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Within-field variations in sugar beet yield and quality and their correlation with environmental variables in the East of England

Salar A. Mahmood, Alistair J. Murdoch*

School of Agriculture, Policy and Development, University of Reading, Earley Gate P.O. Box 237, Reading, Berks, RG6 6AR, UK

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A B S T R A C T

Spatial variability of sugar beet yield and quality within fields and their correlation with environmental variables was investigated in order to explore the potential for more precise agronomy. In three uniformly-managed, commercial sugar beet fields in the east of England spatial variation in the commercial value of the sugar yield ranged from £232 to £3320 per hectare. This variation was not random; there were high and low yielding patches in each field. Sugar beet root yield was positively correlated with the spatial distribution of crop plant population, soil organic matter and soil moisture, but negatively with weed density and canopy temperature. Correlations of sugar beet yield with soil type, elevation and soil available phosphate, potassium and magnesium were, however, inconsistent between the three fields and over two seasons. With respect to sugar beet quality, spatial variation in the amino acid and potassium concentrations in the sugar beet roots was associated with soil type and elevation, whereas sugar percentage varied randomly in two of the fields. Interventions and research that could help to optimize yield on a spatially-variable basis are discussed.

1. Introduction

Commercial sugar beet fields are generally managed uniformly. Soil, however, varies at different spatial and temporal scales within fields (Webster and Oliver, 2007), and this variability, together with spatial variation in biotic constraints such as weeds, pests and diseases, may cause spatial and temporal variability in crop development and yield (Heege, 2013; Oliver et al., 2013). Sugar beet is expected to respond similarly (Richter et al., 2006).

Although yield maps of combinable crops can be produced cheaply and routinely during harvesting (Heege, 2013), yield monitors do not currently feature on sugar beet harvesters. Yield maps reflect crop responses to stresses or other constraints on yield, but different environmental variables may cause similar patterns of stress (Jones and Schofield, 2008). An accurate field map of variables which may be influencing yield variation is required to implement more precise crop agronomy. Such maps usually need to be based on field sampling, which is expensive (Webster and Lark, 2012). Moreover, the samples only quantify soil variables where samples are taken (Scannavino et al., 2011) although Kriging can be used to predict the values at unsampled locations provided adequate numbers of samples are available (Oliver, 2010).

Previous research in sugar beet fields has mapped spatial variability of single factors including soil organic matter (Karaman et al., 2009a), soil available nitrogen and phosphate (Franzen, 2004; Karaman et al., 2009b), soil moisture content (Zhang et al., 2007, 2011) and *Heterodera schachtii*, the beet cyst nematode (Reynolds, 2010; Hbirkou et al., 2011). Associations of this spatial variability with sugar beet growth, yield and quality were not, however, reported. Since within-field variation is likely to be influenced by combined effects of pedo-climatic and biotic factors, it could be misleading to focus on single factors. This paper therefore investigates field scale correlations of sugar beet yield and quality with variation in a range of factors both separately and in combination.

Low plant populations, for example as a result of poor crop establishment, are hypothesised to reduce the yield of sugar beet on a spatially-variable basis. This effect is expected because sugar beet yields follow typical asymptotic yield-density relationships (Holliday, 1960; Jaggard and Qi, 2006). In eleven experiments carried out on a range of soil types in England over three growing seasons, yields were maximised in eight of the experiments with 100000 sugar beet plants per hectare, the economic optimum after allowing for seed costs, being 80000 per hectare (Jaggard et al., 2011). These optima, although not the actual yields, were the same in different soil types and locations.

Other biotic constraints also influence the ability to discern impacts of environmental variables, not least of which is weeds. Sugar beet is highly susceptible to weed competition especially in early stages of growth until canopy closure (Kropff et al., 1992). Reflecting this

* Corresponding author.
E-mail address: a.j.murdoch@reading.ac.uk (A.J. Murdoch).

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Table 1
Field operations, sampling and the dates of some measurements in the fields, White Patch, T32 and WO3.

	White Patch, 2012	T32, 2012	WO3, 2013
Latitude, °N	52.257	52.182	52.167
Longitude, °E	0.573	0.105	0.143
Area, ha	9	12.4	14
Previous crop	Winter wheat	Winter wheat	Winter wheat
Sugar beet variety	Valeska	Bullfinch	SY Muse
Crop drilled	23 March	16 March	5 March
Plots harvested	25 September	2 October	26 November
Crop plants/ha, (range)	91000 [66000–116000]	95000 [70000–115000]	51000 [22000–81000]
Total plots (number)	91	90	114
Nested plots (number)	13	15	36
Sampling intervals, m	24–40 main grid, 10 nested	40 main grid, 20 nested	36 main grid, 9 nested
Soil sampling date	2 July	7 July	8 July
Canopy data logging	31 May to 25 September	1 June to 2 October	22 May to 26 November
No. of data loggers	45	45	90
Soil moisture measured	2 June, 5 July and 13 August	6 June, 6 July and 13 August	6 June, 9 July and 11 Sept.
Weed assessment	13 August	17 August	20 July
Weed species	Mayweed (*Matricaria perforata*), Speedwell (*Veronica hederifolia*), Fat hen (*Chenopodium album*), Black-grass (*Alopecurus myosuroides*) and Wild-oat (*Avena fatua*).		Black-grass (*Alopecurus myosuroides*) and *Brassica napus.*
Nitrogen, kg N per ha	40, 3 April; 80, 13 April	58, 23 March; 80, 25 May	60, 9 April (only)
Herbicide applications, amount per ha	17 May: 1.25 L Betanal Maxxpro; 1 L Bettix Flo; 1 L Oil. 24 May: 1.25 L Betanal Maxxpro; 0.4 L Venzar.	22 March: 3 L Takron. 17 May: 2.5 L Beetup; 0.39 L Oblix 500; 20.5 g Debut; 0.4 L Venzar Flo; 0.5 L Defiant; 1.033 L Cropspray 11E. 22 July: 2.5 L Opteman; 5.16 kg Bittersalz; 0.55 L Laser; 1 L Cropspray 11E.	14 March: 4 L Takron. 25 April: 1 L Beetup; 0.45 L Oblix 500; 0.8 L Target SC; 1 L Opteman. 7 May: 1.6 L Beetup; 1.55 L Defiant SC; 0.8 L Target SC; 1.13 L Opteman. 17 June: 2.46 L Beetup; 0.5 L Defiant; 1 L Cropspray 11E.

vulnerability to weeds, when this research commenced in 2012, UK sugar beet crops were receiving an average of 4.1 herbicide treatments and sugar beet was treated with more herbicide (3.2 kg active ingredients per hectare) than any other arable crop in the UK (Garthwaite et al., 2013). In the fields where this research was carried out, weeds were managed uniformly and received above average treatments, but nevertheless still contained significant weed infestations in patches.

This paper mainly explores associations of both root yield and economic value with pedo-climatic variables within individual fields after accounting for any impacts of crop and weed plant population densities. The long-term goal is to identify opportunities for more precise sugar beet management in relation to pedo-climatic variables.

2. Materials and methods

Three commercial sugar beet fields were selected in the east of England (Table 1). These fields were White Patch at Broom's Barn Research Station, near Bury St. Edmunds (32 km east of Cambridge), and T32 and WO3, near Cambridge (Table 1). Fields were purposively selected on the basis of their having considerable variation in soil type (based on pre-existing soil maps) and topography (elevation and aspect − based on visiting the fields). The farm managers were wholly responsible for managing the crops and applied all inputs (Table 1) uniformly across the sampled areas of each field. White Patch and T32 were studied in 2012, and WO3 in 2013. To facilitate geostatistical analysis (Webster and Oliver, 2007), there were 90–114 samples per field arranged in an irregular grid with some nested samples over shorter distances (Table 1, Fig. 1). Yield maps of the preceding crops in T32 and WO3 and a soil map in White Patch were available and guided sampling, especially for locating the nested samples, which were included to enhance the accuracy of the predicted maps (Pereira et al., 2013).

Sample locations were geo-referenced using a differential Global Positioning System (dGPS), Trimble Nomad 900 B Mobile Computer in White Patch and T32, while an RTK GPS, Topcon Model GRS-1 (Topcon Positioning Systems, Inc., 7400 National Drive, Livermore, CA 94550 USA) provided more accurate geo-referencing in WO3. The latitude, longitude and altitude data provided by the GPS were used to estimate the slope and aspect of each sample location using ArcGIS software edition 10 (ESRI, Redlands, CA, USA). Except where noted otherwise, crop and soil sampling took place in 2 × 2 m plots at each sampling location. These plots comprised four rows of sugar beet with 50 cm spacing between rows.

2.1. Measurements

2.1.1. Crop assessments

To improve accuracy, the sugar beet plant population density at each sampling location was assessed by counting plants in 8 m^2 (4 rows x 4 m) extending the two-metre plot length used for most measurements by 2 m, taking care to avoid tractor wheelings. Counts were multiplied by 1250 to express the densities on a per hectare basis.

The plots were harvested manually (Table 1) shortly before commercial harvest. The two central rows from each plot (2 m^2) were harvested in White Patch and T32. In WO3 the harvested area for some plots had to be increased to include the whole plot (4 m^2) or extended to 8 m^2 to achieve the 10–15 kg samples required for analysis. The roots were dug with a modified (two-pronged) fork to avoid damage and the leaves were separated from the roots by cutting just below the crown using knives designed for hand topping sugar beet. The roots were then put in large woven polypropylene sacks (30 × 45 cm) and sent within 16 h to the British Sugar factory at Wissington, 45 km NE of Cambridge, where they were analysed exactly as for commercial samples for sugar beet fields in the UK.

At the factory the roots were washed and weighed and the clean samples then went through the factory system to determine the concentrations in the sugar beet roots of sugar (sucrose), impurities, amino acids and potassium using standard methods specified by the International Commission for Uniform Methods of Sugar Analysis (Whalley and Siegfried, 1964).

The yield value was computed as follows:

$$\text{Yield value (£/ha)} = [\text{Root yield (t/ha)}] \times P \times F$$

where P was the British Sugar price per tonne of roots (£27.53 and £26.51 in the 2012 and 2013 seasons, respectively), and F is a quality adjustment to that price, which ranged between 0.72 and 1.32 for sugar