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The effect of fertilizer and growing season on tuber dry matter and nitrate content in potato

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Abstract. Field trials with two potato varieties were undertaken at the Estonian Research Institute of Agriculture in 2005 and 2006. Year 2005 was generally optimal for potato growth but year 2006 was dry and very warm, hence, it was adverse for growth. The effect of fertilizing on two main traits of potato, i. e. tuber dry matter (DM) and nitrate content was examined. Five rates of compound fertilizer were applied, $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$, $N_{90}P_{36}K_{153}$, $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$. Results indicated that DM content was largely determined by variety but it also depended on fertilizer amounts and particular environmental conditions of a year. Nitrate content of tubers was quite clearly dependent upon variety, but growing season had significant effect on final nitrate content in tubers. Water stress during early and main bulking periods resulted in high tuber nitrate levels. In order to gain tuber yield fit for intended use, it is necessary to manage nutrient acquisition based on expected yield and nutrient supply from soils.

Key words: potato, fertilization, environmental conditions, dry matter content, nitrate content.

INTRODUCTION

Dry matter (DM) content is one of the most common indicators of tuber quality (Storey, 2007). Proper DM content ensures that a certain lot is fit for intended use, e. g. high percentage of solids is required in starch industry. In the literature, DM content, starch content, tuber solids content, and specific gravity are used interchangeably, although these represent the same variable (Stark & Love, 2003). Both direct and indirect determination methods can be used (Wilson & Lindsay, 1969).

Dry matter accumulates while tubers enlarge and mature (Leszczyński, 1989) as well as composition of DM alters during growth period, the proportion of starch increases and that of protein, sugar and minerals decreases (Snyder et al., 1977; Kolbe & Stephan-Beckmann, 1997). Early potato varieties have generally lower DM content than maincrop potatoes (Gray & Hughes, 1982). Studies undertaken in many countries and in different climates have referred to variety (genotype) being the key factor in determining DM content (Aamisepp, 1936; Stevenson et al., 1964; Hughes, 1974; Burton et al., 1992; Tsahkna, 1996; Putz, 1998). This genetic trait is modified by many other factors. Cultural practises, climate, and soil may largely affect final DM content (Storey & Davies, 1992). There are many comprehensive reviews showing vigorous effect of nitrogen (N) and potassium (K) (e.g. Laboski & Kelling, 2007). Nitrogen is often the limiting nutrient to achieve high tuber yields (Marshall, 2007) but excessive amounts of N may be deleterious to quality traits and pollute ground water due to leaching (Bucher & Kossmann, 2007).

Nitrogen is responsible for the extent of lateral branching of stems and size and life span of individual leaves whereby it affects canopy structure, size and longevity but it impacts neither canopy photosynthesis (Vos & Marshall, 1993; Hay & Porter, 2006) nor dry matter partitioning (Jenkins & Mahmood, 2003). The effect of N mainly results in delayed maturity, which is particularly obvious in the case a shorter growing period (Kunkel & Holstad, 1972; Gray & Hughes, 1982). It has been reported that the optimal rate of N is not detrimental to DM production and content (Stark & Love, 2003). Potassium ions are found in plant cell sap and condition osmotic pressure. Abundant K supply leads to decreasing DM content due to intensified water uptake, the latter is often enhanced with chloride (Marschner, 1995). On the other hand, K deficiency reduces partitioning of DM (Jenkins & Mahmood, 2003). Considering proper K rate, it is critical to be aware of soil potassium status. If the soil contains high concentration of potassium, then applying K fertilizer may reduce DM content but reverse may occur in soils low in K (Allison et al., 2001; Laboski & Kelling, 2007). Potassium also contributes to better uptake of N and N use efficiency (Gething, 1993). Phosphorus affects DM content to a lesser extent, though often positively, but this nutrient aids to alleviate adverse NK interaction in terms of DM content (Herlihy & Carroll, 1969). Regardless of specific interactions among ions, the effect of variety and location on tuber DM must be considered (Schippers et al. 1968). The effect of secondary nutrients and micronutrients on DM content is considered to be minor (Laboski & Kelling, 2007).

Nitrate content is not as crucial for tuber quality as dry matter content but it may impair food safety due to possible hazard to human health since nitrate ions can be converted into nitrite (Santamaria, 2006; Elias et al., 2011). Nitrate is a common ion in plant N metabolism as well as in the N cycle (Santamaria, 2006). Nitrate can normally comprise up to 1.0% of the total protein pool in potato tubers. In general, nitrate content of a crop is mainly controlled genetically (by variety) and modified by management practices (irrigation, fertilization, *etc.*), soil, and climate (Maynard & Barker, 1979; Blom-Zandstra, 1989; Lindhauer & Weber, 1993). Nitrogen fertilizer is an important source of plant-available N in the modern day crop production and it can also affect final nitrate content. Phosphorus chiefly reduces nitrate content through hastening plant senescence (Havlin et al. 2004). Potassium is responsible for activity of many enzymes among which is nitrate reductase (Marschner, 1995). However, the potato tuber is regarded as low-nitrate tissue (Serio et al., 2004) and nitrate content is reduced markedly by peeling and subsequent cooking (Bergthaller et al., 1986; Tartlan, 2005). At present, tuber nitrate content is not of particular concern in potato but it is still under investigation and regulated in some leafy vegetables (Santamaria, 2006; Järvan, 2009).

The objectives of the research were to examine the influence of different fertilizer rates on dry matter and nitrate content in commercially appreciated varieties, cv. 'Maret' in low-input farming and cv. 'Milva' in conventional potato production.

MATERIALS AND METHODS

Field trials were performed at the Estonian Research Institute of Agriculture at Saku in 2005 and 2006. Alsike clover (*Trifolium hybridum* L.) for seed was grown prior to potato experiments. Two potato varieties from different maturity groups, cvs. 'Maret' (middle early) and 'Milva' (maincrop), were examined. Five fertilizer treatments were applied: rates $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$, $N_{90}P_{36}K_{153}$, $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$ added as compound fertilizer Kemira Cropcare 10-10-20 (10% N, 4% P and 17% K, Kemira Growhow Oy, Finland) into the hill before planting. Four replication, systematic block designe. Seed tubers of grade 35–55 mm were presprouted and planted by hand in 70-cm rows at 25-cm apart. Weed control performed by ridging and harrowing in 2005 and Titus+Sencor treatment supplemented cultural measures in 2006. Six sprays in 2005 and five sprays in 2006 were used to protect potato plants from foliar late blight including different fungicides such as Ridomil Gold, Acrobat Plus, Shirlan, and Ranman.

Endogleyic Cambisol (eutric) was the soil type in trial (Deckers et al., 2002) and the soil texture was a loamy sand. The soil contained 2.5–3.0% organic matter and available P 70 mg kg^{-1}, K 85 mg kg^{-1}, Ca 2,300 mg kg^{-1} and Mg 95 mg kg^{-1}. Soil pH_{KCl} was 5.5. Available nutrients were determined according to Mehlich 3 and pH by ISO 10390.

Experimental years differed in mean temperature and rainfall (Table 1). Year 2005 was warm and rainfall was sufficient for optimal growth, but 2006 was warm and dry which was unfavourable for potato.

Table 1. Meteorological data in the experimental years

Month	Temperatures, °C		Rainfall, mm	
	2005	2006	2005	2006
May	9.7	9.7	47	20
June	13.0	15.2	39	19
July	17.2	17.9	82	15
August	15.7	17.0	136	65
September	11.9	13.3	19	19

Year 2006 was adverse for potato development and assimilation because of severe water stress during early and main tuber bulking periods.

In order to determine DM content, tubers of size 35–55 mm were washed after digging up, surface moisture was then allowed to evaporate. Four samples per treatment were used, *i. e.* one sample was taken from a replicate. Each tuber sample of 500 g was cut into thin slices, laid onto paper trays, dried at 65 °C at first and then at 105 °C (24 + 2 h). The residue was weighed and dry matter content was calculated. Tuber nitrate content was determined according to EVS-EN 12014-7.

The results were analyzed with Statistica 11, using ANOVA and Fisher LSD test. Statistically significant differences ($p < 0.05$) between treatments are denoted with letters.

RESULTS AND DISCUSSION

A steady decrease in dry matter content was observed in cv. 'Maret' in 2005 (Fig. 1). The treatment without any additional fertilizer ($N_0P_0K_0$) resulted in the highest DM percentage (25.6%). In most treatments supplied with higher amounts of nutrients, DM content decreased significantly ($p < 0.05$) (minimum value reached 21.7% in $N_{130}P_{52}K_{221}$, i.e. 15% lower than in $N_0P_0K_0$).

Cv. 'Milva' had lower DM value (19.9%) in the treatment without fertilizer than cv. 'Maret', but the effect of increasing fertilizer amounts was less pronounced (Fig. 1). Values obtained with applying fertilizer were significantly lower ($p < 0.05$) than those in $N_0P_0K_0$ treatment. Four treatments led to a decrease in DM content by 0.9–1.4%. The highest rate ($N_{130}P_{52}K_{221}$) had lower DM content (17.7%) compared with $N_0P_0K_0$.

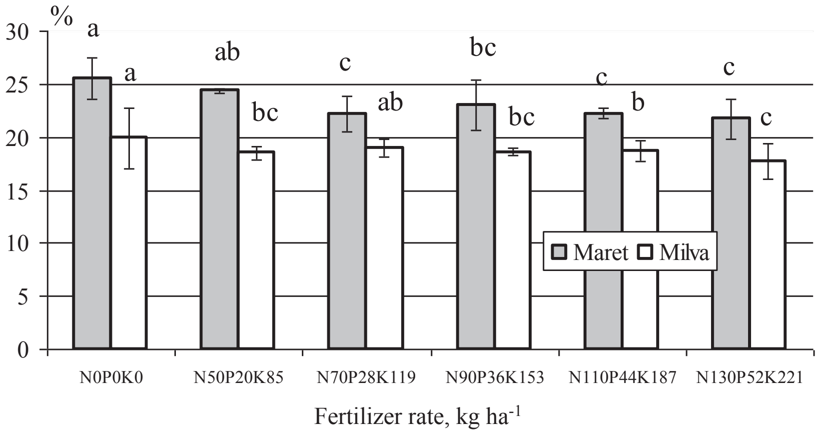

Figure 1. The effect of fertilizer rates on dry matter content, % on cvs. 'Maret' and 'Milva' in 2005. Different lower case letters indicate significant differences ($p < 0.05$) in columns (ANOVA, Fisher LSD test).

In 2006, there was also a definite decrease of DM percentage in fertilizer treatments on cv 'Maret'. Rates $N_{50}P_{20}K_{85}$ and $N_{70}P_{28}K_{119}$ reduced DM levels by 0.9 and 1.3%, respectively, compared with $N_0P_0K_0$ and those differed significantly ($p < 0.05$) from $N_0P_0K_0$. The following treatments ($N_{90}P_{36}K_{153}$, $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$) reduced DM content by 1.7%, on an average (Fig. 2). In cv. 'Milva' in 2006, irregular fluctuations were noticed, regardless of fertilizer amounts, hence, no treatment differed significantly from $N_0P_0K_0$ (17.9%) (Fig. 2).

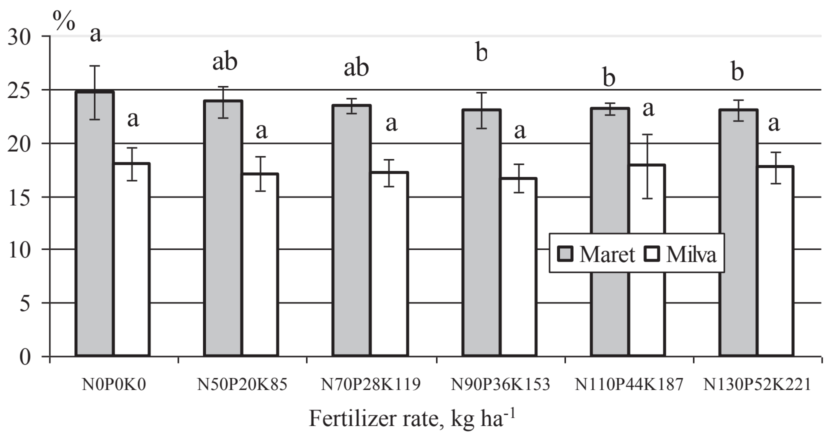

Figure 2. The effect of fertilizer rate on dry matter content on cvs. 'Maret' and 'Milva' in 2006. Different lower case letters indicate significant differences ($p < 0.05$) in columns (ANOVA, Fisher LSD test).

Likewise, the apparent effect of fertilizing on tuber nitrate content was noted in cv. 'Maret' in 2005. Lower values were found in those treatments provided with less nutrients (Table 2). Applying $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$, $N_{90}P_{36}K_{153}$ resulted in nitrate levels below 50 mg kg^{-1} fresh weight (FW), while highest contents were found with $N_{110}P_{44}K_{187}$ and $N_{130}P_{52}K_{221}$ (111 and 126 mg kg^{-1}, respectively). Cv. 'Milva' tubers had nitrate below 100 mg kg^{-1} in $N_0P_0K_0$, $N_{50}P_{20}K_{85}$, $N_{70}P_{28}K_{119}$ (81, 95 and 99 mg kg^{-1}, respectively). The highest content (244 mg kg^{-1} $N0_3$-N) was recorded in the highest fertilizer treatment. The effect of fertilizing was also found in cv. 'Maret' in 2006. The initial value (in $N_0P_0K_0$) was relatively high (133 mg kg^{-1} FW) and increased with increasing nutrient level (Table 2). At the maximum fertilizer rate, nitrate increased to 256 mg kg^{-1} FW . In cv. 'Milva', the effect of increasing fertilizer rate was not significant (Table 2) and initial level (in $N_0P_0K_0$) was exceptionally high (254 mg kg^{-1} FW). Differences between two varieties as well as growing seasons were significant ($P < 0.05$).

Table 2. The effect of fertilizer rates on nitrate content of tubers (mg kg^{-1} FW)

Fertilizer rate,	'Maret'		'Milva'	
kg ha^{-1}	2005	2006	2005	2006
$N_0P_0K_0$	31	133	81	254
$N_{50}P_{20}K_{85}$	35	167	95	374
$N_{70}P_{28}K_{119}$	42	180	99	297
$N_{90}P_{36}K_{153}$	45	161	105	443
$N_{110}P_{44}K_{187}$	111	202	191	460
$N_{130}P_{52}K_{221}$	126	256	244	293

Results obtained in the study are consistent with earlier reports (Kunkel & Holstad, 1972; Gray & Hughes, 1982; Tartlan, 2005; Laboski & Kelling, 2007). DM percentage was inherent to a particular variety, i.e. cv. 'Maret' contained more DM than cv 'Milva'. In terms of DM, cv. 'Maret' responded more clearly to increasing fertilizer rates in 2005 (Fig. 1). In 2006, differences were not so evident due to adverse environmental conditions. Final DM content is regarded as an outcome of interactions of genotype (variety) and environment (Howard, 1974; Hughes, 1974). Environment is complex and interactions are diverse at particular sites and in different years. Consequently, a certain variety performs differently in different years. Another aspect is crop maturity. DM content attains a maximum value shortly before tuber yield is maximized and tubers with the highest DM content are obtained from plants senesced naturally (Maag, 1993; Ierna, 2010). Cv. 'Maret' reached maturity in 2005 but cv. 'Milva' did not in 2005. In 2006, it was impossible to score maturity in either case due to premature death as a result of water stress. Hence, tubers lifted were immature and did not contain maximum levels of DM, although solar radiation and temperatures were adequate for DM assimilation during the bulking period (Kooman et al., 1996). In addition, the effect of main nutrients separately (N, P and K) has been extensively investigated but interactions among them on potato are less understood (Jenkins & Mahmood, 2003).

Nitrate levels appeared to be related to a particular variety, fertilizer rate, maturity and particularly, to water availability. On an average, cv. 'Maret' contained less nitrate in fresh tubers than cv. 'Milva'. In general, nitrate content of tubers has been confirmed to be within the range 10–500 mg kg^{-1} FW (Spaar et al., 1999), but most frequently, values are between 40–250 mg kg^{-1} FW (Leszczyński, 1989). Fertilizer rates clearly affected nitrate levels under adequate water supply but the effect of fertilizer was less definite under stress conditions in 2006. Inadequate water availability led to high nitrate levels. As confirmed by McDole & McMaster (1978) and Spaar et al. (1999), insufficient water supply is the key factor leading to undesired nitrate levels in potato tubers. In the case of water stress, activity of nitrate reductase is supressed more than nitrate uptake (Schuddeboom, 1993) which gives rise to nitrate accumulation. Regardless of N fertilizer rates, tubers from plants affected by moisture stress contained nitrate twice as high as tubers from optimum or excessive irrigation treatments (McDole & McMaster, 1978). Furthermore, one should take into account that potato was preceded by alsike clover which is capabale of N fixation 100–200 kg ha^{-1}. This in turn could have contributed to increased nitrate content in the potato tubers (Kõrgas, 1969).

CONCLUSION

This research demonstrated that increasing fertilizer rates clearly reduced tuber dry matter content in both varieties, but the effect was more pronounced under favourable environmental contitions in 2005 than under water stress in 2006. On the other hand, increasing fertilizer increased nitrate levels in tubers in both years, but the effect of year, particularly due to water stress during the bulking period, promoted higher nitrate levels. Consequently, most traits of potato are determined both by genotype and environment. The latter is very complicated to manage in order to achieve tubers suitable for intended use. As a result, tuber quality is primarily controlled by planting appropriate varieties and implementing proper cultural practises. Above all, installation of irrigation systems is advisable in order to maintain optimal soil moisture level during the growing season and to achieve expected tuber quality in years with inadequate rainfall.

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