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Implementing precision irrigation in a humid climate – Recent experiences and on-going challenges

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ABSTRACT

There is growing scientific interest in the potential role that precision irrigation (PI) can make towards improving crop productivity, and increasing water and energy efficiency in irrigated agriculture. Most progress has been made in arid and semi-arid climates for use in high value crop production where irrigation costs coupled with concerns regarding water scarcity have stimulated PI innovation and development. In temperate and humid climates where irrigation is supplemental to rainfall, PI is less developed but nevertheless offers scope to make more effective use of rainfall, help reduce the non-beneficial losses associated with irrigation (deep drainage, nitrate leaching) and provide farmers with evidence to demonstrate environmentally sustainable practices to processors and retailers. This paper reports on recent experiences in developing precision irrigation in UK field-scale agriculture, drawing on evidence from field research and modelling studies. By combining data from these sources, a critical evaluation focusing on selected technical, agronomic and engineering challenges that need to be overcome are described, including issues regarding PI scheduling, and the delineation of irrigation management zones to ensure compatibility with existing methods of overhead irrigation. The findings have relevance to other countries where irrigation is supplemental and where precision agriculture is gaining popularity.

1. Introduction

Precision farming research and development has demonstrated how significant benefits can be obtained by the variable-rate application of seeds, fertilizers and pesticides. As a result, the concept of precision agriculture (PA) has gained widespread acceptance; it is conceptualised as a system approach, where low input, high efficiency sustainable agriculture are the primary goals (Zhang et al., 2002). PA is also been promoted within the context of achieving the sustainable intensification of agriculture. There is now considerable interest worldwide in seeing if equivalent benefits of PA can be obtained from precision irrigation (PI), particularly in arid climates where water use is high, and where water scarcity is becoming a major constraint to production. But PI in temperate and humid climates, such as northern Europe, where cropping is rotational, water use is relatively low and irrigation schedules have to cope with uncertain and unpredictable rainfall, raises many new issues (Knox et al., 2012). Despite widespread international use of the term, PI, as a scientific concept, is still very much in its infancy (Smith and Baillie, 2009). In industry, the term PI is often used to refer to optimal management of micro (drip or trickle) irrigation where precise volumes of water are applied directly into the root zone. Other researchers often refer to variable rate irrigation (VRI) under centre pivots as being the dominant form of PI.

Traditionally, irrigators have ignored soil and crop variability within an irrigated field (block) and attempted to apply water as uniformly as possible. Indeed, most research efforts have focussed on reducing the impacts of irrigation heterogeneity on crop production. Since soils and crop development are rarely perfectly uniform, this means that under uniform irrigation some parts of the field are implicitly under-irrigated and/or other parts are over-irrigated. PI, in contrast, attempts to apply water non-uniformly to match any required variation in optimum application, for example, in response to soil, crop and/or topographic variability.

The scale, type of production and method of irrigation are all critically important. This paper discusses the opportunities and challenges of developing PI on mobile hose-reel boom systems for vegetable irrigation in a humid environment generally, and then links these to observed measurements and system modelling for a representative field site. Here we attempt to provide a critical evaluation of the key technical, agronomic and engineering challenges that still need to be addressed, including the concept of irrigation management zones and how these should be defined to

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be compatible with existing methods of overhead irrigation. The key questions therefore raised in this paper include, (i) are the potential benefits of PI significant, (ii) at what scale does variable rate application need to be developed, (iii) can mobile hose-reel boom systems apply variable rate irrigation at these scales, and (iv) do the additional costs justify investment in PI.

The paper first presents a brief overview of UK vegetable production to provide context for implementing PI. It then considers some fundamental differences between conventional and precision irrigation and the links with irrigation scheduling, since this is an important determinant in deciding how PI could be managed. Field data are then used to illustrate some of the challenges in deriving and delineating irrigation management zones (IMZ) for PI; finally, a broader discussion of the remaining agronomic and engineering challenges and concluding comments is provided.

1.1. Vegetable production in England

Water for agriculture is becoming increasingly scarce, even in humid countries. In England, irrigation accounts for typically less than 1% of total freshwater withdrawal. However, irrigation is a consumptive water use concentrated in the driest areas and driest months when water resources are most constrained (Knox et al., 2010). King et al. (2006) conducted a baseline assessment of agricultural water use in England and Wales and estimated total on-farm water abstraction was in excess of 300 Mm^3/year, with approximately 60% used for irrigation of outdoor field-scale agricultural and horticultural crops (128 Mm^3/year) most notably potatoes and vegetables.

Despite summer rainfall and a humid environment, water resources are fully committed particularly in the summer months in many catchments across southern and eastern England. About half of all agricultural and horticultural holdings are in catchments defined as either having 'no (more) water available' or are already 'over-licensed'. Nearly a fifth are in 'over-abstracted' catchments. Therefore, in water stressed catchments, where irrigation water demand exceeds available surface or groundwater water supplies, reducing the irrigation water use through improved management and advanced irrigation technologies would mean that water resources could be released to sustain environmental flows or support other uses (Hess et al., 2010). Growers also have to demonstrate efficient and sustainable use of water to renew time-limited abstraction licenses, and increasingly, to comply with supermarket sustainability protocols (Knox et al., 2012). Collectively, these are important drivers for promoting the uptake of advanced or PI technologies, assuming of course that the financial benefits justify the investment.

In dry summers, agricultural irrigation is the first sector targeted for abstraction restriction. A restriction on water supply to growers producing high quality vegetables for supermarkets can be a critical business risk. Failure to supply the contracted quantity and/or (usually more importantly) to meet the contracted quality standards can lead to large penalties, price discounting or, in worst cases, crop rejection and loss of contract (Monaghan et al., 2012). In some instances buyers will not award a contract to a grower unless they can demonstrate access to adequate and reliable water resources. Weather variability, and an expected increase in drought frequency associated with climate change, is encouraging an increasing number of UK growers to invest in water storage reservoirs, despite the large capital cost. Even so, there are strong pressures to reduce water use, not least to allow irrigation of a larger area from the same water resource.

As well as assuring water resources, it is necessary to apply the water efficiently. Relatively few UK growers use trickle (drip) irrigation due to cost and practical issues (Knox and Weatherhead, 2005) and there are very few centre pivots and linear move systems in use, mainly due to small field sizes and cropping mixes. Most UK irrigated crops are grown in rotations with non-irrigated crops, and mobile systems are therefore preferred. Hose reels, fitted with either rain-guns or booms are used on more than 86% of field vegetables irrigated area in the UK (Weatherhead, 2007). They are popular not only for their relatively low capital cost (Morris et al., 2014) but also because they provide the flexibility required for the rotational cropping patterns and for the supplemental irrigation which is typical in humid climate. High energy consumption and the relatively poor uniformity, especially in windy conditions, are notable drawbacks (Weatherhead, 2007); the issue of wind on overhead irrigation uniformity creates additional challenges for PI implantation. Within this context, the authors, working with industry colleagues, are assessing the potential for precision irrigation techniques, using hose-reel boom irrigators in the UK, and the trade-offs against conventional or traditional irrigation methods.

1.2. Traditional versus precision irrigation

Traditionally, irrigators have ignored soil and crop variability within an irrigated block and attempted to apply water uniformly across the field. Therefore, unless the soil is also uniform, this means that some parts of the field will be under- or over-irrigated. Under-irrigation impacts on crop yield and quality which in high-value field-scale vegetable production is a key driver for irrigation investment. Under-watering may also lead to increased nitrate leaching after harvest due to in inefficient uptake of nutrients during the growing season (Groves and Bailey, 1997; Bailey and Groves, 1992). Over-watering is, by definition, a waste of water, and therefore energy. However, by keeping parts of the block wetter than necessary during the growing period, there is also an increased risk of drainage and leaching, either from the irrigation itself, or from subsequent rainfall (Shepherd et al., 1993). This is particularly important in situations where the soil is kept close to field capacity in the spring (e.g. for scab control on potatoes). In the extreme, over-irrigation can cause waterlogging, with impacts on crop yield, quality and soil trafficability.

In contrast, PI offers the potential to eliminate over-irrigation and apply water in a deliberate non-uniform or variable manner, in response to the specific irrigation requirements of different discrete management units, and hence maximise crop response and minimise any adverse environmental impact (Raine et al., 2005). Rather than regarding the field as a single management unit, under PI management, the field is partitioned into a number of sub-units or irrigation management zones (IMZ). In common with principles of precision agriculture, managing fields as zones is believed to improve efficiency of resource inputs (Moore and Wolcott, 2000). The primary objective of optimising the spatial scale and timing of irrigation applications is therefore intended to increase the crop's biological response (improve yield and quality) to water application whilst simultaneously reducing losses of other inputs (fertiliser). It is not surprising, therefore that most attempts to quantify the agronomic and financial benefits of precision irrigation have focused on arid and semi-arid environments where water availability is becoming increasingly unreliable and expensive, and where irrigation is an essential component of production. However, under humid or temperate conditions, where summer rainfall is an important contributor to crop evapotranspiration needs, the rationale and justification of precision irrigation needs to be carefully evaluated, particularly in the context of potential water and energy savings accrued through adopting a different approach to scheduling.

2. Benefits of precision irrigation in a humid climate

The combination of mobile irrigators with current approaches to scheduling mean that the whole field block is typically irrigated