Identification of genotypic variation for nitrogen response in potato (*Solanum tuberosum*) under low nitrogen input circumstances

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Keywords:
Nitrogen use efficiency, selection criteria, tuber yield

Introduction

Nitrogen is an essential nutrient for crop growth. The demand for nitrogen in the potato crop is relatively high. However, in organic farming nitrogen input is rather limited, compared with conventional farming. Möller et al. (2007) stated that in organic potato growing nitrogen availability is one of the most important yield limiting factors. They developed a model which in total accounted for 73% of the observed variation in yield. Almost half of the variation (48%) could be explained by differences in nitrogen availability. The organic nutrient management is based on crop rotations, solid and liquid animal manures, green manures and compost (Finckh et al., 2006). The release of nitrogen from most of these fertilizers is slow and highly dependent on soil moisture and soil temperature affecting mineralization processes (Van Delden, 2001). Therefore, nitrogen management in organic production systems is difficult. The lack of adequate and stable nitrogen supply leads to agronomic uncertainties. Modern potato varieties cannot cope well with these circumstances. They require large quantities of nitrogen to maintain vegetative growth and productivity throughout the growing season (Vos, 1997). Organic potato varieties should be adapted to low and variable nitrogen availability to ensure yield stability.

Nitrogen supply affects an array of physiological processes and morphological traits of the potato crop. These include (1) the rate of canopy development, (2) the rate of leaf appearance, the rate of individual leaf growth, final leaf size, and the life span of individual leaves, (3) the integral of light interception by the crop over time, (4) the rate of photosynthesis, (5) the number of lower and sympodial branches, and (6) the onset of tuberization, final tuber yield and final harvest index (Biemond & Vos, 1992: Ewing & Struik, 1992; Vos & Biemond, 1992; Vos, 1995; Vos & MacKerron, 2000). Nitrogen supply may also affect quality aspects including tuber size distribution, tuber dry matter content, protein content, nitrate content and processing quality (Van Kempen et al., 1996). Studies with high levels of input and contrasting fertilization regimes showed differences in nitrogen use efficiency (NUE). These effects were mainly associated with differences in maturity type (Van Kempen et al., 1996). However, very little quantitative information is available about genotypic differences in response to nitrogen under low levels of nitrogen. Van Delden (2001) mentioned differences in the sensibility to nitrogen shortages between the varieties Junior and Agria. Also breeders and organic farmers experience large genotypic variation in the response to low levels of nitrogen. However, there are no detailed studies into genetic variation for NUE among modern potato varieties used in Europe and its underlying physiological mechanisms and genetic background.

Models are developed for the optimization of nitrogen application rate for optimum performance of varieties (Neeteson and Wadman, 1987). To the best of our knowledge, no research is done on the opposite research question: Given a low and variable nitrogen availability, what kind of genotype will be able to perform well? To answer that question one has to understand the physiological mechanisms behind NUE of potatoes under low and variable nitrogen supply. Up to now there is little information about the genetics of NUE and physiological and morphological characteristics associated with NUE in potato. In this paper we will identify genotypic differences in nitrogen response under low nitrogen input.

Description

In 2008 nine potato varieties were tested at three nitrogen levels. One experiment was at a clay location and conventionally treated. The other experiment was at a sand location and organically managed. See table 1 for the details.

Table 1. Details experimental fields 2008.

	Clay	Sand
Management	Conventional	Organic
Total Nitrogen supply (kg N/ha)	5006	5471
Available mineral nitrogen (0-60) (kg/ha)	90	90
P-PAE (kg P/ha)	6.5	8.5
Potassium (kg K/ha)	314	277
Magnesium (kg Mg/ha)	387	563
Sodium (kg Na/ha)	49	37
Manganese (kg Mn/ha)	< 1	10.5
Cupper (kg Cu/ha)	0.23	0.17
Cobalt (kg Co/ha)	< 0.01	0.03
Borium (kg B/ha)	0.88	0.50
Zinc (kg Zn/ha)	< 0.4	1.7
C-total (kg C/ha)	53040	85680
Organic matter (%)	2.0	3.6

The varieties used in the experiments are in order of maturity (from early to late) Agata, Leoni, Biogold, Santé, Bionica, Fontane, Terragold, Agria and Spirit. At the end of March soil samples were taken (0-30 and 30-60 cm) to assess the mineral nitrogen content. With the NDICEA model (Van der Burgt et al., 2006) the availability of mineral nitrogen was assessed at 90 kg/ha during the growing season (half of April till half of August). The NDICEA model takes also into account: soil type, pre-crops, prior application of organic manures and green manures.

The fertilizer nitrogen application rate we used was 0, 60 and 210 kg N/ha, which resulted in 90 (N1), 150 (N2) and 300 (N3) kg available mineral nitrogen per hectare. At the conventional field Kalkammonsalpeter was used as fertilizer. At the organic field we used feathermeal.

The seed tubers were chitted and planted in ridges of 75 cm wide with a plant distance within the row of 30 cm. See table 2 for planting and harvest time.

The experiment was a randomized split-plot design with four replicates, with the fertilizer nitrogen application rate as whole plot and the varieties as the sub-plots. The plots were 4 ridges wide and 32 plants long (3.0 × 9.6 m). The plants in the middle two rows were used for the observations and (intermediate) harvests.

Table 2. Planting and harvest time.

Location	Clay	Sand

Planting time	23 April	22 April
First harvest	30 June (68 DAP*)	18 June (57 DAP)
Second harvest (only haulms)	19 July (84 DAP)	26 June (66 DAP)
Third harvest	28 July (96 DAP)	7 July (77 DAP)
Foliage killing	15 September (145 DAP)	1 August (100 DAP)
Final harvest	24 September (154 DAP)	13 August (112 DAP)

* DAP = Days After Planting

At the sand location the foliage was destroyed by burning on the first of August because of late blight (*Phytophthora infestans*) infestation. In the Netherlands the canopy of the potato crop has to be destroyed at an infestation level of approximately 7% (HPA regulation, 2003). The crop at the clay location was protected against late blight by regular spraying.

The soil cover was assessed twice a week with a counting frame with 100 squares. Each square that was filled for more than 50% with foliage was counted as 1% soil cover. We surmised that some of the parameters (a to d; see figure 1) in the soil cover curve could be correlated with nitrogen efficiency under low input conditions.

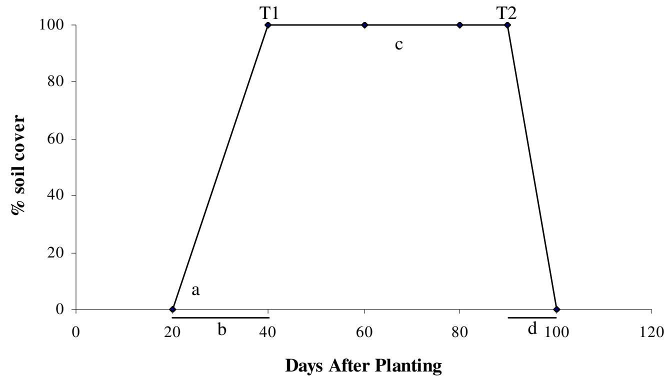

Figure 1. Soil cover curve with the parameters a, b, c and d (Vos & MacKerron, 2000).
a = rate of soil cover (%/day); b = time to reach maximum soil cover (days); c = length of period with maximum soil cover (T2-T1) (days); d = time from maximum soil cover to complete haulm death (days).

Destructive analyses of plants were made on eight occasions, four times per location (see table 2). At the intermediate harvests a sample consisted of six plants, at the final harvest sample size was 16 plants. The whole plants (except at the final harvest when the foliage was dead) and the tubers (except for the second harvest) were harvested. The measurements included number of stems, fresh and dry weight of stems, leaves and tubers and leaf area. After drying (70 ºC for 72 hours) and weighing samples were ground. The samples were analyzed for total nitrogen (N-Kjeldahl) and nitrate.

Results

The results presented here are preliminary because they are of one year. In 2009 the experiments will be repeated. Under Dutch organic conditions a potato crop must produce its yield within 100 days maximum, because of infection by late blight. Therefore, we present in this paper the results of the clay location of the third intermediate harvest (96 DAP) instead of the final harvest, to stay closer to organic practice.
On both locations we found significant genotypic variation at the lowest N level for yield, Leaf Area Index (LAI) and the period of maximum soil cover (T2-T1) (table 3). The LAI is the total green leaf area in square meters above one square meter soil. At the clay location, a genotype × N-level (G×N) was found (results not shown). Different ranking of the varieties

was observed at the three nitrogen levels. At the sand location we observed no G×N interaction.

Table 3. Yield, Leaf Area Index (LAI) and period of maximum soil cover (T2-T1) at the N1-level (90 kg/ha) at the clay location and the sand location.

	Clay location (96 DAP)			Sand location (100 DAP)		
Variety	Yield Mg/ha	LAI (84 DAP) m^2/m^2	T2-T1 Days	Yield Mg/ha	LAI (65 DAP) m^2/m^2	T2-T1 Days
Agata	51.5 cd*	1.51 a	27.5 bc	52.1 c	3.56 b	23.3 a
Leoni	46.4 abc	1.95 ab	24.3 ab	41.3 a	3.65 b	25.3 a
Biogold	39.8 a	1.51 a	21.5 ab	45.7 ab	3.30 b	28.5 ab
Santé	47.4 abcd	2.51 bc	35.5 cd	52.6 c	3.79 bc	35.3 bc
Bionica	43.43 ab	1.65 ab	17.3 a	41.3 a	2.49 a	22.8 a
Fontane	51.3 cd	2.61 bc	42.5 d	46.5 b	4.70 c	38.3 c
Terragold	55.0 d	2.50 bc	30.3 bc	51.8 c	3.02 ab	27.0 a
Agria	47.6 bcd	2.93 c	43.0 d	48.0 bc	3.56 b	35.0 bc
Spirit	49.7 bcd	2.35 abc	42.8 d	50.5 bc	2.93 ab	38.3 c
Lsd ($P<0.05$)	7.8	0.91	9.8	5.1	1.03	7.6

* different letters within a column indicate significant differences between varieties

Table 3 shows that at the clay location Biogold gave the lowest yield (39.8 Mg/ha), whereas Terragold produced most (55.0 Mg/ha). The yield of Agata was similar to the yield of Terragold, but Agata realized this with a much lower LAI at 84DAP. T2-T1 was not significantly different between these two varieties. The LAI and period of maximum soil cover of the varieties Leoni and Biogold were in the same range as those of Agata, but their yields were much lower. Bionica had a low yield, a low LAI and a short period of maximum soil cover.
At the sand location Bionica and Leoni produced the lowest yields. The LAI of Leoni however, was higher than the LAI of Bionica, whereas T2-T1 was the same for the two varieties. The yields of Agata and Terragold were high unless a relatively moderate LAI and short period of maximum soil cover, whereas Santé, with the same yield, had a relatively high LAI and a long period of maximum soil cover. Fontane had the highest LAI and the longest period of maximum soil cover, but the yield was quite moderate.

Table 4 shows the ratio of yield, LAI and T2-T1 of the N1 and N3 level (N1/N3). We assumed that at the N3 level the maximum attainable yield of the varieties at these locations was reached. The ratio between N1 and N3 reflects to some extent the sensitivity of the varieties for N-shortage.

Table 4. N-uptake at the N1 level and the ratio of yield, Leaf Area Index (LAI) and period of maximum soil cover (T2-T1) at the N1-level and the N3-level (N1/N3).

	Clay location (96 DAP)				Sand location (100 DAP)			
Variety	N-uptake kg/ha	Yield	LAI	T2-T1	N-uptake kg/ha	Yield	LAI	T2-T1
Agata	100.8ab*	0.68 ab	0.43 abc	1.03	142.1 ab	0.85	0.63	0.94
Leoni	106.2ab	0.76 bc	0.50 bcd	0.88	120.1 a	0.84	0.62	0.95
Biogold	97.2a	0.56 a	0.36 ab	0.83	143.6 ab	0.87	0.68	0.92
Santé	99.9ab	0.75 bc	0.34 a	0.78	158.4 b	1.00	0.65	0.80
Bionica	95.4a	0.77 bc	0.54 bcd	0.82	143.8 ab	0.84	0.67	0.83

Fontane	123.3c	1.00 d	0.44 abc	0.97	148.8 b	0.87	0.83	1.07
Terragold	124.2c	0.91 cd	0.60 d	0.78	147.4 ab	0.91	0.75	0.67
Agria	117.0c	1.01 d	0.55 cd	1.22	152.1 b	0.91	0.65	0.84
Spirit	114.3bc	0.97 d	0.41 abc	0.98	157.9 b	0.91	0.60	0.87
Lsd ($P<0,05$)	16.2	0.17	0.16	ns	27.5	ns**	ns	ns

* different letters within a column indicate significant differences between varieties, ** ns is not significant

At the clay location the nitrogen uptake of the more late varieties was higher than of the early varieties. At the sand location this phenomenon was less clear. At the clay location N-shortage sensitivity showed genetic variation. The early cultivars seemed more sensitive to N-shortage than late varieties. Biogold and Agata produced 30-45 % less at the N1 level, compared with the N3 level. For the varieties Leoni, Santé and Bionica this was 25%. The yields of the later varieties were the same at both N-levels. The LAI decreased with an average of 40% with the decrease in nitrogen availability from the N3 level to the N1 level. There was no clear contrast between early and late varieties in the extent to which LAI decreased, like was the case for yield. Santé, Biogold and Spirit showed the largest decrease and Terragold and Agria the smallest. At harvest time (96 DAP) the period of maximum soil cover was not affected by the decrease of nitrogen application. In the period between the third and final harvest the period of maximum soil cover was prolonged by a higher level of nitrogen application (data not shown).
At the sand location also sensitivity to N-shortage was found. At the lowest nitrogen level the LAI, T2-T1 and yield were decreased with respectively 33, 13 and 11%, compared to the highest nitrogen level. However, no genetic variation for N-shortage sensitivity was found at the sand location.

Nitrogen efficiency can be dissected into nitrogen uptake efficiency (kg/ha N-uptake/ kg/ha N-application) and nitrogen use efficiency (kg/ha yield/ kg/ha N-uptake). Table 5 compares the varieties on the basis of their different efficiencies at the N1-level.

Table 5. Nitrogen Uptake Efficiency, Nitrogen Use Efficiency and total nitrogen efficiency at the N1 level at the clay location and the sand location.

	Clay location (96 DAP)			Sand location (100 DAP)		
Variety	Nitrogen Uptake Efficiency (N uptake (kg/ha)/ N supply (kg/ha))	Nitrogen Use Efficiency (yield (kg/ha)/N uptake (kg/ha))	Total Nitrogen Efficiency (N Uptake Efficiency × N Use Efficiency)	Nitrogen Uptake Efficiency (N uptake (kg/ha)/ N supply (kg/ha))	Nitrogen Use Efficiency (yield (kg/ha)/N uptake (kg/ha))	Total Nitrogen Efficiency (N Uptake Efficiency × N Use Efficiency)
Agata	1.12 ab*	515 d	403 ab	1.58 b	370 c	579 de
Leoni	1.18 abc	437 ab	343 a	1.33 a	345 bc	459 a
Biogold	1.08 a	410 ab	351 ab	1.60 b	317 ab	507 b
Santé	1.11 ab	479 cd	383 ab	1.76 b	332 b	584 e
Bionica	1.06 a	452 bc	347 ab	1.60 b	287 a	459 a
Fontane	1.37 d	420 ab	365 ab	1.65 b	315 ab	516 bc
Terragold	1.38 d	443 abc	408 b	1.64 b	351 bc	575 de
Agria	1.30 cd	407 a	349 ab	1.69 b	315 ab	533 bcd
Spirit	1.27 bcd	437 abc	374 ab	1.75 b	325 b	560 cd
Lsd ($P<0,05$)	0.18	42	62	0.19	37	47

* different letters within a column indicate significant differences between varieties

At the clay location only minor significant differences were found between the varieties for total nitrogen efficiency. Terragold was more efficient than Leoni. However, there was significant genotypic variation for N-uptake efficiency and N-use efficiency. The late varieties seemed more efficient in N-uptake than the early varieties under low input circumstances. Such a contrast between early and late varieties was not observed for N-use efficiency. The varieties Agata and Santé seemed to be the most efficient varieties in N-use. At the sand location we found genotypic variation for total N efficiency. The varieties Agata, Terragold, Santé and Spirit were the most nitrogen efficient. Agata was efficient because of a very high N-use efficiency. Santé and Spirit had a very high N-uptake efficiency, whereas Terragold was moderately efficient for both N-uptake and N-use. The least efficient variety was Leoni, due to a very low efficiency for N-uptake.

Discussion and conclusion

We found genotypic variation for yield, leaf area index, period of maximum soil cover, sensitivity for N-shortage and nitrogen efficiency under low input circumstances. However, in these experiments varieties differed in their strategies to maximize tuber production under low nitrogen availability. We hope to gather more data while repeating the experiments in 2009, to be able to identify morphological traits that are associated with nitrogen use efficiency under low input circumstances.

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