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The effect of nitrogen and late blight on crop growth, solar radiation interception and yield of two potato cultivars

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ABSTRACT

Late blight (*Phytophthora infestans* (Mont.) de Bary) and nitrogen (N) significantly affect crop growth of potato (*Solanum tuberosum* L.), but little is known about their interactive effects on radiation interception (RI) and radiation use efficiency (RUE).

Two field experiments were conducted in 2006 and 2007 at Braunschweig, Germany, to assess the effects of N supply and late blight infestation on crop growth dynamics of potato in terms of RI, RUE, and dry matter (DM) accumulation. Four nitrogen supply levels (unfertilised up to 160 kg N ha^{-1} N supply (soil mineral + fertilisation) in 2006, unfertilised – 240 kg N ha^{-1} in 2007) were tested in combination with two fungicide regimes (sprayed, unsprayed) in two cultivars differing in maturity. N fertilisation increased leaf area index (LAI), leaf area duration (LAD), and RI, and in consequence, tuber yield, but had no significant effect on RUE within a single cultivar. Late blight infection caused premature senescence and defoliation resulting in smaller LAI, shorter LAD, less RI and lower tuber yields. Late blight had no effect on RUE if leaf area was corrected for disease severity. Significant interactions between N level, fungicide treatment and cultivar on late blight disease spread were found affecting LAI and RI. This study shows that total DM accumulation of potatoes can be predicted by RI and RUE, even if N supply is limited and late blight control incomplete as long as the late blight effect on RI can be properly estimated.

1. Introduction

Nitrogen (N) nutrition, water supply and disease control are the main factors determining growth and final yield of potato crops (*Solanum tuberosum* L.). These factors have to be optimised with regard to the physiological characteristics of the chosen cultivar and the site-specific soil and climatic conditions. Organic potato production in Europe excludes many methods for yield improvement used in conventional systems, especially synthetic fungicides and chemical fertilisers. In consequence, infestation with late blight (*Phytophthora infestans* (Mont.) de Bary) and N shortage are the most limiting factors for tuber yield in organic farming systems, thus mainly account for the difference in tuber yield between organic and conventional potato production (Finckh et al., 2006; Karalus and Rauber, 1996; Möller et al., 2007; van Delden, 2001). Nevertheless, sufficient N supply and late blight controls are regular challenges in conventional potato production systems as well as in lower-input and organic systems. The present research in organic and conventional potato production is mainly focused on either N nutrition or late blight control, but contradictory results have been obtained about the interaction of these two factors, indicating either no positive interaction of N supply and late blight infestation (Cicore et al., 2012) or an increased infestation under high N levels (Juárez et al., 1999). A high N supply to maximise tuber yield may require the use of more fungicides for disease control. Likewise a short N nutrition may allow a reduced amount of fungicides adjusted to the yield potential under limiting N conditions.

The concept of radiation interception (RI) and radiation use efficiency (RUE) represents a framework to analyse yield limiting factors and their interactions in different production environments. Several empirical studies (e.g. Allen and Scott, 1980; Van der Zaag and Doornbos, 1987) confirmed also for potatoes that dry matter (DM) accumulation under non limiting conditions is directly related to the amount of intercepted photosynthetically active radiation (iPAR).

Therefore, variation in total biomass due limiting biotic and abiotic factors can be attributed to changes in either iPAR or RUE or both. For example, potato cyst nematodes (Haverkort et al., 1991) and infestation with the negrophobic fungus *Alternaria solani* (Shah et al., 2004a) decreased both, iPAR and RUE. Based on their findings

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Table 1
Agronomic details of the field trials in 2006 and 2007.

	2006	2007
Experimental site	Braunschweig 52°16′N, 10°34E	Braunschweig 52°18′N, 10°26E
Soil type	Sandy loam	Loamy sand
Previous crops	Winter wheat	Grass/clover mixture
Varieties	Ditta, Finka	Ditta, Gloria
Planting date	19 April	15 April
Plot size (m × m)	6 × 15	6 × 15
Planting pattern (m × m)	0.75 × 0.30	0.75 × 0.30
Emergence (DAP – days after planting)	Finka: 30 DAP Ditta: 31 DAP	Gloria: 31 DAP Ditta: 34 DAP
Sampling dates	62, 75, 89, 103, 113, 124 and 150 DAP	44, 62, 75, 89, 103, 117, 131 and 165 DAP
Sample size	12 plants	12 plants
Basic fertilisation	250 kg K ha^{-1}	250 kg K ha^{-1}
Soil mineral N content before planting (kg N ha^{-1})	37	35
N fertilisation (kg N ha^{-1})	0 80 120 160	0 80 160 240
Irrigation date (DAP) and amount	90, 100, 101, 106, 111, and 114 DAP (each 12 mm)	93 DAP (30 mm)
Precipitation from April to September (mm)	367	560
Weed control	2400 g ha^{-1} Prosulfocarb + 350 g ha^{-1} Metribuzin at 24 DAP	2400 g ha^{-1} Prosulfocarb + 350 g ha^{-1} Metribuzin at 27 DAP
Insect control	17.5 g ha^{-1} Chlorthianidine at 84 DAP	None
Late blight control of the treated plots[a]	mm and f at 84 and 104 DAP	mm + f, fp + f, c + f, fp, c + dmc, fc + f, c, f, c, f, mc and f at 46, 54[b], 58[b], 65, 74, 79, 85, 94, 100, 108, 121[c] and 124[c]

[a] Active ingredients and doses of fungicides used: mm, Metalaxyl-m (60 g ha^{-1}) and Mancozeb (960 g ha^{-1}); f, Fluazinam (200 g ha^{-1}); fp, Flucopiloide (87.5 g ha^{-1}) and Propamocarb (875 g ha^{-1}); c, Cyazofamid + adj. (80 g ha^{-1}); dmc, Dimethomorph (180 g ha^{-1}) and Mancozeb (1200 g ha^{-1}); fc, Famoxadone (100 g ha^{-1}) and Cymoxanil (100 g ha^{-1}); mc, Mancozeb (1350 g ha^{-1}).
[b] All plots treated because of heavy disease progression.
[c] Only Ditta, Gloria showed haulm senescence.

Shah et al. (2004a) suggested that diseases with defoliating effects should be taken into account in estimations of iPAR, if RI is calculated from leaf area index (LAI) measurements. In addition, in that study N fertiliser increased RUE from 3% with low N input (0 and 30 kg N ha^{-1}) to 16% with high N input (150 and 180 kg N ha^{-1}). In contrast, several authors (e.g., Millard and Marshall, 1986; van Delden, 2001; Vos and Biemond, 1992) observed that RUE of potato was insensitive to N supply whereas N fertilisation significantly increased iPAR. Haverkort and Bicamumpaka (1986) and van Oijen (1991) reported that late blight only reduced iPAR, but not RUE. It therefore may be stated that the effect of the late blight by N interaction on iPAR and RUE is still subject of debate.

The objectives of this study therefore were to (i) investigate the effects of fungicide application against late blight and N fertilisation on the dynamics of potato biomass accumulation and (ii) explore whether parameters like iPAR or RUE are suitable to predict tuber yield under conditions of late blight infestation and N shortage, often limiting tuber yield in organic farming. This knowledge may contribute to optimise potato crop management in conventional and organic production systems.

2. Materials and methods

2.1. Treatments

In two field experiments (details on the site see Table 1) during 2006 and 2007, two potato cultivars were planted at 4 N supply levels and two levels of chemical late blight control (with and without). The experiments were arranged as a split plot design with four replicates. The cultivars were assigned to the main plots and N levels and fungicide treatments to the subplots. The harvest areas for the six sampling dates during the growth period were separated from the adjacent plots or from neighbouring harvest areas by at least one border row and one border plant within the row.

In 2006 the two cultivars were Finka (very early maturity) and Ditta (moderately late maturity). In 2007 Finka was replaced by Gloria (very early maturity), while Ditta was used in both years. All seed tubers were graded to 35–50 mm and sprouted for two weeks at 12 °C before planting. Nitrogen was applied as urea ammonium nitrate solution (27% N) with a boom spray before final hilling. Nitrogen levels in 2006 were: 37 (soil mineral N), 80, 120 and 160 kg N ha^{-1}. In 2007 the N levels were modified for a better differentiation to 35 (soil mineral N), 80, 160 and 240 kg N ha^{-1}. The N fertiliser quantities were calculated considering the soil mineral N content, which was analysed immediately before planting (Table 1). Based upon the irrigation advice for potatoes provided by the German Weather Service (DWD), irrigation was scheduled to allow 40% plant available soil water content in the first 60 cm throughout the entire growing season.

Fungicides were applied by a backpack sprayer with water amounts of 450 liter per hectare. Details on fungicides, application timing, plot size and further management are listed in Table 1.

2.2. Measurements

Data on daily rainfall, air temperature and irradiance were recorded at the Agrometeorological Research Station in Braunschweig of the DWD.

Plant sampling started after the beginning of tuber initiation. At each sampling date (Table 1), 12 plants were harvested and stems and tubers per plant as well as green above-ground biomass and tuber fresh weight were determined. The fraction of leaves and stems was determined on a subsample of 1 kg. To measure DM content a subsample of at least 500 g of haulm components and tubers was dried at 80 °C for at least 5 days until constant weights. Total DM of plant components was estimated by multiplying subsample DM content and the total sample fresh weight.