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The influence of organic and conventional fertilisation and crop protection practices, preceding crop, harvest year and weather conditions on yield and quality of potato (*Solanum tuberosum*) in a long-term management trial

Mike W. Palmer[a], Julia Cooper[a], Catherine Tétard-Jones[a,b], Dominika Średnicka-Tober[a], Marcin Barański[a], Mick Eyre[a], Peter N. Shotton[a], Nikolaos Volakakis[a,c], Ismail Cakmak[d], Levent Ozturk[d], Carlo Leifert[a,*], Steve J. Wilcockson[a], Paul E. Bilsborrow[a]

[a] *Nafferton Ecological Farming Group, Newcastle University, Nafferton Farm, Stocksfield, NE43 7XD, UK*
[b] *Molecular Agriculture Group, School of Biology, Newcastle University, Newcastle upon Tyne NE1 7RU, UK*
[c] *Geokomi plc, Sivas, Messara, Crete, Greece*
[d] *Sabanci University, Faculty of Engineering and Natural Sciences, 34956 Istanbul, Turkey*

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ABSTRACT

The effects of organic versus conventional crop management practices (fertilisation, crop protection) and preceding crop on potato tuber yield (total, marketable, tuber size grade distribution) and quality (proportion of diseased, green and damaged tubers, tuber macro-nutrient concentrations) parameters were investigated over six years (2004–2009) as part of a long-term factorial field trial in North East England. Inter-year variability (the effects of weather and preceding crop) was observed to have a profound effect on yields and quality parameters, and this variability was greater in organic fertility systems. Total and marketable yields were significantly reduced by the use of both organic crop protection and fertility management. However, the yield gap between organic and conventional fertilisation regimes was greater and more variable than that between crop protection practices. This appears to be attributable mainly to lower and less predictable nitrogen supply in organically fertilised crops. Increased incidence of late blight in organic crop protection systems only occurred when conventional fertilisation was applied. In organically fertilised crops yield was significantly higher following grass/red clover leys than winter wheat, but there was no pre-crop effect in conventionally fertilised crops. The results highlight that nitrogen supply from organic fertilisers rather than inefficient pest and disease control may be the major limiting factor for yields in organic potato production systems.

1. Introduction

Evidence suggests that organic arable cropping systems generally produce lower, more variable yields than systems employing synthetic fertilisers and chemical crop protection measures (Smith et al., 2007). Recent reviews by De Ponti et al. (2012) and Seufuret et al. (2012) concluded that organic arable yields average 80% and 75% of conventional production respectively. However, the yield gap varies between crop species, with tuber crops having a greater yield gap than cereals. For example, De Ponti et al. (2012) report that organic tuber crop production averages 70% of conventional in European studies, but with high variability (37–114%). The relatively large, variable yield gap between organic and conventional potato production has been mainly attributed to inadequate control of diseases and pests, particularly of late blight caused by *Phytophthora infestans* (Finckh et al., 2006). Fertilisation regimes have also been reported to contribute to lower yields in organic potato production systems (Van Delden, 2001; Haase et al., 2007). However, results from long-term factorial studies in which the relative effect, and interactions between fertilisation and crop protection practices used in organic and conventional farming systems are compared are not currently available.

The main objectives of the study presented here were to (a) quantify the relative effects of fertilisation regimes (mineral NPK versus composted cattle manure) and crop protection practices (based on standard pesticide, fungicide and herbicide treatments or mechanical weed control and Cu-fungicides only), (b) investigate interactions between fertilisation regimes and crop protection

* Corresponding author. Tel.: +44 1661 830 222; fax: +44 1661 831 006.
E-mail addresses: c.leifert@ncl.ac.uk, carlo.leifert@ncl.ac.uk (C. Leifert).

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Table 1
Growing season weather conditions 2004–2009.

Year	Parameter	April	May	June	July	August	September
2004	Precipitation (mm)	58	20	86	88	149	19
	Mean solar radiation (kW m^{-2})	0.11	0.18	0.18	0.16	0.12	0.10
	Mean Relative humidity (%)	85	84	84	84	79	67
	Mean air temperature (°C)	8.2	10.3	13.7	13.9	15.2	13
	Mean soil temperature (°C at 10 cm)	8.8	12.6	15.6	15.5	16.7	13.8
2005	Precipitation (mm)	92	28	55	70	26	54
	Mean solar radiation (kW m^{-2})	0.13	0.17	0.17	0.16	0.15	0.11
	Mean Relative humidity (%)	81	78	81	81	81	83
	Mean air temperature (°C)	7.3	9.6	13.7	14.6	14.5	13.2
	Mean soil temperature (°C at 10 cm)	8	10.7	14.6	16.2	15.6	14.4
2006	Precipitation (mm)	36	33	79	99	27	37
	Mean solar radiation (kW m^{-2})	0.13	0.19	0.17	0.16	0.13	0.10
	Mean Relative humidity (%)	55.0	61.2	49.5	75.3	74.1	84.4
	Mean air temperature (°C)	8.3	10.6	12.6	14.7	15.1	16.6
	Mean soil temperature (°C at 10 cm)	9.3	12.0	15.0	16.1	15.4	14.1
2007	Precipitation (mm)	13	51	118	69	36	23
	Mean solar radiation (kW m^{-2})	0.15	0.17	0.13	0.17	0.14	0.10
	Mean Relative humidity (%)	77	77	83	80	78	78
	Mean air temperature (°C)	9.3	10.0	12.9	13.9	14	12.3
	Mean soil temperature (°C at 10 cm)	10.5	12.9	14.9	15.7	15.5	13.3
2008	Precipitation (mm)	72	7	57	101	107	158
	Mean solar radiation (kW m^{-2})	0.12	0.17	0.17	0.15	0.12	0.08
	Mean Relative humidity (%)	77	72	71	72	71	67
	Mean air temperature (°C)	6.2	10.7	12.6	14.7	14.7	12.1
	Mean soil temperature (°C at 10 cm)	6.8	12.2	14.6	15.9	15.5	13.1
2009	Precipitation (mm)	36	33	79	99	27	37
	Mean solar radiation (kW m^{-2})	0.13	0.19	0.17	0.16	0.13	0.10
	Mean Relative humidity (%)	55.0	61.2	49.5	75.3	74.1	84.4
	Mean air temperature (°C)	8.3	10.6	12.6	14.7	15.1	16.6
	Mean soil temperature (°C at 10 cm)	9.3	12.0	15.0	16.1	15.4	14.1

regimes and (c) investigate the relative effects of climatic and agronomic drivers on potato yield and quality parameters.

2. Materials and methods

2.1. Site description

The data presented were collected from potato crops grown during the 2004–2009 seasons as part of the Nafferton Factorial Systems Comparison (NFSC) trial at Newcastle University's Nafferton Experimental Farm, Northumberland, UK (54:59:09 N; 1:43:56 W). The soil of the 4 ha trial site is a uniform clay loam formed in slowly permeable glacial till deposits; *Cambic Stagnogley* (Avery, 1980); *Stagnic Cambisol* (FAO, 1998). Weather data recorded by an on-site automated station for the experimental period is presented in Table 1.

2.2. Field trial design

The NFSC trial was established in 2001 and consists of four plots (24 × 96 m) each representing a different stage in the rotation, replicated four times in a randomised block design (Fig. 1). The main plots are split into two sub-plots (12 × 96 m) consisting of 'organic' (rich in legume and horticultural crops as recommended by organic farming principles) or 'conventional' (less diverse, cereal-based) eight year rotations (Figure 1 and Table 2). Each rotation is split into two sub-sub-plots (12 × 48 m) in which crop protection was carried out either to organic (Soil Association) or conventional (Red Tractor Assured) standards. The crop protection treatments are further split into two fertility management sub-sub-sub-plots (12 × 24 m) managed to either organic or conventional farming standards. The arrangement of crop protection and fertiliser treatments is randomised, and 10 m and 5 m uncultivated grass buffer strips are established between crop protection sub-subplots and fertility management sub-sub-subplots respectively (Fig. 1)

2.3. Agronomic management

The trial field was managed conventionally prior to 2000, and initially all plots were cropped with untreated grass/red clover ley until 2003 in compliance with organic conversion standards (Soil Association, 2010). In order to facilitate the presence of a different rotational stage simultaneously in each of the four main plots, first cultivation year was staggered, meaning two of the four plots remained in grass/red clover until 2004.

The same potato variety (*Sante*, which is widely used by both organic and conventional producers in the UK) was cultivated in all treatment plots. *Sante* is a variety exhibiting moderate to high resistance to both foliar and tuber blight (Agrico UK, 2012). Potatoes were grown following winter cereals (wheat or barley) in the conventional rotation, and following winter cereals or field beans in the organic rotation (Table 2). As a result of the staggered rotation described above, potatoes were also grown following a grass/clover ley as pre-crop in the 2004 season (Table 2). Potatoes were sown in late April or early May using a commercial planter in rows that were 75 cm apart with a spacing of 35 cm between seed tubers within the row. Ridging was carried out in late June in all plots to control weeds mechanically and to keep tubers covered with soil to minimise greening.

Whenever potatoes were grown within either rotation, they were always grown adjacent to vegetables i.e. these 12 × 24 m plots were planted with one half (6 × 24 m) with potatoes and the other 6 × 24 m half of the plot with vegetables (cabbages, lettuces, onions, and carrots) on the other 6 × 24 m half of the plot. The location of potato/vegetable plots was reversed the next time that these crops appeared in the rotational sequence, so that potatoes were not grown on the same plot areas at any time from 2002 to 2009.

Conventionally fertilised potatoes received 180 kg N ha^{-1} as ammonium nitrate, plus P_2O_5 and K_2O additions of 135 and 200 kg ha^{-1} in the form of 0:20:30 compound fertiliser in late April or early May. Organically fertilised potatoes received 170 kg N ha^{-1}