Real-time 2D visualization of soil fertilizer dynamics in potatoes using a multi-sensor capacitance probe array.

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Abstract:
The use of intensive soil water monitoring with multiple-depth sensor arrays in representative soil volumes can indicate plant water usage rates in the broader scale. Multiple Sentek TriSCAN soil moisture monitoring probes were installed in a cross-hair arrangement adjacent to potatoes (var. Ruby Lou) irrigated with a centre pivot. Volumetric soil Water Content (VWC – site-specifically calibrated) and Volumetric Ion Content (VIC) data was collected for the full growth season on a near-continuous basis simultaneously across the probe array. This was analysed using IrriMAX™ 2D Viewer and VIC Filter software to visualise the water and salt distribution within the soil in 2-dimensions. This software uses automated cubic spline interpolation techniques to generate contour maps and video animations of the water and salt dynamics. The parameter scales are obtained from the whole dataset and planar views (transects) are painted with false colours to visualise the dynamics of the water and salt movements throughout the soil profile. When this is interpreted with known fertilizer input records, this method allows the visualisation of the spatial distribution of nutrients within the soil and the duration of time over which such a distribution persists. This gave insights into the plant usage and soil drainage characteristics that were then applied over the larger area, thus helping the operator to optimize fertilizer and irrigation inputs to best suit plant requirements. Of particular benefit was the routine timed application of irrigation waters to control salt build-up within the soil.

Keywords: fertilizer, capacitance, 2D array, soil water management, transect.

INTRODUCTION
The use of soil moisture monitoring probes has continued to increase in popularity as crop managers grapple with increased water and pumping costs worldwide. What is sometimes overlooked is the bond between soil moisture content and fertility (Dean et al., 1987, McCann et al., 2007). The movement of water throughout the soil profile also moves soluble fertilizers at a variety of much slower rates, depending upon soil texture. In free draining sands, fertilizer is poorly retained and has a limited lifespan in the soil. Greater clay contents in the soil profile tend to decrease the rate at which fertilizer moves through the profile. This is due primarily to the smaller particle size requiring a higher incident angle to be overcome during the transfer of water from one soil crumb to the next, but is also dependent upon the soil surface chemistry, characteristics which are set by the parent material and the chemical erosive forces acting on them. Charged ions provided via the irrigation waters exchange with ion moieties already on the surfaces of soil particles. Hence the progression of salts and fertilizers is very much inhibited by this chemistry.

The decreasing cost of soil moisture sensors had made them more accessible to an expanding market, particularly in the arena of research. The design of a new probe from Sentek called the Drill & Drop makes the intensification of monitoring possible. Sensors are available in probes at regular 10cm depths, and the faster installation method allows for more probes to be installed in a more concentrated manner. The data collected from such an array of probes allows for the generation of 2-dimensional colorimetric displays which can be viewed
at discrete time points or viewed as a continuous video. This was possible through the use of a calculation protocol which estimates the unknown soil water content between two known points using a cubic spline approximation (Fuentes et al., 2004, Press et al., 2002 and Ross, 1992). The idea behind this is to mimic (albeit imperfectly) the shape of standard drainage curves that exist in soils. No adjustment is made to this calculation for different soil types, so the videos must be viewed with these assumptions in mind.

The site was more heavily instrumented than would be practical in a commercial setup, but this was done deliberately to more fully cover the observable water and salinity dynamics. Only the more complete data sets collected along the hill row are discussed here. This was done to simplify the analyses and to confine the discussion to the root zone of the crop which, in a commercial setting is principally restricted to the hill and does not spread significantly into the interrow.

MATERIALS AND METHODS

The Ruby Lou potato crop was monitored with six 60cm Drill & Drop™ probes (Sentek, 2014) positioned in a cross-hair arrangement around 2 potato plants (West to East transect across the row only is shown in figure 1) and connected to three EnviroSCAN MULTI data logging and transmission systems. Two rain gauges were used: one within and one outside of the irrigation zone of the centre pivot. Exact water application volumes were calculated by the difference of these two instruments. Additional external temperature sensors were employed to draw comparisons between inside and outside instrumentation. This work has been summarised elsewhere (Dalton et al., 2014).

To more accurately monitor the VWC, a site-specific soil calibration procedure was performed at the site (Sentek, 2001). This involved correlating the Sentek sensor responses to the gravimetrically determined soil water content. Additional Drill & Drop probes were installed into prepared ground at different water contents. Sensor readings were taken, followed immediately by excavated soil samples of consistent volume at various depths. These samples were weighed in the field and again after drying in an oven at 105°C for one week. This is the industry standard methodology.

RESULTS AND DISCUSSION

Figure 2 shows the site-specific soil calibration curve used in this study. This allowed for more accurate VWC values to be calculated, rather than utilising the factory default settings. The relationship used to relate Scaled Frequency (SF) to VWC was determined to be:

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SF = a \times VWC^b + c
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Where: \(a=0.092\), \(b=0.555\) and \(c=0.189\). The relationship was characterized by an \(r\)-squared of 0.911, considered to be a highly significant correlation.

Figure 3 shows an image of the 2D transect along the hill row, running North to South. Two clear areas of the soil profile may be observed: the hill and the sub-hill. Most of the root development of the crop occurs in the upper hill region. When run as a video, dynamic changes can be seen to occur in this region with alternate wetting and drying cycles as the centre pivot crosses the area and the sun and natural drainage dries the hill. The lower region remains consistently wet, fed not only from above, but also from lateral movement of water that collects temporarily in the valleys between the hills.

It was also clear that greater water harvesting occurred as the plants reached different growth stages. Initially small plants did not remove much water and there was greater evaporation from the exposed soil surface. It was at this point that diurnal fluctuation was at its greatest. As the plant matures, more water was taken from the soil and concentrated in the
developing tubers. Evaporation became less from the soil surface (reducing the diurnal fluctuation) as the canopy began to close, but ET losses increased with the developing canopy area. All of these different water usage patterns could be visualized with the 2D View software, helping the grower to make better decisions regarding management strategies.

For example, it is known that potato plants may shut down their transpiration later in the day in response to high evaporative demand. Leaf exposure to the sun is reduced by this action of wilting. It may not be in direct response to water deficit, but a survival mechanism for hot days. In this situation, the application of more water may have no effect on the wilting, but a reduced irrigation may help to cool the canopy and may be enough to avoid significant crop damage. Waterlogging and high temperatures can work together to destroy a plant very quickly.

Figure 4 shows the same 2D transect discussed above, but displays the VIC within the soil profile. When run as a video, dynamic changes in the soil salinity were realized, although the changes were slower as the ionic passage was wholly related to the water content. It was possible to intimate that some of the observable changes were due to previous fertilizer applications, although there was a level of time delay between applications of different types of materials. These dynamic changes were not confirmed by other means, so these conclusions are speculative at this stage. This is for a future study.

Of special interest here is what appears to be the relative signature tracings of different types of fertilizer. Soluble highly ionic fertilizer appears to be readily detected by the Sentek sensor as it enters the soil profile. By contrast, a covalent fertilizer such as urea are initially less easily detected. Over time, however, the urea enters the microbial biota of the soil, is used by bacteria and the processed nitrogen is released upon its death. The form of nitrogen released is primarily ionic, so can easily be detected. Hence, urea may take 2 to 3 weeks to appear in the VIC data. By contrast, ionic fertilizers such as potassium and calcium nitrate produce immediate TriSCAN sensor responses.

Figure 5 shows several examples of where the rainfall has leached the previous applications of fertilizers. Rainfall often has a greater effect on the leaching of fertilizers than irrigation water alone. Presumably, this is because irrigation water usually contains its own salinity load. It also shows a gentle increasing trend in salinity over a period of three weeks from 7th to 27th April. The VIC is seen to increase from 1375 to 2329 at the 25cm depth over this period, an increase of 954 VIC. This is not considered to be a dangerous increase, but it is significant. A salinity benchmarking procedure was not carried out at the site, but this could be done in the future to directly relate VIC to soil Electrical Conductivity (EC). These levels are all considered to be in the low range. Values above 5000 VIC are generally considered to be causing significant plant stress and loss of yield, but this degree of risk is dependent upon soil type.

Also shown is that the salinity did not exhibit any dynamism at depth greater than 35cm. It is assumed that any leached fertilizer that was not taken up by the plant was diluted into these wetter depths.

Figure 6 shows that the standard graph of VIC can often be punctuated with spikes in the data due to the effects of high water content causing ionic flux within the soil profile. This sensor operates at a lower frequency than normal and is sensitive to minute variations in water content (resolution of ±0.01mm) so when ions are moving rapidly, the sensor detects this as an exaggerated ion content. A way to better analyse this data is to select a water content where sufficient VIC values have been taken, and to plot VIC at this level only. This sometimes makes the trends in soil salt changes clearer to see.

The link between evapotranspiration (ET) and plant water use is shown in figure 7. It shows that a plant uses more water during a day when ET is high and less water when ET is low. In the example, rainfall and irrigations on the 21st April initially replaced the losses from
ET. However, less rain in the following week and sustained high levels of ET began to cause stress in the plants by the 26\textsuperscript{th} April, as the irrigations were not keeping up with the evapotranspiration.

CONCLUSIONS

The Sentek 2D Imager software was shown to be a useful tool for visualizing the dynamic changes of water, salts (fertilizer) and temperature within the soil profile. Knowing these trends helps the operator to better manage salt and fertilizer loads within the soil profile. Of key use was the timed application of water to wash fertilizers into the root zone and to leach out dangerous salt build-up at the end of the growing season.

The Sentek 2D Imager videos can be used in conjunction with daily ET data to more fully understand the environmental stresses experienced by the crop and the way in which the plant reacts to them.

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REFERENCES


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Figure 1: Drill & Drop probe array in potatoes across hill.

Figure 2: Site-specific soil calibration curve.

SF = 0.092 x VWC^{0.555} + 0.189
r^2 = 0.911

Figure 3: 2D Transect of Volumetric Water Content along hill.

Figure 4: 2D Transect of Volumetric Ion Content along hill.
Figure 5: Fertilizer applications detected as Volumetric Ion Content (VIC).

Figure 6: Viewing Volumetric Ion Content (VIC) independent of soil water content.

Figure 7: Matching evaporative demand to plant water supply.