Evaluation of Soil and Plant Nitrogen Tests in Potato (*Solanum tuberosum* L.) Production

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Summary

Nitrogen (N) management is critical in optimizing potato (*Solanum tuberosum* L.) yield and reducing environmental pollution. Several plant and soil based tests were proposed for assessment of N status in crop plants. Aim of this study was to evaluate the convenience of plant based tests (leaf chlorophyll content index (CCI) and petiole nitrate-nitrogen (NO_3-N) concentrations) and soil based test (soil nitrogen (N_{min}) content) for estimating potato N status. Experiment was conducted in North West region of Croatia in 2011 growing season as randomized complete block design with four replications. Treatments were four N rates, 50, 100, 150 and 200 kg N ha^{-1}. At pre-plant 50 kg N ha^{-1} was applied as NPK 7:20:30. Four side-dressed N rates, 0, 50, 100 and 150 kg N ha^{-1} were applied 45 days after planting (DAP). CCI and petiole NO_3-N concentrations were measured at 58 and 98 (DAP), while soil N_{min} content was measured before planting, 58 DAP, 98 DAP and after harvest. No significant differences in total tuber yield were determined between 100, 150 and 200 kg N ha^{-1} treatments. Significantly highest residual N_{min} content (33.25 kg ha^{-1}) after harvest was determined on plots fertilized with 200 kg N ha^{-1}, indicating potential N leaching during fall and winter. Significant linear relationship between petiole N-NO_3 and N treatments were determined at 58 DAP (R^2=0.32) and 98 DAP (R^2=0.75) and between CCI and N treatments at 98 DAP (R^2=0.62). Significant linear relationship between soil N_{min} content and N treatments were determined at 58 (R^2=0.57) and 98 DAP (R^2=0.56). Plant based tests are better correlated with N treatments at later growth stages in which applied N could be utilized by the crop.

Key words

nitrogen management, potato, chlorophyll content index, petiole nitrate-nitrogen concentration, soil nitrogen content

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Introduction

Nitrogen is the plant nutrient that most frequently limits crop production and is needed by most crops at higher quantities than other plant nutrients (Olfs et al., 2005). To maximize yield, farmers often apply higher amount of N fertilizer than the minimum required for maximum crop growth (Lemaire and Gastal, 1997). However, the application of N at rates exceeding plant utilization, represent an unnecessary input cost for producers and may harm environment, because the residual soil mineral N after harvest represents a potential source for nitrate leaching during fall and winter. Potatoes as shallow-rooted crops need a high level of nitrogen to ensure acceptable yield (Darwish et al., 2006). Nitrogen management, rate and timing of nitrogen application are critical factors in optimizing potato tuber yield and quality (Haase et al., 2006; Poljak et al., 2007). Assessment of several soil and plant test methods that could improve N management in potato and other crops has been reported in the literature (Olfs et al., 2005; Wu et al., 2006; Poljak et al., 2007; Poljak et al., 2008). Analysis of soil mineral nitrogen at the beginning of the growth period and/or during the vegetation period has been used in many developed countries for the N-fertilizer recommendation of arable crops (Olfs et al., 2005). Usage of plant analysis is based on idea that the plant itself is the best indicator for the N supply from soil within the growth period (Olfs et al., 2005). Actual plant N status is the result of current N status of the soil and N uptake by the plant (Olfs et al., 2005). Chlorophyll content of a plant is a good qualitative indicator for leaf N concentration due to strong correlation between chlorophyll and leaf N concentration (Olfs et al., 2005). Plant sap nitrate test is widely accepted for assessment of the vegetable crops N status, especially in potatoes (Olfs et al., 2005). The aim of this study was to evaluate the convenience of plant based tests (leaf chlorophyll content index (CCI) and petiole nitrate-nitrogen (NO_3-N) concentrations) and soil based test (soil nitrogen (N_{min}) content) for estimating potato N status.

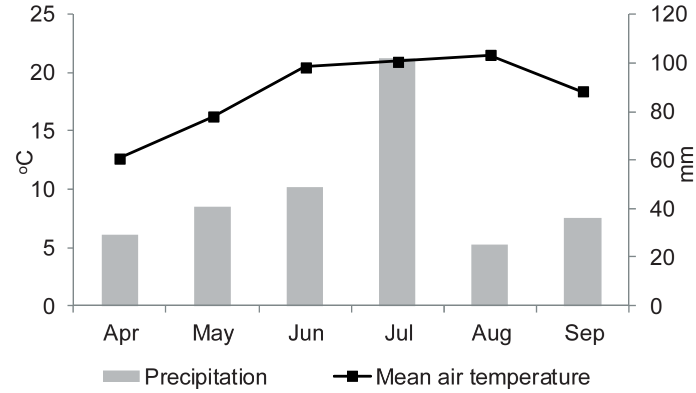

Figure 1. The mean air temperature (line; °C) and sum of precipitation (bars; mm) during the potato vegetation period at the experimental field

Materials and methods

Field experiment was conducted in North West region of Croatia in 2011 growing season on potato variety Sylvana. The mean air temperatures and sum of precipitation during the potato vegetation period at the experimental field are summarized in Figure 1. The experiment was set out as randomized complete block design with four replications. Before setting up the experiment, soil samples from the Ap horizon (30 cm) were collected from the experimental site and the physical and chemical analysis of the soil was performed (Table 1). Fully sprouted tubers were planted on 4 April 2011, with 0.75 m between row space and 0.33 m within row space. The size of each experimental plot was 36 m^2. N treatments of 50, 100, 150 and 200 kg N ha^{-1} were obtained by pre-plant fertilization with 50 kg N ha^{-1} (applied as NPK 7:20:30) and by N side-dressing at rates: 0, 50, 100 and 150 kg N ha^{-1} (applied as calcium ammonium nitrate (27%) 45 days after planting (DAP). Chlorophyll content index (CCI) and petiole NO_3-N concentrations were measured by Chlorophyll content meter (CCM-200 by Opti-Sciences, Inc.) and Cardy twin nitrate meter (Spectrum Technologies, Inc.), respectively. Soil mineral nitrogen (N_{min}) contents, CCI and petiole NO_3-N concentrations were determined at 58 and 98 (DAP). Average soil samples were collected from the Ap horizon to depth of 25 cm. All measurements were performed on youngest fully developed leaves from the main stem (4th or 5th leaf from the top of the canopy) collected from 30 plants from two middle rows per experimental plot. Fresh tuber yield was calculated by harvesting two middle rows of each plot on 14 September 2011. Tuber diameter was used for classification of tuber size. Tubers >5.0 cm were classified as first class, while tubers between 5.5 and 3.5 cm were classified as second class. After harvest, soil samples (25 cm) were collected and analyzed for determination of the residual N_{min}.

Table 1 Physicochemical properties of the soil used in the study

Sand[a] (%)	Silt[a] (%)	Clay[a] (%)	pH[b]		C_{org}[c] (%)	N_{min}[d] (kg ha^{-1})	K_2O[e] (mg 100 g^{-1})	P_2O_5[e] (mg 100 g^{-1})
			H_2O	KCl				
12.1	77.3	10.6	6.01	4.97	1.53	50.56	23.45	16.45

Basic soil characteristics were determined by standard methods: [a]Soil particle size distribution was determined by pipette-method with sieving and sedimentation (HRN ISO 11277:2004); [b]pH in H_2O and in 1 M KCl potentiometrically (1:2.5) (HRN ISO 11464:2006); [c]Organic carbon content (C_{org}) according to Tjurin (JDPZ 1966); [d]Mineral nitrogen is sum of nitrate and ammonium nitrogen ($N_{min} = NO_3$-N + NH_4-N determination of nitrate and ammonium in field-moist soils by extraction with KCl solution (HRN ISO 14256-2:2009) [e]Potassium and phosphorus by ammonium lactate method in accordance with Egner-Riehm-Domingo (Egner et al. 1960); Results are means from 24 soil samples.

Data were analyzed using the SAS system for Windows 9.2 (SAS Institute Inc., Cary, NC, USA, 2002). Polynomial regression was used to analyze the response of dependent variables (CCI, petiole sap NO_3-N concentrations and soil N_{min} content) versus nitrogen treatments, at different measurement time (DAP). Regression coefficients were tested for significance and best-fitted equation was selected for each dependent variable at each measurement time. Analysis of variance was performed for yield and residual N_{min} and Tukey's Honestly Significant Difference Test was used for comparison of the mean values.

Results

First class, second class and total tuber yields of potato are presented in Table 2. Total tuber yield, first and second class tuber yields of potato were significantly affected by rate of nitrogen application. Significantly lowest total tuber yield was determined on plots fertilized with 50 kg N ha^{-1}, while no significant difference in total tuber yield were determined between treatments with 100, 150 and 200 kg N ha^{-1}. Significantly higher first class tuber yield was determined on 200 kg N ha^{-1} treatment, compared to 50 and 100 kg N ha^{-1} treatments. Significantly higher second class tuber yield was determined on 100 kg N ha^{-1} treatment, compared to 150 and 200 kg N ha^{-1} treatments.

After polynomial regression analysis, the linear regression was selected for describing relationships between CCI, petiole sap

Table 2. First class, second class and total tuber yield of potato (t ha^{-1})

N (kg ha^{-1})	Tuber yield (t ha^{-1})		
	1st class	2nd class	total
50	21.17c	3.84ab	25.01b
100	23.06bc	4.3a	27.36a
150	24.48ab	3.39b	27.87a
200	25.92a	3.16b	29.08a
LSD (Tukey's HSD test)	1.97	0.80	1.93

1st class are tubers >5.0 cm, 2nd class are tubers 5.5 - 3.5 cm. Different letters denote significant differences between N treatments. Means with the same letter are not significantly different (Tukey's HSD test P < 0.05).

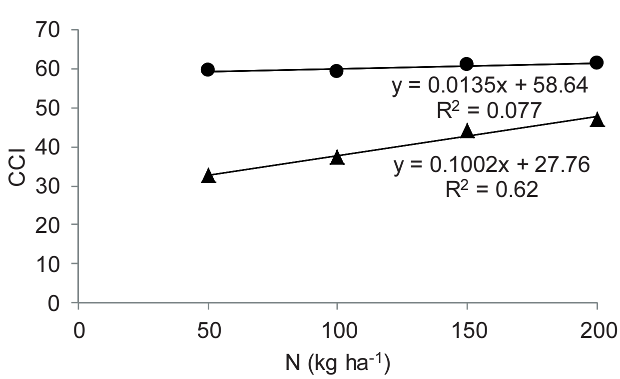

Figure 2. Relationship between nitrogen applied and leaf chlorophyll content index (CCI) of potato at 58 (●) and 98 (▲) day after planting

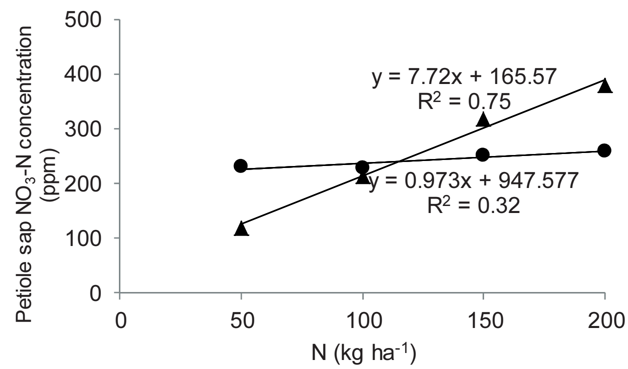

Figure 3. Relationship between nitrogen applied and petiole sap nitrate nitrogen (NO_3-N) concentrations of potato at 58 (●) and 98 (▲) day after planting

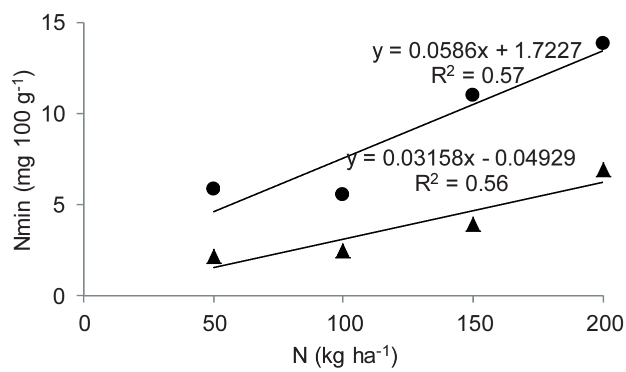

Figure 4. Relationship between nitrogen applied and soil mineral nitrogen content (N_{min}) of potato at 58 (●) and 98 (▲) day after planting

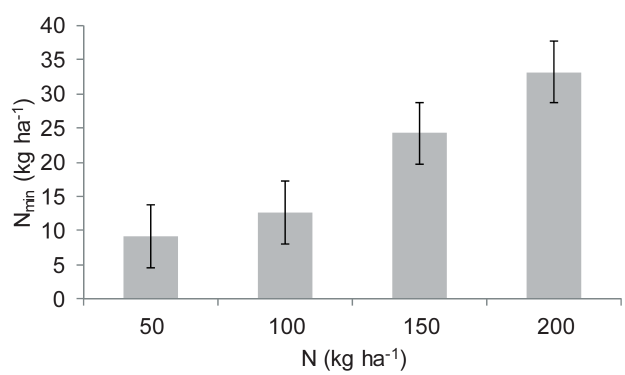

Figure 5. Residual mineral nitrogen (N_{min}) in soil after potato harvest. Bars represent mean values (n = 4 replicates), error bars represent LSD (Tukey's HSD test) = 4.53

NO_3-N concentration and soil N_{min} content with nitrogen treatments. There was a significant linear relationship between CCI and N treatments at 98 DAP (R^2=0.62) (Figure 2) and between petiole sap N-NO_3 concentrations and N treatments at 58 DAP (R^2=0.32) and 98 DAP (R^2=0.75) (Figure 3). Significant linear relationship between soil N_{min} contents and N treatments were determined at 58 (R^2=0.57) and 98 DAP (R^2=0.56) (Figure 4).

Table 3. Correlation coefficients among yield, yield classes, leaf chlorophyll content index, petiole sap nitrogen concentrations and soil nitrogen content

Parameter	CCI 1	NO_3-N 1	N_{min} 1	CCI 2	NO_3-N 2	N_{min} 2	2nd yield	1st yield	Total yield
CCI 1	–	$0.442^{n.s.}$	$0.374^{n.s.}$	$0.450^{n.s.}$	$0.255^{n.s.}$	$0.397^{n.s.}$	$0.089^{n.s.}$	$0.087^{n.s.}$	$0.119^{n.s.}$
NO_3-N 1		–	0.613^{*}	0.693^{**}	0.634^{**}	$0.382^{n.s.}$	$-0.197^{n.s.}$	$0.439^{n.s.}$	$0.409^{n.s.}$
N_{min} 1			–	0.628^{**}	0.637^{**}	0.569^{*}	$-0.380^{n.s.}$	0.670^{**}	0.600^{*}
CCI 2				–	0.756^{**}	0.514^{*}	$-0.212^{n.s.}$	0.546^{*}	0.519^{*}
NO_3-N 2					–	0.615^{*}	$-0.189^{n.s.}$	$0.323^{n.s.}$	$0.287^{n.s.}$
N_{min} 2						–	$-0.141^{n.s.}$	$0.405^{n.s.}$	$0.389^{n.s.}$
2nd yield							–	$-0.358^{n.s.}$	$-0.079^{n.s.}$
1st yield								–	0.959^{**}
Total yield									–

CCI 1: leaf chlorophyll index on 58 day after planting, CCI 2: leaf chlorophyll index on 98 day after planting, NO_3-N 1: petiole sap nitrogen concentrations on 58 day after planting, NO_3-N 2: petiole sap nitrogen concentrations on 98 day after planting, N_{min} 1: soil mineral nitrogen content on 58 day after planting, N_{min} 2: soil mineral nitrogen content on 98 day after planting, 1st yield: first class yield (tuber diameter >5.0 cm), 2nd yield: second class yield (tuber diameter 5.5 - 3.5 cm), Tot. yield: total tuber yield, n.s.: not significant, *: significant with P < 0.05, **: significant with P < 0.01.

Residual soil mineral nitrogen (N_{min}), remained after harvest, is presented in Figure 5. Statistically highest residual N_{min} content was determined on 200 kg N ha^{-1} treatment. No significant differences in residual N_{min} were determined between 50 and 100 kg N ha^{-1} treatments.

Correlations among investigated characters relating to total yield, 1st class yield, 2nd class yield, leaf chlorophyll content index, petiole nitrate nitrogen concentrations, and soil mineral nitrogen contents are presented in Table 3. There were significant correlations among soil and plant based nitrogen tests. At first measurement time (58 DAP) significant correlation between soil N_{min} content and petiole sap NO_3-N concentration was found (r=0.613). Stronger correlation between soil and plant based N tests were found at second measurement time (98 DAP), r=0.514 and r=0.615, for soil N_{min} content x CCI and soil N_{min} content x petiole sap NO_3-N concentration, respectively. At second measurement time (98 DAP), there was strong positive correlation between petiole sap NO_3-N concentration and CCI (r=0.756). Soil N_{min} content determined at 58 DAP significantly correlated with soil N_{min} content determined at 98 DAP (r=0.569), as well as with CCI at 98 DAP (0.628) and with petiole sap NO_3-N concentration at 98 DAP (r=0.637). First class yield and total yield significantly correlated with soil N_{min} contents at first measurement time (r=0.670 and r=0.600, respectively) and with CCI at second measurement time (r=0.546 and r=0.519, respectively).

Discussion

Increasing N fertilization rates increased total tuber yield of potato, but significant differences were obtained only for 100, 150 and 200 kg N ha^{-1} compared to 50 kg N ha^{-1}. The absence of significant difference in total tuber yield among treatments with 100, 150 and 200 kg N ha^{-1} can be explained by significantly higher second class tuber yield obtained on 100 kg N ha^{-1} when compared to 150 and 200 kg N ha^{-1} (Figure 2). As in our experiment, Majić et al. (2008) have also reported absence of significant difference in total tuber yield between 100 and 200 kg N ha^{-1} fertilization rate. No significant differences in 1st, 2nd class and total tuber yield were determined between 150 and 200 kg N ha^{-1}. On the other hand, significantly highest residual N_{min} was determined on plots fertilized with 200 kg N ha^{-1}, indicating potential nitrate leaching during fall and winter. The linear regression equations explain relationships between CCI, petiole sap NO_3-N concentration and soil N_{min} content with nitrogen treatments. The strongest correlation (R^2=0.75, P<0.001) was found between N rates and petiole sap NO_3-N concentrations on 98 DAP. Wu et al. (2007) reported that petiole sap NO_3-N concentrations are better in detection of N treatment differences compared to CCI values, later in the season. Absence of stronger correlation between N rates and petiole sap NO_3-N concentration, earlier in the season (58 DAP, R^2=0.32, P=0.0224) could be explained by very low precipitation during April-July period (Figure 1). Low precipitation, which caused low nitrogen uptake by crop and/or low leaching rates of nitrates in the soil, could be the reason of similar correlations between N rates and soil N_{min} contents obtained at 58 DAP and 98 DAP (R^2=0.57, P=0.0007 and R^2=0.56, P=0.0009, respectively). Absence of significant correlation between N rates and CCI values early in the season (58 DAP, R^2=0.077, P=0.2973), can be explained by high soil N_{min} content at the planting (50.56 kg N ha^{-1}, Table 1). Gianquinto et al. (2004/5) stated that chlorophyll meter reading reacts poorly to fertilizer application, mainly at early sampling dates, due to either natural nitrogen abundance or nitrogen-rich residues of a previous crop. In addition, the relationship between chlorophyll meter readings and crop yield may be weak or absent (Gianquinto et al. 2004/5), which also proved to be true for our research (Table 3). Later in the season (98 DAP) strongest correlation was found between CCI and total tuber yield, and between CCI and 1st class tuber yield. Similar results were obtained by (Majić et al., 2008; Poljak et al. 2008). Overall, total tuber yield and 1st class tuber yield are in strongest correlation with N_{min} content at earlier growth stages (58 DAP) (Table 3).

Conclusions

Potato is inefficient in uptake and use of N fertilizers, especially in unfavorable environmental conditions. Soil N_{min} content is better indicator of N fertilization in the early stages of vegetation, while plant based tests are better correlated with N treatments at later growth stages in which applied N could be utilized by the crop. When compared two plant based tests, stronger linear relationship were found between petiole N-NO_3 and N treatments compared to CCI and N treatments. Due to the significant impact of environmental factors on the uptake and use of N fertilizers, further longer lasting researches in this area are needed.

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