The Role of Polyacrylamides (PAM) in Onion Production

A Final Report prepared for the South Australian Murray-Darling Basin Natural Resources Management Board by **Tandou Limited** for **Project 71.2007:** *Optimising Irrigation WUE by reducing deep percolation losses*

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- CIBA Specialty Products
- Mr. Richard Wheaton
- Sentek Sensor Technologies

Onion grower Richard Wheaton (Wellington East) pictured in the trial site.

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Executive Summary

Fieldwork conducted during the 2006 growing season (Cutting) revealed that increased bulb diameter in onions was not solely a function of soil moisture levels but was rather strongly correlated to humidity around the leaf tissue. The trial work in 2007 confirmed the validity of the observations in 2006 but also looked at using polyacrylamide applications (PAM) to not only alter soil hydraulic properties on these light textured soils but potentially impact on leaf zone humidity as a function of altered soil hydraulic states. PAM surfactant formulations were also investigated to determine the effectiveness in reducing the non-wetting characteristics of some of light textured fine sandy soils. Data in this trial strongly supports the use of these formulations in reducing the impact of non-wetting sands in vegetable production.

Finally some preliminary investigative work was undertaken to look at the potential of using PAM as a coating mechanism for beneficial fungi (VAM) and trace elements prior to planting onion seed. The changes in leaf tissue data was consistent with expectations from what was coated and yield increases over controls to warrant further investigative work in seed coating to improve nutrient use efficiency in onion production.

The use of PAM could be seen to significantly reduce deep percolation losses in onions via electrical capacitance monitoring, and result in increases in bulb sizes at harvest. Leaf humidity was also increased in PAM treated sites. By reducing deep percolation losses and altering preferential flow pathways in non-wetting sands the use of PAM can be considered to be an effective way to manage deep percolation losses in onion production and increase leaf zone humidity levels.

Section 1 Introduction

The Lower Murray regions of South Australia have developed into one of the most productive onion growing regions in Australia. The light sandy soils under essentially centre pivot irrigation have enabled onion production to be highly cost competitive on a world scale. Not only are the soils sandy in texture parts of the area can be described as non wetting. These non-wetting soils are difficult to wet up, create preferential flow pathways so water and nutrients are readily leached and plant production is low. The aim of the project was also to assess management methods that would best reduce the non-wetting traits of these soils. Breaking the non-wetting traits of these soils requires large volumes of water. This trial investigated the potential of PAM/surfactant blends to not only break the non-wetting tendency of the soil but, retain sufficient soil moisture to ensure that it was able to rewet.

Figure 1: *Non-wetting soil: note the dry area adjacent to the root zone following irrigation. October 2007*

With water becoming an increasingly precious resource and continued reductions in allocations across the Murray Darling Basin this trial aimed to look at the integrated use of PAM in an onion growing operation to increase irrigation and nutrient efficiencies in light sandy soils.

Rather than looking at point source applications of PAM, this trial aims to look at multiple uses of PAM in an integrated onion growing operation. PAM/surfactant blends were used to stop water repellence (and therefore preferential flow pathways), preplant PAM applications (to reduce leaching losses of water), PAM seed coats (looking at VAM and trace element coats), and PAM applied applications via fertigation as a means to increase humidity levels around the plant and thus enhance bulb size will all be assessed in this project.

Section 2 Literature Review

2.1 Introduction

The world is faced with a rapidly increasing population with an overall decline in arable land and increasing pressure on water resources. The pressures facing agriculturalists to produce more food with less land and possibly poorer quality water is becoming a reality for farmers in many parts of the world. With projected changes to climate in Australia to result in at least drier conditions the ability to maintain water within the root zone will become more critical to ensuring that available soil water is used for crop production and not lost to deep percolation.

The sandy soils of the Mallee are viewed favourably by vegetable growers (particularly for root and onion crops) as they facilitate good root growth and shape as well as easier harvesting with less skin damage in onion crops. The presence of non-wetting sands is a problem in many areas as soils wet unevenly creating problems of preferential flow pathways where water and nutrients are lost to the root zone in deep percolation issues. Plants grown in these soils struggle to grow to economically viable production levels. In some instances it is best to avoid such plantings but with an increase in centre pivot production the ability to exclude all poor soil types becomes increasingly difficult. The aim therefore is to understand the variable soil types that are to be farmed in a pivot rotation and manage them individually to ensure production is maximised.

The aim of this project was to show the role that the use of PAM can play in increasing the effectiveness of applied water and more effective use of applied nutrients. The project will also assess the use of PAM (as an inverse PAM oil emulsion) to increase plant uptake of trace elements and the potential use of VAM (vesicular arbuscular mycorrhizae) as an inoculum onto onion seed. By focusing the work in the Mallee region of South Australia it is recognised that these are some of the most difficult conditions in which to effectively manage soil water content due to high leaching fractions and low water holding capacity. The low organic nature of these soils is such that native VAM populations are low and natural inoculation of the emerging roots highly unlikely.

This project aims to assess if by altering the hydraulic properties of sandy soils used for onion production not only can water use efficiency gains be realised but more efficient use of fertilisers can be achieved.

2.2 Non Wetting soils

When water is applied to the soil how it enters the soil depends on several factors. The hydraulic conductivity of the soil (how it takes water), soil water content and soil aggregation all determine how water enters the soil. The problem with non-wetting soils is that the even though in the case of the sands there should be no impediment to infiltration, repulsion of water by soil particles exist. The infiltration capacity of the soil is reduced so that even after weeks of being in contact with water the soil can remain dry (Lal, Shukla 2004). These water repellent soils also have irregular wetting patterns as can be seen in Picture 2. The flow of water through these soils is exaggerated as much of the profile remains dry and non-wetting so total water-holding capacity on a volumetric basis is less than what would be expected.

2.3 Organic polymers and their effects on soil physical and hydrological properties.

Organic polymers such as polyacrylamide (PAM) and polyvinyl alcohol (PVA) have been used to stabilise soils, control erosion and to increase water and nutrient infiltration and retention. Considerable success in using organic polymers has been demonstrated by Williams *et al* (1967), who showed that soil aggregate stability in water was greatly increased in soils treated with PVA. Wallace *et al*. (1986) describe how polymers created 100% water stable aggregates compared with only 38% in the control. Aase et al (1998) also writes on how PAM reduced runoff and erosion in sprinkler irrigated laboratory tests. In terms of herbicide management wetter soils would therefore be more successful in implementing an effective herbicide management program as weeds would be under less stress than drier soils and more conducive to uptake and translocation of applied herbicide.

Polymers can be seen to adsorb readily onto solid surfaces. Each polymer group or polymeric ion can have many groups or segments that can be potentially adsorbed, the groups being essentially free of mutual interaction (Stumm 1992). The extent of adsorption can be seen to generally increase with an increasing polymer molecular weight. The number and type of functional groups within the polymer molecule also affect the extent of adsorption (Stumm 1992).

Of particular interest to this study is the potential use of polyacrylamides (PAM) in herbicide management. Wallace and Wallace (p205, 2003) note the effect of anionic PAM on the sorption characteristics of four widely used herbicides (metolachlor, atrazine, 2,4-D and picloram). Results showed that PAM treatment kinetically reduced the sorption rate of all herbicides. This supports some earlier work conducted at Taplan, South Australia that showed in soils where anionic PAM was applied at 2-4 kg/ha with planting fertiliser in wheat, greater wheat damage to SU herbicides occurred. This occurred even when the rate of SU was decreased to half that of the recommended label rate. The impact of PAM not only on the distribution of residual herbicides in soil but also longevity is something worthy of further post-graduate studies.

2.4 Impact of PAM on plant growth and development

2.4.1 Plant and soil nutrient levels

The application of PAM to soil has been shown to have an impact on plant and soil nutrient levels. Leaching of nutrients through the soil profile can contribute to ground water contamination and runoff from furrows can lead to nutrient losses from paddocks. The addition of high molecular weight PAM molecules and the large number of carbon binding sites has been seen to significantly reduce nitrate leaching into sub-soils.

Wallace *et al.* (1986) grew wheat and tomatoes in soils containing amounts of anionic polymers than would be in excess of those required for soil stabilisation. The 1% rate increased the vegetative growth rate over the controls. The anionic polymer decreased the accumulation of phosphate and silicon in both wheat and tomatoes and decreased manganese and boron in wheat only. Applying 5% polymer was seen to depress accumulation of some of the macro-element cations.

Assessment of furrow runoff reveals water containing organic matter, sediments and nutrients. The addition of PAM with the water was seen to markedly reduce furrow runoff losses of sediment, orthophosphate, total phosphorus and chemical oxygen demand. The use of PAM did not appear to influence nitrate runoff Lentz *et al.* (1998a). PAM applied at 10mg/L during the furrow advance had 5-7 lower phosphate loads than the control areas (Lentz *et al.* 1998b).

Applications of polymers to soil have been observed to affect the nitrogen surface area of soil. Willams *et al.* (1966) used polyvinyl alcohol to change surface area and pore distribution of a clay soil. The amount of this polymer absorbed by aggregated material was less than the maximum absorbed by a dispersed soil. The data shows significant differences in nitrogen absorbed between controls and polymer treated soils at differing partial pressures. The addition of polymer revealed reduced absorption of nitrogen onto particles in montmorillonite soil.

Water absorbant PAM gels have been observed not only absorb water but reduce leaching losses of nitrogen in soilless medium (Bres and Watson 1993). PAM (HydroSource and Agri-gel) were incorporated into the growing medium at 1,2 and 3 g/L with 88g of ammonium nitrate. Water retention by the growth medium increased linearly with gel application. Nitrate N and ammonium N was higher when 3 g/L of PAM was added to the growth media. Total foliar nitrogen concentration in the tomato leaves was significantly higher in the HydroSource PAM than in either the control or Agri-gel treatments.

PAM has been used in coating urea (Abraham *et al.* 1995). N,N' methylene bisacrylamide crosslinked polyacrylamide was coated onto urea. The coated urea was found to have a greater slow release characteristic than when uncoated. There were differences in release of urea depending upon the PAM used in coating. In nutrient application the use of PAM treated fertiliser may be useful in reducing leaching losses and groundwater recharge.

2.4.2 Seedling survival and emergence

Maintaining moisture around the rootzone should theoretically increase a germinating plant's chances of survival. Lehrsch (1996) investigated the effects of PAM on sugar beet emergence. PAM was sprayed onto the soil that was later irrigated in with a lateral spread irrigator. The PAM tended to act as a soil stabiliser. PAM applications did not increase sugar beet emergence at varying sprinkler droplet energies. Seedling emergence was greatly increased by lowering the energy of the water droplet. For onion crops where seedling survival is often compromised by heat and high winds, this research may be of particular relevance to the industry.

Huttermann *et al* (1999) used water absorbent PAM on sandy soils when planting pine seedlings. PAM was added to the soils at rates ranging from 0.4% to 4.0%. The water content of the soil was seen to increase with increasing concentrations of PAM. The highest concentration altered the soil water holding ability from that of sand to a loam / silty clay. During drought conditions, treated seedlings exhibited pronounced growth of shoots and roots which were three fold higher than that of the controls. In drought prone Australia the use of water absorbent PAM could greatly increase the success of tree planting operations. Where growers are planting trees, the use of PAM could lead to quicker establishment and earlier returns on investments. Again the research data is scant and highlights the need for ongoing research into soil and water relationships and how these can be modified.

It is not unreasonable to assume that from the literature the use of PAM has significant implications for plant growth and development. The alteration of water (and by association fertiliser) in time and space in the soil profile can be expected to have a significant impact on the development of weed species. In my thesis for Adelaide University (2007), the addition of PAM to irrigation water in field trials could be seen to change the weed species between the treated and untreated areas.

2.5 The influence of PAM on soil microorganisms

2.5.1 Impact on culturable heterotrophs

Shoemake-Kaye *et al.* (1998b) revealed that in PAM treated areas numbers of culturable heterotrophs were significantly elevated. This observation was recorded in potatoes but not dry beans. In the soils planted to potatoes, total soil nitrogen levels were significantly higher in PAM treated soils. Nitrate N and Ammonium N levels ranged from 36.7+/- 2.2 (Nitrate N) and 1.3+/-0.3 (Ammonium N) mg/kg in treated soils, versus 10.7+/- and 0.5+/- mg/kg for the same nitrogen form in untreated soils. The effect of PAM on inorganic nitrogen levels from this work appears to be very site specific. However inputs of nitrogen onto a potato crop would be higher than for dry beans and this additional nitrogen may bind to PAM in the soil and become a subsequent food source for soil microorganisms. However Shoemake-Kaye *et al.* (1998) points out that PAM is able to support bacterial growth as the sole nitrogen source in enrichment cultures. This would suggest that PAM plays a significant role in reducing the leaching losses of N from the root zone.

Seybold (1993) acknowledges that PAM if used correctly, does not pose any threat to higher organisms. The only concern is the residual monomer, which is a known neurotoxin to humans. PAM is resistant to microbial degradation. However in aqueous solutions PAM provides a substrate for mould if nutrients are present. Seybold (1994) reports that PAM can be broken down by cultivation, sunlight and the mechanical breakage of the monomer chain. Levy *et al.* (1992) suggested that the wetting and drying cycle that occurs in soils may cause degradation and reduced efficiency of the PAM. In the South Australian mallee, drying and occasional wetting cycles would dominate the rural landscape. How this would affect the longevity of the PAM in soil solution is unknown at this stage. However, the ability of PAM to increase soil nitrogen levels may indicate enough structural change to the monomer through attachment of nitrate and ammonium ions to facilitate microbial breakdown in soils.

The aim of this trial is to investigate the role of PAM in centre pivot irrigation systems, and the ability to have an impact on soil hydraulic conductivity, wettability and water retention. In Australia, which suffers from variability of flows in its rivers and severe droughts, PAM may have great potential in future irrigation scheduling practices.

PAM has been shown to alter water infiltration rates. As a result there have been significant changes to soil nutrient levels, changes to microbial populations and impacts on plant growth and development. In Australia the emerging crisis in soil water management in the Murray Darling Basin makes the investigation into PAM applications worthy of more detailed attention.

1.6 Conclusion

The amount of research that has been undertaken with regards to the role of PAM in agriculture is huge but it is the comments raised by Burgess (1998) that are most relevant to these studies. It is the comments made in his book 'Formulation of Biopesticides' that show the true potential of PAM formulations in pest and disease management.

Super absorbent PAM is being used as controlled release matrices for creating slow released products in Culigel granules to deliver slow release pesticide applications (p94). On page 216 Burgess further writes on the potential for PAM to reduce the percentage of germination of germlings from viable spores in two species of *Alternaria*. The use of PAM in granules for soil and spray applications is further discussed on page 245 and 246. The potential use in the formulation of beneficial organisms applied to the soil is raised here. Further more on page 267 the suitability of PAM as an inoculant carrier is raised as an alternative to peat. The use of Alcosorb (super absorbent PAM) was reported to have doubled the shelf life of the entomo-pathogenic bacterium *Serratia entomophila (*p273). Using PAM in the coating formulation resulted in 50% of the bacteria surviving for 11 weeks in storage. It is therefore a reasonable consideration that PAM may play an important role in enhancing VAM inoculation. Further work on the interaction between PAM and VAM would be a valuable addition to our understanding of both sciences and how these altered hydraulic states around the seed piece influences VAM inoculation of the seed.

Using PAM as a binding agent in inoculating onion seed for trace element deficiencies, beneficial micro-organisms and protection against plant pathogens is a field that is poorly understood. The potential that correcting problems before they occur would increase water, nutrient and chemical use efficiency significantly for the producers.

Multiple research papers show the benefits that soil applied PAM has in altering wetting patterns within the soil. Applications to spray tanks, has shown significant reductions in spray drift and drying times. The ability to keep weeds wetter for longer should enable greater translocation of chemical from the outer layers of the leaf into the plant. This same observation has significant implications for increased

In a world that is becoming increasingly reliant on declining water quality and quantity, to feed itself by removing competition to our food system, the necessity to find ways to increase the effectiveness of these products is increasingly important.

Section 3 Design Layout and Discussion of Monitoring Data Results

3.1 Soil Moisture Monitoring

Soil moisture monitoring was conducted using the Sentek EnviroSCAN. This is a electrical capacitance sensor that takes continuous logged soil moisture readings through the profile over the life of the trial. The sensors were installed in PAM treated and untreated parts of the centre pivot. EnviroSCAN were installed to monitor the following treated areas:

- Control no PAM applications,
- PAM @ 2.5kg/ha preplant, 1 and 3 kg side dressing,
- PAM surfactant preplant treatment,

These were installed on site on the 30/9/07.

Figure 2: EnviroSCAN soil moisture monitoring

Additional soil moisture monitoring using the Phytech sensors was installed via the resources of the SA MDB NRM Board officer Michael Cutting.

Figure 3: Phytech in-canopy sensors

3.2 Mathematical Crop Water Use x Tailem Bend

Growing Season Rainfall

Total growing season rainfall during the onion crop was 157mm. Hotter and drier conditions than average were recorded in October 2007 with extremely hot weather in late December and early January.

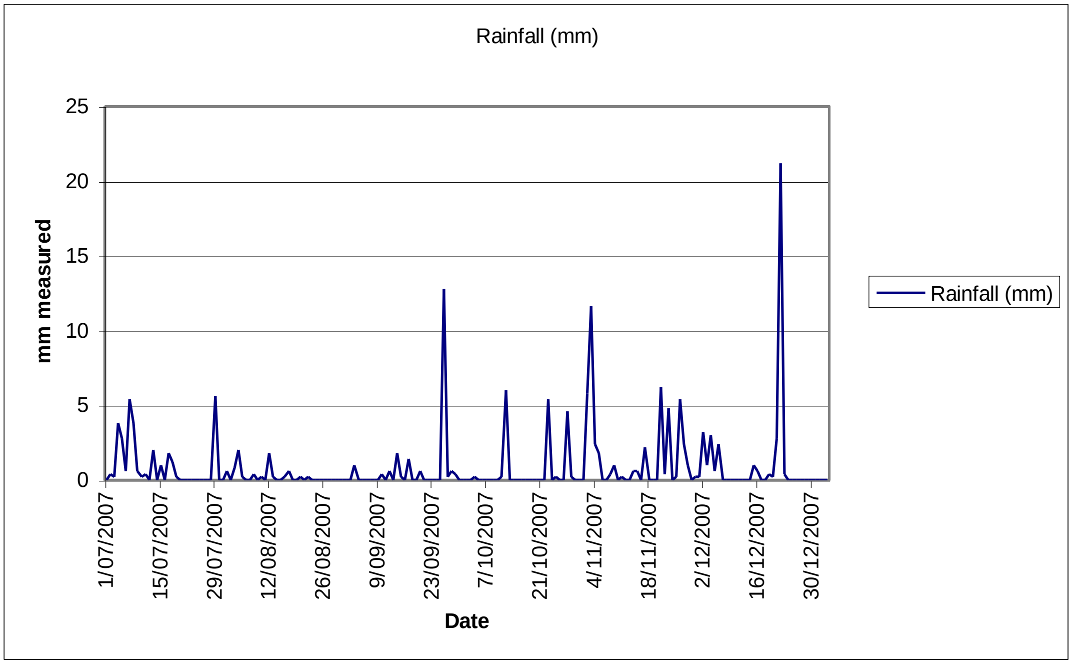


Figure 4: Growing Season Rainfall

It could well be argued that rainfall events less than 5mm have little value in terms of supplying crop water requirements and only provide increased humidity to aid crop growth. Total growing season rainfall was 158.4mm but if disregarding all rainfall less than 5mm, only 79mm of growing season rainfall occurred at this site. This is important to recognise that not all rainfall is effective and in these soil types a minimum effective rainfall should be considered as a critical part of irrigation management strategies. It should also be asked what impact other than salinity mitigation did rainfall events over 10mm have other than adding to the overall system.

The 2007 growing season brought an exceptionally dry October with very low humidity levels and a hot finish to the season towards the end of December. Salinity levels were higher than long-term averages in the irrigation water and it would have been expected that crop water use would have been higher than long-term historical data. Theoretical models do not take salinity levels and drainage requirements into consideration so additional water would be required under high EC irrigation conditions.

These figures were modelled on established crop factors and water use and averaged regional climate data from previous years.

Table 1: Theoretical Crop Water Use

Month	Kc	ET	mm/ha	ML/ha budget
July	0.4	2.2	24	0.28
August	0.8	2.8	32	0.66
September	1.0 0.6	3.5-4.0	60-80	1.02
October	0.65 0.8	5	120	1.20
November	0.8 1.0	6	140	1.40
December	1.0	7	200	2.00
January	1.0 0.6	7	120	1.20
Crop Budget				**7.76**

Actual Crop Water Use Figures

Actual 2007/08 ET_o figures from weather station against crop factors

Table 2: Theoretical Crop Water use considering seasonal climatic conditions

Month	Kc	ETo	mm/ha	ML/ha budget
July	0.4	2.03	24	0.25
August	0.8	3.2	32	0.79
September	1.0 0.6	4	60-36	0.96
October	0.65 0.8	5	120	1.20
November	0.8 1.0	7		1.40
December	1.0	8	240	2.40
January	1.0 0.6	7	120	1.20
Crop Budget				**8.20**

Using actual weather data the hotter season is reflected in a calculated water budget of 8.2ML/ha for the 2007/08 growing season.

Total irrigation application for the onion crop was 6.37ML
Effective growing season rainfall was 0.76ML

Total Applied Water = 7.03ML/ha.

Water use against average long term ET_o = 90%

Water use against 2007/08 ETo = 88%

However assuming a salinity management strategy with a 15% allowance for leaching, then 8.20ML could realistically become a 9.43ML water requirement. Under this scenario the property operated at 74% of budgeted water requirement.

3.3 Soil moisture, Humidity v Stem Growth

Previous work by Cutting (2005/06) revealed that onion bulb size could be increased as long as humidity levels were sustained around the plant. Soil moisture levels within root zone while important, were less important in increasing bulb diameter than humidity levels around the canopy. As a function of the outcomes of this research Richard Wheaton had implemented a farm management strategy that involved maximising humidity levels that often resulted in quick irrigations being conducted in the middle of the day.

The following graphs show the interaction between soil moisture levels, bulb size and the influence of humidity on overall bulb development. As can be seen in the report of Cutting (2006) the same trends can be seen with bulb diameter increasing more as a function of humidity levels around the leaf than with actual changes in soil moisture levels in the root zone.

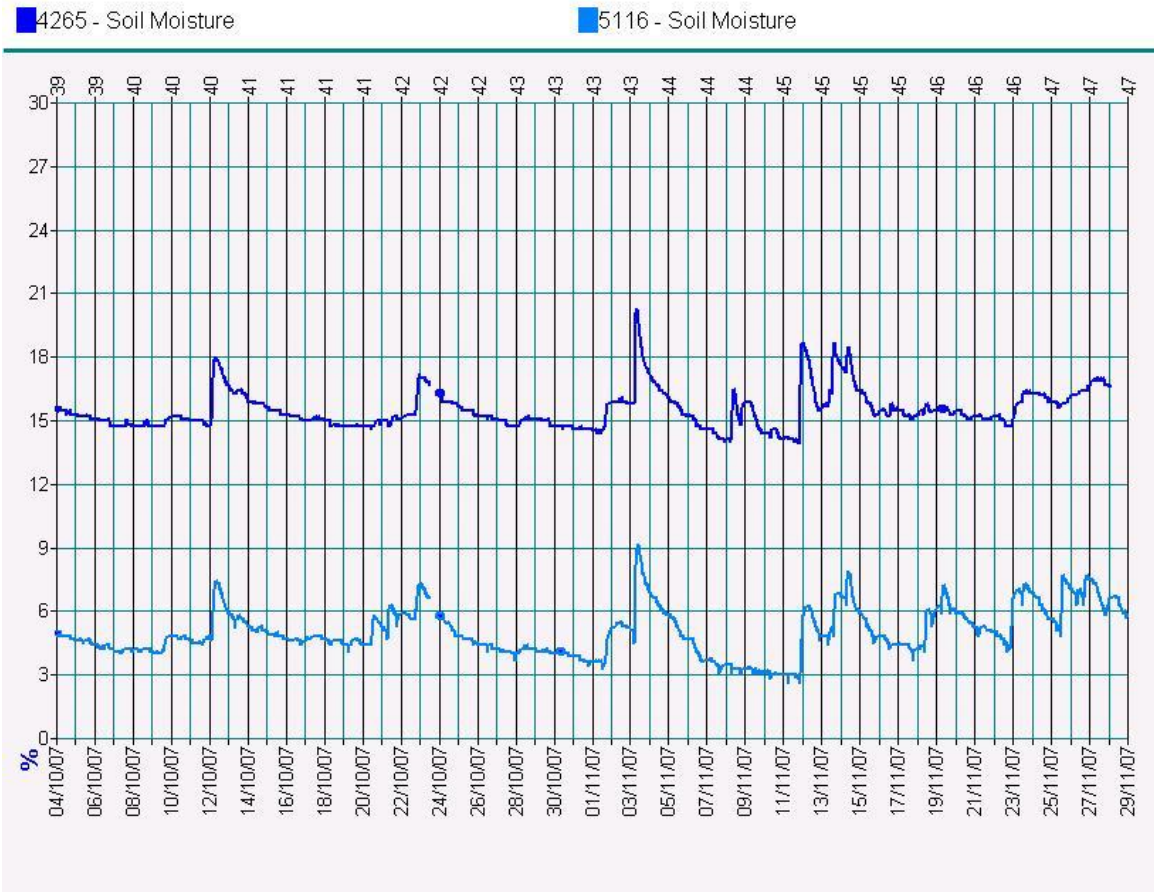


Figure 5: 4265 = + PAM; 5116 = Control

Figure 5 confirms data obtained with the EnviroSCAN™ that showed increased soil water content within root zone as a function of the PAM application. The other interesting observation from these graphs is the is that not only is the PAM treated site higher in soil water content but the decline in water content is also significantly less. This sits with published research (Phillips 2007) that indicated that the use of PAM slowed down the rates of hydraulic conductivity for sandy Mallee soils. With higher soil water content in root zone the likelihood that such treated soils would have relatively higher humidity levels around the leaf zone also exists. Higher soil water levels would therefore facilitate greater evaporation rates and higher humidity levels in the leaf area. The reduction in deep percolation losses (as shown by the decline in how quickly soil moisture levels drop following an irrigation) also suggests more water is being held within root zone as a function of PAM applications.

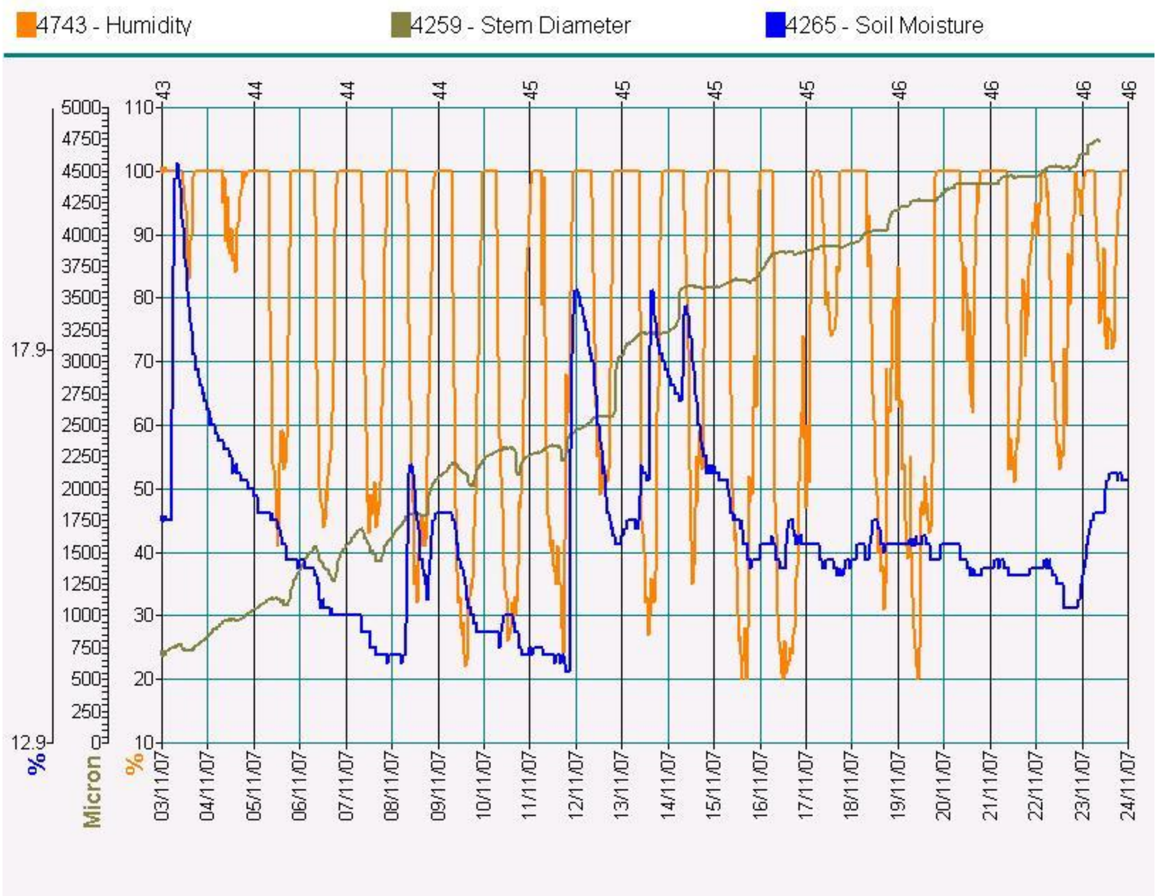


Figure 6: Soil water, humidity and stem diameter in PAM treated plots

The interesting aspect of Figure 6 is that stem diameter is increasing with general declines in soil water content. The decline or slowing in plant stem diameter growth can be linked to sharp decreases in humidity levels. The importance in evaporative cooling (irrigating during the middle of the day) cannot be under estimated in ensuring the maximum number of bulbs reach marketable sizes.

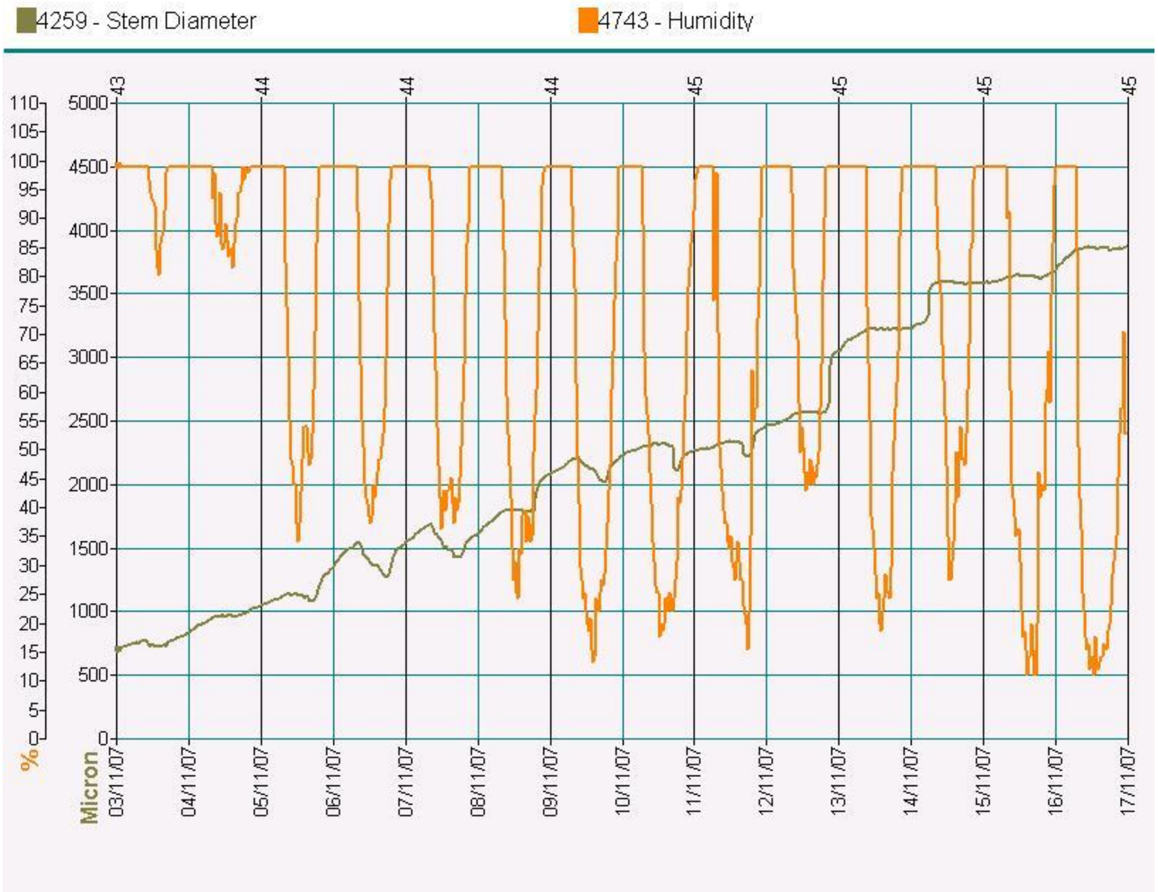


Figure 7: Humidity and stem diameter in PAM treatments.

Figure 7 without soil water content more easily highlights the impact that leaf zone humidity has on stem diameter.

2.4 Soil Moisture Monitoring

Multiple sensors were installed on site to investigate the impact that each soil treatment would have on soil water levels. The Sentek EnviroSCAN™ was used to measure soil moisture levels in the Control, PAM surfactant and Preplant PAM and PAM side dressing treatments. Each monitoring site was 9 metres apart and soil was uniform across the monitoring site. The area was light sandy soils with non-wetting characteristics.

Figure 8: Installation of Sentek EnviroSCAN™ in each of the different soil treatments (from L to R, preplant PAM and side dressing, PAM surfactant and control.

<u>EnviroSCAN™ Identification</u>

717: Control No Applied PAM
710: PAM Surfactant
709: Preplant PAM and PAM side dressing

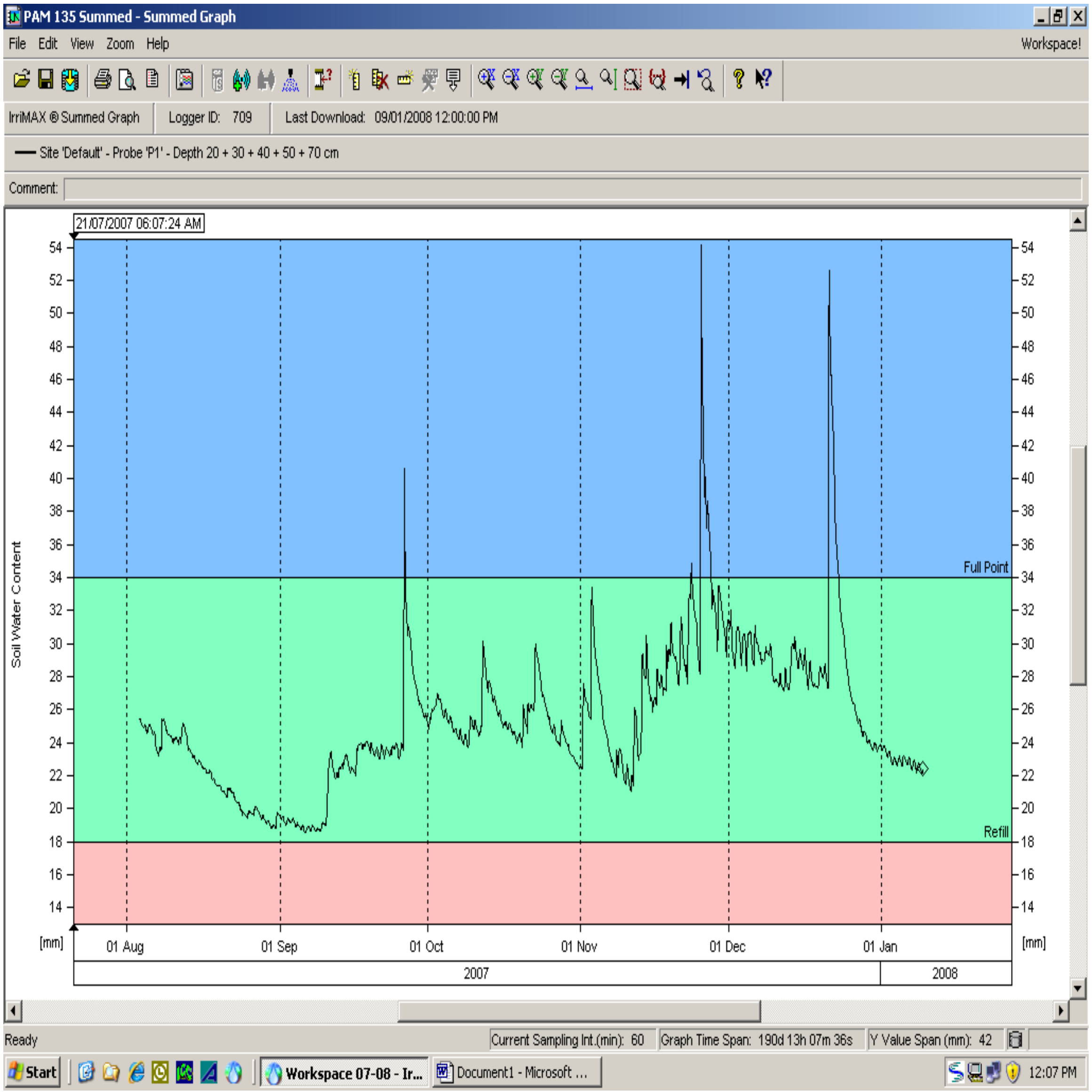


Figure 9: Summed graph - Soil Applied PAM

In Figure 9, PAM was applied pre-plant and at 2 stages during the growing season. The first application was in early September (note the spike in soil water content coming off a general drying at the start of the month) and the second in early November (again note the spike in soil water content).

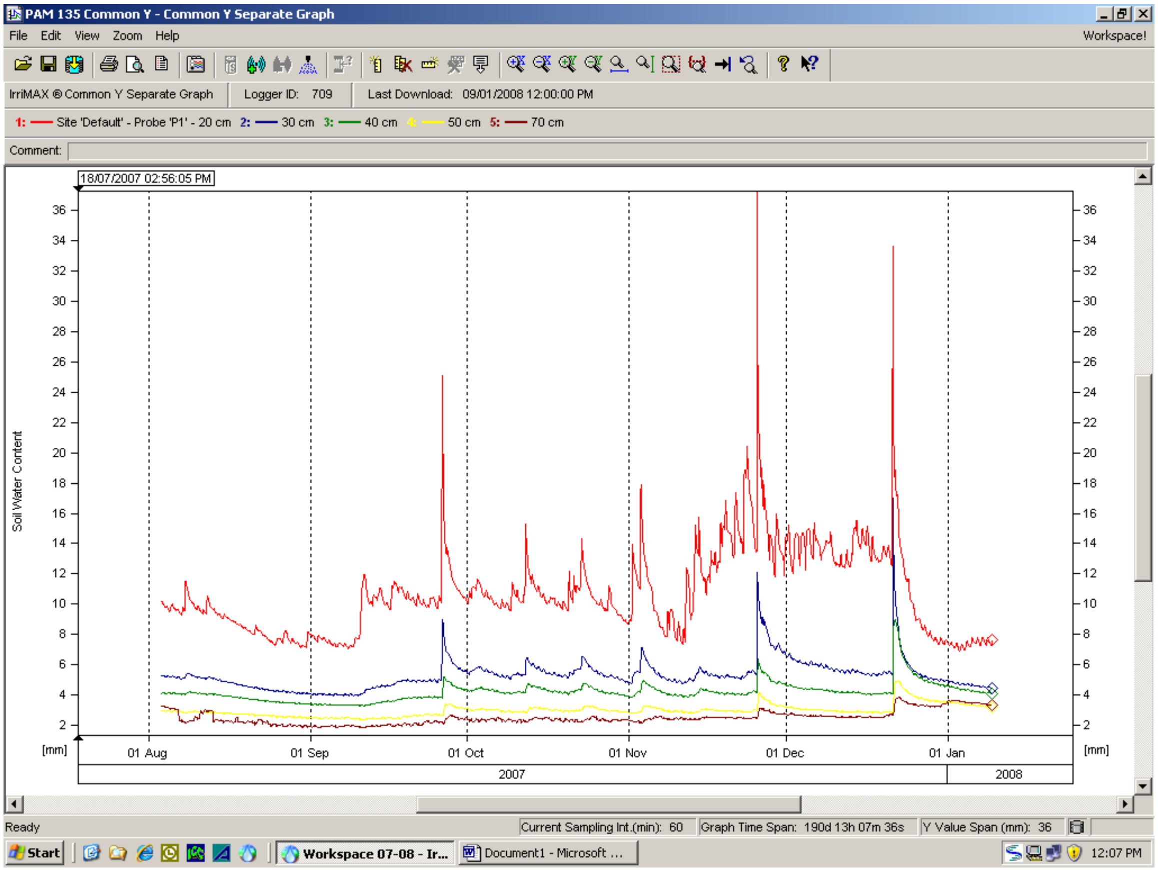


Figure 10: Separate Graphs - Soil Applied PAM Treatment

What is noticeable in Figure 10 and more so than in the summed histograph is that the greatest flux in soil moisture readings occurs essentially in the 20cm sensor where most of the roots are located. Considering the growth stages of the plant soil moisture levels are quite even in root-zone for the growing season.

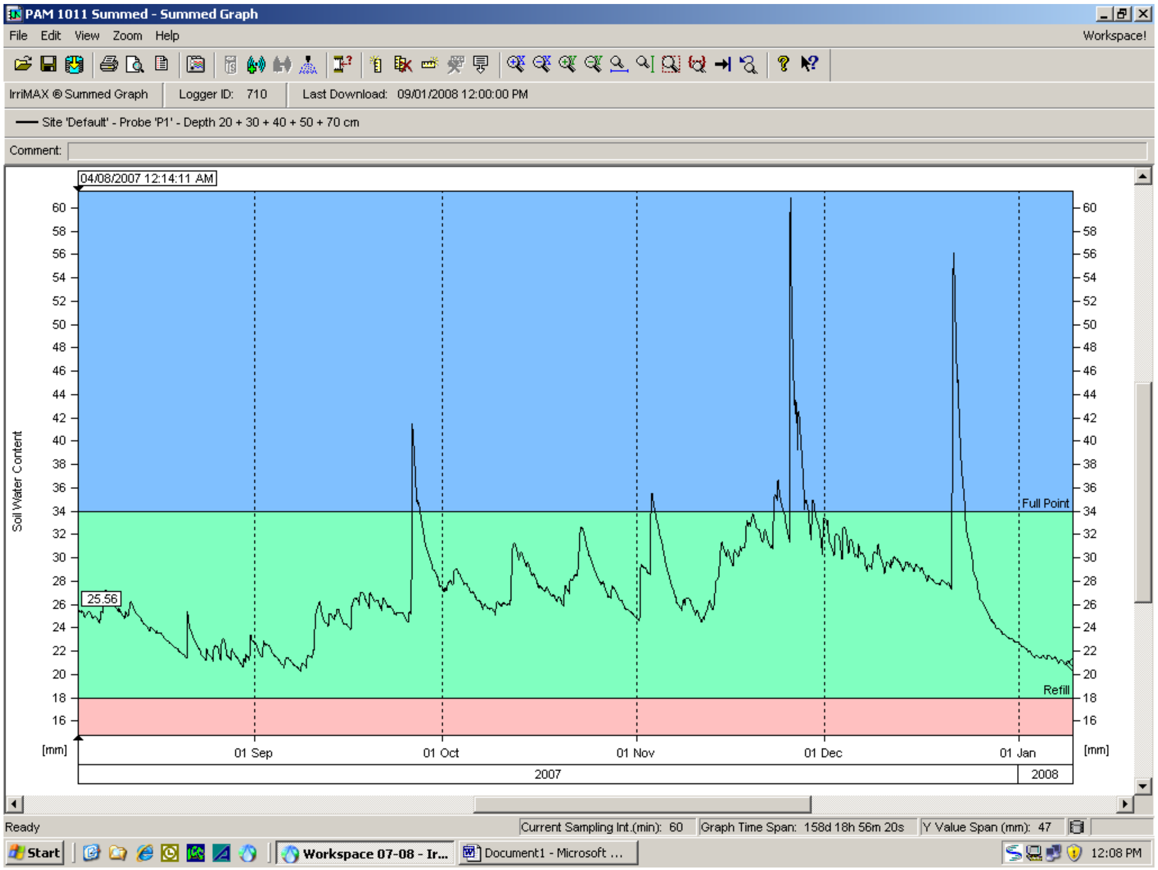


Figure 11: PAM surfactant treatment in soil water content

Sensor 710 (Figure 11) represents PAM surfactant applications to help reduce the risk of non-wetting sands reducing crop yield and water use efficiency. In non-wetting sands it is not unusual to find preferential flow pathways. The presence of these pathways can create soil moisture conditions where some wet and dry variances through the profile can occur where dry zones are encountered in the soil.

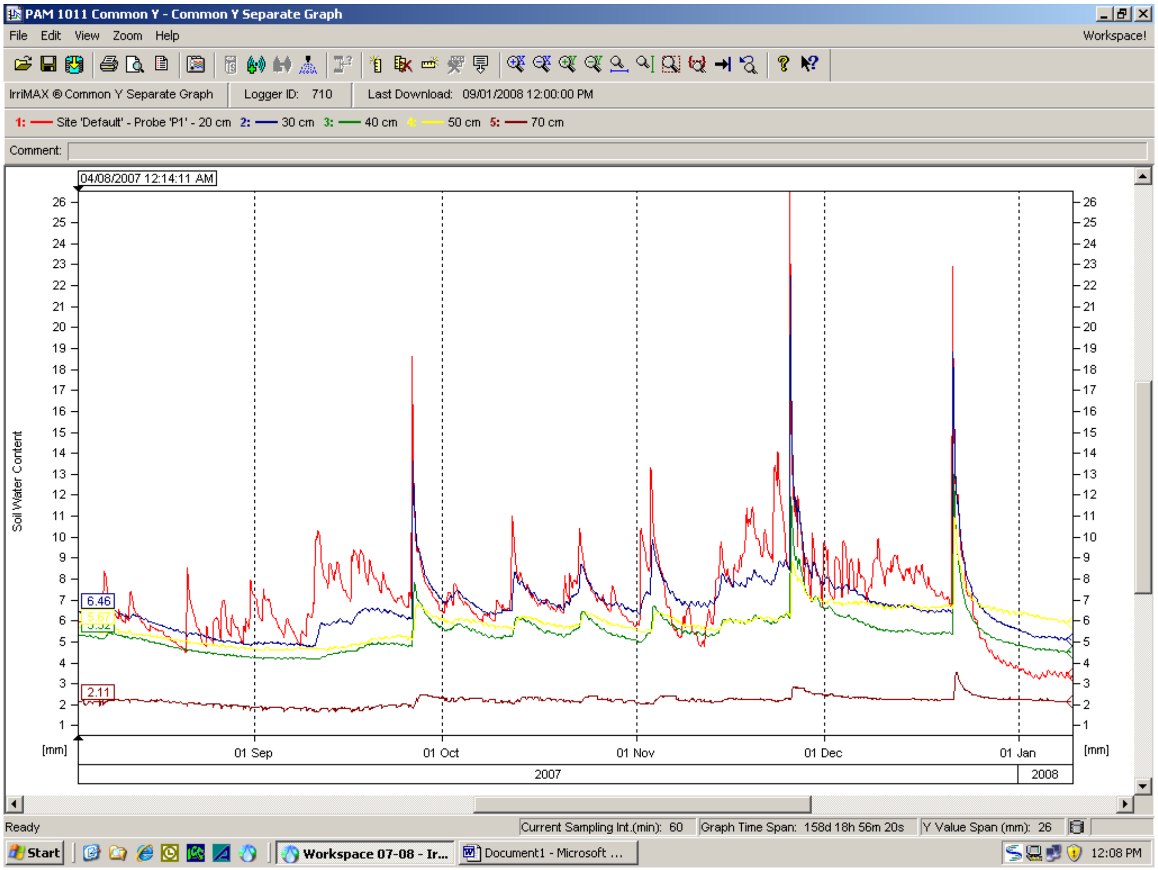


Figure 12: Separate Graph for PAM surfactant treatment.

The aim of the surfactant PAM blend was to overcome the natural non-wetting characteristics that existed in this area. As such some deep percolation was to be expected. What is noticeable in this graph is the amount of water movement into the deeper parts of the soil profile as a result of surfactant applications. For soils with non-wetting characteristics the use of surfactants to increase infiltration rates as a result of soil non-wetting tendencies is worth consideration.

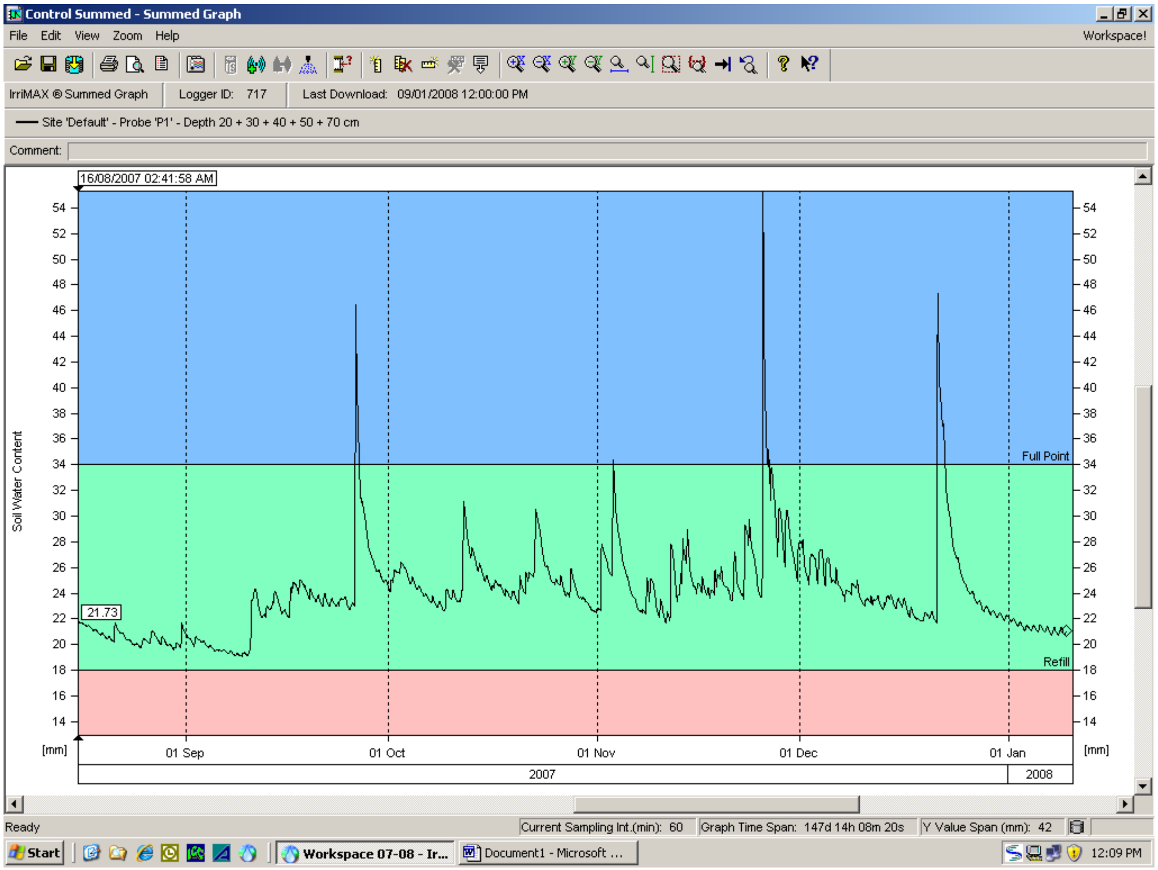


Figure 13: Summed Graph; Control

While following similar general lines to the other treatments, the control site in Figure 13 has lower overall soil water content levels than either of the two soil treatments.

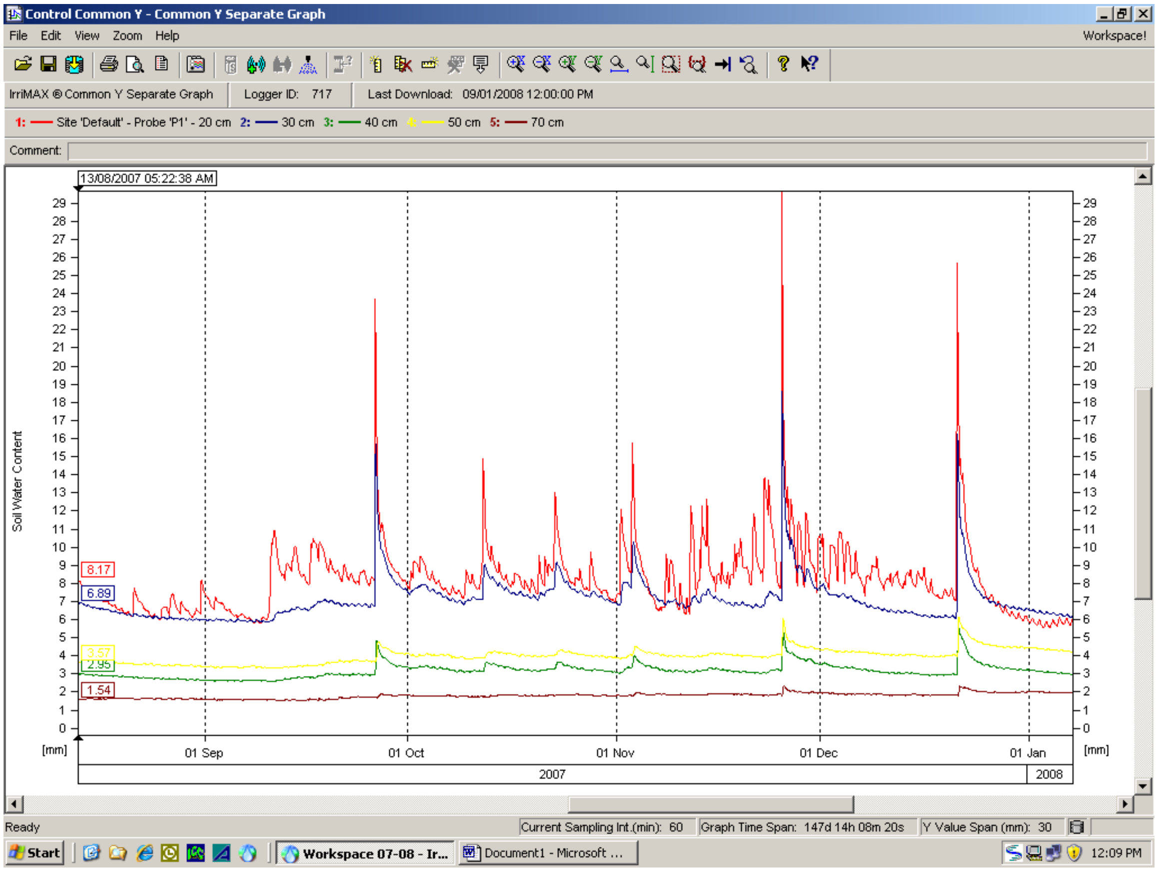


Figure 14: Separate Graph: Control

What is noticeable in Figure 14 is the difference in soil water content between the control and PAM treated sites. The control graph shows considerable more movement in the soil water sensor at 30cm in comparison to the PAM that was applied to the soil. The increase in soil water content following the application of PAM confirms work done in other areas that PAM plays an important role in slowing the rate of hydraulic conductivity in sandy soils. In effect the soil that has been treated is staying wetter for longer than the untreated site. This must have significant implications for humidity levels with the topsoil remaining wetter for longer and leaching of nutrients past the root-zone.

In overall summation as the quantity of applied PAM increased, soil water content in the topsoil also increased. It appears in the PAM treated site that soil water content is increased by approximately 10% as in the control sample levels only rarely spike above a reading of 12 whereas in the PAM treatment, soil water content is above 12 for a considerable portion of the growing season. The surfactant treatment is more in line with the control. Considering the aim of the surfactant treatment was to increase soil-wetting characteristics it is not surprising that soil moisture monitoring has revealed greater movement through the profile than in either the control or PAM treated sites.

3.5 SoluSAMPLER™ Monitoring

The SoluSAMPLER (Sentek trade named product) is used to extract soil solutes from within the soil profile to gain an understanding of root-zone salinity and nutrient levels. The solution was extracted under suction then analysed for sodium, potassium and nitrate nitrogen levels.

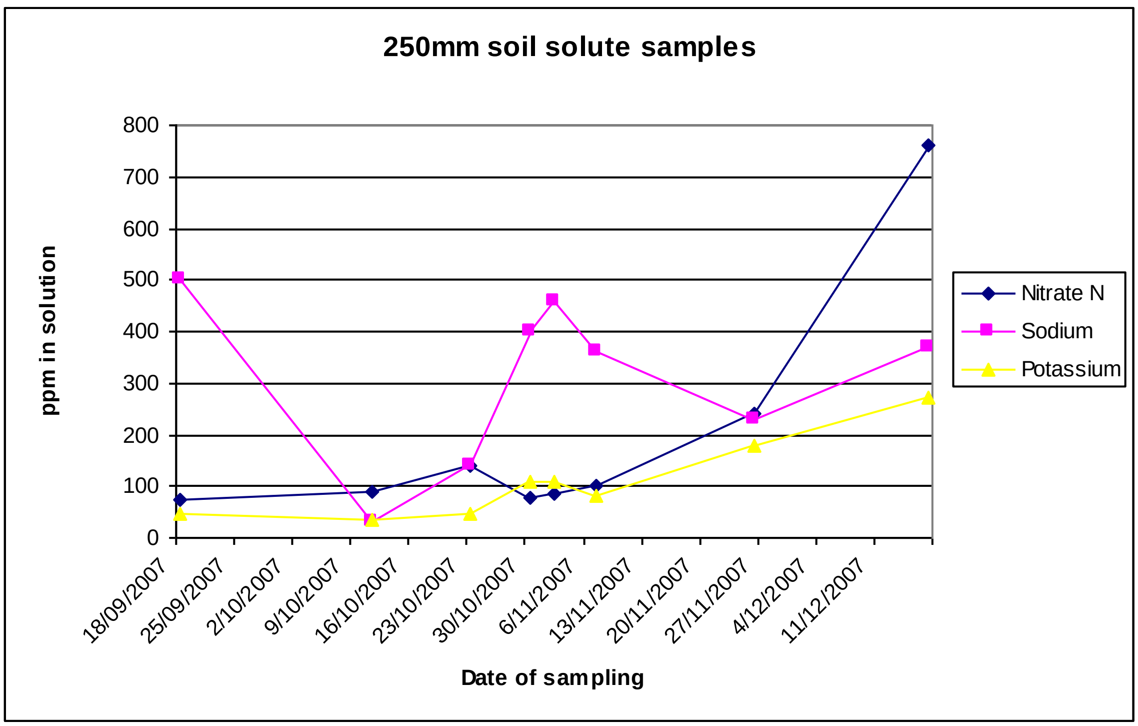


Figure 15: Soil solute data using the Horiba Cardy meter over time at 250mm

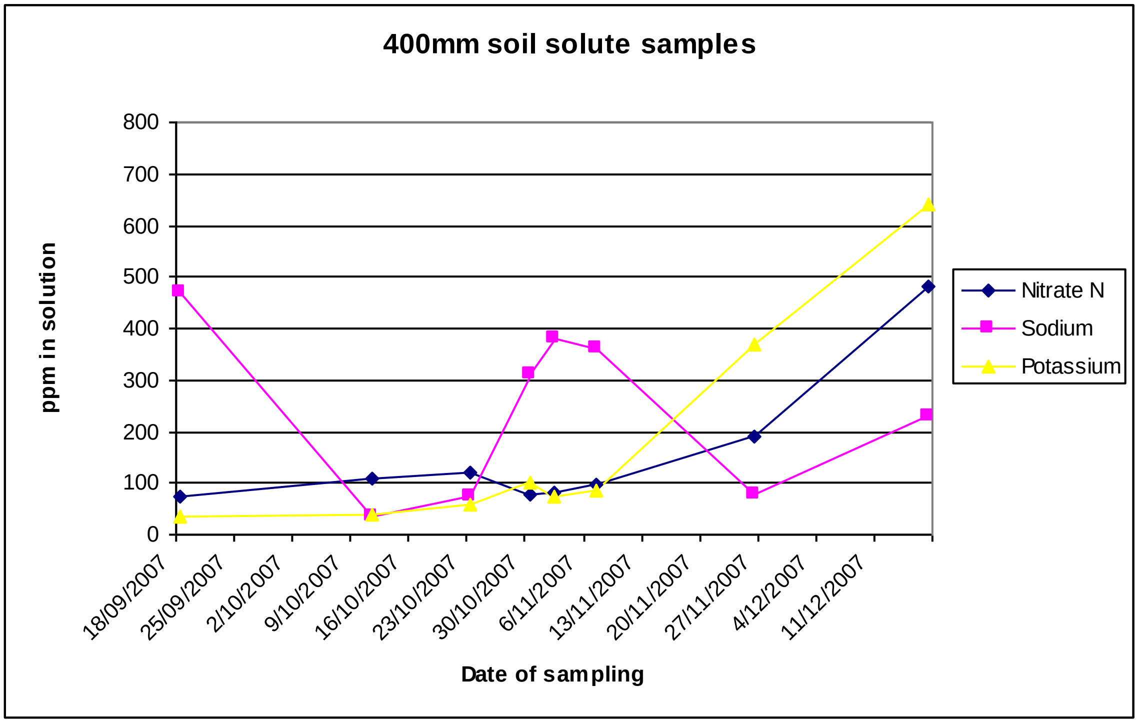


Figure 16: Soil solute data using the Horiba Cardy meter over time at 400mm

Data taken from both 250 and 400mm depths reveal strong similarities at both depths. Irrigation water salinity levels ranged from 700-1500 EC over the growing season and as a result the fluctuations in soil sodium levels are not unexpected. The only rainfall events that may have provided a leaching event were on the 26/9/07 (12.8mm), 3/11/07 (11.6mm) and 22/12/07 (21.1mm). However insufficient samples were taken over the trial to determine what was the impact of rainfall events on lowering soil solute levels of sodium.

The increased potassium levels correlate with late season applications of potassium nitrate. It is interesting to note that in this sampling site lower levels of nitrate and higher levels of potassium are recorded in the 400mm sensor with opposite readings seen in the 250mm sampler. This would be the opposite of what would normally be expected with nitrate ions being highly mobile in the soil profile. However in general from these limited readings levels of sodium, nitrate nitrogen and potassium are similar at either 250 or 400mm soil depth.

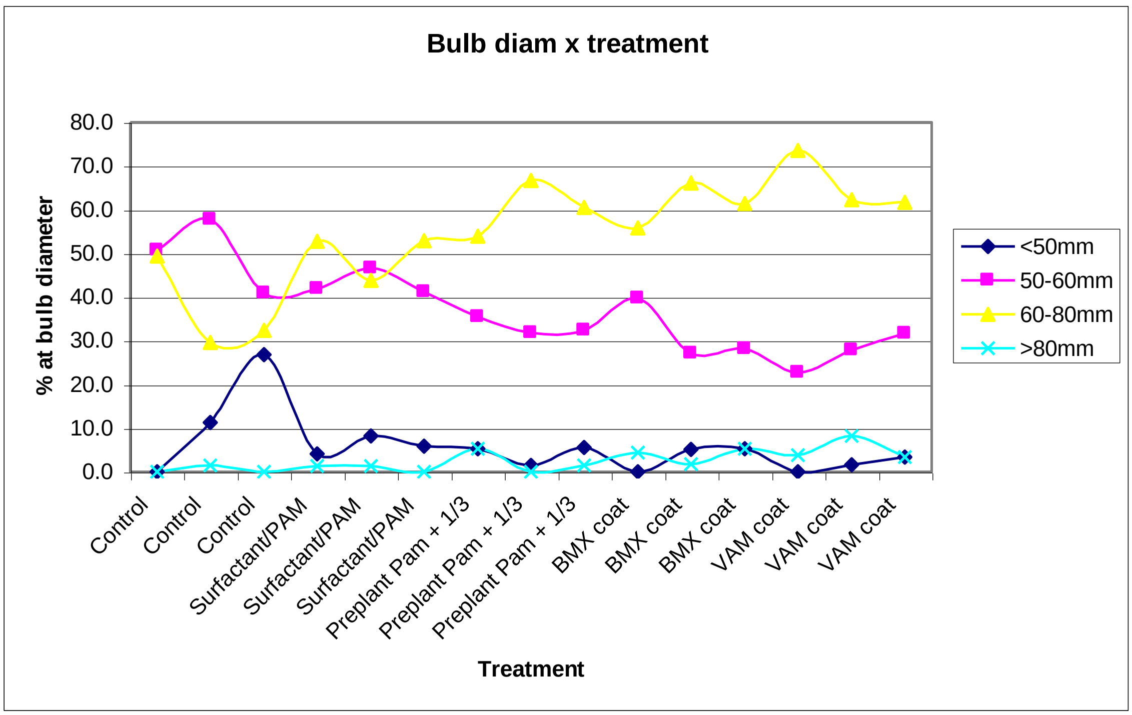
Section 4 Plant Growth and Yield Data

4.1 Bulb Diameter Measurements

Yield was measured as bulb size across the row rather than weight. The reason for this is that yield was perceived not to be an accurate representation of potential economic profitability as growers are paid on mm/diameter per bulb.

Bulbs were taken across the row and graded according to bulb size. The following graphs represent each individual plot with the average mean and standard deviation and error bars included last.

Figure 17: Bulb diameter by harvested plot



Overall numbers of large onions over 80mm diameter and those less than 50mm, were very low. The control, PAM surfactant and PAM treatments were assessed in similar soil types at the southern end of the pivot in the area of greatest non-wetting soil characteristics. The coated seed treatments were located in better soil in southern end of the field. An expected trait of non-wetting soils would be to create a larger degree of size variability than evenly wetting soils as some plants would experience periods of water deficit's as soils remain dry for longer periods. The aim of the PAM treatments was to see if the non-wetting characteristics of these soils could be overcome and result in increased pack-outs from this section of the pivot.

The bulb diameter data shows that the control area has the largest number of bulbs below 60-80mm with the largest amount of variability (as can be seen in the graph showing standard deviation and error bars).

The surfactant PAM treatment was specifically designed in this experiment to investigate the role of PAM and surfactants in over coming non-wetting soil characteristics. The surfactant was used to break soil surface tension and allow water to evenly infiltrate the soil; and the PAM to slow down the hydraulic movement of water through the soil profile and keep the soil wetter longer therefore allowing the soil to re-wet easier than untreated soils. The PAM treatment was to keep the root zone area wet. The coating treatments were specifically aimed at looking at the potential of seed coating and what implication this form of management would have on bulb diameter at harvest.

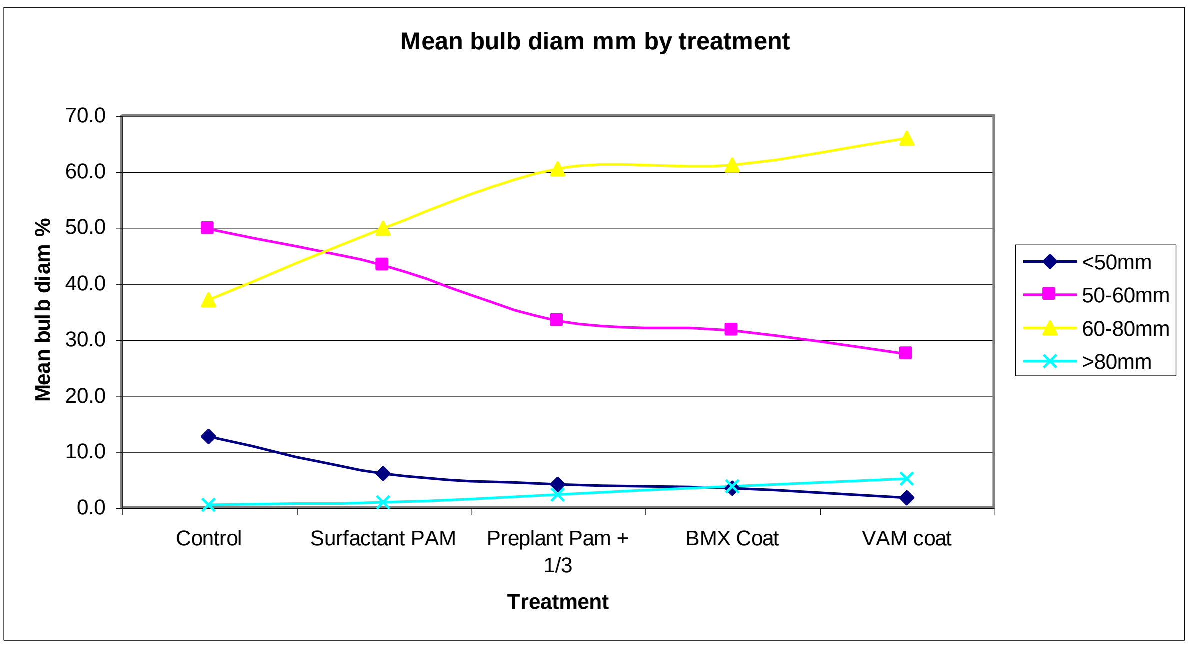


Figure 18: Mean bulb diameter by treatment

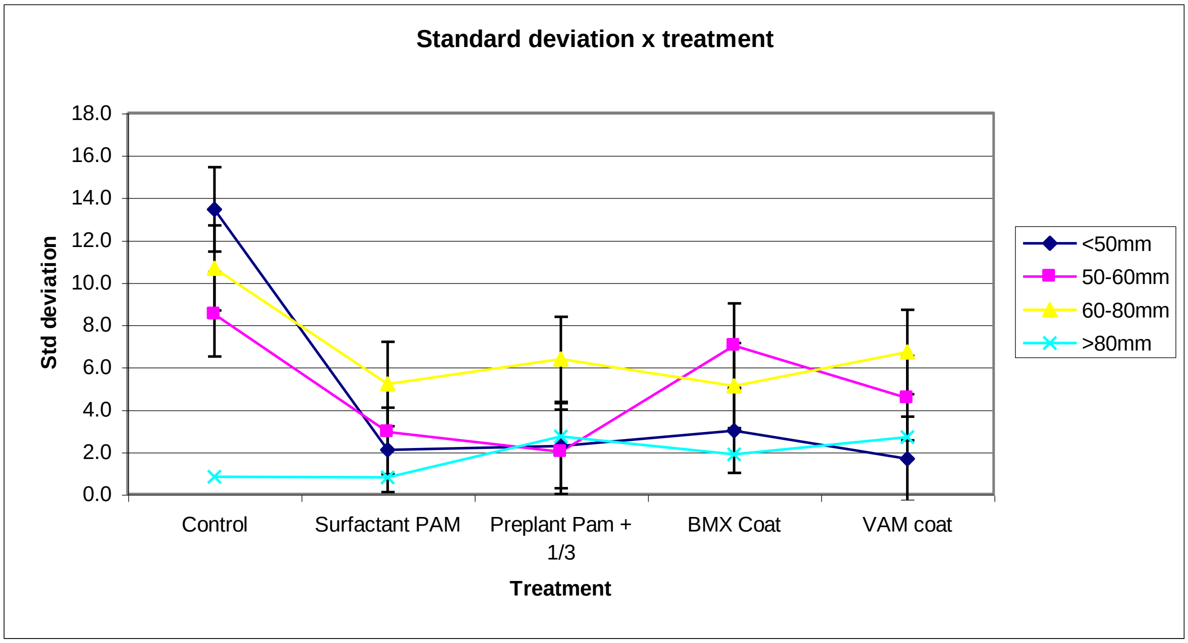


Figure 19: Applied standard deviation to each treatment

Section 5 Seed Coating

5.1 Introduction

Onions are very responsive to vesicular arbuscular mycorrhizae (VAM) infections. The problem with most Australian soils is that conditions do not exist that favours the existence of large numbers of these species to ensure adequate infection of host species. A trial was conducted to coat onion seed with 1% PAM 135 and 5% VAM (as supplied commercially) and 1% PAM and 10g/kg seed BMX (Ciba commercially provided product).

Previous trial work by the author in seed coating indicated that germination could be affected when seed coating in excess of 1% PAM 135 was applied in the coating process. Visual observation of seed with greater than 1% PAM coat revealed high levels of fungal infection on mallee sands under natural rainfall indicating that the moisture held around the seed was creating an environment where seed piece breakdown occurred due to excessive moisture levels. It is worth raising the question on rates of PAM coating seed and if lower PAM coating rates should be considered.

In 2003, a trial was initiated that looked at the potential of coating wheat and cotton seed's with a high molecular weight anionic petroleum polyacrylamide emulsion (Ciba 135tm). Initial trial results showed significant increases in nutrient levels for plant nutrients in particular manganese, calcium and potassium. The

2004 trial results in the Northern Mallee of South Australia indicated that there was a synergism between Cu and Zn that led to not only a yield increase but also less variance in yield than other treatments. Importantly the same nutrients trends that were seen in plant tissue in the wheat coating in South Australia were observed with cotton at the Tandou farm in South-western New South Wales.

The results obtained in 2003 led to the hypothesis that soil physics plays a significant role in facilitating nutrient availability for root uptake. The use of polymer coating was aimed at increasing soil moisture levels around either the seed piece or fertiliser granule thus increasing the availability of nutrients in solution.

Understanding the transport of solutes in soil is important in understanding many of the management problems in agricultural systems. Depending upon chemical stability and reactivity the solutes are classified into two groups (a) conservative solutes (those which remain unchanged physically or chemically and (b) non conservative solutes (those which can undergo irreversible reactions that change their physical or chemical phase). The non-conservative solutes are divided into labile solutes and reactive solutes. Labile solutes can undergo a wide range of changes (physical, microbial and chemical). Such examples can be seen with nitrate, sulphate and ammonia that are involved in mineralization, immobilisation or redox reactions. Reactive solutes undergo reversible or irreversible reactions with soil by way of absorption (Ca^{++}, Mg^{++} on clay particles), precipitation ($CaSO_4$, $CaCO_3$). At Tandou soil chemical analysis through the profile in buried drip systems highlights the positioning of metallic ions as a function of these conservative and non-conservative solutes, with Na concentrations being increased further away from the drip emitter.

The movement of solutes inside the soil matrix is caused by mass flow or convection. While water flow in saturated soils leads to movement of nutrients and solubility of plant unavailable forms, soils in the mallee are rarely saturated and under buried drip saturation is governed at point sources. It is these point sources of saturation (and altered states of hydraulic conductivity and increased osmotic gradients) under buried drip irrigation that raises significant questions on long-term sustainability of these systems.

Fertigation relies on water as the primary mover of nutrient into the soil. What is important to note is that is that solutes do not always flow with water but sometimes go ahead of it due to the twin processes diffusion and dispersion (or exclusion), lag behind due to adsorption (observe the formation of calcium carbonates at the Tandou Menindee property under certain conditions). Diffusion can be seen to be an active process whereas hydrodynamic dispersion is a passive process. Added to this is the complexity of the different macroscopic mixing that occurs in the soil that influences the transport of the solute within the soil matrix.

Convective or mass transport is the passive movement of solute that flows with soil water. Where only convective transport occurs water and solute move at the same average flow rate. Diffusive transport on the other hand is a spontaneous process resulting from the random thermal motion of dissolved ions and molecules. For onion crops growing in hot weather during the October to December months, plant nutrient uptake can be critically influenced by not only soil water content; but soil temperature within the root zone. Diffusive transport tends to decrease the existing concentration gradients and moves the process towards homogeneity quite quickly. This observation was seen at the orchard when rainfall created equal soil moisture conditions throughout the soil profile and a subsequent escalation in sap sodium levels where seen in grapevine petioles. Dispersive transport observes how flow rates vary through each pore sizes and as such a constant flow rate is difficult to predict. Structural breakdown of the soil matrix creating 'tighter soils' can create dispersive transport conditions. An example of this can be seen with the buried drip of cotton at the Tandou Farm.

While such conditions are important considerations it is also the interactions between soil and solute that must be considered. Tortuous flow paths in the soil profile result in the fluid element remaining at different positions from the same starting point even when they travel the same pore water velocity. Sorption where ions and molecules are attached to the surfaces of soil solids can result in a higher concentration of solute at the surface of a solid phase. Anion exclusion can also occur which results in a soil solution higher than the solid phase. These processes are important in modifying the movement of chemicals through the soil domain.

As well as physical parameters influencing soil water movement, temperature must be acknowledged as a major influencing factor in solute movement and behaviour. The release of soil nutrients for root uptake is dependant upon the soil temperature regime. Soil water movement, soil water availability, evaporation and aeration are governed by soil temperature. Chemical reactions within the soil can be determined by the amount of energy required by the reaction at various stages. These reactions are therefore governed by water availability and temperature to drive the reaction. Hence nutrient deficiencies can be more pronounced during cold or dry conditions.

The aim of the coating process is to create a steady state environment where a saturated state can be maintained around either the seed or fertiliser granule to facilitate an environment where root availability to nutrients is effectively increased over other forms of coating technology. The PAM coat aims to overcome some of the natural inhibitions to solute flow that occurs in a wide range of soil conditions. In low rainfall environments it is the variability of soil moisture that can influence solubility of nutrients, whereas on the sodic lakebeds that Tandou farm on it is the numerous conditions that occur in these heavy clay soils. In buried drip the degradation of soils in a continuously cropped cotton environment raise questions on soil aeration and respiration. It is possible that under buried drip systems (in heavier soil types) the decline in soil structure may be a result in deoxygenation of the soil as ionic bonds between the cations and oxygen anions that hold soil structure together are broken down over time. It is this observation that is the focus for major studies in the 2004 season.

The significance of water as the liquid medium in soil chemistry must never be understated. Water in the soil is the key solvent and percolation in the soil is the key mover of ions but not in the same amount or same proportions to each other. The physical factors mentioned earlier explain the natural variance that occurs.

The aim therefore of PAM coating seed and fertiliser is to increase the availability of plant nutrients in the soil by overcoming the many soil physical factors that can result in decreasing availability during a growing season. The use of polyacrylamides (complex carbon molecules) creates the possibility that many aspects of soil science can be addressed through its applications to the soil. The unique ability of carbon to form covalent bonds in the soil and create carbon dioxide and carbonates, the presence of CO2 dissolved in soil water increases the weathering potential of the water.

5.2 Tissue Analysis

Tissue analysis was conducted through the ACML laboratory at Loxton, South Australia.

Location	Variety	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	B	Cu
		%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg
BMX Coat	Destiny	5.5	0.49	4.1	0.72	0.27	0.31	1.3	34	64	18	15
Control	Destiny	5.5	0.45	5.4	0.99	0.33	0.35	2.1	22	43	27	6
PAM x soil	Destiny	5.7	0.55	5.4	1.1	0.35	0.37	1.6	24	65	27	6.3
VAM coat	Destiny	5.2	0.37	5.8	1.3	0.4	0.47	2.6	23	118	31	4.4
Standard	Onion	>2.5	>0.25	>2.5	>0.6	>0.3	<0.4	<1.5	>20	>40	>30	>6

Table 3: Sampling: Onion blade early growth

Location	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	B	Cu
	%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg
BMX Coat	3.7	0.41	2.6	0.55	0.18	0.2	0.76	22	74	19	4.2
Control	3.8	0.27	3.5	1.1	0.3	0.29	1.4	12	47	20	4.8
PAM x soil	3.4	0.31	2.8	0.8	0.2	0.24	0.98	13	21	14	3.8
VAM coat	3.7	0.38	2.4	0.48	0.16	0.19	0.69	23	93	23	4.2
Standard	>2.75	>0.25	>2.5	>1.5	>0.3	<0.29	<1.5	>20	>60	>25	>4

Table 4: Sampling: youngest mature leaf at bulbing

What is worth noting here from the tissue data is that foliar zinc sprays were applied throughout the growing season and that levels yet still were not excessively high in tissue samples (either as spray contamination). The work of Steven, Pech and Grigg (2007) raises some interesting questions on foliar uptake in onions and salinity management.

5.3 Comment on Sodium and Chloride Tissue Levels

Recently published work by Stevens, Petch and Grigg (2007) on the uptake of salts in onions is very significant and needs to be seriously considered not only for its implications for salinity management but also with what this may suggest for the effectiveness of foliar nutrients. The focus of the work was looking at the impact of saline irrigation water on the growth and development of the onion and if the use of 'fresh' water at the end of an irrigation to flush the salt off the leaves would have a major influence on the plants ability to tolerate higher salinity irrigation water during the growing season.

Onion Irrigation Trial (Stevens, Pech & Grigg, 2007)

	EC base dS/m	$Ca(NO_3)_2$ mmol/L	NaCl mmol/L
FRESH	0.3	1.6	0
85% SALT	0.3	1.6	24
SALT	0.3	1.6	28

Table 5: Irrigation Water Quality

	Fresh	Salt	Salt + 15% fresh	85% salt
Water (dS/m)	0.6	3.9	3.4	3.4
Soil (dS/m)	1.2	3.2	2.6	2.8
Cond (mol.m-2S-1)	0.44a	0.26b	0.32b	0.27b
Photo. (umol.m-2s-1)	10.5	8.4	9.6	9.2

Table 6: Impact of water quality on soil salinity chemistry and plant photosynthetic activity

	Fresh	Salt	Salt + 15% fresh	85% salt
Leaf (Cl)	501	2133	1314	1373
Bulb (CL)	39	76	59	64
Leaf (Na)	275	2108	1584	1659
Bulb (Na)	23	72	57	66

Table 7: Onion tissue chloride (mmol/kg)

The significance of the work in the onions is that flushing the leaves with good quality water following saline irrigation was of no advantage to the onions (as compared to potatoes where flushing the leaves was a significant benefit). This has led to the summation that onion leaves do not readily absorb either sodium or chloride through the leaves but rather salinity damage is done through root absorption. The significance of this work is that it highlights in onion production at least the possibility that salinity management should seriously consider soil hydraulic issues to ensure that salinity uptake as a focus of soil water content within root zone and not as much concern over foliar absorption.

The work also raises the question and this is more significant in that if onions do not readily absorb either sodium or chloride through the leaf what is the effectiveness of foliar absorption of other ions such as zinc and manganese. The tissue data in this trial would suggest that foliar uptake of either of these nutrients is not that effective.

Figures 20 & 21 show sodium and chloride levels over the two sampling periods. What is noticeable in all samples is that sodium and chloride levels have decreased over the growing season. Levels of both these salts are higher in the control samples at bulbing compared to any of the treatments. While irrigation salinity levels were in excess of 1000 EC ds/m for most of the growing season root growth and soil water content has a major role in influencing plant uptake of both sodium and chloride.

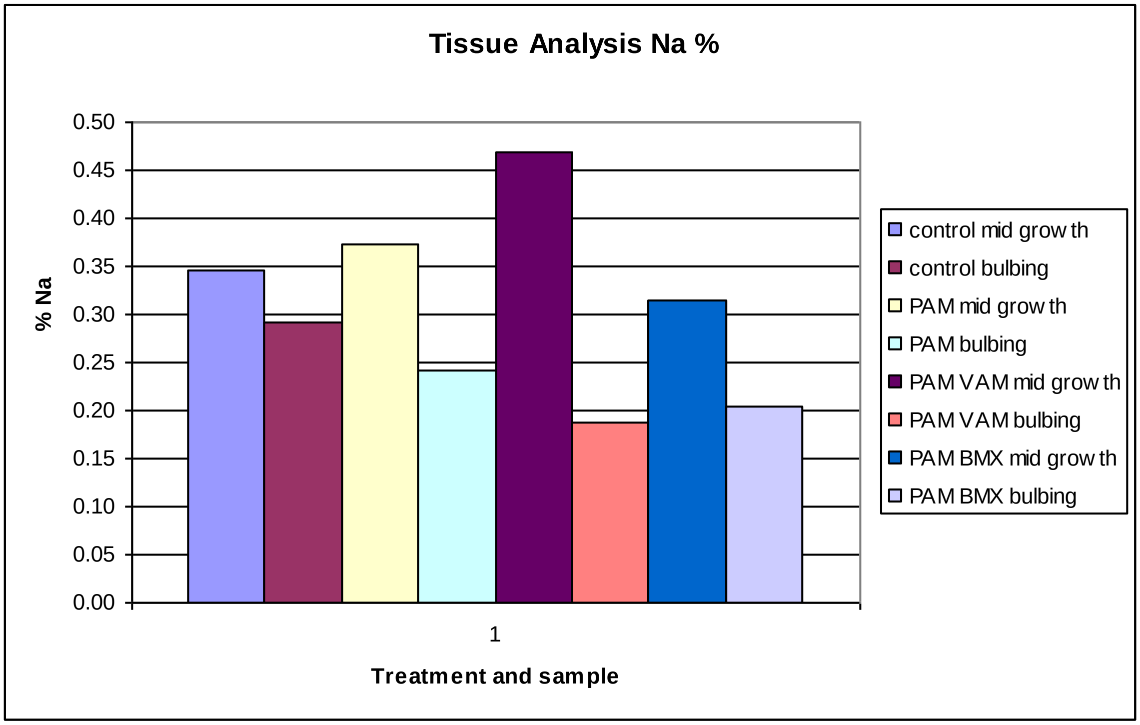


Figure 20: Influence of each treatment on leaf tissue analysis for sodium levels

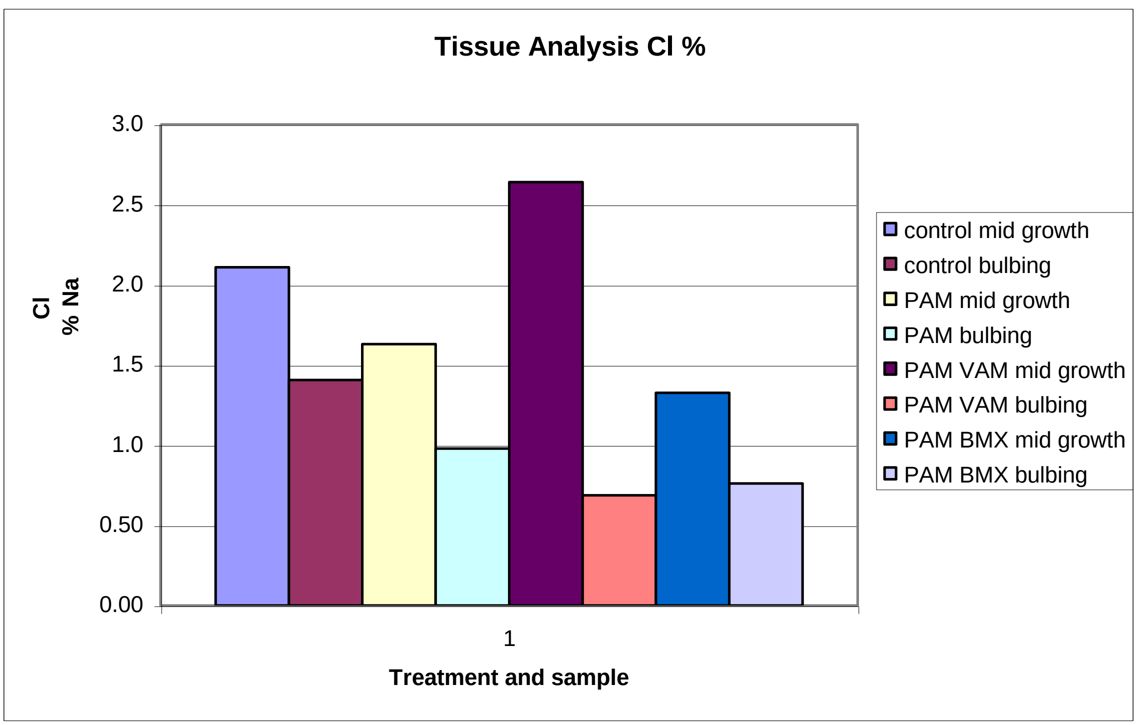


Figure 21: Influence of each treatment on leaf tissue analysis for chloride levels

5.4 Zinc availability, relationship with other nutrients and uptake.

Onions are regarded as being very zinc responsive and generally preplant and foliar zinc applications are applied throughout the growing season.

Zinc is regarded as a major limiting micronutrient across many areas of Australia. As a result many growers apply zinc to crops both in a pre-plant, post plant and foliar form to minimise deficiencies and yield loss attributed to deficiencies of this nutrient.

Plant demand for zinc where critical deficiency occurs is in the range of 10-15 mg/kg dry weight in most grass species and 20-30 mg/kg in dicotyledon species. The supply of zinc to the roots is mainly confined to diffusion and therefore to a zone around the root which does not extend beyond the root hair cylinder. This is similar to phosphorus uptake and the depletion of zinc around the root zone in wheat has been demonstrated using radioactive zinc isotopes. This depletion was confined to a labile fraction and not the total water extractable fraction. Zinc bioavailability is limited by low mobility in soil solution and therefore low spatial availability. Soil pH has the greatest influence on plant availability of zinc. Increasing from pH 5.5-7.0 can result in a decrease in the equilibrium constant of zinc up to 30-045 times for each increase in soil pH.

Much has been made of the role of VA mycorrhizae (VAM) in increasing plant nutrient uptake. The same mycorrhizal effect may also be achieved with the micronutrients zinc and copper. Much research has documented the beneficial effect of VAM on zinc uptake by the host plant. The effects being greatest in soils of low extractable zinc or low zinc mobility. While the benefits of VAM are well documented, the ability for soils to maintain viable VAM are influenced by the proportion of non-host plants and the length of fallows between crops. Hence the importance of the VAM coating in the onion trial and possibilities that an effective coating procedure may have on the alkaline low zinc soils in South Australian that are used for onion production.

The accumulation of zinc in plant tissue is variable and dynamic. Zinc accumulation in roots is influenced by the availability of zinc within the root zone and by the interaction with other nutrients. Zinc uptake in root cell walls can be seen to be high in Zn tolerant varieties but not in Cu tolerant species indicating that zinc accumulation was due to specific zinc adsorption sites in the zinc tolerant varieties.

The stem is an important transport pathway. In low zinc situations the stems can contain higher concentrations of zinc than either roots or leaves. In zinc deficient plants more of the total zinc is present in the leaf blade than in the petiole. With increasing zinc supply the zinc concentrations are more equally apportioned between the leaf parts. As such deficiency symptoms can be observed when tissue data indicates the same level of nutrients, where other plants appear to have adequate levels. In plants with an adequate zinc supply, the concentration of zinc in the leaf blades is similar with little indication of zinc accumulation and remobilisation. This is an important consideration when comparing treatments indicating similar results and visual assessment of the plant over its entirety should be considered. Zinc mobilisation out of old leaves depends upon the zinc status of the plant. The decrease of zinc from old leaves is greatest in plants with adequate zinc supply than with a deficient supply. Hence it can be recorded that reported results of adequate plant tissue levels when obvious visual deficiencies can be seen.

Zinc deficiency causes decreased internode elongation and stunting of young leaves. This has led to what is regarded as an incorrect assumption that Zn is immobile in the phloem. Zinc transport in the tissue is not via passive movement in the transpiration stream. If this was not true then the highest rates of zinc in plant tissue would be seen at the sites of greatest transpiration. This is not true!

Relocation of zinc in the plant is variable and depends on the supply of zinc to the plant. Zinc decreases more in senescing leaves of plants with adequate supply than those with deficient supply. With this observation perhaps the figures obtained in the recent tissue analysis are more easily explainable. There is a conflict on whether foliar applied zinc is re-translocated to other parts of the plant. Again our tissue data would tend to indicate that translocation in wheat and onions are limited. Research has shown that in covered leaves of plants receiving foliar applied zinc, zinc did not move from the sprayed areas to the apices.

The interaction of zinc with other nutrients is particularly interesting and highlights the need to consider the basic tenants of thermodynamics when considering plant nutrition. For example when zinc is added to the soil any of the following three factors other than the nutrient itself could be responsible for affecting a zinc response:

- another ion in the salt
- zinc as a contaminant in the nutrient salt (ex: single super)
- a change in the root environment

It is interesting to note that zinc levels in shoot tissue (in sorghum) are greatest when the crop had been fertilised using ammonium sulphate as the N source. It has also been reported that P can decrease Zn plant concentrations. However these observations are recorded generally when supplies of both nutrients are both marginal. Evidence that P can suppress Zn uptake are related to the following:

- P suppresses root infection by VAM
- cations added with P salts inhibit Zn absorption from solution
- hydrogen ions generated by P salts inhibit P absorption from solution (unlikely in alkaline soils
- P enhances the sorption of Zn to soil components

In cotton high P supply coupled with low Zn can be seen to cause P toxicity by enhancing the rate of P absorption into the plant and causing P to accumulate preferentially in the leaves.

Nitrogen salts can both ameliorate and enhance Zn deficiency. Field data has shown where excessive N applications are made an increase in Zn deficiency has been reported. However where N inputs are more responsible increasing N levels are often associated with increasing Zn levels in plant tissue.

A strong negative N-Zn interaction was observed in a wheat experiment when Cu was omitted from the basal fertiliser. Cu and Zn may interact in several ways:

- Zn strongly depresses grain yield of wheat by depressing Cu absorption
- Cu competitively inhibits Zn absorption
- Cu nutrition affects the redistribution of Zn within the plants
- Cu has an important role in skin quality in onion crops and the potential link between Cu/Zn should not be neglected.

Very strong interactions have been reported in grain yield of wheat crops growing on soils deficient in both Cu and Zn. In soils Cu and Zn are often present in complex forms where a much greater percentage of the Cu is complexed. In soil where Cu and Zn were present in chelated forms, increasing Cu 2+ activity had little effect on Zn concentrations in roots and shoots in maize (Bell et al 199 ex Zinc in Soils and Plants)

Copper nutrition in plants has been shown to affect the re-distribution of Zn from wheat leaves. In Cu deficient plants the export of N, Cu and Zn was delayed compared with plants given adequate Cu. The effect of Cu on Zn was probably indirect through its effect on senescence.

Low Zn concentration can be seen lead to enhanced B toxicity in barley. This raises the issue that low Zn availability in semi arid regions on alkaline soils may depress crop yields by enhancing B toxicity. This suggestion is viable, since in soils, Zn deficiency enhanced B concentration of wheat while decreasing wheat dry matter.

While the tissue data may not look conclusive the research offers plausible reasons for the decline in plant tissue levels. It also raises the question on the most important time of application and the method of treatment. The interaction of trace elements in soil and water and influence on other nutrients must also be considered.

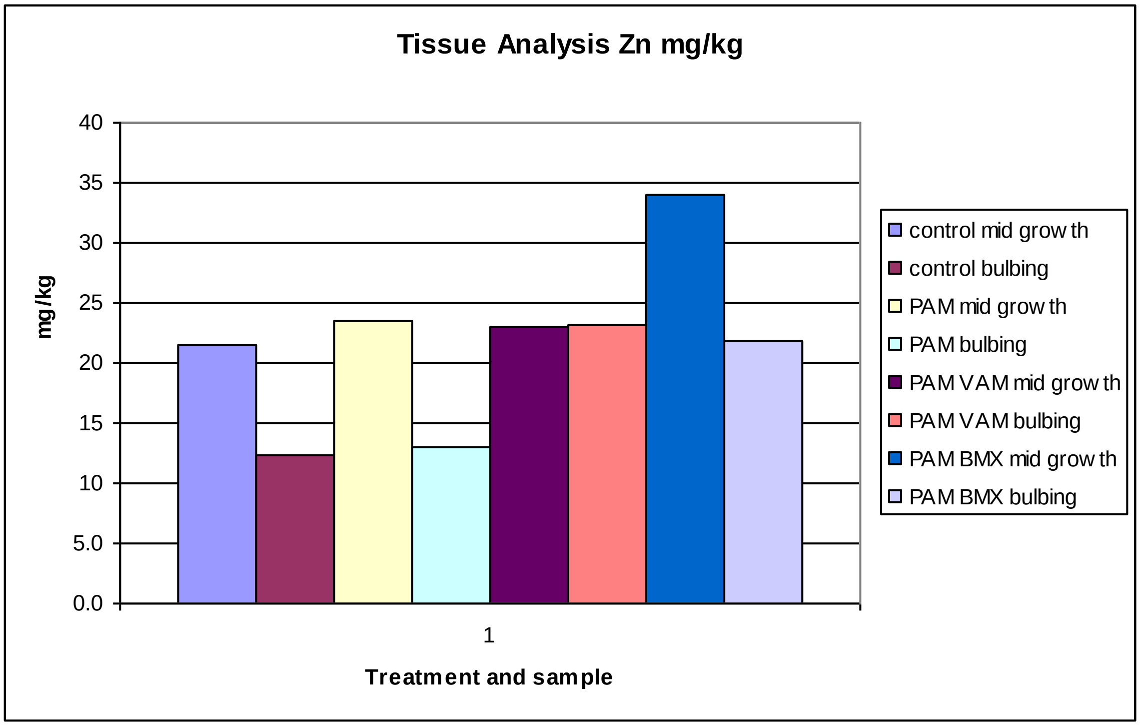


Figure 22: Influence of each treatment on leaf tissue analysis for zinc levels

In the above Figur22 on plant tissue zinc levels a decline in zinc levels at bulbing below the desired critical can be seen in both control and soil PAM samples. It is interesting to observe that tissue levels in the BMX coated sample (a product that contains Zn,Mn, Fe and B) and the VAM coating are significantly higher at bulbing.

5.5 Discussion

Both seed and fertiliser PAM coats are showing similar trends as was observed in the 2003 trials. It appears in these trials that the formation of insoluble zinc phosphates is not occurring as a result of the coating process on fertiliser, and that plant uptake of both phosphorus and zinc is enhanced through either the seed or fertiliser coating process.

In this initial stage it is worth considering the implication of soil moisture reserves on the preferred coating technique. In low rainfall conditions (<275mm/pa) seed coating may be the preferable option as large fluctuations in soil water levels result in variable levels of nutrient availability to root uptake. The relatively small root zone of the onion plant creates little chance for interfacing with zinc in soil. This would suggest that coating onion seed may be a practical means of applying zinc and increasing plant zinc levels during the early stages of plant growth and development.

The ability of the PAM to maintain relatively high point sources of moisture around the seed may enable plant nutrients to be kept in solution longer than under normal environmental conditions. In onions with small root zones the potential for leaching losses of nutrients under centre pivot irrigation systems may suggest that seed coating of trace elements to be an effective way of increasing plant absorption and minimising trace element deficiencies in this crop.

In higher rainfall or irrigated conditions PAM coated fertiliser could well reduce hydraulic movement of the fertiliser into unavailable forms in the soil. In lighter soils leaching losses could be significantly reduced as a result of the loose carbon bonds that are formed when the PAM is re-hydrated off the fertiliser granule. This assumption needs further investigation.

Nonetheless similar plant analysis trends were being seen in 2004 and 2003 trials. This is indicating that altering soil water relationships either around the seed or fertiliser granule greatly influences the availability of these (and other nutrients) in soil. It is the opinion of the writer that the physics of solubility and sorptivity is the greatest influence on PAM performance in either seed or fertiliser coating.

Sampling over time shows a decline in Zn tissue levels in the PAM Zn fertiliser coat. However this does not necessarily mean that the application is ineffective but rather re-distribution in the plant and the form of application has a significant role in nutrient availability and longevity. As in all trials the final proof is in on impact on yield. This will be discussed in a separate paper after harvest.

Section 6 Onion Bulb Sap Analysis

Sap analysis was conducted on the onion bulb to see if any significant differences could be seen to exist between the different treatments. The bulb was sliced then crushed to extract juice that was analysed using the Horiba Cardy Meter.

Sap analysis has been found to be useful for determining general trends in vine and other vegetable crops. The aim of this monitoring was to see if significant differences could be seen between treatments. As can be seen in dried tissue analysis the amount of variance between plants from the same treatment but of different stages of development. The most interesting observation from the data in the table below was the overall lower sodium levels in the PAM treated area than the control on the 26/11/07. However variance between plants was quite high and shows the importance of taking sufficient samples to reduce the impact of natural variation within the sampling program.

In soils where non-wetting characteristics exist the impact of these soils on plant nutrient uptake creates not only an interesting aspect on plant nutrient uptake but on fertiliser management decisions.

PAM Treated				
Date	Nitrate N	Potassium	Sodium	Comments
26/11/2007	500	2100	120	
	400	2200	24	
	500	2400	85	
Mean	***467***	***2233***	***76***	
17/12/2007	830	2600	530	
	1100	3500	550	
Control				
Date	Nitrate N	Potassium	Sodium	Comments
26/11/2007	340	1800	53	
	430	2200	130	
	400	2100	280	Bulb size from the PAM treated areas was
Mean	***390***	***2033***	***154***	larger than the control samples
17/12/2007	480	2800	280	Large bulbs
	530	3500	390	
	1000	2300	590	
	960	1500	140	
	2100	2100	120	Wheel track areas Smaller bulbs

Table 8: Bulb analysis

Sap analysis is used extensively in grape and potato production and as such a large amount of data to determine plant growth trends is currently available. The suitability for such monitoring of onions would require additional field studies over several seasons.

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