Technical Document

Capacitance Soil Moisture Probe

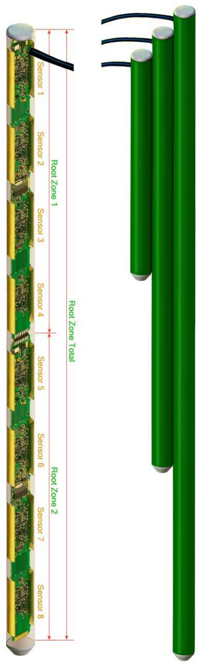
Data Interpretation

Version 3.0
Febraury 2023

Table of Contents

1 Data Interpretation – Capacitance Probes

A Capacitance sensor monitors changes in the dielectric properties of the soil to provide users with continuous monitoring of soil moisture. Some sensors also measure soil salinity and soil temperature. Sensors are typically built into a probe which can return moisture levels through the soil profile.



2 Measurement Parameters

2.1 Soil Temperature

Most capacitance probes include a thermistor which measures the temperature at each sensor. Under most conditions, this will reflect the soil temperature.

The temperature sensor range is set to cover that expected in the various applications in which the probes will be used. The upper limit for example allows the sensor to make measurements in compost.

Because the electronics on the probe printed circuit boards are typically potted in resin, it takes time for changes in soil temperature to transfer first through the wall of the PVC tube and then to the sensor where they are detected. This means that it can take some time for changes in soil temperature to be observed on the temperature sensor, especially if the soil temperature changes rapidly (e.g. when rain falls on hot soil).

Most capacitance probes do not however apply compensation for the change in moisture readings generated when the soil temperature changes. The change occurs because the dielectric properties of all materials are temperature dependent: as temperature increases, the water molecules can move more freely and hence store more energy, which is seen as an increase in capacitance. This is evident as an increase in indicated soil moisture as soil temperature rises. It is particularly noticeable in dryland agriculture over the post harvest period, when the soil progressively dries, but, as it heats, starts to show an increase in moisture. In irrigated agriculture the change is not as pronounced, because irrigation helps keep soil temperature changes to a smaller range. Often the change that does occur is dismissed as “diurnal variation due to capillary rise” rather then rise due to temperature change.

The compensation must be done externally to the probe. This can be completed in the presentation software or after exporting the data to a spreadsheet. The compensation can be expressed as:

SMcomp = SM – (SM * F * (ST-Tref)

Where

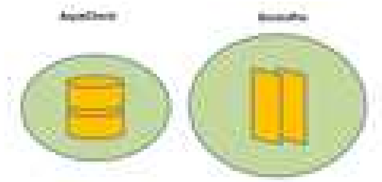
SM soil moisture reading

SMcomp	compensated soil moisture value
ST	soil temperature reading
Tref	Reference temperature i.e. 15 °C
F	Scaling factor 0.002 to 0.004

2.2 Soil Moisture

Capacitance probes respond to changes in the dielectric properties of the soil. The relationship between dielectric properties and volumetric moisture content is well understood and widely documented. However it varies from one probe design to another and from one soil type to another.

In most probe designs the sensor element is made up of a pair of concentric rings (stacked one above the other) which make up the capacitive leg of an L-C oscillator. If either the L (inductive) component or C (capacitive) component change in value, the frequency of the circuit changes. Typically the L component is fixed and the capacitance changes with changes in the dielectric (energy storage) properties of the material inside and outside of the rings. The circuit connected to the oscillator measures the change in frequency of the oscillator.



At the time of manufacture, probes are typically calibrated to a standardized soil media and it is the accuracy of the sensors in this media which is given in the sensor specifications. The accuracy in a given soil type will depend on how well the calibration (either the default or one added in software) matches the characteristics of the soil.

2.3 Electrical Conductivity

Very early in the development of capacitance probes it was found that the sensors are influenced not just by moisture content of the soil but also by its salt content. The first capacitance based conductivity sensors operated over two frequency bands: firstly one at which the influence of moisture was greatest and salt least then again at a lower frequency where the influence of water content is lowest and salt highest. Mathematical models then tried to separate the two frequency responses into soil moisture and soil conductivity components. This approach tended to be acceptable in sandy soils but becomes less useful as clay content rises.

One manufacturer uses an alternative approach of looking at the two components of change in the dielectric properties of the soil: a “real” component which reflects the moisture induced change and an “imaginary” component (a phase change or time delay) which represents the salinity component.

The conductivity relationship is however quite complex: conductivity is firstly influenced by temperature, so readings must first be adjusted with information from the thermistor. Secondly, the ability to make a good conductivity measurement is also influenced by moisture content: the higher the moisture content the easier it is to read conductivity.

If a sample of soil is carrying a fixed amount of salt, the concentration will change as moisture is added: i.e. as the moisture content increases, the amount of salt in any given volume of water decreases. But one problem of the salinity measurements made by the capacitance probes is that as moisture content increases (e.g. with irrigation) even though the salt content has not risen, the indicated salinity increases. This is because they are responding to the total quantity of salt rather than the concentration.

Some SWR based conductivity sensors (e.g. Stevens HydraProbe) can measure the bulk conductivity and then, using values of soil temperature and soil moisture, determine the salt burden – a figure which does not change with water content. They can do this because they are able to make a direct conductivity measurement (i.e. measuring the current flow between two conductive electrodes). However because capacitance sensors are not able to measure conductivity directly (i.e. they have no pins in contact with the soil) and because of the interaction between the various factors controlling measurement, they cannot yet provide measurement of salt burden, only of the conductivity at a given moisture level.

Conductivity values from capacitance probes should not be analysed as a trend. Instead, you must identify points in time where the moisture content is the same and then, look at the change in indicated conductivity from one point to the next.

The relationship between bulk conductivity and true pore water conductivity is site specific. To convert the indicated EC to pore water conductivity, the values obtained from the probe should be compared with those obtained from soil samples or from a suction sampler. The latter provide a very cheap and simple method of monitoring EC and nitrate levels in the plant root zone.

3 Data Interpretation and Use

3.1 Soil Temperature

Soil temperature provides useful information for the management of crops, particular in the areas of germination and nutrient uptake. Soil temperature also has an impact on root growth as perennial plants emerge from senescence.

As profiling capacitance probes provide temperature measurement through the full soil profile, you can examine soil temperature at any or all levels in the root zone.

3.1.1 Nutrient Uptake

Farmers must often choose between the application of ammonium nitrate or Urea. Of the nitrogen in ammonium nitrate half is present as nitrate (which is available directly to the plant) and half as ammonium (which must be converted to nitrate by soil microbes before becoming readily available to the plants). Urea is cheap and easy to apply, but should be incorporated into the soil as quickly as possible: 2/3 of the Urea-N resent will be hydrolyzed to ammonia-N within 24 hours but some of this will be lost as ammonia gas (de-nitrification) reducing the efficiency of the urea as a fertiliser. The bacteria which convert the nitrogen are more active at high temperatures, so losses increase with temperature. But the mineralization process stops in low temperatures, so urea should not be applied when soil temperatures are below 7 °C at a depth of 10cm.

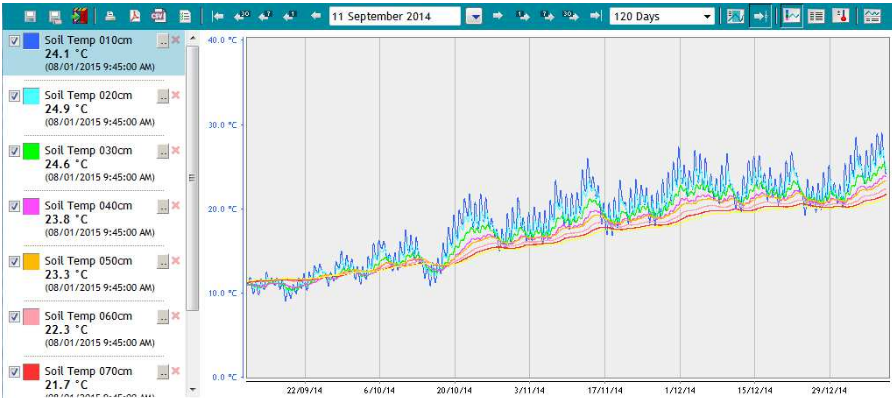
3.1.2 Phenological analysis

Plants which shut down over the cooler months will typically undergo a root growth surge just before entering senescence and then again once they emerge. The soil conditions at these times have an impact on root growth and hence the amount of biomass produced. There are thresholds at both the low and high temperatures and at different stages of the growth cycle: the temperature in cold areas must rise to a species specific threshold before root growth can occur; overly high temperatures at these times can restrict root growth and hence biomass accumulation.

Research on Maize has also shown that dry matter yield and nutrient uptake were higher at soil temperatures above 28 °C than they were below 22 °C (Hussain and Maqsood, 2011 p1)

3.1.3 Long Term Analysis

Plotting soil temperature over longer time frames provides a good basis for evaluation of changes in root zone conditions over a growing season. The 10cm sensors show the greatest amount of movement – with a clear diurnal pattern – but the daily changes are superimposed on shorter cycles which follow the 1 to 2 week weather patterns and then again on longer seasonal patterns.



It is also useful to add rainfall totals to soil temperature data so that the cooling effect of rain events can be examined. This is best done using daily rainfall totals.

3.2 Soil Moisture

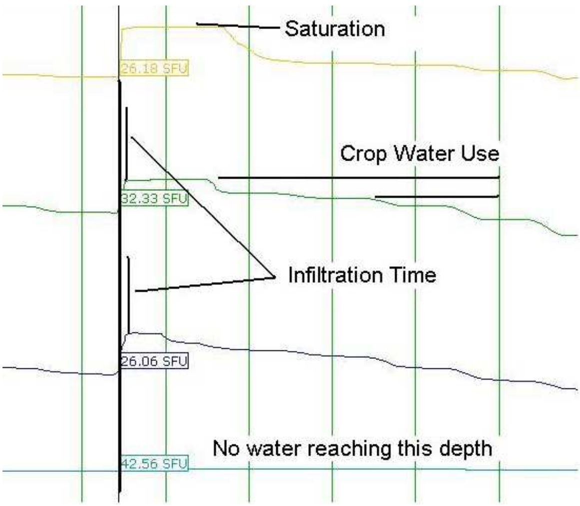
Soil moisture monitoring provides critical information for crop management in both irrigated and dryland farming.

3.2.1 Monitoring Irrigation Events

An irrigation event usually displays a set of similar characteristics:

- A rapid rise in soil moisture at the surface
- Infiltration down through the profile at a rate determined by both the soil's current water status and its texture (infiltration rate increases as relative water content increases and decreases as the clay content rises)
  - This is evident as a delayed rise in moisture level at the next sensor in the profile
- A sharp fall off at the end of irrigation as the soil quickly drains
  - At the top sensors you will see a rapid rise in water level, a peak when irrigation stops and then a rapid fall
- If a sensor climbs and stays at that level for a period of time, it is likely that the soil at that depth is saturated and water is being lost through the profile as drainage. This behaviour is not often seen in micro irrigation but is common in flood/surface irrigation.

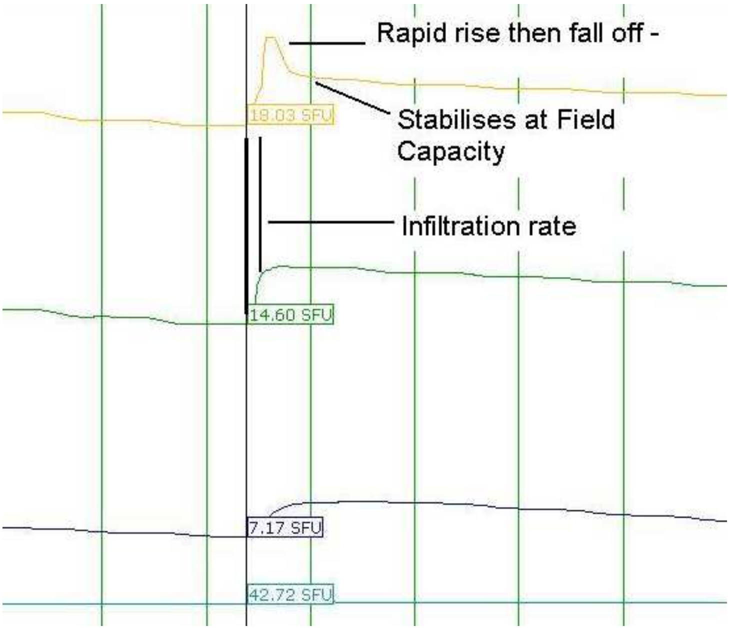
The image below shows a representation of an irrigation event with data from sensors at 10 through 40cm (10cm at top).



3.2.2 Irrigation Depth

If a plant's roots can only draw water to a given depth (whether because of the plant physiology or limitations in the soil structure), it makes sense to irrigate to the same depth. Irrigating to a shallower depth means that the plant's growth will be restricted. It also means that the reserve of water for the plants in the event of a hot spell will be reduce. Irrigating more will waster water (in deep soils) or create waterlogging (in soils with an impervious layer).

To identify the depth of irrigation and its corollary, where in the profile the plants are drawing water from, it is common to look at the data from all of the sensors at the one time – a separate level graph. For clarity, the sensors are all placed on the one graph, but the traces are stacked one on top of the other. The graph thus gives a very clear picture of changes in moisture through the profile.



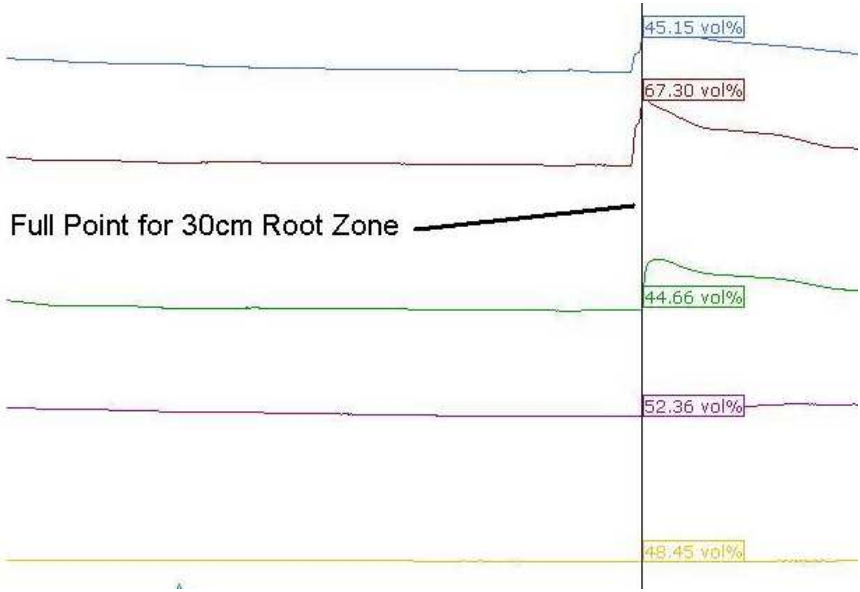
In the above graph, the water reached the third sensor but not the 4th. The top sensor rises quickly at the start of irrigation and then, at the end, falls off quickly with drainage. The water level then stabilises at field capacity and then you start to see daily water use. As you move through the profile you can observe the increase in infiltration time and a slowing in the rate of rise. This is because the soil at depth is often a heavier texture and because as the wetting front moves through the profile it gets weaker.

It is good practice to install a sensor below the root zone. If the water reaches this level, too much is being applied. Ideally this sensor should start at a reasonable moisture level (assuming the profile has been filled by winter rains) and then slowly dry down over the season. It should only rise after prolonged rainfall.

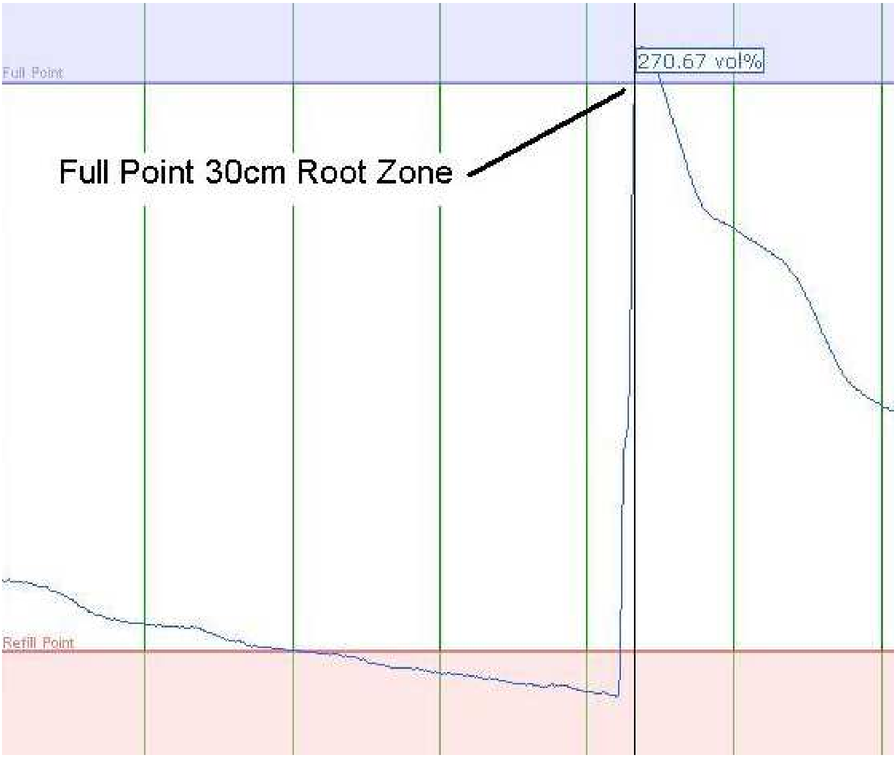
3.2.3 Setting Full and Refill Points

To set full and refill points, the data in the “Separate level” view described above is used to gain insight in to where in the profile water is reaching during irrigation.

First off, users can seek out a point in time where the water level at all of the sensors in the root zone has risen to somewhere close to field capacity (below the point where drainage occurs) and mark the date/time where this occurs.



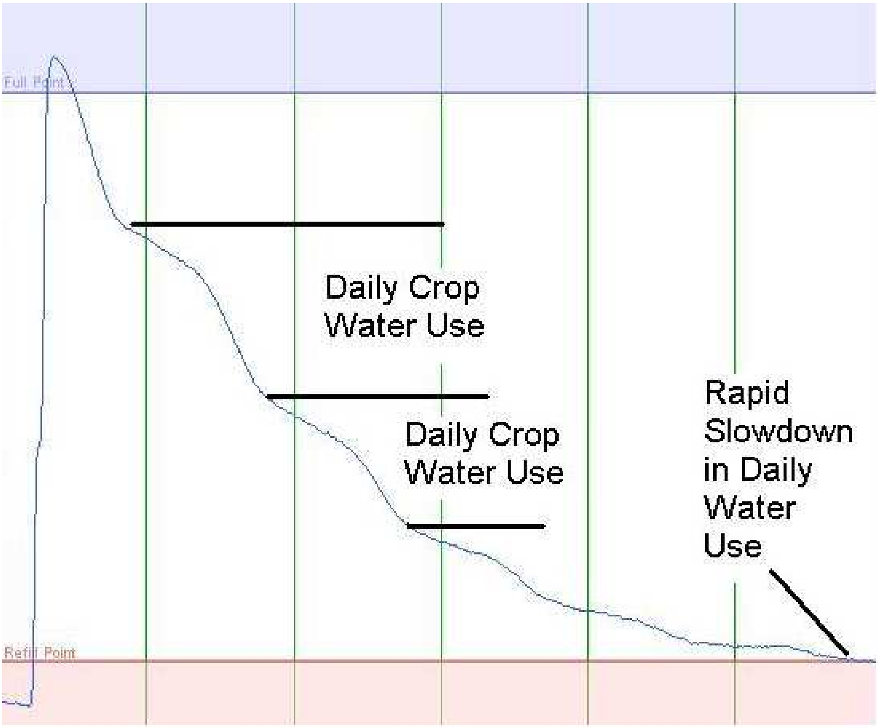
The next step is to create a graph which shows the sum of the soil moisture readings through the profile (or the average). If you have a sensor installed below the root zone, this drainage sensor would normally be excluded from the summed graph. A reference line would then be placed on the graph at the point in time identified in the previous step. This would be used as the Full Point.



The refill point is harder to define. In permanent crops, it pays to review a couple of months (or better still a seasons) worth of data. When the profile is full, the plants can easily obtain moisture. On the summed graph, if you look at the readings at 6:00 pm on successive days, you will see that the step change is fairly large (high daily water use). As water availability falls, so too does the daily crop water use (and hence the size of the steps. Initially the slowdown is fairly linear, then after a period of time, the curve flattens out quickly. The point where this flattening commences is the onset of stress. The refill point should be set at just above this level.

It pays to always err on the conservative side when beginning to use the system: start with a higher refill point and then fine tune it over time.

In annual crops, the task of setting full and refill points is made even harder, as there is no historic data to work from: decisions need to be made from the day of planting. This is why soil tension sensors (matric potential sensors) are much easier to use – the full and refill points can be set immediately in kPa, e.g. Full point -8 kPa, Refill point for permanent crops typ -60 kPa, for annual crops -20 to -30 kPa.



The best approach here is to initially apply a deep irrigation to fill the root zone (typically to 20 or 30cm), then use that information to establish a starting Full Point. While the plants are very small, irrigation should be applied in regular, small events, to keep the profile moist. As the plants grow and harden up, the time between irrigation can be extended. The first planting year will always be the hardest to manage. In subsequent years, information from the previous year can be used as the starting point for each new planting. The newer potted sensors are less susceptible to variation across installations than the larger access tube based units, making it easier to transfer readings from one sensor or one site to another.

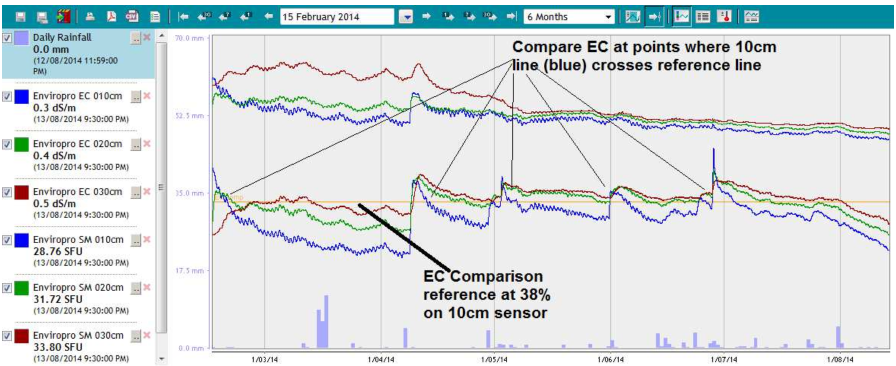
3.3 Soil Conductivity

The salinity sensor on capacitance probes respond to the total level of salt in the soil (the bulk conductivity). This changes as the soil moisture content of the soil changes, which is why users will see changes in indicated salinity as the irrigation is applied.

When interpreting the EC data, you must thus compare readings at points in time when the moisture content is the same. The simplest approach to take is that if for example you are looking at the 10cm EC and soil moisture, that you add a Threshold or horizontal marker at a set moisture level : this should normally be done at a steady point 12 hours or so after irrigation. You can then compare the EC readings each time the moisture is at that level.

In citrus, for instance, most of the active feeder roots are in the top 10 to 20cm of soil. So if looking from a nutrition viewpoint, this is the area of most interest. If instead, you were concerned about the accumulation of salt over time (through irrigating with salty water) you may be interested in looking further down in the root zone.

If the software that you are using to display the data supports this functionality, you should add display of daily rainfall and fertilization events – this may be through either automatically logged readings or through manual entry of readings. If you cannot add fertilization and rain events in the display software, you may need to export the data to a spreadsheet file and perform your analysis in that program.



The above picture shows data from the 10, 20 and 30cm soil moisture and EC sensors for a 6 month period with the EC sensors at the top and soil moisture at the bottom. The 10cm values are blue, the 20cm green and the 30cm red. At the very bottom of the graph is the daily rainfall total.

A reference line has been inserted at a soil moisture value of 38% on the 10cm sensor. The EC values can then be compared at each time when the moisture equals this value – i.e. where the blue soil moisture line crosses the reference line.

This process can be made easier with some of the more sophisticated data evaluation programs: for instance by setting up a query to extract the EC values each time the soil moisture values are within say +/- 0.2% of the chosen reference; by then saving the results to a new table and then looking at the changes in EC over time.

References

Hussain S and Maqsood MA, Journal of Pakistan Botanical Society 2011, 43(3):1551:1556, Rootzone temperature influences nutrient accumulation and use in maize.

Web References

http://farmercommunity.incitecpivotfertilisers.com.au/Articles%20and%20Publications/Fertiliser%20Facts/Urea Incitec Pivot - Urea

http://www.depi.vic.gov.au/agriculture-and-food/dairy/pastures-management/fertilising-dairy-pastures/nitrogenous-fertilisers - Nitrogenous fertilisers