00 (Table 2). The 6-30-6 formula at optimum rate resulted in a marketable tuber yield of 2.2 t ha^{-1} (8.1%) higher than 4-14-8 formula (Figure 1b); i. e. with more 146 kg ha^{-1} P_2O_5 and less 4 kg ha^{-1} N and 80 kg ha^{-1} K_2O (Table 1). Moreover, this difference was equivalent to less 633 kg ha^{-1} fertilizer and economy of R$ 215.40 ha^{-1}, with additional gross revenue of R$ 2,028.00 ha^{-1} and profit resulting from R$ 2,243.40 ha^{-1} (50.1% increase). Therefore, higher marketable tuber yield and profit levels were obtained with the more concentrated 6-30-6 formula.

In counterpart, with the rate of 420 kg ha^{-1} P_2O_5 there was increase ($p<0.05$) of 2.7 t ha^{-1} (10.1%) in marketable tuber yield with 6-30-6 formula (1.4 t ha^{-1}) in relation to 4-14-8 formula (3.0 t ha^{-1}) (Figure 1b). This difference resulted in less 1.6 t ha^{-1} NPK fertilizer and with economy of R$ 1,560.00 ha^{-1}, additional gross revenue of R$ 4,270.36 ha^{-1} and profit of R$ 5,830.36 ha^{-1} or 239.6% (Tables 1 and 2). The higher marketable tuber yield obtained with 420 kg ha^{-1} P_2O_5 and 30% less N and 65% less K applied in the planting furrow using the 6-30-6 formula were consistent with the nutritional demands (Fernandes *et al*., 2011), validating our hypothesis. In addition, the more concentrated 6-30-6 formula increases the efficiency in planting operation with less need for potato planter refill; however, more concentrated fertilizer formula requires more accurate equipment because it is harder to calibrate a fertilizer distribution machine with 6-30-6 formula (Trani & Trani, 2011). Less N and K_2O rates with same or higher P_2O_5 rate in the planting furrow provided cost savings and higher profits with greater operational efficiency in the planting.

The percentage of non-marketable tuber yield was not affected by rates of 4-14-8 and 6-30-6 formulas and there were no differences ($p>0.05$) between them at each rate of P_2O_5 (Figure 1c). On average of the rates, the NPK fertilizer formulas 4-14-8 and 6-30-6 yielded 4.3 and 3.4 t ha^{-1} of non-marketable tuber yield (i.e., 14.2% and 14.1% of the total tuber yields), respectively. The large minimum significant difference ($p<0.05$)

Table 1. Total rates of NPK formulas in the planting furrow (PF) based on P_2O_5 rates and respective N (in the PF and total) and K_2O rates, according to minimum guarantees of primary macronutrients of commercial NPK fertilizers. Lapa, IAPAR/Dzierwa Group, 2014/2015.

P_2O_5 rate in the PF (kg ha^{-1})	4-14-8 NPK formula				6-30-6 NPK formula			
	Total fertilizer in the PF (t ha^{-1})	N in the PF (kg ha^{-1})	Total N (kg ha^{-1})	K_2O in the PF (kg ha^{-1})	Total fertilizer in the PF (t ha^{-1})	N in the PF (kg ha^{-1})	Total N (kg ha^{-1})	K_2O in the PF (kg ha^{-1})
0	0	0	60	0	0	0	60	0
210	1.5	60	120	120	0.7	42	102	42
420	3.0	120	180	240	1.4	84	144	84
630	4.5	180	240	360	2.1	126	186	126

Table 2. Costs with fertilizer, increased gross revenue, and profit obtained at the maximum efficiency rates of P_2O_5 and with the application of 420 kg ha^{-1} of P_2O_5 as 4-14-8 and 6-30-6 NPK fertilizers. Lapa, IAPAR/Dzierwa Group, 2014/2015.

Rate of P_2O_5 (kg ha^{-1}) - NPK formula	Cost (R$ ha^{-1})	Increased revenue* (R$ ha^{-1})	Profit (R$ ha^{-1})
294 – 4-14-8	2,856.00	7,332.00	4,476.00
440 – 6-30-6	2,640.00	9,360.00	6,719.40
420 – 4-14-8	4,080.00	6,513.81	5,153.81
420 – 6-30-6	2,520.00	10,784.16	8,984.16

*Increased revenue calculated as the difference between each fertilizer rate and unfertilized control.

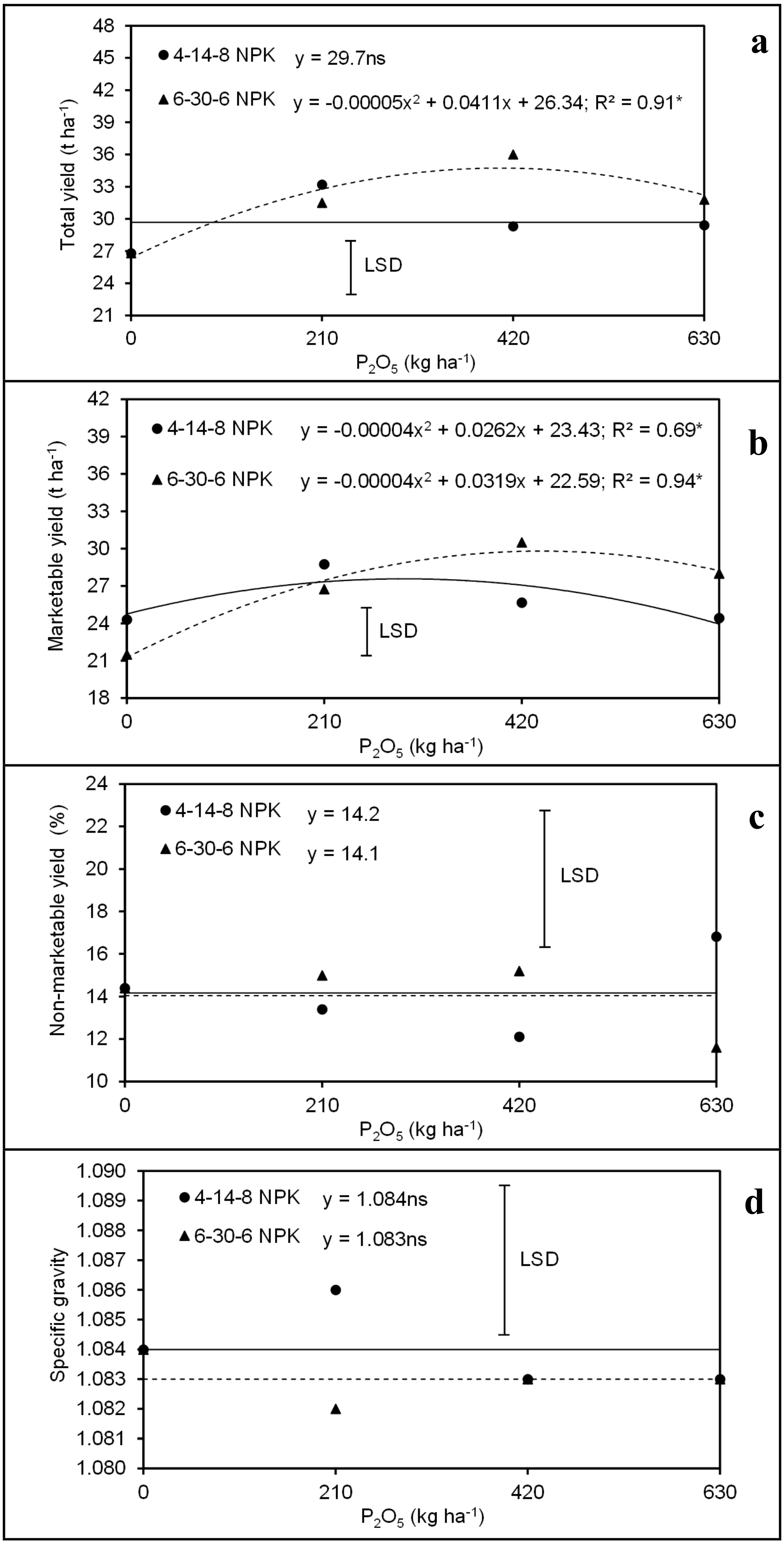

Figure 1. Total (a) and marketable tuber yields (b), percentage of non-marketable tuber yield (c) and specific gravity (d) as a function of NPK formulas based on P_2O_5 rates. ns, * and LSD: non-significant, significant (p<0.05) and least significant difference (LSD; p<0.05) by Tukey test. Lapa, IAPAR/Dzierwa Group, 2014/2015.

of 4.2 t ha^{-1} non-marketable tuber yield between the NPK formulas at each P_2O_5 rate reflects the high coefficient of variation (60.4%) observed. High variability of non-marketable tuber yield may have affected the non-significant results.

The fertilizer rates and formulas did not affect specific gravity of marketable tubers (Figure 1d), despite previous indicatives of greater specific gravities with less N and/or K to potatoes (Westermann *et al*., 1994; Reis Junior & Fontes, 1996; Cardoso *et al*., 2007). On the other hand, the high soil fertility, uniform rain distribution, and great rainfall (~120 mm registered) around 85 DAP probably attenuated the deleterious effect related to excessive N and K application at higher fertilizer rates (Kumar *et al*., 2012).

Under the edaphoclimatic conditions of this study, a typical of potato farms in the south-central region of Paraná State, the application of less N and K in the 'Atlantic' potato planting furrows, using 6-30-6 formula, increased marketable tuber yield and promoted a lower cost and higher profit. The use of a fertilizer formula more concentrated in P_2O_5 could also improve the efficiency of the potato planting operation. In addition to the 6-30-6 formula, other concentrated NPK formulas are commercially available and also could have better efficiency than traditional 4-14-8 formula.

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