Grower Summary

FV454

Improving quality and shelf-life of Romaine and Iceberg lettuce crops using precision, deficit and alternate wetting and drying irrigation techniques optimised for different soils

Final Report, August 2018

Project title:	Improving quality and shelf-life of Romaine and Iceberg lettuce crops using precision, deficit and alternate wetting and drying irrigation techniques optimised for different soils
Project number:	FV 454
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Report:	Final Report, August 2018
Previous report:	NA
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Location of project:	NIAB EMR
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Date project commenced:	01 April 2017

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The results and conclusions in this report are based on an investigation conducted over a one-year period on potted lettuce plants. The controlled conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial irrigation recommendations.

GROWER SUMMARY

Headlines

1. Leaf responses of Romaine and Iceberg varieties to drying peat and silt soils were triggered at similar soil matric potentials, but at very different volumetric soil moisture contents
2. Thermal imaging of lettuce hearts detected a loss in transpirational cooling in response to very mild soil water deficits; this preceded significant reductions in stomatal conductance which were triggered at lower soil matric potentials
3. The Romaine varieties “Scala”, *Actina”, and Iceberg varieties “Challenge” and “Etude” have different sensitivities to drying soil therefore water management practice needs to be optimised for each variety
4. Post-harvest mid-rib pinking was not detected in any Romaine and Iceberg lettuce varieties grown in peat or silt soil under well-watered or mild soil drying treatments
5. Irrigation set points based on soil matric potentials have been identified for Romaine and Iceberg lettuce varieties grown in peat and silt soils

Background

UK lettuce growers strive to supply a consistently high quality product to achieve customer satisfaction but this can be challenging in changeable UK growing conditions. Anecdotal evidence suggests that lettuce crops grown overseas with reduced water inputs often have better leaf quality and a longer shelf-life than those grown under typical UK commercial conditions. Over-wet soils due to excessive rainfall or ineffective irrigation scheduling can promote postharvest mid-rib pinking and reduce shelf-life in some varieties *e.g*. Romaine and Iceberg. Although growers recognise the importance of optimising irrigation scheduling, matching crop demand for water with supply is challenging for many. New guidelines are needed to help UK growers to increase returns on investment through the efficient use of resources, and access to real-time field data is vital to avoid unplanned soil moisture deficits that have the potential to reduce head fresh weight and diameter, and lower leaf quality.

The removal of the Abstraction Licence exemption for trickle irrigators and the hot dry summer of 2018 have focussed attention on the availability and efficient use of water for irrigation in the production of leafy salads. UK’s recent failure to meet the objectives set out in the Water Framework Directive around achieving “good quality status” of UK water bodies means that on-farm fertiliser use efficiencies must also be improved across the industry. At the same time, a greater consistency of supply of high quality fresh produce with an assured shelf-life must be achieved, alongside reductions in labour costs associated with crop management and harvesting.

There is evidence that using precision irrigation, alternate wetting and drying regimes and “beneficial stresses” such as deficit irrigation has the potential to improve leaf quality, and shelf-life in cut lettuce leaves, but head fresh weights are often reduced by more severe soil water deficits. A more rigorous scientific understanding of how the physiology of leafy salads is altered by mild and more severe soil drying is needed in order to identify new opportunities to use beneficial stresses in commercial production to improve leaf quality without reducing head fresh weight or diameter. In tandem, new uncomplicated grower-facing tools and approaches are needed to facilitate the integration of new innovative growing practices into existing commercial infrastructure.

In this work, we have imposed gradual soil drying to identify the most appropriate irrigation set points for Romaine and Iceberg lettuce varieties grown in two different soil types; this is the first step towards the longer-term aim of developing on-farm precision irrigation (PI) strategies that ensure marketable yields are maintained and leaf quality and resource use efficiency is optimised. Our approach is to derive irrigation set points based on soil matric potentials rather than using volumetric soil moisture contents or soil moisture deficits which are more commonly used in the industry. Soil matric potentials are not influenced by soil bulk density and so irrigation set points should be similar for specific varieties growing in a range of different soil types. Soil matric potentials can be converted to volumetric soil moisture contents by reference to a moisture release curve, which is a plot of the relationship between the water content, and the soil matric potential (see Science Section).

Summary

The aim of Phase I of this project was to develop scientifically-derived irrigation set points for use in precision irrigation, alternate wetting and drying regimes, and deficit irrigation to improve consistency of leaf quality and shelf-life potential of Romaine (“Actina” and “Scala”) and Iceberg (“Challenge” and “Etude”) lettuce without reducing head fresh weight. This was achieved by applying mild and gradual soil drying and measuring the first plant adaptive responses to declining soil water availability. The point of first wilting and widespread wilting was also noted.

Experimental details

Two varieties of Romaine lettuce (“Actina” and “Scala”) and two varieties of Iceberg lettuce (“Challenge” and “Etude”) were used in three separate experiments. Each variety was grown in either a peat or a silt soil and two irrigation treatments (well-watered or drying down) were imposed. Lettuce blocks were supplied by Jepco Ltd and G’s Fresh Ltd and planted in 13 L pots containing peat (G’s, Cambs.) or silt (Jepco, Lincs.) soil. All plants were maintained in the GroDome (a controlled environment facility) at NIAB EMR (Figure GS1). Day and night temperatures were set to 18 °C and 12 °C, respectively; these values are the long-term historical averages for May-July at East Malling. Temperatures were adjusted to 22 °C and 14 °C for experiments in October to ensure plant establishment. Relative humidity was uncontrolled. There were 12 biological replicates for each variety, soil and treatment. A randomised block design that maximised statistical degrees of freedom was used and any statistically significant differences between treatments were identified.

Figure GS1. “Scala” and “Challenge” lettuce plants in 13 L pots of silt or peat soil in the GroDome at NIAB EMR (Experiment 1).

Soil matric potential and volumetric moisture content sensors (Figure GS2) were buried at different depths within the pots. In addition, “spot measurements” of volumetric soil moisture content, soil temperature, and pore E.C. were made at three positions within the pot using a hand-held “WET” sensor and HH2 meter (Delta-T Devices Ltd, UK). Irrigation was scheduled to match demand with supply and applied *via* pressure compensated emitters and a four-way spider to help to ensure even distribution of water throughout the pot. Two weeks before plants reached market specifications, a drying down treatment was applied to half of the pots by reducing the daily irrigation volume to 80% of the volume of water lost by transpiration each day. In this way, gradual soil drying was imposed. Leaf physiological responses to drying soil including leaf chlorophyll content, leaf water relations, stomatal conductance, lettuce heart temperature and photosynthesis were measured three times a

Figure GS2. A) Sensors used to measure volumetric soil moisture content, soil temperature and pore E.C. (Delta-T Devices Ltd). B) Sensors used to compare soil matric potential and volumetric soil moisture content (METER Group, Inc. USA).

week and compared to those of well-watered plants to identify the degree of soil drying at which agronomically important traits were first affected. At harvest, measurements of whole lettuce fresh weight, lettuce head fresh and dry weights, the propensity for mid-rib pinking in cut leaves, and leaf antioxidant capacity at harvest were also made.

For brevity, results are reported here from experiments with Romaine “Actina” and Iceberg “Challenge” in peat and silt soils. Results from experiments with “Scala” and “Etude” in peat and silt soils are summarised in the Science Section.

Romaine “Actina” - changes in soil volumetric moisture content and matric potential

In the peat soil, the volumetric soil water content at pot / field capacity was around 40% and the corresponding soil matric potential was -6 kPa. Throughout the experiments, soil in the well-watered treatment was maintained around pot capacity, and in the drying down treatment, volumetric soil moisture content and soil matric potential fell to 27% and -300 kPa, respectively, by the end of the experiment.

In silt soil, the volumetric soil water content at pot (field) capacity was around 24% and the corresponding soil matric potential was –10 kPa. Throughout the experiments, soil in the well-watered treatment was maintained around pot capacity, and in the drying down treatment, volumetric soil moisture content and soil matric potential fell to 13% and -126 kPa, respectively, by the end of the experiment.

Romaine “Actina” - plant responses to soil drying

In drying peat soil, a small but significant increase in the temperature of lettuce hearts in plants under the drying down treatment was detected by thermal imaging. This reduction in transpirational cooling was first noted at a soil matric potential of -36 kPa (~VSMC of 36%). As the peat soil dried further, stomata began to close and a subsequent reduction in the rate of photosynthesis was detected (Figure GS3). Wilting was first detected at -160 kPa and was widespread at -280 kPa (Figure GS3). Leaf chlorophyll content was similar in plants under the two treatments. A significant difference in stomatal conductance between plants in well-watered peat soil and

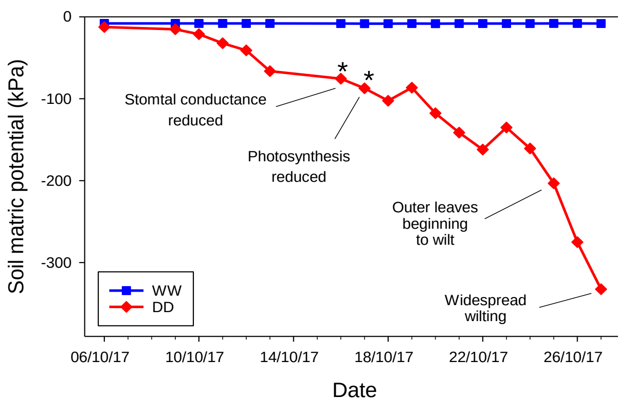

Figure GS3. The soil matric potentials at which statistically significant reductions in stomatal conductance and photosynthesis were detected in “Actina” lettuce growing in drying peat soil. The onset of mild and severe wilting is also shown.

Table 1. Volumetric soil moisture content (VSMC) and soil matric potential (soil ψ_m) at which statistically significant reductions in stomatal conductance (g_s) and photosynthesis (Pn) were first detected in “Actina” in response to gradual drying of peat and silt soil.

Soil	Pot Capacity		Significant reduction in g_s (p<0.05)		Significant reduction in Pn (p<0.05)	
	VSMC (%))	soil ψ_m (kPa)	VSMC (%))	Soil ψ_m (kPa)	VSMC (%)	Soil ψ_m (kPa)
Peat	40	-6	30	-78	27	-86
Silt	24	-10	14	-84	13	-94

those in drying peat soil was first detected at -50 kPa (~VSMC of 30%), and photosynthesis was reduced significantly at -65 kPa (~VSMC of 27%). (Table 1).

In drying silt soil, a small reduction in transpirational cooling was first noted at a soil matric potential of -38 kPa, corresponding to a volumetric soil moisture content value of 18%. A significant difference in stomatal conductance was first detected at a soil matric potential of -84 kPa and a corresponding volumetric moisture content of *c.* 14%. Photosynthesis was reduced significantly at -94 kPa and a corresponding volumetric moisture content of 13% (Table 1). Plants began to wilt at -167 kPa and more widespread wilting was apparent at -230 kPa. Leaf chlorophyll content and water potential were similar in the well-watered and drying down treatments.

Romaine “Actina” - derivation of irrigation set points for use in alternate wetting and drying regimes

We have demonstrated conclusively that leaf adaptive physiological responses to drying soil occur at similar values of matric potential in the peat and silt soils, whereas the corresponding volumetric soil moisture contents were very different. This outcome was expected since matric potentials are not influenced by differences in soil bulk density, whereas volumetric water contents are. These results highlight the advantage of using matric potentials to schedule irrigation to crops in various soils with very different bulk densities, and moisture release curves linking soil matric potential with volumetric moisture content will be derived for different soils to help to inform growers’ irrigation strategies.

In the pot experiments described above, “Actina” first perceived a moisture deficit stress at a soil matric potential between -78 and -84 kPa. Continued and sustained soil drying past this value would likely reduce final head weights and diameters, as well as leaf quality and so the recommended irrigation set point for further testing in field experiments is -65 kPa. This set point could be used to develop an Alternate Wetting and Drying treatment where the frequency and duration of irrigation is scheduled to return soil to field capacity once the average soil matric potential in the rooting zone reaches -65 kPa. This would correspond to an average volumetric soil moisture content in the rooting zone of 15 and 33% in silt and peat soils, respectively.

Iceberg "Challenge" - plant responses to soil drying

In drying peat soil, a significant difference in stomatal conductance was first detected at -44 kPa, and photosynthesis was also reduced significantly at -54 kPa (Table 2). The corresponding volumetric moisture content was 30%. Wilting was first detected at -180 kPa and was widespread at -320 kPa. Leaf chlorophyll content and water potentials were similar in the well-watered and drying down treatments.

In drying silt soil, a significant difference in stomatal conductance was first detected at a soil matric potential of -36 kPa and a corresponding volumetric moisture content of 16% (Table 2). Photosynthesis was reduced significantly at -65 kPa and a corresponding volumetric moisture content of below 14%. Plants began to wilt at -70 kPa and more widespread wilting was apparent at -155 kPa. Leaf chlorophyll content and water potentials were similar in plants under the well-watered and drying down treatments.

Table 2. Volumetric soil moisture content (VSMC) and soil matric potential (soil ψ_m) at which statistically significant reductions in stomatal conductance (g_s) and photosynthesis (Pn) were first detected in "Challenge" in response to gradual drying of peat and silt soil.

Soil	Pot Capacity		Significant reduction in g_s ($p<0.05$)		Significant reduction in Pn ($p<0.05$)	
	VSMC (%))	soil ψ_m (kPa)	VSMC (%))	Soil ψ_m (kPa)	VSMC (%)	Soil ψ_m (kPa)
Peat	45	-10	30	-54	30	-54
Silt	24	-10	16	-36	>14	-65

Iceberg "Challenge" - derivation of irrigation set points for use in alternate wetting and drying regimes

In the pot experiments described above, "Challenge" first perceived a moisture deficit stress at a soil matric potential between -36 and -54 kPa. Continued and sustained soil drying past this point would likely reduce final head weights and diameters, as well as leaf quality and so the recommended irrigation set point for further testing in field experiments is -25 kPa. This set point should be used in an alternate wetting and drying treatment where irrigation is scheduled to return soil to field capacity once the average soil matric potential in the rooting zone reaches -25 kPa, which is equivalent to a volumetric moisture content of 18 and 39% in silt and peat soils, respectively.

Mid-rib pinking was not observed in any variety in either well-watered or drying down treatments. The conditions that predispose leaves to mid-rib pinking are not yet known but over-irrigation or excessive rainfall are thought to be involved. Deficit irrigation has also been shown to increase the propensity for mid-rib pinking. In our work, over-watering was avoided by scheduling irrigation to match demand with supply and so the absence of any pinking was not unexpected.

Financial Benefits

The cost / benefit of adopting the irrigation strategies investigated in this project cannot be quantified at this early stage. The irrigation set points derived for potted Romaine and Iceberg varieties need to be tested in a controlled environment and validated in scientific field experiments where alternate wetting and drying strategies are deployed on commercial grower sites over the course of a full growing season, and are compared to commercial irrigation regimes.

Action Points

1. Consider using changes in soil matric potential to inform irrigation decisions for crops in different soils rather than changes in soil volumetric moisture content
2. Review commercial irrigation strategies and identify where improvements could be made to optimise soil water availability in the rooting zone
3. Recognise that varieties have differential sensitivity to soil drying and schedule irrigation accordingly to avoid limiting photosynthesis and leaf quality
4. Improve irrigation scheduling to avoid unplanned soil water deficits and optimise leaf transpirational cooling in hot weather
5. Avoid over-irrigation, especially after rainfall, which exacerbates post-harvest pinking