Impact of enhanced-efficiency fertilisers on potato productivity in a temperate cropping system

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ABSTRACT

Nitrification inhibitors are intended to improve the productivity of agricultural crops, however there is limited data available on the efficacy of this approach in potato crop production. A field experiment was carried out in temperate Australia to compare the effect of standard commercial fertiliser nitrogen (N) management with fertiliser treated with two nitrification inhibitors, 3,4-dimethylpyrazole phosphate (DMPP) and 1H-1,2,4-triazole and 3-methylpyrazole (3MP+TZ) on potato productivity and soil N dynamics for three irrigation regimes. Despite evidence of increased soil ammonium (NH_4^+) concentrations in the DMPP and 3MP+TZ treatments, crop yield and quality parameters (tuber number, average tuber size, potato specific gravity, three tuber size classes and grade yields) were similar across treatments. Further, DMPP and 3MP+TZ treatments did not reduce either the concentration or the flux of nitrate leached. These findings suggest that further research into the agronomic benefits of nitrification inhibitors for potatoes grown in cool temperate regions is needed.

Additional keywords: vegetable crops, soil ammonium, soil nitrate, temperate climate, Ferrosol.

Introduction

The demand for potato (*Solanum tuberosum* L.) makes it the fourth most important cultivated food crop in the world (Burlingame *et al*., 2009; FAOSTAT, 2013). Compared to other cultivated crops, high yields of potato require high water and nitrogen (N) inputs (Darwish *et al*., 2006; Vashisht *et al*., 2015). This high N demand is illustrated in Tasmania, Australia by N fertiliser application rates ranging between 279 to 442 kg N/ha albeit, modelling suggests that the average surplus to crop demand is on average 89 kg N/ha (Lisson *et al*., 2011).

Excessive fertilizer use increases the risk of environmental pollution, in particular, groundwater pollution via the leaching of nitrate (NO_3^-) and release of the greenhouse gas nitrous oxide (N_2O) (Ongley, 1996; Chen *et al*., 2008). Therefore, novel field management practices are needed to improve fertiliser use efficiency and to minimize environmental risk (Zebarth *et al*., 2012). The use of new technologies such as enhanced efficiency fertilisers with formulations that include nitrification inhibitors (NIs) (Chen *et al*., 2008; Scheer *et al*., 2017) is one potential practice that may mitigate N losses to the environment.

NIs developed for soil application aim to slow the conversion of ammonium ($NH4^+$) to NO_3^- by inhibiting the bacterial enzyme, ammonium monooxygenase, thereby blocking the first step of nitrification, i.e. the oxidation of NH_4^+ to nitrite (NO_2^-) (Subbarao *et al*., 2006). As such, NIs can give the crop a longer opportunity to absorb nitrate when required and thereby increase N-use efficiency. NIs have shown been to reduce nitrate leaching, which can be intensified by excessive rain or irrigation as well as by use of N fertiliser levels that are surplus to crop requirements (Diez-Lopez *et al*., 2008; Li et *al*., 2008). A meta-analysis of the effects of NIs in agricultural systems at the field scale found that NIs reduced N_2O emissions by an average of 38%, and nitric oxide (NO) emissions by 65%

compared with those of conventional fertilizers for upland field, grassland, and paddy field land-use types (Akiyama *et al*., 2010).

Apropos to agronomic benefits, NIs have been reported to increase, decrease or have no significant effect on yield for a range of crops including broccoli (Sheer *et al*., 2014), lettuce-cauliflower (Pfab *et al*., 2012), broccoli-lettuce-cauliflower rotation (Riches *et al*., 2016), lettuce (Scheer *et al*., 2016) and green bean-sorghum-broccoli-lettuce rotation (Scheer *et al*., 2017). In a recent meta-analysis, Abalos *et al*. (2014) found an average yield increase of 4% (95% confidence limits 2–7.5%) for NIs based on 62 comparisons from 16 studies of cereals, vegetable/industrial and forage crops. In general, the effectiveness of NIs in improving crop productivity has been shown to vary with soil temperature, texture and moisture, type of NI, and field management practices such as water management (Scheer *et al*., 2014; Akiyama *et al*., 2015).

Similarly, yield responses to NIs are reported to be variable in potato, with detrimental effects in some cases (Pasda *et al*., 2001; Kelling *et al*., 2011). This negative response has been related to the potato's sensitivity to NH_4^+ (Prasad & Power, 1995). The majority of the studies in potato have focused on crops grown in sandy soils and there remain uncertainties about the impact of NIs on N utilization and agronomic performance of temperate potato production in clay and loam soils. Clay soils containing high proportions of clay particles have a higher affinity for water than coarser-textured soils, which may influence N mineralization rates (Pelster *et al*., 2012).

In addition to N, potato also has a high demand for water, particularly during the tuber bulking stage (van Loon, 1981). Over the growing season in north-west Tasmania, 350 and 450 mm/ha of water is applied via irrigation (Cotching, 2012). Previous studies that examined the impact of N and water management in potato have shown that site-specific N and water management can be used to better synchronize the supply and demand of N, even without the use of NIs (Darwish *et al*., 2006; Gao *et al*., 2017). Chen *et al*. (2008) argue that the aim of better water management should be to ensure that the water-filled pore space of the soil does not exceed 60% to limit denitrification and NO_3^- leaching and thereby improve N use efficiency. The effects of NIs, as modified by water management, on both potato productivity and NO_3^- leaching have rarely been studied.

The objective of this research was to compare the effect of two enhanced-efficiency fertilisers (DMPP (3,4-dimethylepyrazole phosphate, as ENTEC®, Incitec Pivot, Australia) and 3MP+TZ (1H-1,2,4-triazole and 3-methylpyrazole, Piadin®, SKW Piesteritz, Germany) with standard commercial fertiliser N (NH_4^+ and urea) on potato productivity under three irrigation regimes. The selected irrigations regimes aimed to determine if reduced irrigation volumes could reduce NO_3^- leaching below the effective root zones whilst maintaining yield. The main hypothesis of this study was that both NI treatments would increase potato productivity (as indicated by crop yields and yield parameter measurements) more than standard commercial fertiliser N by enhancing retention of soil NO_3^- by minimising the potential for leaching. The results aim to help growers make informed decisions on the use of NIs in intensively managed potato production systems in temperate Australia.

Materials and methods

Field site

The trial was established at ‘Forthside’, an experimental farm in the north west of Tasmania, Australia (41°13’S, 146°16’E). The site has a long cropping history including potatoes, onions, peas, beans, brassica species, carrots, barley and poppies (Sparrow, 1999). The soil is a red Ferrosol (Australian Soil Classification; Isbell, 2002). The soil profile was described and classified according to McDonald *et al*. (1990), with chemical analysis conducted by AgVita Analytical Pty Ltd, Tasmania. The A1 horizon (0-30 cm) consisted of a red to brown silty clay loam, with a pH_{CaCl2} of 5.8, an organic carbon content of 4.7%, %N contents of 0.36% and phosphorus (P; Bray) 16.7 mg/kg, while the particle size analysis was 21.7% clay, 50% sand, and 28.3% silt.

North-west Tasmania is characterized as a high rainfall temperate climate with an annual mean precipitation of 1152 mm (Bureau of Meteorology, 2015). Rainfall, maximum and minimum temperatures, and pan evaporation data were collected from the Bureau of Meteorology weather station located on the farm 100 m from the crop. During the potato crop season (from November to April), the mean maximum and minimum temperatures of the 30-year period 1981–2010 were 19.3 °C and 10.1 °C, respectively.

Experimental design, plant material and management practices

The experiment was laid out over 0.7 ha using a split plot design of three irrigation rates (main plots x 3 blocks) and three fertiliser regimes (a total of 27 subplots). Each plot was 10 m wide and 8 m in length, containing 5 beds of 2 rows (67 plants). Five meter row buffers were left between each plot to avoid confounding fertiliser treatments, with buffers between main plots consisting of an entire irrigation bay. On 15 September 2014, Tranzflo® passive-wick flux meters (Green *et al*., 2012) were installed in each subplot such that a total of 27 flux meters were used to measure nutrient leaching from the base of the A1 horizon at a soil depth of 50 cm.

Potato seed (*cv.* Russet Burbank) provided by Agronico Technology Pty Ltd. (Leith, Tasmania) and treated with thyabendazole (Storite ®) and imazalil (Magnate ®) at 2 L tonne^{-1} for *Fusarium* and Pronatural® + cement at 40 kg per 20 kg of potato was planted on 31 October 2014. The soil was rotary hoed to a depth of 30 cm prior to intallation of the flux meters.

The irrigation treatments included 100% (IR100), 85% (IR85), and 70% (IR70), of the recommended schedule based on crop development i.e. 25 mm/week from 35 to 63 days after planting (DAP), 40 mm/week from 63 to 98 DAP and 25 mm/week from 98 to 140 DAP. The irrigation treatment IR85 was determined by subtracting accumulated weekly rainfall (276 mm total for season) from accumulated weekly pan evaporation (599 mm total for season) obtained from the Bureau of Meteorology (2015) and then multiplying by a crop factor relative to the crop stage and water requirement. For example, IR85 = (599 – 276 mm) x 1.175 (average seasonal crop factor) = 379 mm. The application volume to IR70 was 15% less than IR85. Between emergence and crop maturation, water was applied by overhead solid set sprinklers with the interval between irrigations ranging between 4 to 8 days for a total of 14 irrigation applications. The total quantity of irrigation water supplied was 448 mm (IR100), 380 mm (IR85) and 323 mm (IR 70) (Figure 1).

The three fertiliser treatments included application of untreated fertiliser(conventional; CONV), and two NI coated fertiliser treatments, DMPP and 3MP+TZ, applied separately The NIs were added at a rate of 5 L DMPP per tonne and 4 L of 3MP+TZ per tonne of fertiliser and mixed with only the NH_4^+ and urea components of the fertiliser blends. The fertiliser application rate and timing (SuppTable 1) was the same for the whole trial and based on agronomic recommendations.

Drainage collection and leachate analysis

The Tranzflo® passive-wick flux meters operate by maintaining tension on the base of an in situ soil core via a fiberglass wick (65-cm-long; ψ -6.5 kPa), which creates a self-priming hanging-water column (Gee *et al*., 2004; Gee *et al*., 2009). Percolated water was collected in the bottom half (15 cm depth) of the tube housing the wick (80 cm length in total). Installation holes were created by steel pipes of appropriate diameter driven into the soil using a hydraulic ram, to a total depth of 1.4 m from the soil surface. Flux meters were installed below 30 cm of repacked cultivated soil and a 25-cm-diameter × 20-cm-deep intact soil core from the lower A1 horizon. The intact soil core was manually rammed onto a sand/diatomaceous earth pad housed by a 10-cm high x 20 cm wide convergence ring (collar). Preferential flow was mitigated by sealing the external perimeter of the collar with clay, and by the diameter of the intact soil extending 2.5 cm beyond that of the convergence ring. Drainage samples were pumped from the flux meter reservoirs in Dec, Jan, Feb 2014 and Mar 2015. At each sampling event, leachate volume was recorded, and filtered aliquots of approximately 30 to 40 mL were subsampled and stored at -20 °C. Nitrate concentration was determined by Cd-Cu reduction according to the USEPA method 353.3 (O’Dell, 1993).

Soil sampling and chemical analyses

Soil samples from 0-10 cm soil depth were collected for NO_3^- and NH_4^+ analyses 15 times throughout the growing season (38, 47, 66, 67, 68, 69, 73, 75, 80, 81, 82, 84, 89, 91 & 166 DAP). Samples from lower soil depths (20-30 and 50-60 cm) were collected at 159 and 166 DAP. At each sampling date, eight samples were taken randomly from each replicate plot with a soil auger then combined into a bulk sample. From this, three replicate samples were taken per treatment. Soil samples were first air-dried and passed through a 2-mm sieve prior to chemical analysis (Rayment & Higginson, 1992). Soil NH_4^+ and NO_3^- were determined from 5 g of soil extracted with 50 mL of 2M potassium chloride solution on a shaker for 1 h at 200 rpm at ambient temperature and measured colorimetrically on a

Lachat QuikChem 8500 Series 2 Flow Injection Analyser (Hach Co., Loveland, CO, USA) according to the ASPAC method code 7C2a (ASPAC, 2017).

Soil moisture was measured at three soil depths, 0-10, 20-30 and 50 cm every hour in one plot per irrigation treatment (i.e. a total of 3 sensors, randomly located across the three blocks) using an Onset Hobo RX3000 with EC5 soil moisture smart sensors (Onset Computer Corporation, Notting Hill, Victoria, Australia) that were calibrated for the soil at the research site (Figure 1).

Crop yield parameters

The tubers were hand harvested from a centrally located 2 m single row in each plot on the 15 April, 2015 (167 DAP), bagged and assessed on the same day. Yield assessments included total biomass yield, number, tuber size and average tuber biomass. Tuber specific gravity was determined using the weight-in-water/weight-in-air method (fresh weight/fresh weight – displaced weight when submerged in water) using approximately 3.0 kg sample of medium-sized tubers (Dean, 1994). Tuber (< 2 cm pieces), leaf and petiole were oven dried at 65 °C for 48 hours and analysed for total N by AgVita Analytical Pty Ltd, Tasmania on an Elementar Vario Max TC/TN Analyser (Hanau, Germany) according to the ASPAC method code 7A5 (ASPAC, 2017).

Statistical analyses

All analyses were performed using Proc Mixed in SAS version 9.3 using a random effects approach. Treatment effects on yield and yield parameters were tested by analysis of variance (ANOVA) assuming a split plot layout with irrigation as the main plot factor and fertiliser treatment as the subplot. The split plot arrangement was replicated within each block. Leachate data (NH_4^+ and NO_3^- concentration, total leachate volume, total NH_4^+ and

NO_3^- content) was analysed using the same method as for yield however, the method also assumed a repeated-measures framework and a Kenward-Rogers degrees of freedom adjustment. Repeated measures were taken within each sub plot. Similarly, soil NH_4^+ and NO_3^- concentrations (sampled at 0-10 cm, 20-30 cm and 50-60 cm depths) and petiole N data were analysed using the same method however, sampling date was included in the three-way ANOVA. The assumptions of ANOVA such as homogeneity of variance and the Gaussian distribution were evaluated by examining the residuals via quantile plots. It was necessary to log transform the soil NH_4^+ and NO_3^- to normalize the residual – no transformation was required for the other variables. Tukey's method was used to compare pairs of treatments and when treatment differences were significant, with Dunnett's test used to compare the treatment means with the CONV treatment mean.

Results

Soil moistures, NH_4^+-N and NO_3^--N concentrations

Soil moisture at 0-10 and 20-30 cm depths showed similar variation patterns over time with values ranging from 0.210 to 0.303 for IR100, 0.224 to 0.313 for IR85 and 0.213 to 0.314 for IR70 at soil depth 0-10 cm, and ranging from 0.269 to 0.313 for IR100, 0.286 to 0.340 for IR 85 and 0.282 to 0.327 for IR70 at soil depth 20-30 cm (Figure 1). In contrast, there appeared to be marked treatment differences in soil moisture at 50-60 cm depth (Figure 1). In particular, during the measurement period, soil moisture for IR100 ranged from 0.287 to 0.389 – values that were much higher than observed for IR85, which ranged from 0.304 to 0.358 and IR70, 0.299 to 0.348.

At 0-10 cm soil depth, NH_4^+ concentrations varied from 4.5 to 78.5, and NO_3^- from 4.9 to 45.1 mg/kg across the different fertiliser treatments over the measurement period

(Figures 2 and 3). Mean soil NH_4^+ concentrations were significantly increased by the use of NIs (SuppTable 2) with higher concentrations being observed for both NI treatments (DMPP = 18.5 ± 1.07; 3MP+TZ = 18.7 ± 1.07) compared to conventional application (CONV = 14.7 ± 1.07 mg/kg).

In contrast, mean soil NO_3^--N concentrations (0-10 cm depth) were affected by fertiliser × date treatment (SuppTable 2) however, significant treatments effects occurred across sampling dates rather than within a single sampling date (data not presented). Although non-significant, soil NO_3^--N concentrations were at least 20% higher in the IR70 treatment (18.8 ± 1.06 mg/kg) than either the IR100 (15.5 ± 1.06 mg/kg) or the IR85 treatments (IR 85 – 15.6 ± 1.06 mg/kg) (SuppTable 2).

There were no significant differences between the fertiliser treatments at any depth on either date, except in soil NH_4^+ concentrations at 50-60 cm depth 9 DAP (SuppTable 3). In these samples, soil NH_4^+ concentrations were at least 62% higher in the NI treatments compared to the CONV treatment (Figure 4).

NO_3^--N leaching (concentration, total volume and NO_3^--N content)

Total NO_3^- leaching ranged from 0 mg from all fertiliser treatments under the IR70 irrigation treatment during the later stages of the growing season (70-150 DAP) to 90 mg from the 3MP+TZ fertiliser treatment under irrigation IR70 45 DAP. This range, and the patterns in total NO_3^- leaching from all treatments appeared to be influenced more by changes in leachate volumes over time (e.g. leachate volumes from the IR70 treatment were relatively high [5.4 L] 45 DAP and very low [0 L] 70-150 DAP; SuppFigure 2), rather than changes in leachate NO_3^- concentrations (SuppFigure 3). Leachate NO_3^- concentrations ranged from 0 to 25 mg N/L and they were fairly consistent over time in the IR100 and IR85 treatments, but declined over time in the IR70 treatment. However, there were no significant differences in leachate volumes, NO_3^- concentrations or total NO_3^--N leaching in between the fertiliser and irrigation treatments (SuppTable 3).

Crop yields and yield parameters

Mean crop yields were not affected by treatments and ranged from 62.1 to 76.6 t/ha across treatments (Table 1). Fertiliser, irrigation and the interactions between those factors had no effect on all other parameters including tuber number, average tuber size, potato specific gravity, and yield within tuber size classes. The only yield parameter to vary significantly between treatments was tuber N concentration (Table 1). Specifically, tuber N concentration was lowest under CONV fertiliser within the IR100 treatment and highest with the use of 3MP+TZ within the IR85 treatment, while all other treatments were comparable (Table 1).

Irrigation levels and the use of NIs or their interactions did not influence petiole N concentrations for any of the four sampling dates (SuppTable 4 and SuppFigure 4). In contrast, by harvest, irrigation treatment significantly influenced leaf N concentration such that leaves in the IR70 treatment (1.53 ± 0.1% N; mean ± SE) had higher concentrations than those measured in the IR100 (1.30 ± 0.05%) or IR85 (1.27 ± 0.04%) treatments ($p < 0.05$).

Discussion

In this study, the application of NIs did not improve potato yields and associated yield parameters as hypothesized. Yield responses were similar across fertilizer and irrigation treatments even though both NI treatments increased overall soil NH_4^+ (but not NO_3^-) concentrations at 0-10 cm and 50-60 cm soil depths. Several studies have also demonstrated little improvement in crop yield with NI treatment for a range of vegetable crops, irrespective of changes in soil nitrogen dynamics (Kelling *et al.*, 2011; Pfab *et al.*, 2012; Scheer *et al.*, 2014; Zhang *et al.*, 2015; Scheer *et al.*, 2017). For example, in a three-year study, NI treatment (dicyandiamide) was shown to increase soil NH_4^+-N and NO_3^--N concentrations (at least up to 36 days after emergence) which was related to an 8% increase in total yield however, this response was observed in the first year only – total yield was similar in years 2 and 3, regardless of NI treatment (Kelling *et al.*, 2011). Similarly, Scheer *et al*. (2017) found that increased soil NH_4^+-N concentrations in the NI treatments (DMPP and 3MP + TZ) did not directly translate to increased crop yield for a green bean/broccoli/lettuce rotation. Collectively, these results suggest that under non-limiting N conditions, the agronomic benefits of NI treatments may not be fully realised in intensively fertilised and irrigated potato production systems.

Although not examined in this study, other studies have shown that NIs may reduce annual N_2O emissions by up to 60% compared to the commercial fertiliser in intensive vegetable production systems (Pfab *et al.*, 2012; Riches *et al.*, 2016; Scheer *et al.*, 2017). Therefore, while NIs may not improve crop yield in non-N limiting agricultural soils, they may minimise the environmental impacts of fertiliser N (both mineral and organic fertilisers e.g. Vallejo *et al.*, 2006) use when used judiciously, at least by reducing N_2O emissions though the benefits of NIs in reducing N leaching is less clear.

In this study, NIs did not reduce the amount of N lost through leaching mineral N. The few studies that have examined the effect of NIs on N leaching report variable responses in wheat, dairy pastures, and rice-oilseed rape cropping systems (Li *et al.*, 2008; Jamali *et al.*, 2016; Kochi & Nelson, 2016) suggesting that the potential of NIs to mitigate N leaching remains unclear, possibly because of the challenges in capturing the spatial variability in leaching and the unknown contribution of dissolved organic N as a source of N-loss (van

Kessel *et al*., 2009). Irrespective of NI treatments, the results show that up to 6.5 kg/ha of NO_3^- is being lost from potato production through leaching over the season (152 days). This value is less than that reported in a modelling study that examined N losses for a range vegetable crops grown on the same soil type and region as this study (Lisson & Cotching, 2011). The authors reported N leaching losses of 32 kg/ha for potato, which was much higher compared to other vegetables crops (<10 kg/ha). The low values observed in this study may potentially be due to the unseasonably low rainfall over the growing season. The results of this study was for one variety and one year field trial on clay soil only – clearly further studies will be necessary to determine the potential of NI's in mitigating leaching over a larger range of N rates and in seasons when rainfall events exceed soil water holding capacity within the effective root zone.

A result that warrants further investigation is the increase in crop yield (by at least 20%, albeit non-significant) in the IR70 treatment for both NI treatments compared to the conventionally fertilised control. This observation provides preliminary evidence that NIs may be able to help maintain productivity under lower moisture status. The reason for this yield gain remains unclear, although higher (non-significant) soil NH_4^+-N concentrations were noted in IR70 treatment across all fertiliser treatments. Also, from 70 days after planting until the end of the experiment, total leachate and therefore the mass of NO_3 passing below the top soil in the IR70 treatment was lower than the other IR treatments, irrespective of fertiliser treatment. This study was for one variety and one year field trial only, therefore, further studies would be needed to examine this observation. However, the results of our study indicate that the relatively large amount of N input required by potatoes during middle to late season (Zebarth & Milburn, 2003) may potentially be managed by the strategic use of NIs, particularly in production areas where access to irrigation water is limited and/or in rain-fed production areas. However, overall, the results of our single season study suggested that NIs may have limited benefits in increasing potato productivity and reducing nitrate leaching under some production conditions.

Conclusion

Application of two NIs (DMPP and 3MP+TZ) increased soil NH_4^+ but not NO_3^- concentrations providing some evidence that NIs did alter nitrogen transformation. However, NIs did not improve yield nor mitigate leachate losses for an intensively fertilized potato crop under three irrigation regimes. Nonetheless, this study does not exclude the possibility that NIs may be beneficial for potatoes grown under N limited conditions.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Table 1. Effect of irrigation (IR100, IR85, IR70) and fertiliser (CONV, DMPP, 3MP+TZ) treatments on potato crop yield and yield parameters during the 2014/15 growing season at Forthside. Values are the means of three replicates ± SE. Different letters denote a significant treatment effect across all treatments. n = 3.

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	IR100			**IR85**			**IR70**			**P values**		
Variable	**CONV**	**DMPP**	**3MP+TZ**	**CONV**	**DMPP**	**3MP+TZ**	**CONV**	**DMPP**	**3MP+TZ**	**Irrigation (I)**	**Fertiliser (F)**	**I × F**
Crop yield (t ha^{-1})	71.8 (4.0)	70.2 (1.8)	71.2 (3.9)	65.9 (6.7)	68.7 (2.7)	62.1 (2.4)	60.8 (10.1)	76.6 (1.6)	73.4 (9.2)	0.60	0.35	0.30
Tuber number	67.7 (7.5)	64.7 (2.7)	69.0 (4.7)	62.0 (2.7)	72.0 (2.1)	65.0 (3.5)	51.3 (3.4)	75.0 (7.4)	71.3 (9.1)	0.96	0.08	0.17
Average tuber size (g)	215.0 (13)	217.7 (10)	208.5 (20)	211.6 (13)	190.8 (4)	192.3 (14)	241.4 (51)	209.2 (25)	206.6 (15)	0.50	0.50	0.94
Potato specific gravity	1.092 (0.001)	1.096 (0.002)	1.096 (0.005)	1.097 (0.002)	1.096 (0.002)	1.096 (0.0001)	1.094 (0.002)	1.091 (0.001)	1.094 (0.004))	0.37	0.67	0.43
Yield of tuber class <75 g (%)	2.6 (1.0)	1.8 (0.5)	2.5 (0.8)	2.3 (0.1)	2.2 (0.4)	4.1 (1.5)	1.0 (0.4)	3.3 (1.1)	1.6 (0.7)	0.54	0.53	0.20
Yield of tuber class 75-250 g (%)	40.2 (7.5)	39.1 (7.4)	46.6 (4.6)	49.2 (5.0)	56.1 (2.6)	43.3 (7.3)	40.8 (9.4)	42.4 (8.3)	45.3 (7.7)	0.57	0.86	0.48

Yield of tuber class 250-850 g (%)	57.3 (8.5)	59.1 (6.9)	50.9 (5.3)	48.6 (5.1)	41.7 (2.2)	52.6 (8.4)	52.4 (4.2)	54.4 (9.4)	53.1 (8.3)	0.59	0.97	0.48
Tuber N (%)	**1.18** **(0.05) a**	**1.30** **(0.03) ab**	**1.36** **(0.05) ab**	**1.24** **(0.05) ab**	**1.30** **(0.03) ab**	**1.53** **(0.09) c**	**1.36** **(0.03) ab**	**1.47** **(0.03) ab**	**1.29** **(0.10) ab**	**0.37**	**0.01**	**0.007**