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Potential effects of different irrigation and drainage regimes on yield and water productivity of two potato varieties under Estonian temperate climate

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ABSTRACT

To examine the potential effect of water management on potato yields, the crop model POMOD (POtato MODel) was used. The effects of irrigation, drainage and two-way water management (irrigation + drainage) were simulated with and without natural outflow (percolation to deeper soil layers and runoff). Calculations were performed for two Estonian mainland locations (subcontinental Tallinn for the period 1920–2011, continental Tartu, 1901–2011) and one insular, maritime region (Kuressaare, 1923–2011) as well as for an early and a late potato variety, 'Maret' and 'Anti', accordingly.

In the reference series without water management, the average yields were 18% higher for the late variety compared to the early variety. The mean reference yield in Kuressaare was 8% lower than in mainland locations. The mean water productivity (WP) calculated per evapotranspiration was nearly 45 kg mm^{-1} ha^{-1} (dry mass), somewhat higher for the late variety compared to the early variety. The highest and most statistically significant ($P < 0.05$) increase of yield was achieved from the two-way water management. In the case of natural outflow (water losses to deep percolation and runoff exist), the effect of irrigation prevailed over drainage in all locations. Without outflow, the effects of irrigation and drainage were comparable in the mainland, but the effect of drainage remained negative in Kuressaare. Generally, a positive effect on tuber yield occurred more often from irrigation than from drainage. However, in the case of restricted outflow in the mainland locations, the maximum yield gain from drainage exceeded the yield increase from irrigation by approximately two-fold. The extra yield depended on the amounts of irrigation or drainage by a second order polynomial, while the productivity of irrigated or drained water was, on average, markedly lower than the WP calculated per evapotranspiration, which had a linear relation. Irrigation and drainage water amounts under 50 mm did not have any positive effect on yield.

The need for irrigation is highest in maritime climate covering Estonian islands and Western and Northwestern coast. In these regions, irrigation increases the mean yield by 18–26% and decreases its variability two-fold. In continental locations, if natural outflow is restricted, implementation of two-way water management projects should be considered, as its effects on yield quantity as well as on stability exceed the sum of separate effects from irrigation and drainage.

1. Introduction

With continuing population growth, the need for food and thus agricultural water is increasing. Global agriculture is therefore presented with a new challenge: to increase food production for the growing population under increasingly scarce water resources (Bouman, 2007). Presently, irrigated agriculture covers approximately 20% of the arable land and accounts for 40% of global food production (FAO, 2003). The FAO has also noted that to meet future food demands, it is expected that relatively more crops will have to be grown on irrigated land rather than on rain-fed land, such that about equal amounts of production will come from both types of areas.

To describe water consumption in plant production, several terms are developed and used. Viets (1962) proposed the term "water-use efficiency" (WUE), which is now a common tool and

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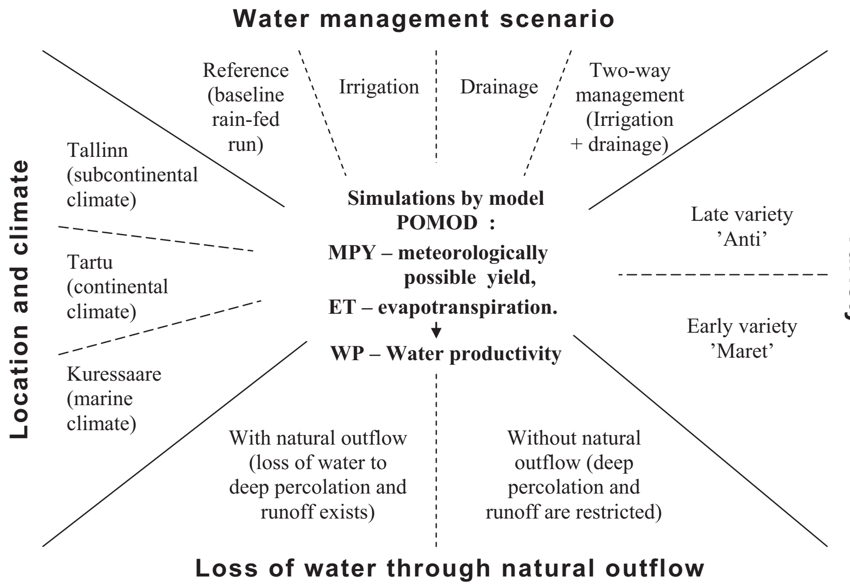

Fig. 1. Scenarios of simulation and groups of analysed factors.

has been used for decades to describe the relationship between crop growth/development and water use. WUE has been widely used and has several different meanings to describe the yield (photosynthesis, biomass, or economic) per unit of water (transpiration, evapotranspiration, or applied water) (Sinclair et al., 1984; Howell, 2001; Bacon, 2004), as well as the irrigation efficiency. Perry (2007) evaluated WUE as a rather unfortunate misnomer, since in reality only a very small portion of the water taken up is actually used in the composition of plant tissue, and efficiency is a term conventionally reserved for the dimensionless ratio between the output of a quantity and its input (Jones, 2004). Therefore, to avoid confusion, the term water productivity (WP) is suggested (Rockström, 1995; Kijne et al., 2003; Ali and Talukder, 2008; Sadras et al., 2011; Heydari, 2014) to denote the amount or value of a product over a volume or value of water that has been depleted or diverted (FAO, 2003).

Potato (*Solanum tuberosum*), a major food crop throughout the world (Scott et al., 2000), is more sensitive to water stress than many other crops. At the global scale, the potato yield gap (difference between potential and actual yield) has been quantified at approximately 20–30 t ha^{-1} (Supit et al., 2010). To a great extent, this difference is a consequence of non-optimal soil moisture. Usually, in mitigation studies of soil water impact, only irrigation is considered because drought is globally the most common risk in agriculture. There have been many reports on the effects of water stress and irrigation regimes on potato crop in many parts of the world (e.g., Fabeiro et al., 2001; Onder et al., 2005; Cantore et al., 2014; Carli et al., 2014; Karam et al., 2014). Irrigation requirements differ with locations, soil types, potato varieties/genotypes and cultural practices. However, on a regional rather than global scale, there are also areas where excess water may be as important limiting factor as drought and potato is vulnerable to both. Despite its water restriction susceptibility, potato is an efficient water user (Monneveux et al., 2013).

Estonia is a temperate-climate country where the annual amount of precipitation exceeds evaporation by a factor of two, so the climate is generally excessively humid; however, there are considerable differences in precipitation between regions and years as well as within growing seasons. Due to the very high variability of precipitation, drought periods as well as excessive wet periods occur quite often in Estonia during the warm half-year and are

Table 1
Water contents (mm or kg m^{-2}) in soil layer 0–0.5 m corresponding to soil hydrological parameters.

Parameter	Tallinn	Tartu	Kuressaare
Wilting point	39	25	34
Field capacity	148	122	130
Maximum capacity	224	210	224

evaluated as comparable causes of failure in agriculture (Tammets, 2007; Ingver et al., 2010).

In a recent paper (Saue and Kadaja, 2014), the main focus was on defining the nature of water deficit and excess in Estonia, using model simulation methods. We described different water regime in different regions of the country. For example, water deficit was assessed in 60–80% of years in mainland Estonia and in >90% on islands, while excess water occurred in 70–90% of years on the mainland and in 30–50% on the islands. Water deficit and excess during the same growing period existed in 30–60% of years. The average water deficit was 30–45 mm per year for the early and 47–58 mm for the late variety in continental locations, over two times higher in maritime location. Excess water is more characteristic to the mainland part of Estonia. Those results provided some important points for discussion because the prevalent hypothesis until now has been that irrigation is neither important nor economically feasible in our area. Historically and currently, drainage is considerably more prevalent in Estonia than irrigation.

In this paper we advance the topic. The main purposes of the study are to simulate the gain of potato yield from irrigation, drainage and two-way water management (installing of drainage and irrigation systems on the same field), and evaluate the water productivity of those water management regimes. We address the dependences of yield gain as well as irrigation and drainage water productivities on added and/or removed water amounts. We continuously study two different varieties, the early variety 'Maret' and the late variety 'Anti', in three localities reflecting different climatic conditions of Estonia: continental climate (Tartu), subcontinental climate (Tallinn) and maritime climate (Kuressaare). Additionally, we simulate two different hydrological situations: if natural outflow from soil due to deep percolation and surface and subsurface runoffs is included and short-term water excess exists only after