Nutrient stratification in soil under irrigated and dryland systems

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Abstract

In Australia, cotton (*Gossypium hirsutum L.)* is grown in both rain-fed and irrigated systems, but the majority of production is irrigated. Despite this, little is known about the impact of these irrigated production systems on soil nutrient distribution in comparison to dryland systems. This study aims investigate and compare the distribution of soil nutrients and properties in adjacent irrigated and dryland crop production systems in different regions of NSW. Soil samples were collected from four different farms in southern, central and northern regions of NSW. Soil types at the sampled sites included Vertosols and a Chromosol. Soil properties were analysed to a depth of 90 cm, which is the typical rooting depth of cotton plants.

The topsoil pH for irrigated samples was found to be significantly higher than adjacent dryland samples from Narrabri and Darlington Point, and some Narromine samples. Throughout the soil depth, pH increased for all samples. As pH increased, plant micronutrient availability (Fe, Cu, Mn, Zn), appeared to decrease. Topsoil stratification of phosphorus (P) and potassium (K) was also apparent in both irrigated and dryland systems. The irrigated samples from Narromine were found to have a significantly greater electrical conductivity (EC) and exchangeable sodium percentage (ESP) (%) than their adjacent dryland samples. It is speculated this significant difference may be due to the use poor quality irrigation water with a high concentration of dissolved salts. It is believed the higher salt content of these irrigated soils may have a negative flow on effect to crop production, reducing nutrient availability, uptake, and crop yield.

Introduction

Cotton (*Gossypium hirsutum L.)* is a crop mainly grown in the irrigated regions of eastern Australia. In recent decades extensive research and development of the cotton crop has occurred. This has been to both understand the specific climatic, nutrient and water requirements of the crop, and also to improve water and nutrient efficiency of the cotton crop (CRDC, 2021).

One factor that has remained of particular interest to scientists, farmers and consumers alike is the water demand and usage of cotton. In recent decades new cotton varieties have continually been developed, including those which require less water than previous varieties whilst producing a greater yield (CRDC, 2020). Despite this development, water usage of cotton has remained a major focus of discussion and development in the sector. Currently, ~80% of cotton produced in Australia is irrigated (Roth *et al.,* 2013). Whilst this generally produces a crop of greater quality and yield than its dryland alternative (Roth *et al.*, 2013), concerns remain regarding the potential on- and off-site environmental impacts of using irrigation water.

The other integral input for cotton production is fertile soil containing essential nutrients for successful crop production. In Australia, cotton is mainly grown on Vertosols (Nachimuthu *et al.,* 2018), but some Chromosols are also used for growing cotton. These soils, particularly Vertosols, are well suited to cotton production due to their ability to store water and nutrients (Kurtzman *et al.,* 2016). This is made possible by a high proportion (>30%) of 'shrink swell' clay minerals in the soil, which can store soil water (Kurtzman *et al.,* 2016).

Over time, nutrients in soil can be depleted by crop production, or intensive cultivation can change some soil properties or soil composition. Whilst research has been conducted on the impacts of irrigation water on soil properties (Entry *et al.,* 2002; Mudge *et al.,* 2021; Nachimuthu *et al.*, 2018), limited research has been conducted on deeper soil samples. The importance of the impact at depth is of particular interest in cotton production as cotton plants have tap roots which can reach a depth of > 1 m (CRDC, 2021). Understanding the impact of irrigation water on soil properties at depth allows for a better understanding of the best steps to be taken to encourage and retain soil quality for long term crop production.

The aims of this investigation are to determine the distribution and concentration of total and plant available nutrients in soils to 90 cm, and to compare these findings to irrigated and dryland soils across different locations in NSW.

Materials and Methods

Sampling

Soil samples were collected from three cotton-growing locations near the towns of Darlington Point (34.5667° S, 146.0000° E), Narromine (32.2327° S, 148.2395° E), and Narrabri (30.3324° S, 149.7812° E) in NSW (Figure 1). Paired irrigated and dryland soil cores were collected from each site. At each site the irrigated field had a history of (>10 years) of irrigated crop production, including cotton, whilst the adjacent dryland field had a history of dryland crop production. One paired sample was collected from Darlington Point, two from Narromine, and one from Narrabri (Figure 2). At each site, four 1 m soil cores in close proximity to each other (i.e. four replications) were collected from each irrigated cotton growing, and paired dryland field.

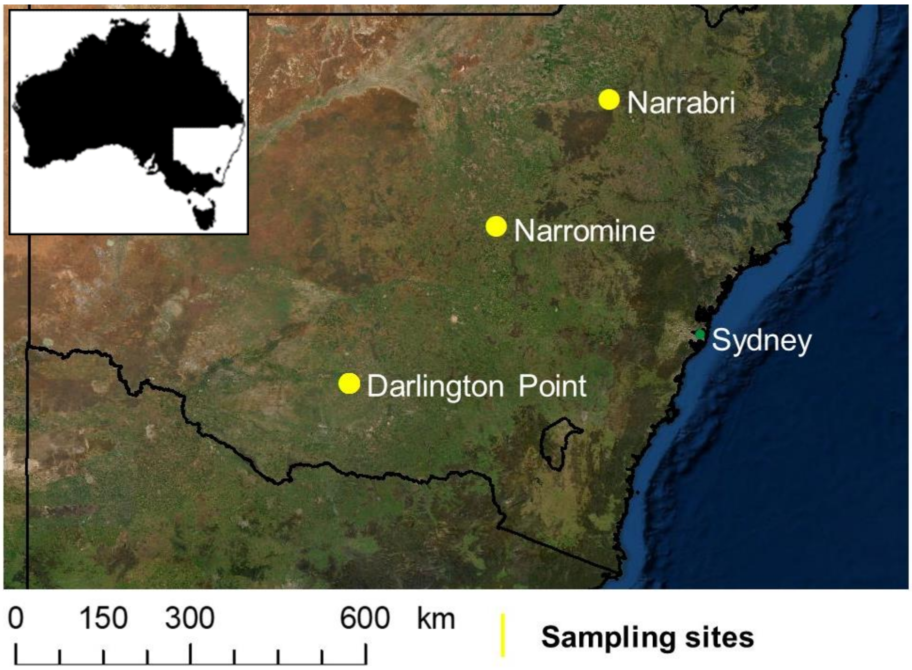

Figure 1 *- The map showing the locations of soil sampling sites in NSW.*

At the Darlington Point and Narrabri sites, the soils are Vertosol, whereas at Narromine, the soils are Chromosol. In total, 32 cores were collected across three locations, four paired sites, two soil types, and two land uses.

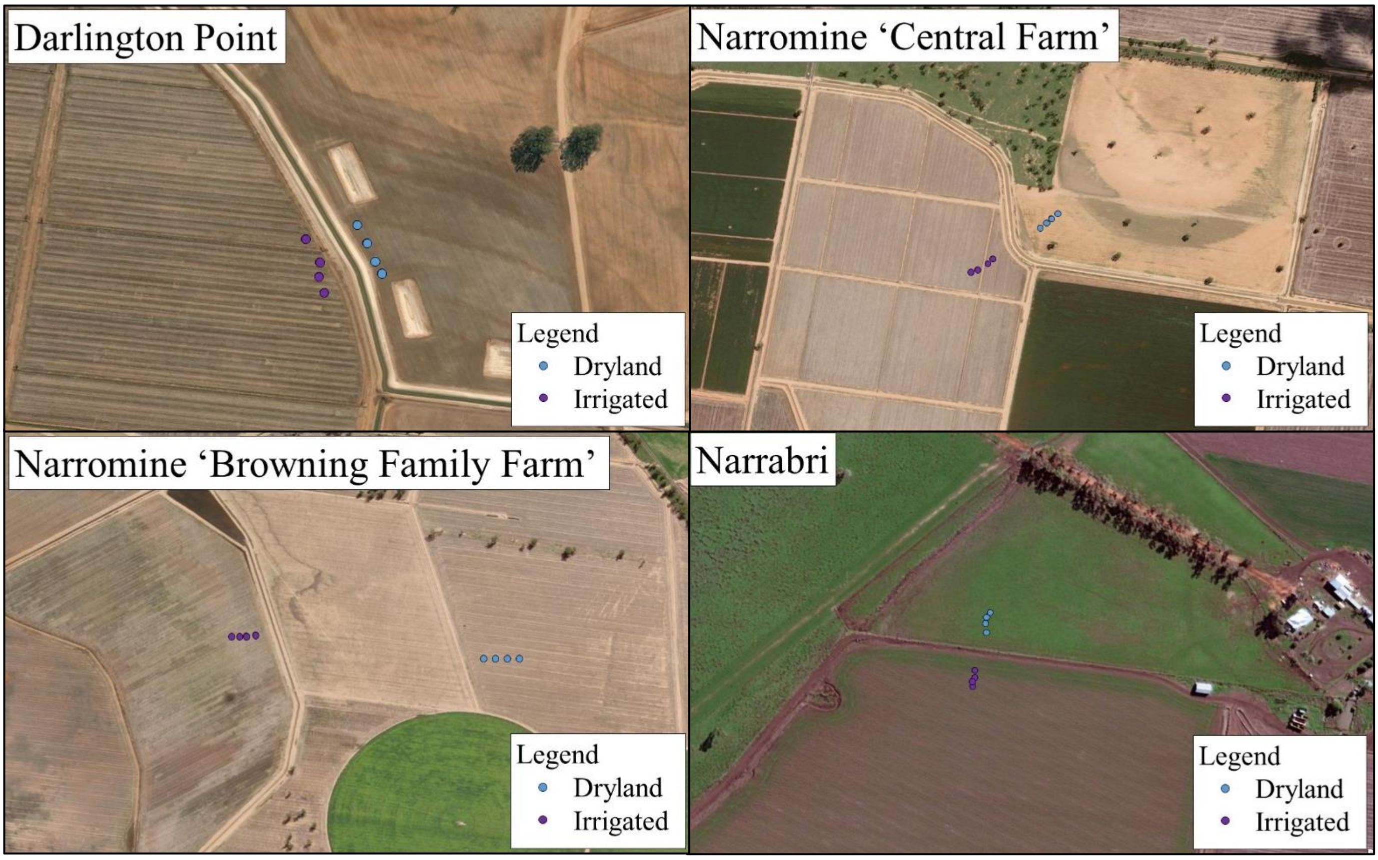

***Figure 2** – Maps of sample sites with dryland and irrigation soil core collection points*

Sample preparation and analyses

Each soil core was segmented into six soil samples at 15 cm increments, i.e. 0–15 cm, 15–30 cm, 30–45 cm, 45–60 cm, 60–75 cm and 75–90 cm. Segmented soil samples were dried for about 14 days at 40 °C in an oven. The dried samples were ground and sieved to < 2 mm for laboratory analysis.

Soil analyses

Soil pH and EC were determined in a 1:5 soil:water solution (Methods 4A1 and 3A1 in Rayment and Lyons, 2011). To determine soil organic carbon (SOC) content, the Walkley-Black method was used, as outlined in Rayment and Lyons (2011) procedure 6A1. Ammonium and nitrate-nitrogen concentrations of the soil samples were determined colorimetrically in 2M KCl extracts using Rayment and Lyons (2011) method 7C2a. Plant available P (Colwell P) was determined in 0.5M $NaHCO_3$ (pH 8.5) extracts (Rayment and

Lyons, 2011: method 9B2). Extractable S was determined using the KCl-40 method (Rayment and Lyons, 2011: method 10D1). Exchangeable cations (Ca, Mg, K and Na) were determined by ICP-OES analysis after extraction with a 1 M ammonium acetate solution at pH 7.0 (Rayment and Lyons, 2011: method 15D3). Micronutrients (Fe, Cu, Mn, Zn) were determined by ICP-OES analysis after extraction with a Diethylenetriamine penta-acetic acid (DTPA) solution (Rayment and Lyons, 2011: method 12A1).

Calculations of soil attributes

Cation exchange capacity (CEC) is a measure of the total capacity of the soil to hold exchangeable cations (Soil Science Australia, 2013). It can be measured directly, or calculated as the sum of the exchangeable (exch) cations (called effective cation exchange capacity) measured individually using the following formula:

$$\mathrm{CEC}\ (\mathrm{cmol_c\ kg^{-1}}) = (\mathrm{exch\ Ca} + \mathrm{exch\ Mg} + \mathrm{exch\ K} + \mathrm{exch\ Na})$$

Exchangeable sodium percentage (ESP) is a measure of soil sodicity and is determined using the following formula:

$$\mathrm{ESP}\ (\%) = \left(\frac{\mathrm{exch\ Na}}{\mathrm{CEC}}\right) \times 100$$

The occurrence of Covid-19 restrictions meant all analyses except soil pH and EC data was conducted at a commercial laboratory. After obtaining laboratory data corrections were made to the CEC and exchangeable cations data of soil samples with high soluble salts (EC > 250 µS cm^{-1}). The following steps were undertaken for samples that had an EC value > 250 µS cm^{-1} (Rayment and Lyons, 2011).

1. If EC value (x) was more than 250 µS cm^{-1}, the following formula was used:

$$\mathrm{Excess\ EC} = \mathrm{x} - 250$$

2. To determine the total dissolved solids (TDS, in mg L^{-1}) from the excess EC (1:5 H_2O), first EC (1:5) was converted to EC_e (saturation extract) using a multiplier of 6.4, and then the EC_e (in dS m^{-1}) was converted to the TDS using a multiplier of 640 (Corwin and Yemoto, 2020). This was then divided by 1000 to convert value from microsiemens (µS cm^{-1}) to decisiemens (dS cm^{-1}) as given below:

$$\mathrm{TDS} = \frac{(\mathrm{y}\ \times 6.4\ \times 640)}{1000}$$

3. To convert the (excess) total salt concentration in saturation extract to soil, the following formula was used, using total dissolved solids value (z) from above:

$$\text{Total Salt Content (mg kg}^{-1}) = \mathrm{z}\ \times 1.25$$

4. The mean sulfur (S) value for the soil profile was then determined. This value was used to calculate the excess S (v, in mg kg^{-1}) in the sample at any depth. If there was little or no apparent excess S, the exchangeable Ca value was deemed reliable (the source for both Ca and S being gypsum ($CaSO_4^{\cdot}2H_2O$) in some sub-surface soil samples, and it was assumed that high EC (excess soluble salt) was only due to excess sodium (NaCl) in the sample. Therefore, corrections were only applied for exchangeable sodium values. Steps 4-7 were skipped).
5. The excess calcium (mg) (c) of the sample was then determined by working out the number of moles of calcium that were present for each mole of S, as previously determined. Thus, the atomic masses of calcium (40.08) and S (32.065) were required. The following formula resulted:

$$\text{Excess Calcium (mg)} = \left(\frac{40.08}{32.065}\right) \times \mathrm{v}$$

6. This value was converted into $cmol_c\ kg^{-1}$, using the following formula, including the value (c) from step 5.

$$\text{Excess Calcium}\ \left(\frac{cmol_c}{kg}\right) = \left(\frac{c}{20.04}\right) \div 10$$

7. The value obtained from step 6 was then subtracted from exchangeable calcium value supplied by the lab to obtain corrected exchangeable Ca value.
8. Excess S (step 4) and calcium (step 5) previously determined were subtracted from the excess soluble salt ($mg\ kg^{-1}$) to obtain the contribution of NaCl.
9. Total sodium value ($mg\ kg^{-1}$) was determined using the total salt content value determined in Step 3 (w) or Step 8 and assuming this was from dissolved NaCl using the following formula:

$$\text{Total Sodium} = w \times \left(\frac{22.99}{58.5}\right)$$

10. Excess sodium was determined using the value determined from step 9 (d) and dividing it by the molecular weight of Na (22.99):

$$\text{Excess Sodium}\ \left(\frac{mmol}{kg}\right) = \frac{d}{22.99}$$

Statistical analysis

All statistical analysis was conducted using the software R. Analysis of Variance (ANOVA) was conducted using the ‘stats’ R package. This was done to compare each soil property at each depth segment between irrigated and dryland sites at each farm. Each core collected from each respective location and land use was treated as one replication. In total, for each location, (eg. Darlington Point, Dryland. 0-15), there were four replications as four soil cores were collected from each land use and depth.

From this, the probability (P) of there being a significant difference between dryland and irrigated systems could be determined. Significant difference was determined to be $P < 0.05$. Least significant difference (LSD) test in the ‘agricolae’ R package was also conducted to see if there was a difference between land use groups at each depth. The LSD test is conducted after the ANOVA, and only if the ANOVA shows that there is a significant difference between groups being investigated. This test is used to show which groups are statistically different to each other.

Finally, interrelationships between measured soil properties were explored using Pearson’s correlation coefficient, tabulated as a correlation matrix (Appendix A).

Results and Discussion

Soil pH

The pH of all soil samples was either similar or greater (more alkaline) for the irrigated soil samples than corresponding dryland soil samples (Figure 3). This was found to be significantly different in the top 30 cm of both Vertosol samples at locations (a) and (d) and in differing portions of soil profile at location (b). In contrast, a different trend was found for location (c), where pH of the irrigated sample was higher than dryland > 30 cm. This may be due to poor irrigation water, leading to an accumulation of salts at depth. Alternatively, the contrast between this and results for other locations also implies this site may not be a true paired site.

The higher pH of the irrigated samples previously mentioned may also be due to poor irrigation water quality, alongside potential fertiliser leaching from the topsoil (Filippi *et al.,* 2018b). Both bore water and river water can have dissolved ions (such as Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and HCO_3^-) present which, over time can increase the soil pH. Depending on water composition, this can increase soil salinity, sodicity, or both (Cattle and Field, 2013).

For all locations and land uses, soil pH increased through the soil depth. At all locations, a larger pH range was present for the dryland samples between topsoil and final subsoil samples. High pH decreases plant micronutrient availability (Filippi *et al.,* 2019; Palmer *et al.,* 2021), which was reflected in the results found (Figures 15–18). For the sample from location (d), this finding was consistent with a previous study by Filippi *et al.,* (2019) in the region. The higher pH at depth is possibly due to the precipitation of Ca in calcite ($CaCO_3$) and gypsum ($CaSO_4 \cdot 2H_2O$) at depth, and Na carbonate and bicarbonate in solution increase the pH greater than 8.5 in the soil.

At all sample location the irrigated soil samples were more alkaline than dryland samples. This high alkalinity may affect crop growth and yield maximisation. Previous studies have indicated that a higher pH can result in a less successful cotton crop due to reduced nutrient availability and non-optimal pH for the cotton plant whose ideal pH range is 5.5-7, (Filippi *et al.,* 2018a; Filippi *et al.*, 2019). The high pH of the subsoil may limit root growth at depth, meaning it does not grow to the ~ 1.2 m depth it is capable of growing to, limiting nutrient availability.

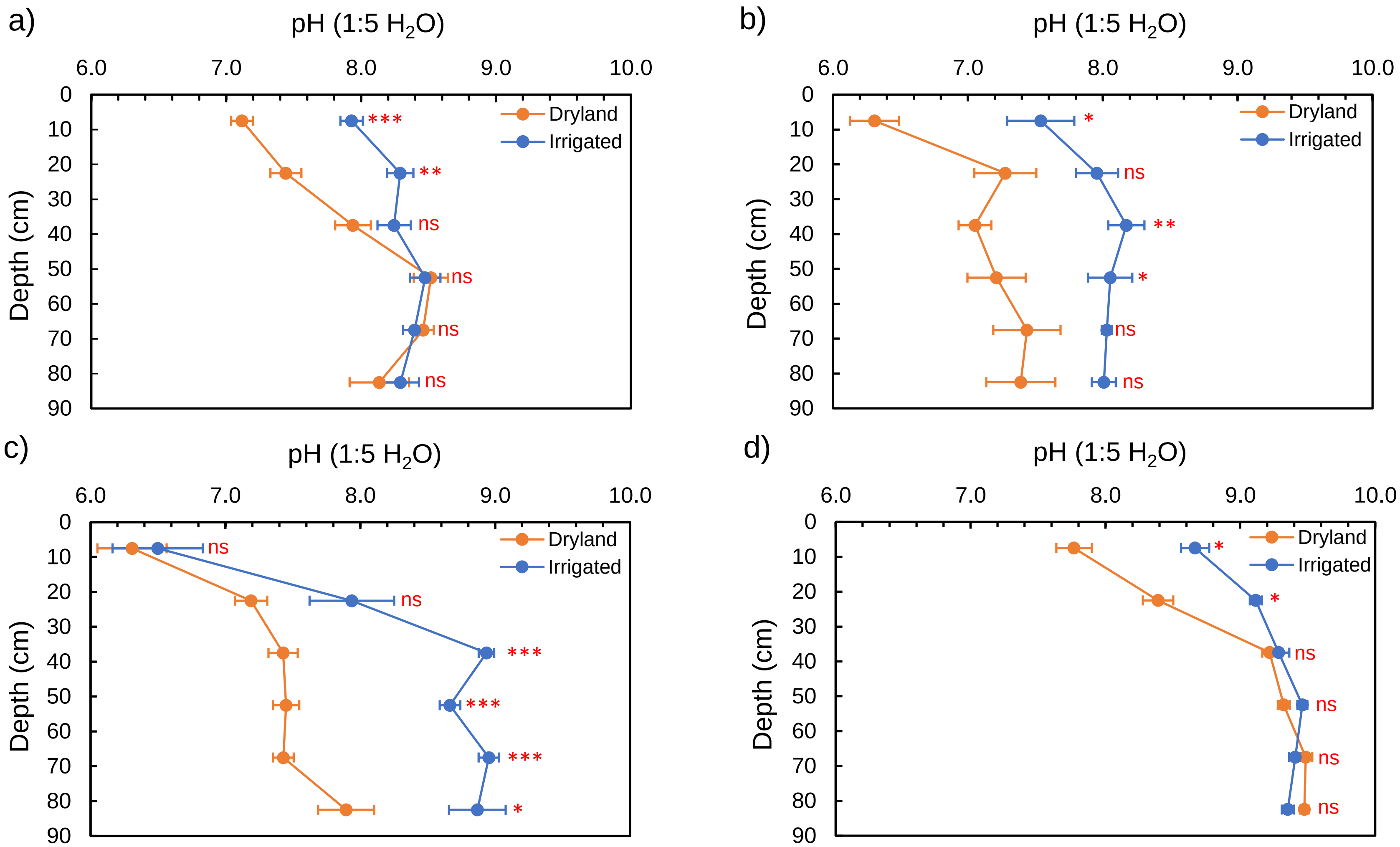

Figure 3 *– pH (1.5 H_2O) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns $P > 0.05$*

Electrical conductivity (EC)

EC measures the concentration of soluble salts in solution and shows how saline soil is. This is usually dominated by NaCl, but other salts also contribute to this. Salt presence in soil restricts, oxygen availability, the ability for water and nutrients to move through the soil and resulting nutrient uptake by crops.

(Filippi *et al.*, 2020b). The EC (Figure 4) of irrigated samples was higher than or similar to dryland samples. This is potentially due to the use of poor quality irrigation water with high EC, a finding consistent with pH results, suggesting higher salinity of irrigated soil samples (Cotton Info, 2015).

The subsoil of the irrigated samples from Narromine (b and c) particularly were found to be more saline than the dryland samples. Whilst the salinity of dryland samples remained consistently low.

In contrast, there were different findings for the Vertosol samples (a and d). In both irrigated and dryland samples, EC increased through the soil depth. The top 45 cm of the irrigated sample from location (a) was found to have a significantly higher pH than the dryland sample. This again is potentially due to irrigation water quality.

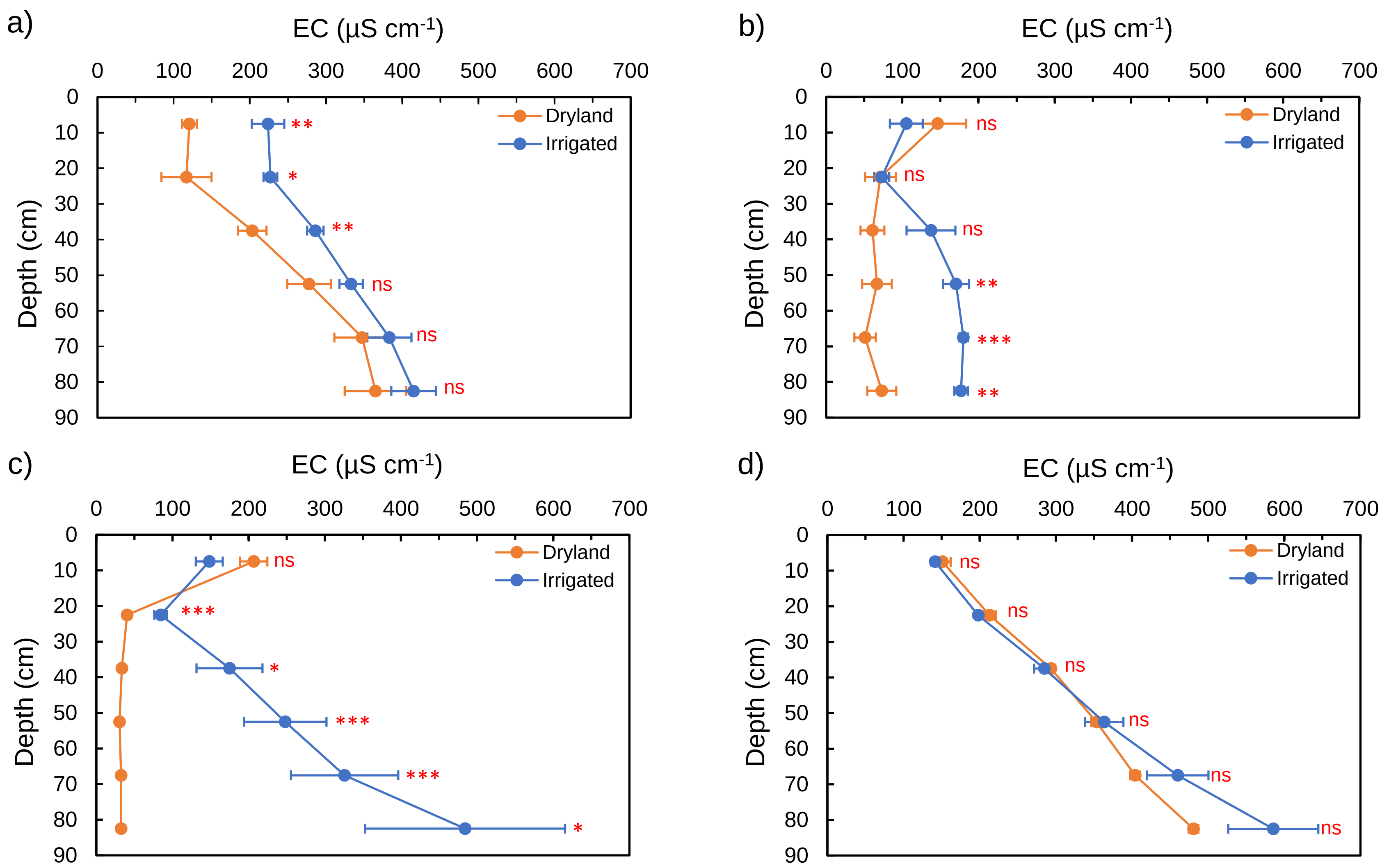

Figure 4 *– EC (µS cm-1) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Exchangeable Sodium Percentage (ESP) (%)

ESP shows the proportion of soils cation exchange surfaces that are occupied by exchangeable sodium. When ESP is high, soil is sodic, resulting implications such as a breakdown of soil structure and natural aggregates, clogging of soil pore spaces, displacement of desirable nutrients to plants and reduced ability to store soil water (Department of Environment and Resource Management, 2019). Soil sodicity is characteristic of much of Australia's arid and semi-arid environments where agricultural production occurs (Filippi *et al.,* 2018b). Despite this, sodicity can be accentuated by agricultural production practices. ESP was found to differ between different locations and soil types (Figure 5). The ESP of the irrigated samples from Narromine (b and c) was found to be significantly greater than the adjacent dryland samples. In contrast, the ESP of both the dryland and irrigated samples from Darlington Point and Narrabri (a and d) was found to be similar, with the exception of the deepest samples. The contrast in results between locations is potetially due to differing quality irrigation water, with the irrigation water from locations (b) and (c) likely having a higher concentration of dissolved sodium in irrigation water than locations (a) and (d). The higher sodicity in these samples will likely result in soil quality impacts previously outlined, likely affecting future crop growth.

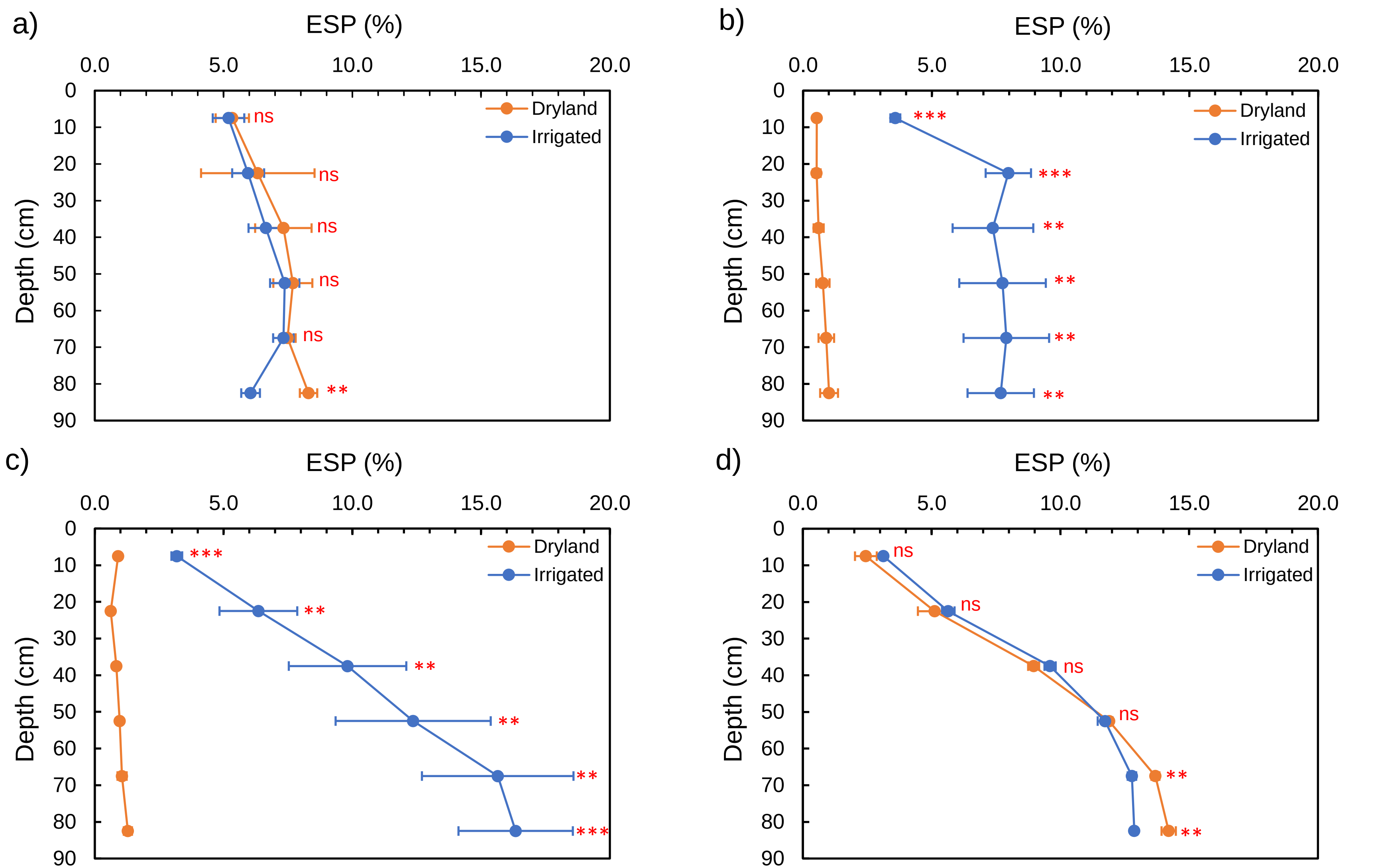

***Figure 5** – ESP (%) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Soil Organic Carbon (SOC)

The SOC (Figure 6) concentration was highest in the topsoil (0-15 cm) before declining throughout the soil depth. This was an expected finding (Peverill *et al.,* 1999) given the role that plants play in soil biomass formation, particularly in the topsoil where plant mass and root concentration is higher, leading to plant residue decomposition and recycling (Entry *et al.,* 2002).

In the Vertosol samples (a) and (d), dryland SOC concentration was found to be greater than irrigated SOC content. In cotton production, intensive tillage practices are often used after production, one being pupae busting where insect larvae in the soil are killed so they do not destroy a following crop (Rossiter *et al.,* 2007). This intensive tillage operation the loss of SOC into the atmosphere (Rendon *et al.*, 2016). Whilst tillage is likely used for most seasons under dryland production from sites sampled, farmers may use low or minimum till systems which are less intensive and result in less SOC loss (Lopez-Garrido *et al.,* 2011). In contrast, pupae busting is a more intensive process which may lead to greater SOC loss from the topsoil of irrigated sites (Filippi *et al.*, 2021).This finding is consistent with McLeod *et al.,* (2013) where vertosol samples from a similar location to sample (d) produced similar results. The SOC concentration at location (b) was found to be similar between irrigated and dryland land uses. The results for site (c) were found to contrast to the other three locations, with a significantly high SOC concentration in the irrigated topsoil in comparison to the adjacent dryland system. This again, suggests that this site may not be a true paired site. Whilst this may be due to greater biomass accumulation, the contrast between this and the other samples creates doubt.

It is also important to note that in previous studies conducted, accumulation of SOC in soil has also been found to differ based on external factors such as cropping intensity (Zibliske *et* *al.*, 2002), soil type, land use (Mudge *et al*., 2021), or even climatic conditions, amongst others (Nachimuthu *et al.*, 2018). Thus, these factors too may impact the results found. Overarchingly, SOC concentration in the dryland Vertosols was found to be greater in some profiles when compared with irrigated samples. Despite greater biomass production in irrigated systems, the higher SOC content of dryland systems is likely due to less intensive tillage operations.

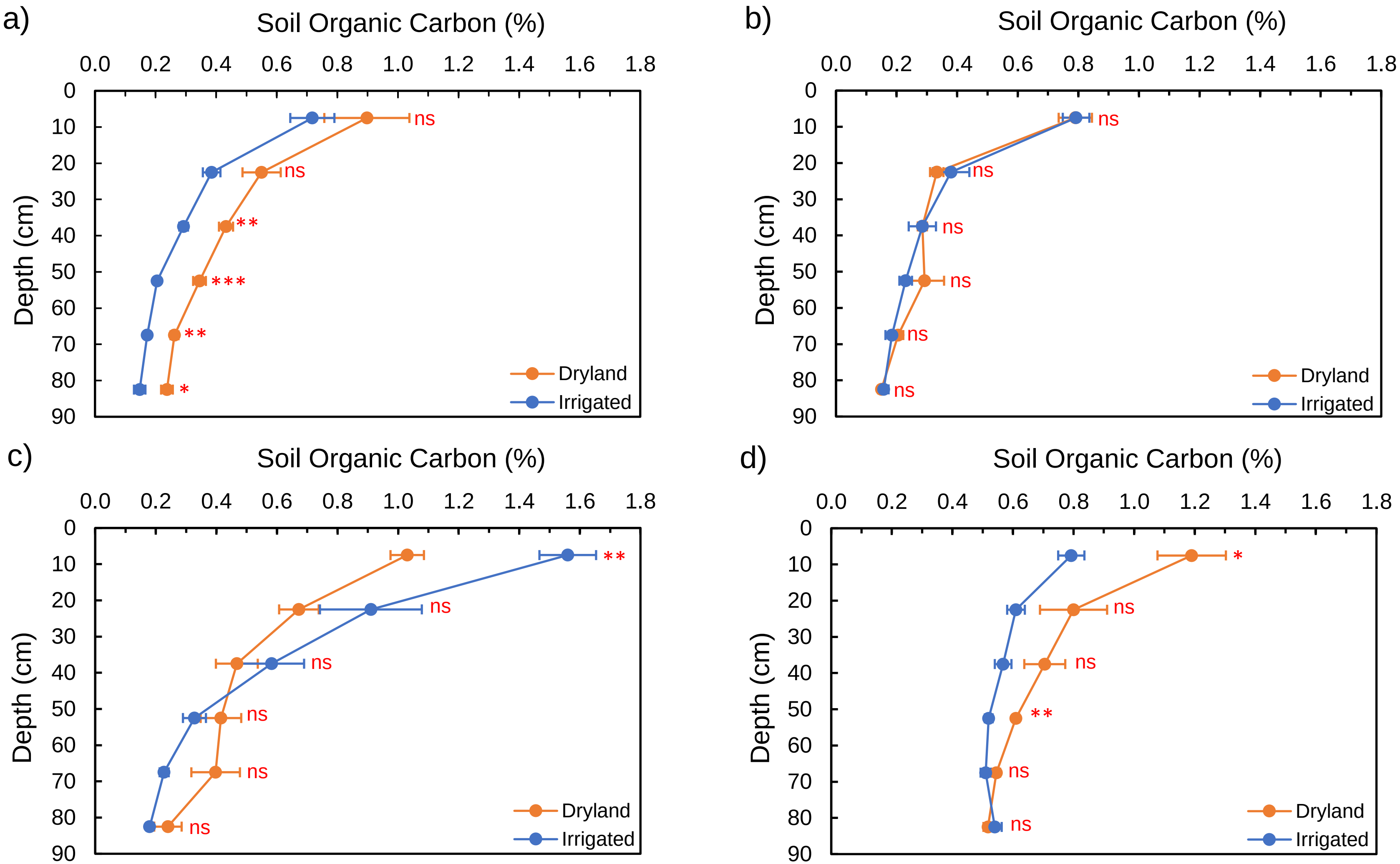

Figure 6 *– Soil Organic Carbon (SOC) (%) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Nitrate N

Nitrogen is an essential nutrient in cotton production thus, it can be one of the most limiting nutrients to yield maximisation as it is the element required in greatest amount by crops (Hulugalle et al., 2017; McDonald *et al.*, 2018). Nitrogen is taken up by plants in the form of nitrate and ammonium (Singh *et al.*, 2014), thus the presence of nitrogen in soil in either form is important for crop uptake.

At sample locations (a), (b), (c), and the dryland sample at location (d), (Figure 7) nitrate concentration was found to be highest in the topsoil. This higher concentration is likely due to topsoil fertiliser application and also plant residue recycling in the topsoil from the decomposition of previous crops.

Through the soil depth, different trends were seen at different locations. At locations (c) and (d), there was a higher nitrate concentration at depth for irrigated soils, suggesting leaching of nitrate deep in the soil with the assistance of irrigation water (Nachimuthu *et al.*, 2019). In contrast, locations (a) and (d) were both found to have higher nitrate concentration in some profiles of their dryland soils. This may be due to limited water availability, leading to reduced nutrient uptake and crop productivity. In the case of results at location (d), the high nitrogen concentration in topsoil samples may be from the occurrence of a dryer season. Thus, whilst fertiliser may have been present, the shortage of water means crops were unable to access the nutrients.

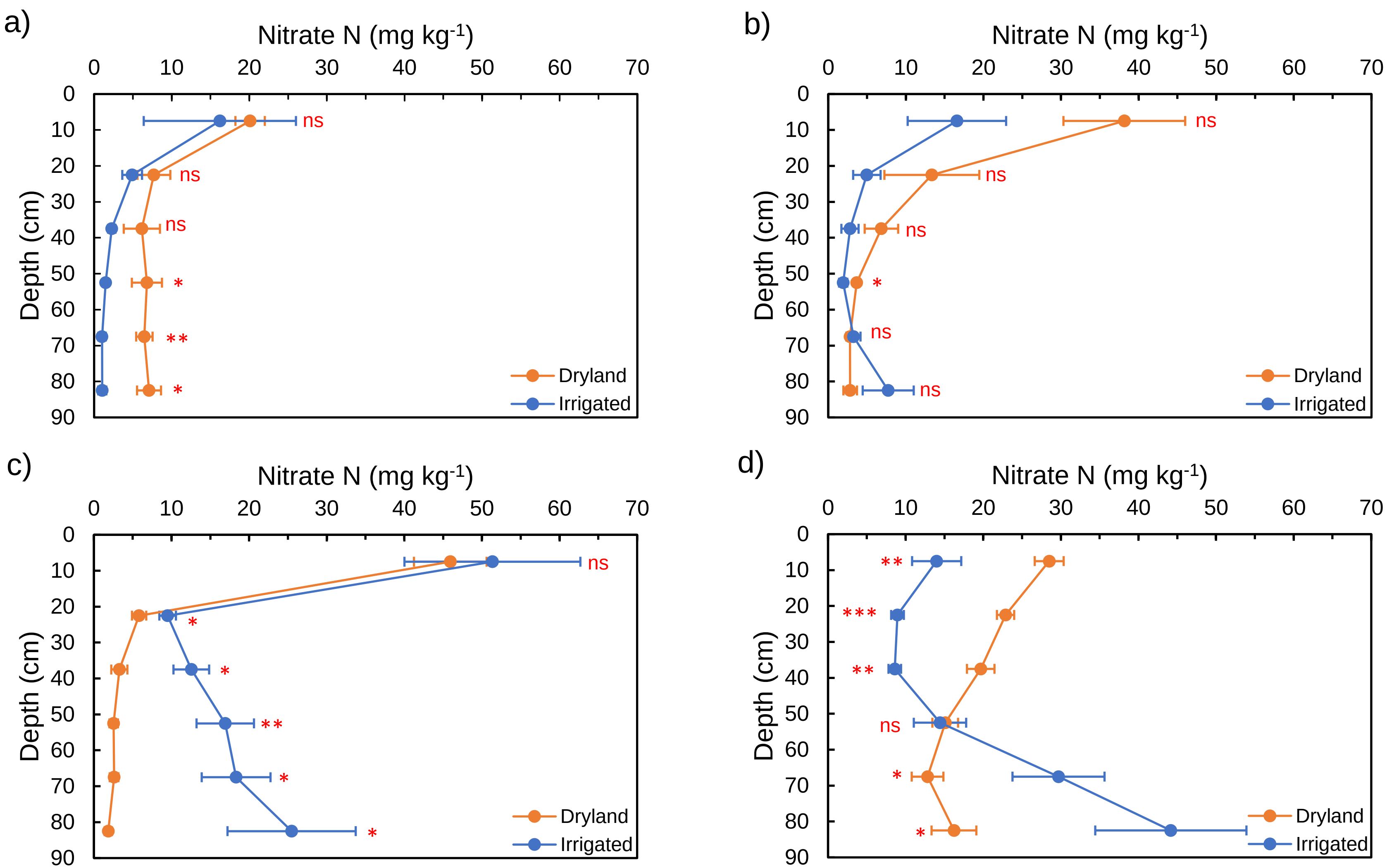

***Figure 7** – Nitrate (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Ammonium nitrogen

Nitrogen is also taken up by plants in the form of ammonium (Singh *et al.*, 2014). Ammonium (Figure 8) concentration in soils was either similar between production systems, or greater in dryland soils. Over time ammonium in soil is converted into nitrate, although this does not happen if the soil is too dry. The reduced water availability in dryland fields in comparison to irrigated may slow conversion into nitrate, accounting for the higher ammonium concentration in dryland systems at locations (a) and (c). Alongside this, the reduced plant productivity of dryland systems potentially accounts for higher ammonium concentration in soil. At location (b), ammonium concentration of dryland topsoil was greater than corresponding irrigated ammonium concentration. This was likely due to fertiliser application of ammonium.

Overall, nitrogen is an essential nutrient in crop production, water availability and fertiliser application were found to impact the concentration of ammonium in soil between dryland and irrigated systems.

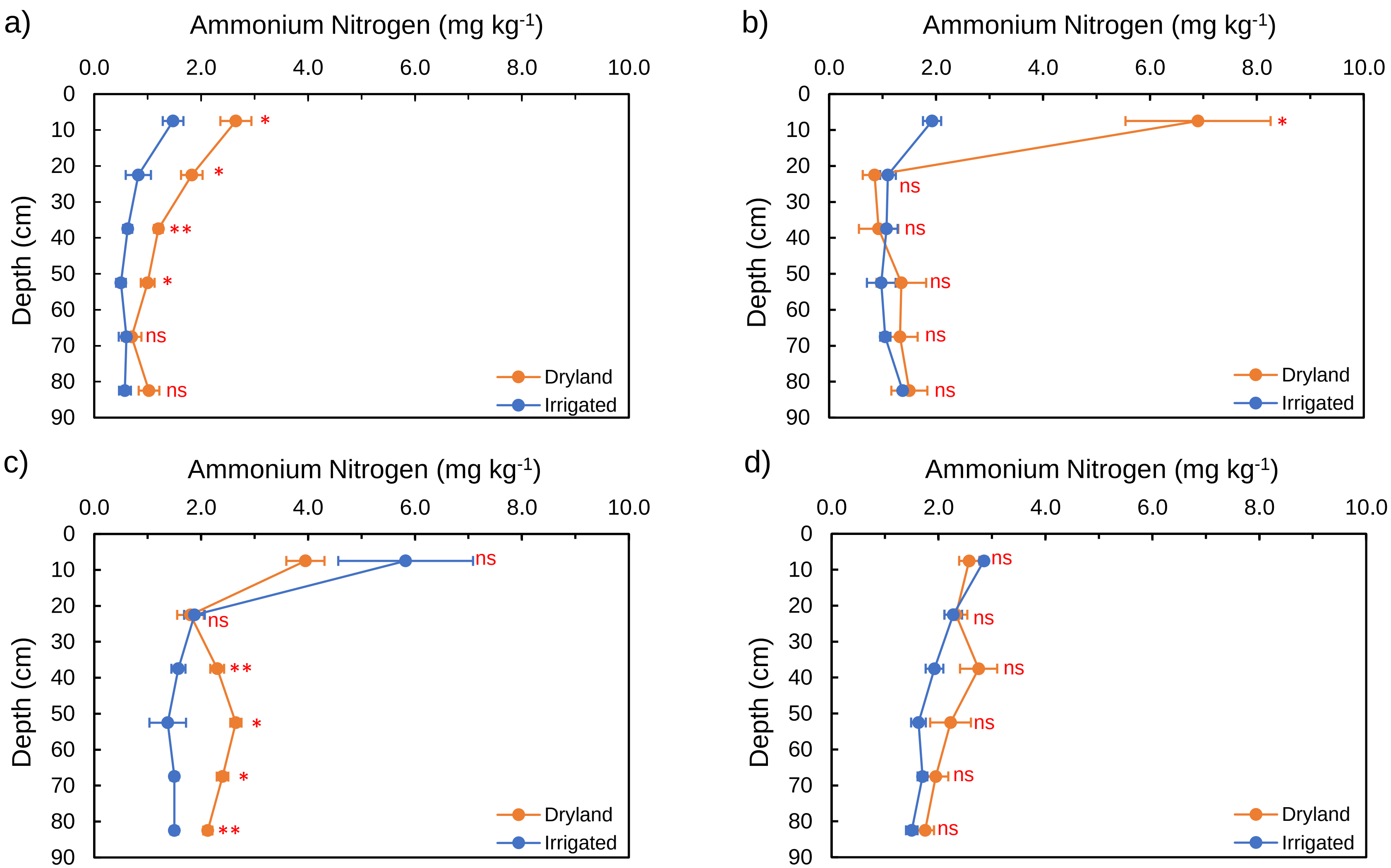

***Figure 8** – Ammonium Nitrogen (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns $P > 0.05$*

Colwell Phosphorus (P)

Phosphorus is an essential nutrient in plant growth and development but is immobile in most soils due to its ready fixation with soil minerals (Singh *et al.*, 2014). This can lead to plant P deficiencies. Given the limited soil mobility of P, it is often applied by farmers to retain a continuous P pool in the soil.

The critical soil concentration of P (Colwell) in soil for cotton production is <10 mg kg^{-1} (CRDC, 2018). For all locations, P content of soil was >10 mg kg^{-1}, but > 15 cm, this value was ≤ 10 mg kg^{-1}, highlighting the limited P availability, and greater depths, and thus the importance of the topsoil in providing adequate P fertiliser.

For all samples, locations and land uses, P concentration was highest in topsoil (Figure 9). For locations (a), (b), and (d), soil P concentration was similar between dryland and irrigated land uses. At location (b), the dryland topsoil had a higher concentration of P than the irrigated samples. This may have been due to higher plant productivity in irrigated soils, reducing potential supply of plant available P as the P removed was not replaced, (Rochester, 2007). The similar values at greater depths between dryland and irrigated samples at locations (a), (b), and (d) support the known low mobility of P. This shows that production system does not impact P availability at depth.

In the case of location (c), findings were very different with there being a significantly higher concentration of P for the dryland soil sample at greater depths. These differing results suggest that this paired site may be comparing inherently different soil types.

The low mobility of P in soil is reflected here both in the dryland and irrigated samples. Stratification has occurred with a higher concentration of P in topsoil samples.

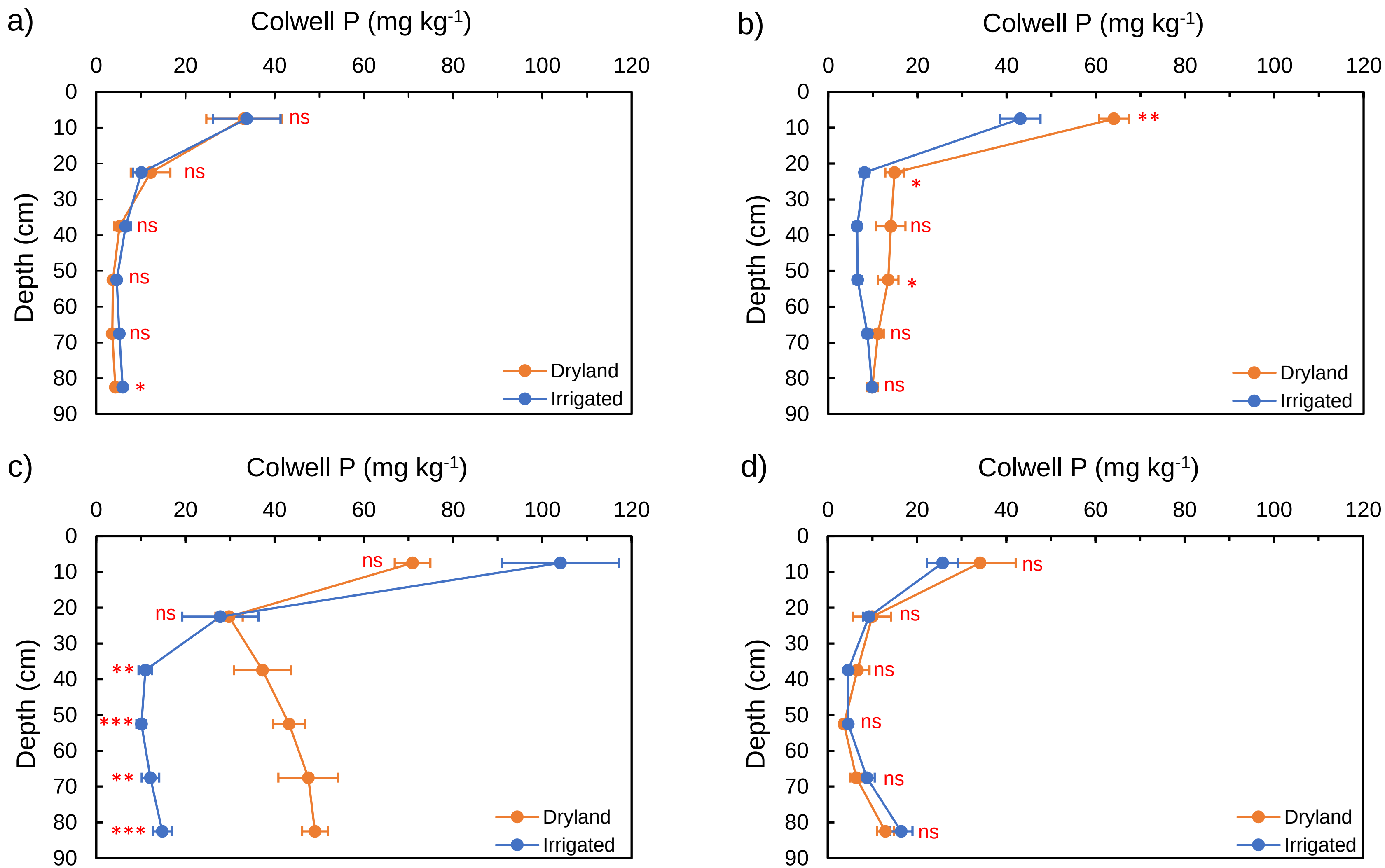

Figure 9 *- Colwell P (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Potassium (K)

Potassium, like phosphorus is immobile in soil, thus is typically naturally stratified (Singh *et al.*, 2014). K also plays an essential role in crop production (Xiao and Yin, 2019). The low mobility of K means nutrient stratification often results.

For all locations, soil types and land uses, K concentration was highest in topsoil. This is likely due to the low mobility of K in soil as well as the continual plant residue breakdown in topsoil, allowing for constant topsoil replenishment of K. K is often present in plant stems, leaves and roots (CRDC, 2018) rather than the harvested crop. This allows for continual K cycling in soil, accounting for a high topsoil concentration of K.

The critical soil concentration of K in soil for cotton production is 0.3 $cmol_c$ kg^{-1} in top 10cm of soil, and 0.2 $cmol_c$ kg^{-1} at 10-30 cm (CRDC, 2018). For all samples, locations and land uses, these critical topsoil values were met and often exceeded showing there was sufficient K supply in soil.

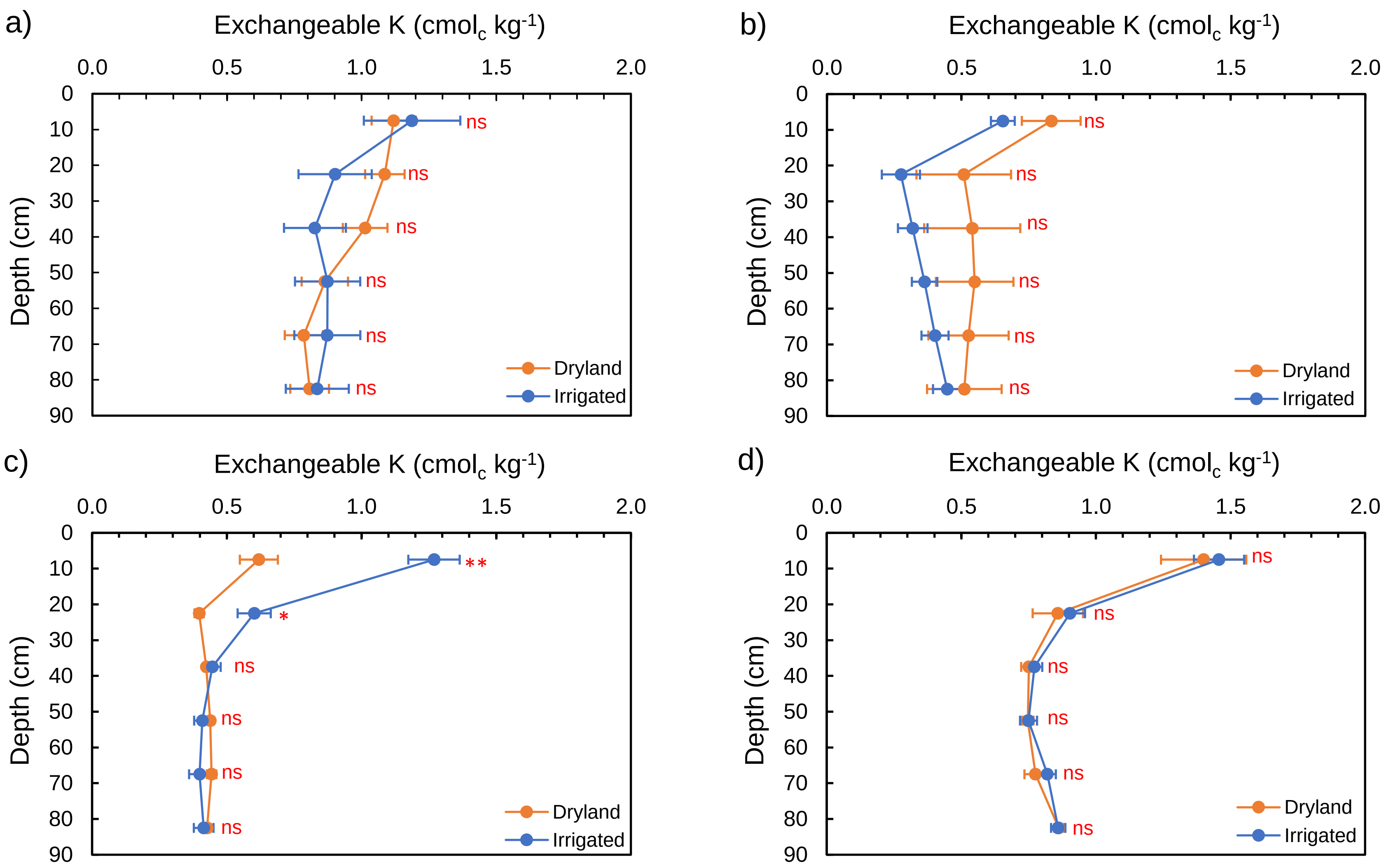

Figure 10 *– Exchangeable K (cmol$_c$ kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Sulfur (S)

The sulfur content of soil (Figure 11), in most cases increased through the soil depth. The only exception was the dryland samples from Narromine (b and c) where S was highest in topsoil, then declined. S was also found to be present in a significantly higher concentration in some portions of the irrigated soil samples in comparison to the dryland systems. This is likely due to increased water availability resulting in S leaching through the soil depth. For location (c) the apparent increase in S in the irrigated sample suggests differing soil makeup in comparison to the other samples, suggesting gypsum presence in the irrigated soils accounting for the increase in S. The higher concentration of S in this sample will be a contributing factor for the higher EC value of this sample observed previously (Figure 4).

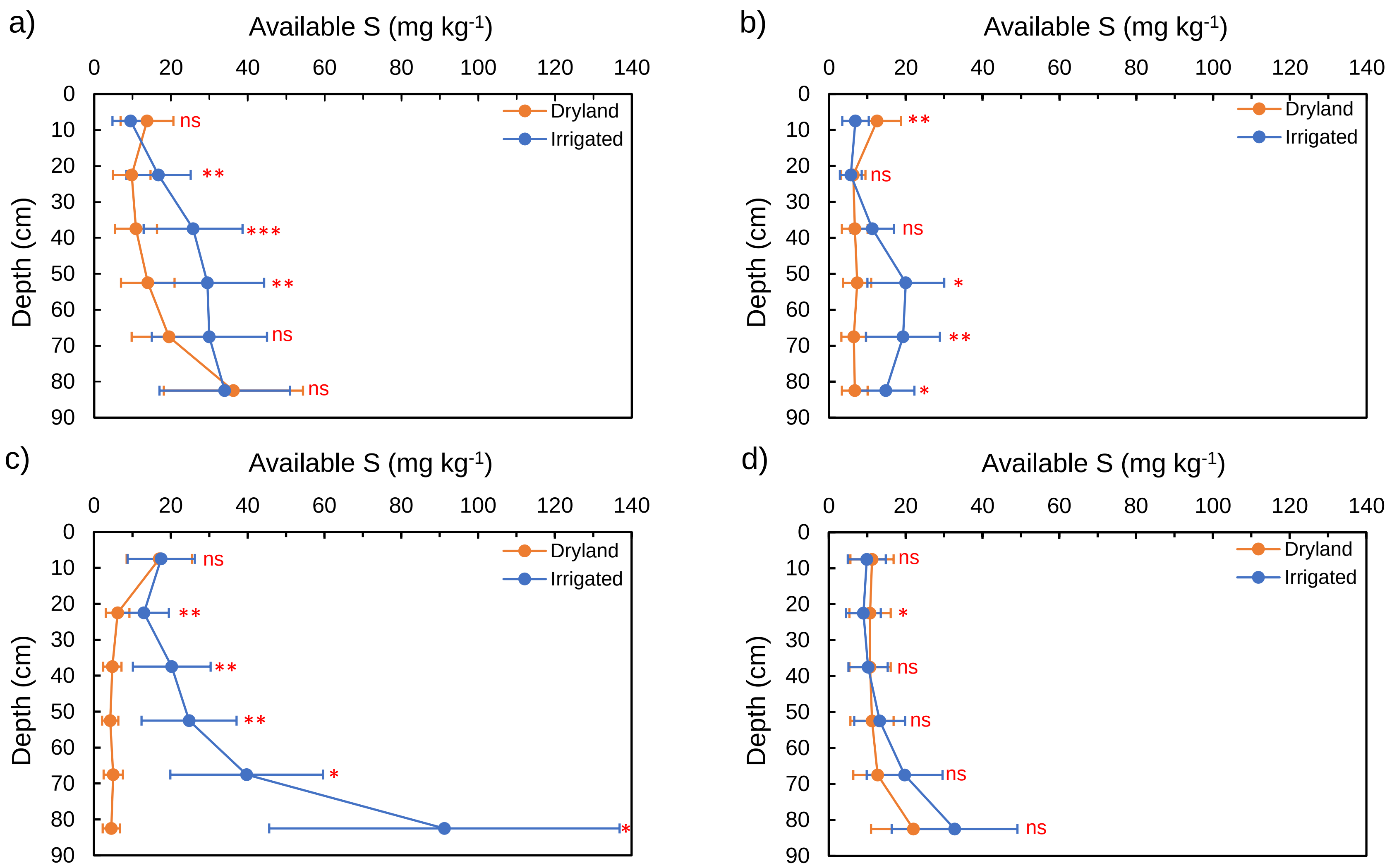

Figure 11 *– Available S (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

CEC, calcium and magnesium

As soil texture was not analysed, the CEC value typically provides a surrogate measure of soil clay content—provided clay mineral type is consistent in the soil. Calcium and magnesium are major contributors to soils CEC (Rayment and Lyons, 2011), thus these graphs (Figure 13 and 14) follow similar trends to the CEC graph (Figure 12). This was confirmed in the correlation matrix where calcium and magnesium are seen to have a strong positive correlation with CEC (Appendix A).

In most instances, dryland and irrigated CEC, Ca and Mg were fairly similar, with no clear significant difference between production systems. The most notable difference is seen in the sample from location (c). This again suggests a potential difference in the soil type between the dryland and irrigated site, possibly due to a difference in pre-cultivation landscape features or parent material.

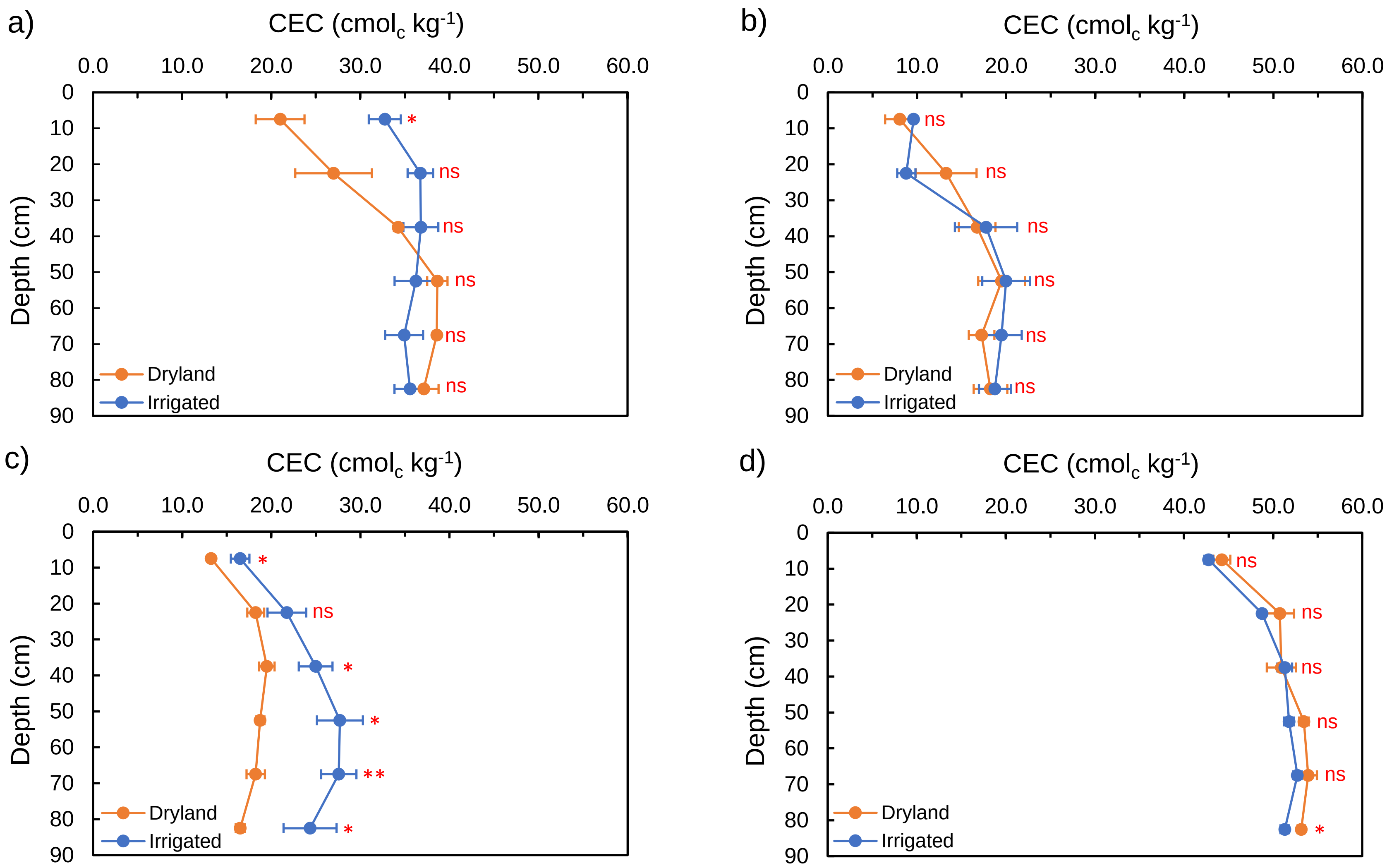

***Figure 12** – CEC (cmol$_c$ kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

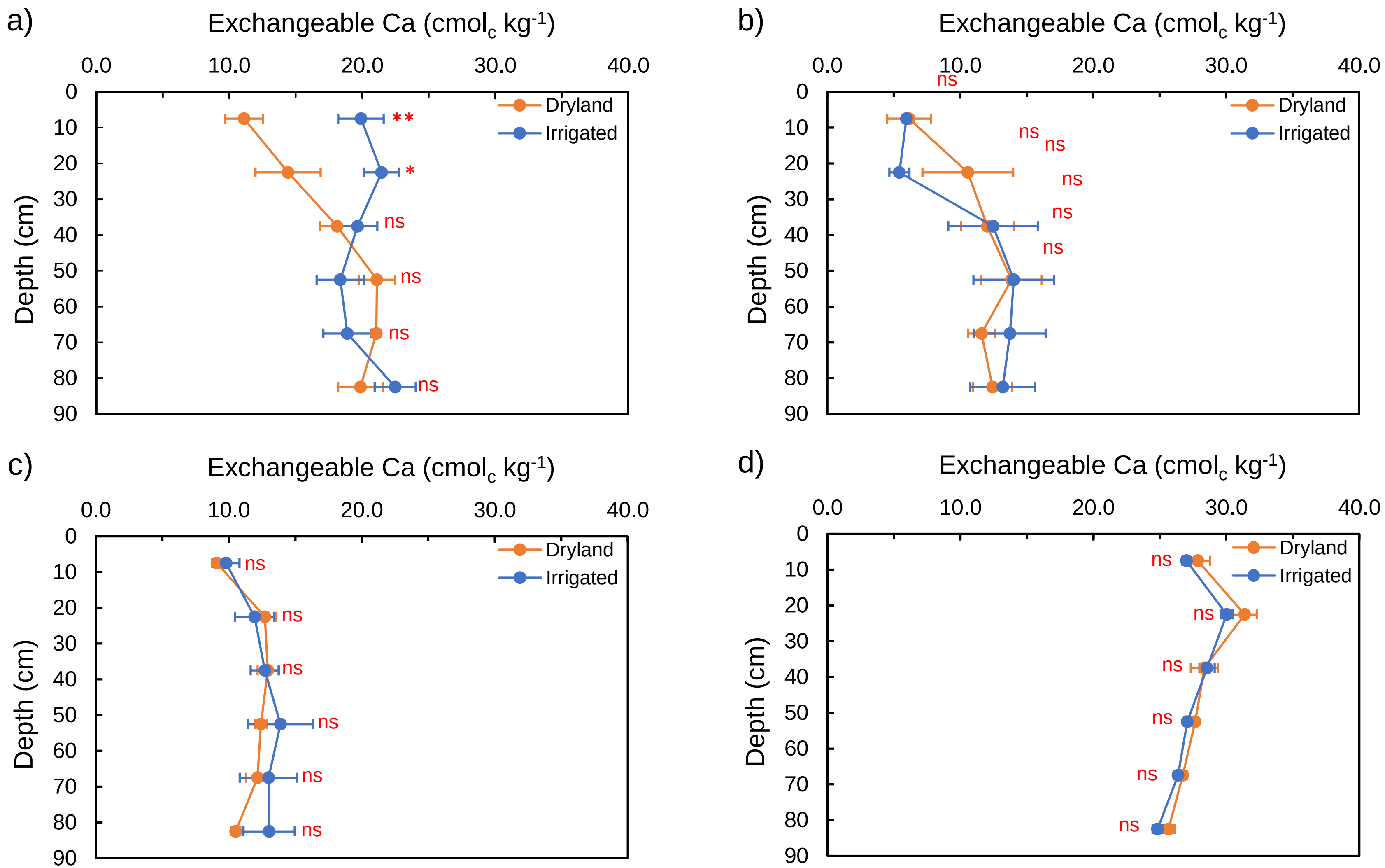

Figure 13 *- Exchangeable Ca (cmol$_c$ kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

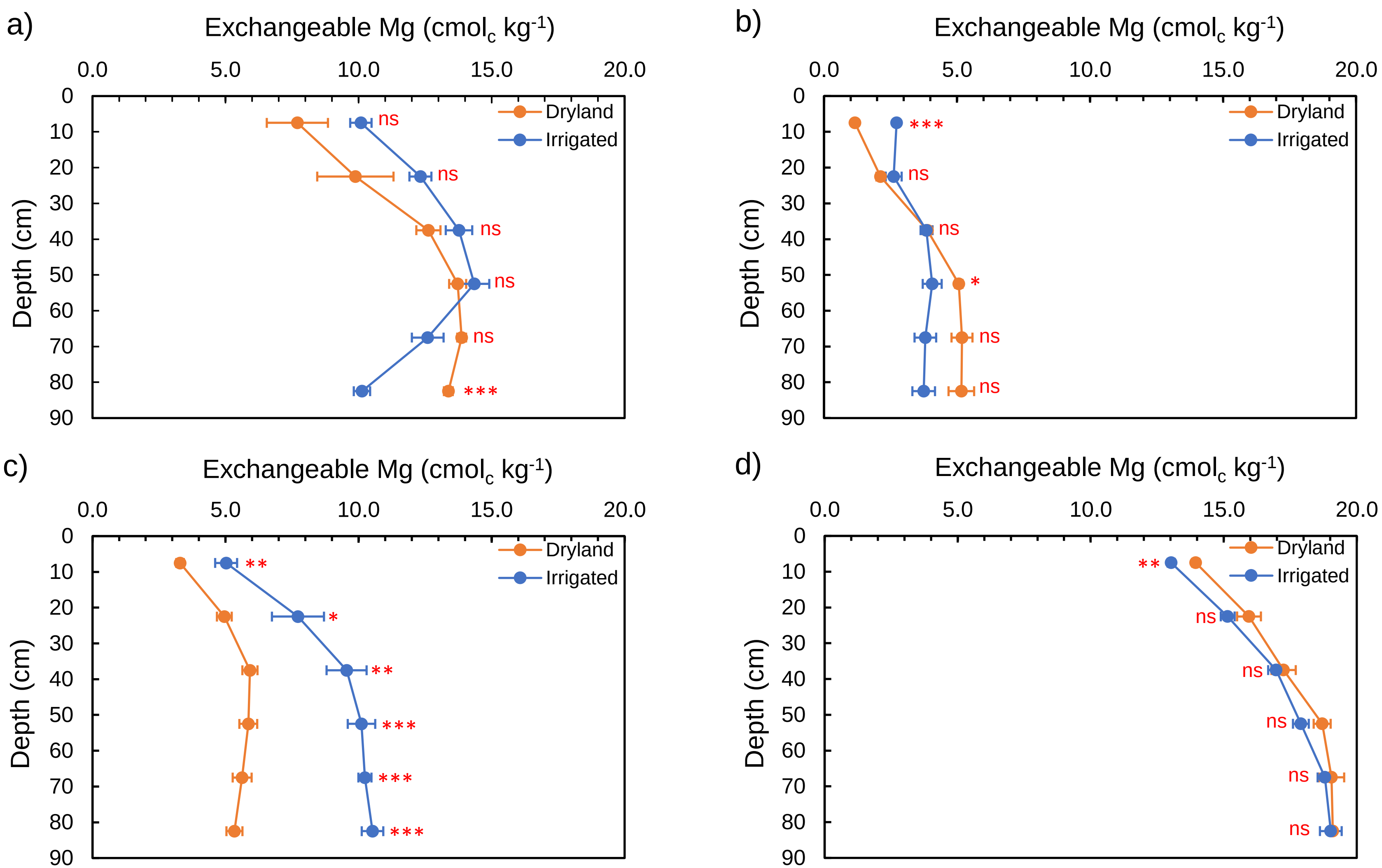

Figure 14 *- Exchangeable Mg (cmol$_c$ kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Available Micronutrients (Fe, Mn, Cu, Zn)

There is a strong relationship between soil pH and plant micronutrient availability whereby as pH increases, micronutrient availability declines. This has been found previously by Wright, *et al.*, (2007), was recently reaffirmed by Palmer *et al.*, (2021) and is supported in the correlation matrix which shows as pH increases, concentration of all micronutrients decreases (Appendix A). This can also be seen in the pH and micronutrient graphs (Figures 3, 15-18). The DTPA extractable method used to measure the availability of Fe, Cu, Mn and Zn measures plant available micronutrients rather than total concentration in soil (Rayment and Lyons, 2011). Whilst micronutrient elements may be present in high concentrations in soil, plants can still be deficient in these nutrients if they are not available in the correct forms. Therefore, the results presented show the concentration of nutrients available to crops and the influence that pH has on this availability.

Iron (Fe)

At sample locations (a), (b), and (d) Fe (Figure 15) content was found to be significantly higher in dryland topsoil samples than the corresponding irrigated system. This may suggest increased nutrient uptake in irrigated systems. This is likely also due to lower pH of the dryland samples as plant availability of Fe sharply declines at pH >7 (CRDC, 2018). Despite this difference, all topsoil samples were found to contain well above the critical Fe value of 2 mg kg^{-1} (CRDC, 2018), meaning despite higher pH of irrigated soil, a future cotton crop will not be Fe deficient.

Manganese (Mn)

The concentration of Mn in soil decreased through the soil depth as pH increased (Figure 16). At locations (a), (b), and (c), the concentration of plant available Mn in dryland soils was greater than or equal to Mn concentration in irrigated soils. This may be due to lower water availability in the dryland system resulting in reduced nutrient uptake or higher pH of irrigated systems reducing available Mn (Wright *et al.*, 2007).

The critical value of plant available Mn in topsoil for cotton crops is 2 mg kg^{-1} (CRDC, 2018). For all systems, Mn concentration was greater than this critical value.

Copper (Cu)

At locations (a), (b), and (c), plant available Cu (Figure 17) was present in equal or higher concentration in dryland soils. The most significant contributing factor to this is soil pH, as outlined previously.

The critical value of plant available Cu in topsoil for cotton crops is 0.3 mg kg^{-1} (CRDC, 2018). For all locations and land uses, topsoil Cu concentration was well above this critical value.

Zinc (Zn)

Zinc (Figure 18) concentration was significantly higher in irrigated topsoil samples at locations (b) and (c), than dryland samples. This high concentration is believed to be due to fertiliser application. At locations (c) and (d) Zn samples had either a higher or equal concentration of Zn in soils in comparison to dryland samples. Aside from the topsoil sample at location (b), no significant difference in Zn concentration between land uses was found at locations (a) or (b).

The critical value of plant available Zn for cotton crops in topsoil is 0.5 mg kg^{-1} (CRDC, 2018). For all locations and land uses, this critical value was met, although, unlike other previously mentioned micronutrients, the dryland topsoil concentration of Zn was quite close to the critical value. Thus, plant available Zn is more likely to become an issue for producers in the near future.

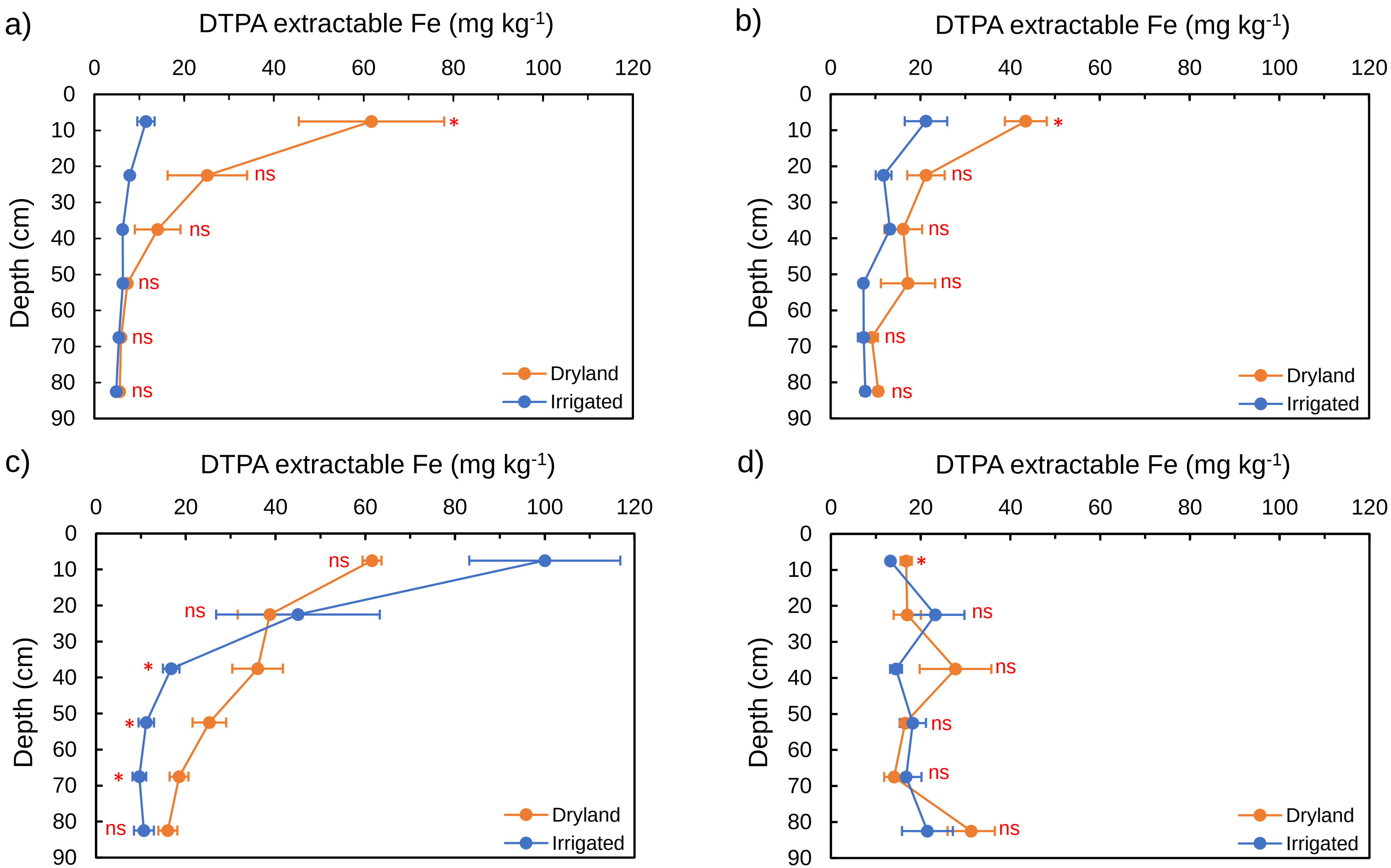

Figure 15 *– DTPA extractable Fe (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

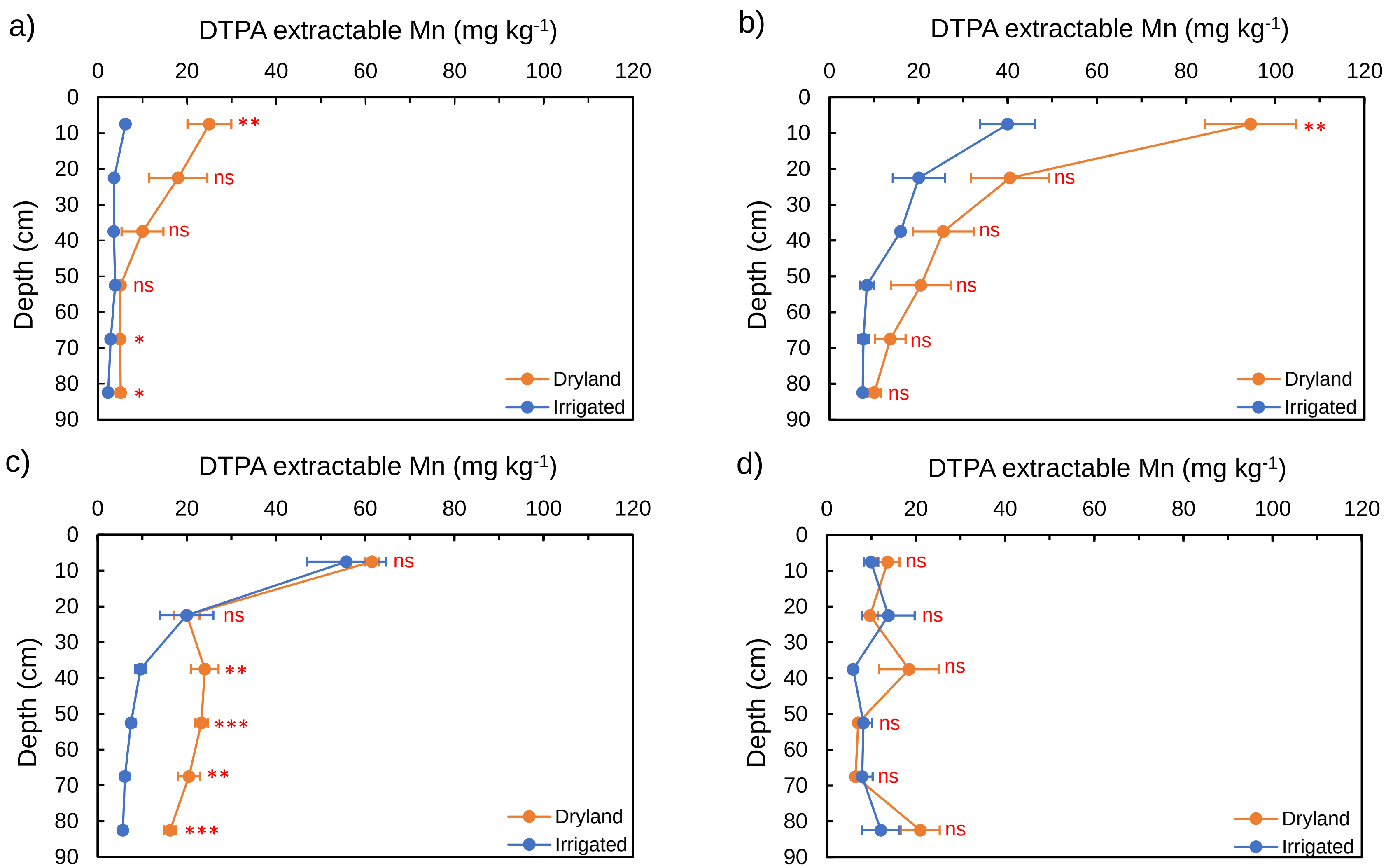

***Figure 16** – DTPA extractable Mn (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

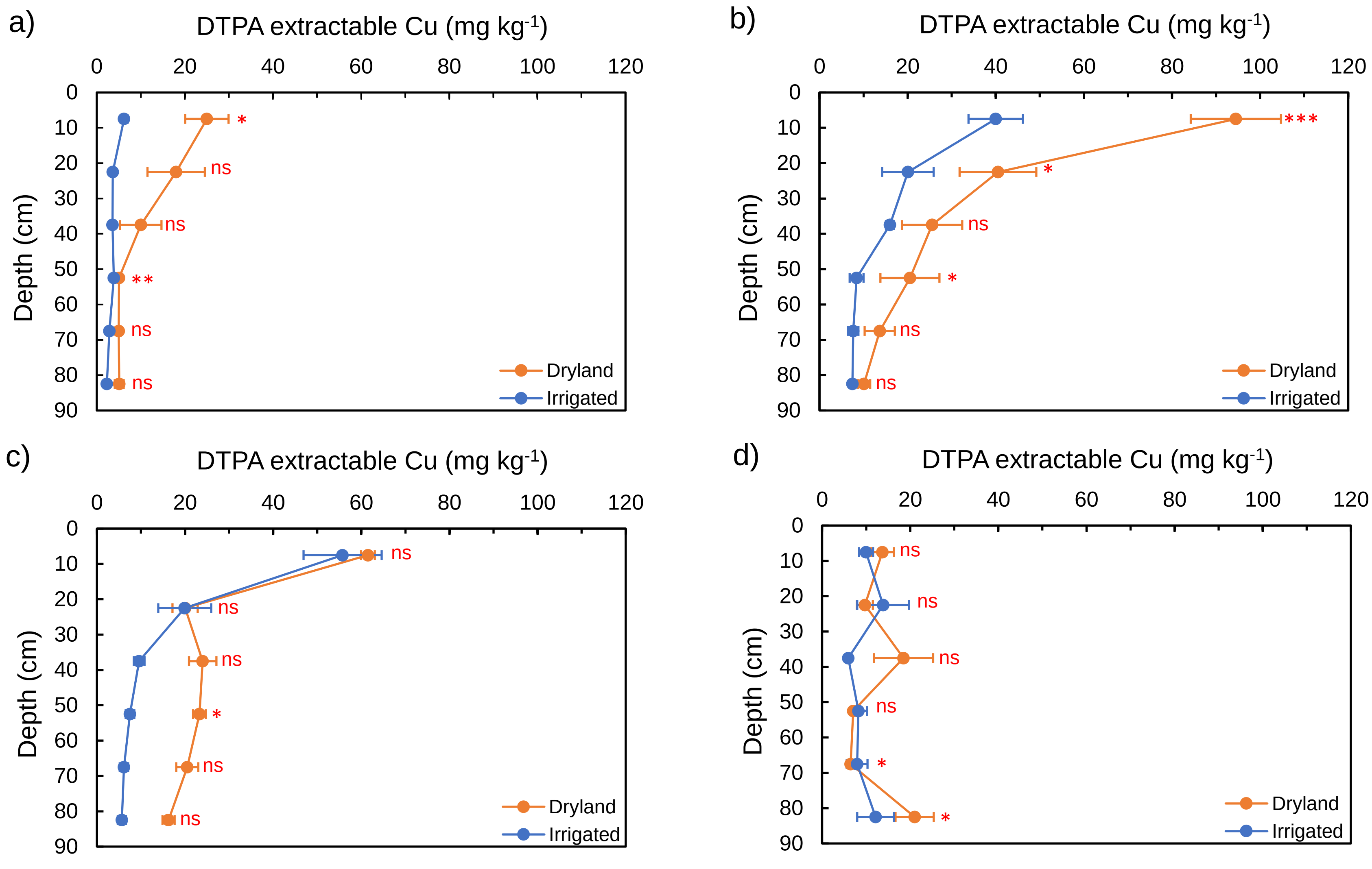

***Figure 17** – DTPA extractable Cu (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

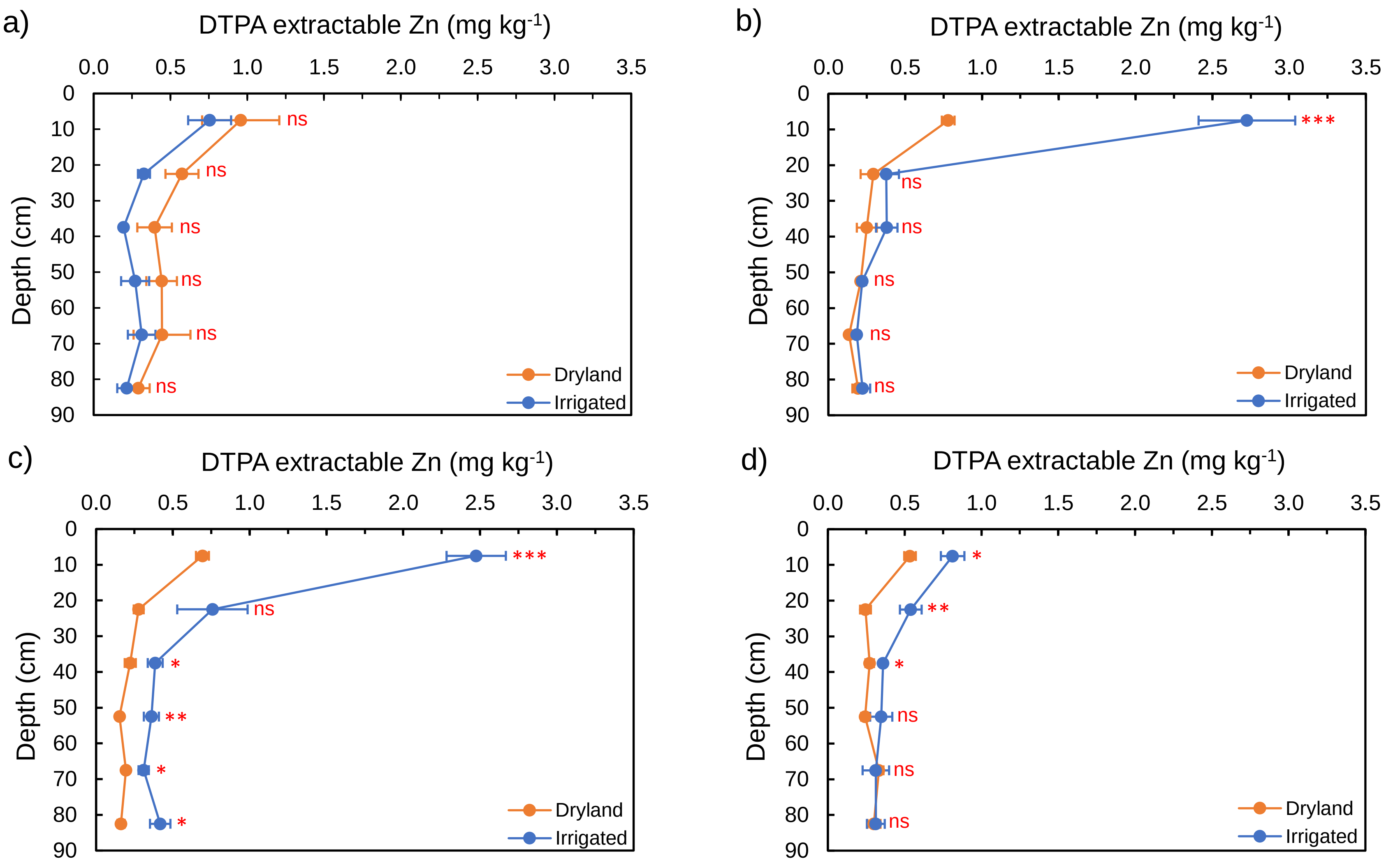

***Figure 18** – DTPA extractable Zn (mg kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Recommendations

Given Covid-19 restrictions, it was not possible to measure X-Ray Fluorescence (XRF) micronutrients or soil texture in this investigation meaning there are some limitations in the conclusions that can be drawn. The addition of XRF micronutrient data would have provided total micronutrient concentrations in soil, which would have been useful to compare with DTPA available micronutrient data obtained. Texture data would have provided indication of soil types – a result that would have been of particular use given findings from location (c). It has been noted previously that the differences between dryland and irrigated results from this location, as well as in comparison to the other data suggest this may not have been a true paired site. There is potential that each site may be a different type of soil.

In this investigation, irrigation water type was not investigated. Given the findings, and speculation that has resulted, this would be another useful factor for inclusion if further investigation were to occur.

Conclusions

There were some differences found between irrigated and dryland production systems across cotton producing regions in NSW.

- The pH of irrigated systems was found to be greater than or equal to dryland systems. The higher pH in irrigated systems may be due to poor quality irrigation water.
- EC and ESP (%) of irrigated systems was found to be greater than, or equal to dryland systems, particularly for samples at locations (b) and (c). This is speculated to be due to poor quality irrigation water with a higher concentration of dissolved salts which have accumulated in soil over time. Over time, this may lead to soil salinity or sodicity issues, impacting future crop production.
- P and K were stratified in topsoil in both irrigated and dryland systems, found in highest concentration in topsoil (0-15 cm) samples. Despite greater water presence in irrigated systems, these nutrients remained immobile in soil. Therefore, little difference was seen between production systems.
- Plant micronutrient (Fe, Mn, Cu, Zn) availability declined through the soil depth. The micronutrient availability in irrigated systems in most instances was less than, or equal to dryland systems. This is likely due to higher pH at depth (Palmer *et al.,* 2021) which reduces micronutrient availability.

Overall, there were some differences noted in soil property and nutrient concentrations in irrigated and dryland production systems. The measurement of each of the soil properties to a depth of 90 cm allowed for a greater understanding on the impact of irrigated and dryland production at depth, which few studies have recorded for such a large range of soil properties.

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I would also like to thank Jonathon Moore and Graeme Schwenke who collected soil cores from Darlington Point and Narromine respectively, and Patrick Filippi and Mikaela Tilse who led and assisted with the soil core collection at Narrabri.

I would also like to thank the farmers who allowed soil cores to be collected from their properties. Finally, I would like to thank my supervisors Balwant Singh, Partick Filippi and Graeme Schwenke for their support, assistance, and advice throughout this project.

References

Cattle, S.R., Field, D.J., 2013. A review of the soil science research legacy of the triumvirate of cotton CRC. Crop Pasture Sci. 64, 1076-1094. https://doi.org/10.1071/CP13223.

Corwin, D.L., Yemoto, K., 2020. Salinity: Electrical conductivity and total dissolved solids. Soil Sci. Soc. Am. J. 84, 1442-1461. https://doi.org/10.1002/saj2.20154.

CottonInfo, 2015. Water & Soil Quality: Australian Cotton Industry BMP. https://www.cottoninfo.com.au/sites/default/files/documents/Water%20and%20Soil%20Quality_3.pdf (accessed 23 October 2021).

Cotton Research and Development Corporation (CRDC), 2021. Nutripak: A practical guide to cotton nutrition https://www.cottoninfo.com.au/sites/default/files/documents/NUTRIpak%202018.pdf. (accessed 23 October 2021)

Cotton Research and Development Corporation (CRDC), 2021. Australian Cotton Production Manual 2021. https://www.cottoninfo.com.au/sites/default/files/documents/ACPM%202021.pdf (accessed 24 October 2021).

Department of Environment and Resource Management., 2019. Salinity management handbook, Second ed. Department of Environment and Resource Management, Brisbane.

Entry, J.A., Sojka, R.E., Shewmaker, G.E., 2002. Management of Irrigated Agriculture to increase organic carbon storage in soils. Soil Sci. Soc. Am. J. 66, 1957-1964. https://doi.org/10.2136/sssaj2002.1957.

Filippi, P., Cattle, S.R., Bishop, T.F.A., Odeh, I.O.A., Pringle, M.J., 2018a. Digital soil monitoring of top- and sub-soil pH with bivariate linear mixed models. Geoderma. 322, 149-162. https://doi.org/10.1016/j.geoderma.2018.02.033.

Filippi, P., Cattle, S.R., Bishop, T.F.A., Pringle, M.J., Jones, E.J., 2018b. Monitoring changes in soil salinity and sodicity to depth, at a decadal scale, in a semiarid irrigated region of Australia. Soil Res. 56, 696-711. https://doi.org/10.1071/SR18083.

Filippi, P., Cattle, S.R., Pringle, M.J., Bishop, T.F.A., 2020a. A two-step modelling approach to map the occurrence and quantity of soil inorganic carbon. Geoderma. 371, 114382. https://doi.org/10.1016/j.geoderma.2020.114382.

Filippi, P., Cattle, S.R., Pringle, M.J., Bishop, T.F.A., 2021. Space-time monitoring of soil organic carbon content across a semi-arid region of Australia. Geoderma Reg. 24, e00367. https://doi.org/10.1016/j.geodrs.2021.e00367.

Filippi, P., Jones, E.J., Bishop, T.F.A., 2020b. Catchment-scale 3D mapping of depth to soil sodicity constraints through combining public and on-farm soil databases – A potential tool for on-farm management. Geoderma 374, 114396. https://doi.org/10.1016/j.geoderma.2020.114396.

Filippi, P., Jones, E.J., Ginns, B.J., Whelan, B.M., Roth, G.W., Bishop, T.F.A., 2019. Mapping the depth-to-soil pH constraint, and the relationship with cotton and grain yield at the within-field scale. Agronomy. 9, 251. https://doi.org/10.3390/agronomy9050251.

Hulugalle, N.R., Strong, C., McPherson, K., Nachimuthu, G., 2017. Carbon, nitrogen and phosphorus stoichiometric ratios under cotton cropping systems in Australian Vertisols: a meta-analysis of seven experiments. Nutr. Cycling in Agroecosyst. 107, 357-367. https://doi.org/10.1007/s10705-017-9837-y.

Kurtzman, D., Baram, S., Dahan, O., 2016. Soil–aquifer phenomena affecting groundwater under Vertisols: a review. Hydrol. Earth Syst. Sci. 20, 1-12. https://doi.org/10.5194/hess-20-1-2016.

López-Garrido, R., Madejón, E., Murillo, J.M., Moreno, F., 2011. Short and long-term distribution with depth of soil organic carbon and nutrients under traditional and conservation tillage in a Mediterranean environment (southwest Spain). Soil Use Manag. 27, 177-185. https://doi.org/10.1111/j.1475-2743.2011.00329.x.

Macdonald, B.C.T., Latimer, J.O., Schwenke, G.D., Nachimuthu, G., Baird, J.C., 2018. The current status of nitrogen fertiliser use efficiency and future research directions for the Australian cotton industry. J. Cotton Res. 1, 15. https://doi.org/10.1186/s42397-018-0015-9.

McLeod, M.K., Schwenke, G.D., Cowie, A.L., Harden, S., 2013. Soil carbon is only higher in the surface soil under minimum tillage in Vertosols and Chromosols of New South Wales North-West slopes and plains, Australia. Soil Res. 51 (8), 680-694. https://doi.org/10.1071/SR13032.

Mudge, P.L., Millar, J., Pronger, J., Roulston, A., Penny, V., Fraser, S., Eger, A., Caspari, T., Robertson, B., Mason, N.W.H., Schipper, L.A., 2021. Impacts of irrigation on soil C and N stocks in grazed grasslands depends on aridity and irrigation duration. Geoderma. 399, 115109. https://doi.org/10.1016/j.geoderma.2021.115109.

Nachimuthu, G., Hulugalle, N.R., Watkins, M.D., Finlay, L.A., McCorkell, B., 2018. Irrigation induced surface carbon flow in a Vertisol under furrow irrigated cotton cropping systems. Soil Tillage Res. 183, 8-18. https://doi.org/10.1016/j.still.2018.05.011.

Nachimuthu, G., Watkins, M.D., Hulugalle, N.R., Weaver, T.B., Finlay, L.A., McCorkell, B.E., 2019. Leaching of dissolved organic carbon and nitrogen under cotton farming systems in a Vertisol. Soil Use Manag. 35, 443-452. https://doi.org/10.1111/sum.12510.

Palmer, B., Guppy, C., Nachimuthu, G., 2021. Effects of soil management on micronutrient stratification and decline in irrigated Vertosols. Poster presented at: Soil Science Australia and the New Zealand Society of Soil Science Joint Conference, Cairns. (27 June–2 July 2021).

Peverill, K.I., Sparrow, L.A., Reuter, D.J., 1999. Soil Analysis: An Interpretation Manual. CSIRO Publishing, Victoria, Australia.

Rayment, G.E., Lyons, D.J., Shelley, B., 2011. Soil Chemical Methods - Australasia. CSIRO Publishing, Victoria, Australia.

Rendon, D., Whitehouse, M.E.A., Taylor, P.W., 2016. Consumptive and non-consumptive effects of wolf spiders on cotton bollworms. Entomol. Exp. Appl. 158, 170-183. https://doi.org/10.1111/eea.12390.

Rochester, I.J., 2007. Nutrient uptake and export from an Australian cotton field. Nutr. Cycling Agroecosyst. 77, 213-223. https://doi.org/10.1007/s10705-006-9058-2.

Rossiter, L., Murray, D., Miles, M., Downes, S., Wilson, L., Kauter, G., 2007. Better Pupae Busting Decisions in Sprayed Conventional Cotton, in: Dowling, D., (Eds.), The Australian Cotton Grower., Toowoomba, pp.21-22.

Roth, G., Harris, G., Gillies, M., Montgomery, J., Wigginton, D., 2013. Water-use efficiency and productivity trends in Australian irrigated cotton: a review. Crop Pasture Sci. 64, 1033-1048. https://doi.org/10.1071/CP13315.

Singh, B., Cattle, S.R., Field, D. J., 2014. Introduction to Edaphic Soil Science, in: Van Alfed, N. K., (Eds.), Encyclopaedia of Agriculture and Food Systems. Elsevier Science & Technology., Amsterdam, pp.35-58. https:///doi:10.1016/B978-0-444-52512-3.00092-9.

Soil Science Australia, 2013. Measuring Soil Cation Exchange Capacity & Exchangeable Cations. https://www.soilscienceaustralia.org.au/wp-content/uploads/2021/02/Measuring-Soil-Cation-Exchange-Capacity-Exchangeable-Cations.pdf (accessed 6 November 2021).

Wright, A.L., Hons, F.M., Lemon, R.G., McFarland, M.L., Nichols, R.L., 2007. Stratification of nutrients in soil for different tillage regimes and cotton rotations. Soil Tillage Res. 96, 19-27. https://doi.org/10.1016/j.still.2007.02.005.

Xiao, J., Yin, X., 2019. Nutrient Management in Cotton, in: Jabran, K., and Chauhan, B.S., (Eds.), Cotton Production. John Wiley & Sons, New York, pp. 61-83. https://doi.org/10.1002/9781119385523.ch4.

Zibilske, L.M., Bradford, J.M., Smart, J.R., 2002. Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil Tillage Res. 66, 153-163. https://doi.org/10.1016/S0167-1987(02)00023-5.

Appendix A – Correlation Matrix

Table 1 *- Correlation Matrix (created including all soil types, production systems and depths.)*

	pH	**EC**	**Soil Organic Carbon**	**Nitrate N**	**Ammonium Nitrogen**	**Colwell Phosphorus**	**Sulfur**	**Exch-Calcium**	**Exch-Magnesium**	**Exch-Potassium**	**Exch-Sodium**	**CEC**	**ESP**	**DTPA-Iron**	**DTPA-Manganese**	**DTPA-Copper**	**DTPA-Zinc**
pH	1																
EC	0.65	1															
Soil Organic Carbon	-0.26	-0.12	1														
Nitrate N	-0.1	0.26	0.61	1													
Ammonium Nitrogen	-0.37	-0.19	0.65	0.54	1												
Colwell Phosphorus	-0.62	-0.34	0.66	0.51	0.74	1											
Sulfur	0.27	0.64	-0.19	0.2	-0.13	-0.12	1										
Exch-Calcium	0.65	0.55	0.08	0.02	-0.15	-0.43	0	1									
Exch-Magnesium	0.78	0.71	0.04	0.11	-0.18	-0.45	0.19	0.84	1								
Exch-Potassium	0.01	0.23	0.53	0.3	0.22	0.19	-0.04	0.47	0.42	1							
Exch-Sodium	0.82	0.81	-0.07	0.19	-0.16	-0.45	0.33	0.63	0.86	0.14	1						
CEC	0.75	0.68	0.06	0.09	-0.17	-0.46	0.12	0.95	0.96	0.46	0.81	1					
ESP	0.73	0.7	-0.18	0.13	-0.23	-0.45	0.51	0.29	0.59	-0.06	0.85	0.49	1				
DTPA-Iron	-0.46	-0.23	0.72	0.5	0.66	0.74	-0.13	-0.29	-0.23	0.17	-0.2	-0.26	-0.23	1			
DTPA-Manganese	-0.6	-0.34	0.48	0.49	0.69	0.71	-0.18	-0.49	-0.49	-0.02	-0.39	-0.5	-0.4	0.69	1		
DTPA-Copper	-0.28	-0.25	0.56	0.33	0.49	0.56	-0.14	-0.19	-0.12	0.04	-0.11	-0.16	-0.13	0.72	0.42	1	
DTPA-Zinc	-0.29	-0.11	0.55	0.34	0.35	0.49	-0.04	-0.23	-0.16	0.32	-0.15	-0.19	-0.09	0.5	0.41	0.19	1

Appendix B - Additional Graph

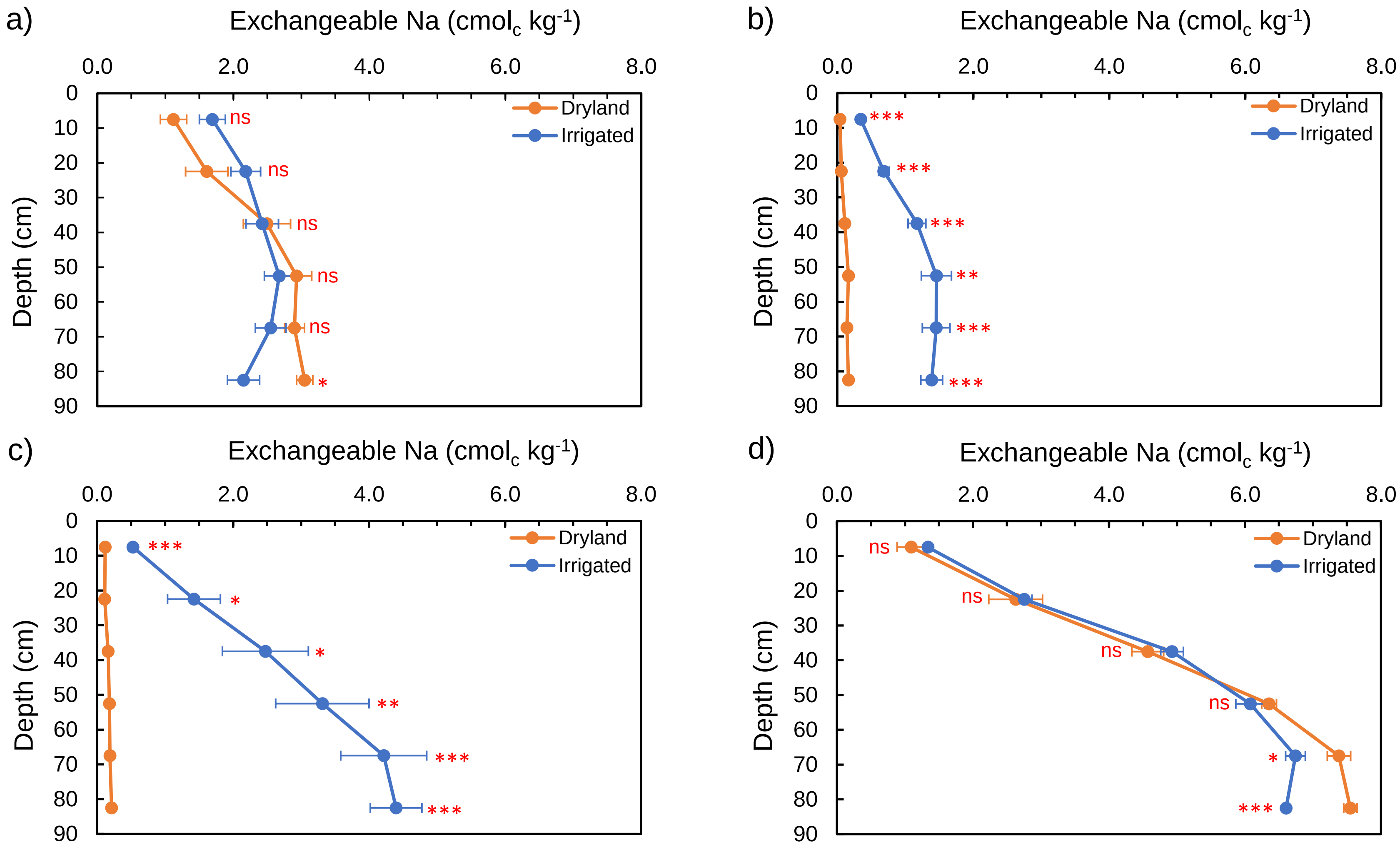

Figure 1 *- Exchangeable Na (cmol$_c$ kg^{-1}) of samples to a depth of 90cm. a) Darlington Point, b) Narromine 'Central Farm', c) Narromine 'Browning Family Farm, d) Narrabri. * P < 0.05, ** P < 0.01, *** P < 0.001, ns P > 0.05*

Appendix C – p-values between irrigated and dryland land uses

Darlington Point

Table 1 *- Darlington point p-values between irrigated and dryland land uses*

	Soil Property																
Depth (cm)	pH	EC	SOC	Nitrate	Ammonium	P	S	Ca	Mg	K	Na	CEC	ESP	Fe	Mn	Cu	Zn
0-15	0.00	0.00	0.30	0.71	0.02	0.96	0.09	0.01	0.10	0.74	0.08	0.01	0.87	0.02	0.01	0.03	0.51
15-30	0.00	0.02	0.06	0.30	0.18	0.69	0.01	0.05	0.15	0.28	0.18	0.08	0.88	0.10	0.07	0.18	0.07
30-45	0.20	0.01	0.00	0.15	0.00	0.45	0.00	0.46	0.14	0.24	0.87	0.25	0.61	0.18	0.22	0.15	0.13
45-60	0.84	0.14	0.00	0.04	0.02	0.19	0.01	0.27	0.37	0.95	0.44	0.39	0.75	0.32	0.09	0.01	0.25
60-75	0.66	0.47	0.00	0.00	0.68	0.08	0.15	0.22	0.08	0.56	0.24	0.14	0.75	0.54	0.02	0.55	0.54
75-90	0.61	0.36	0.02	0.01	0.09	0.01	0.87	0.30	0.00	0.84	0.01	0.54	0.00	0.25	0.03	0.34	0.47

*Green = * P < 0.05, blue = ** P < 0.01, yellow = *** P < 0.001, white = ns P > 0.05, (to 2 d.p.)*
EC = Electrical conductivity, SOC = Soil organic carbon, Nitrate = Nitrate N, Ammonium = Ammonium nitrogen P = Colwell phosphorus, S = Available Sulfur, Ca = Calcium, Mg = Exchangeable magnesium, K = Exchangeable potassium, Na = Exchangeable sodium, Fe = DTPA Iron, Mn = DTPA Manganese, Cu = DTPA Copper, Zn = DTPA Zinc

Narromine 'Central Farm'

Table 2 *- Narromine 'Central Farm' p-values between irrigated and dryland land uses*

	Soil Property																
Depth (cm)	pH	EC	SOC	Nitrate	Ammonium	P	S	Ca	Mg	K	Na	CEC	ESP	Fe	Mn	Cu	Zn
0-15	0.01	0.38	0.97	0.08	0.01	0.01	0.01	0.91	0.00	0.18	0.00	0.39	0.00	0.02	0.01	0.00	0.00
15-30	0.78	0.94	0.49	0.24	0.38	0.03	0.66	0.19	0.19	0.26	0.00	0.26	0.00	0.08	0.10	0.02	0.49
30-45	0.00	0.07	1.00	0.15	0.73	0.07	0.08	0.92	0.91	0.28	0.00	0.81	0.01	0.52	0.22	0.23	0.22
45-60	0.04	0.01	0.39	0.30	0.51	0.03	0.01	0.97	0.04	0.27	0.00	0.90	0.01	0.15	0.13	0.01	0.77
60-75	0.09	0.00	0.50	0.67	0.45	0.20	0.01	0.48	0.05	0.46	0.00	0.43	0.01	0.40	0.15	0.05	0.10
75-90	0.10	0.00	0.71	0.20	0.73	0.96	0.02	0.80	0.07	0.68	0.00	0.85	0.00	0.06	0.14	0.45	0.64

*Green = * P < 0.05, blue = ** P < 0.01, yellow = *** P < 0.001, white = ns P > 0.05, (to 2 d.p.)*
EC = Electrical conductivity, SOC = Soil organic carbon, Nitrate = Nitrate N, Ammonium = Ammonium nitrogen P = Colwell phosphorus, S = Available Sulfur, Ca = Calcium, Mg = Exchangeable magnesium, K = Exchangeable potassium, Na = Exchangeable sodium, Fe = DTPA Iron, Mn = DTPA Manganese, Cu = DTPA Copper, Zn = DTPA Zinc

Narromine 'Browning Family Farm'

Table 3 *- Narromine 'Browning Family Farm' p-values between irrigated and dryland land uses*

	Soil Property																
Depth (cm)	pH	EC	SOC	Nitrate	Ammonium	P	S	Ca	Mg	K	Na	CEC	ESP	Fe	Mn	Cu	Zn
0-15	0.71	0.06	0.00	0.67	0.20	0.05	0.91	0.54	0.01	0.00	0.00	0.02	0.00	0.64	0.55	0.37	0.00
15-30	0.10	0.00	0.24	0.04	0.82	0.84	0.00	0.67	0.03	0.02	0.01	0.19	0.01	0.76	0.99	0.43	0.08
30-45	0.00	0.02	0.40	0.01	0.01	0.01	0.00	0.87	0.00	0.51	0.01	0.04	0.01	0.02	0.00	0.06	0.03
45-60	0.00	0.00	0.30	0.01	0.01	0.00	0.00	0.58	0.00	0.42	0.00	0.01	0.01	0.01	0.00	0.01	0.01
60-75	0.00	0.00	0.08	0.01	0.01	0.00	0.02	0.74	0.00	0.34	0.00	0.01	0.00	0.01	0.00	0.06	0.01
75-90	0.03	0.01	0.24	0.03	0.00	0.00	0.04	0.25	0.00	0.75	0.00	0.04	0.00	0.13	0.00	0.32	0.01

*Green = * P < 0.05, blue = ** P < 0.01, yellow = *** P < 0.001, white = ns P > 0.05, (to 2 d.p.)*
EC = Electrical conductivity, SOC = Soil organic carbon, Nitrate = Nitrate N, Ammonium = Ammonium nitrogen P = Colwell phosphorus, S = Available Sulfur, Ca = Calcium, Mg = Exchangeable magnesium, K = Exchangeable potassium, Na = Exchangeable sodium, Fe = DTPA Iron, Mn = DTPA Manganese, Cu = DTPA Copper, Zn = DTPA Zinc

Narrabri

Table 7 *- Narrabri p-values between irrigated and dryland land uses*

	Soil Property																
Depth (cm)	pH	EC	SOC	Nitrate	Ammonium	P	S	Ca	Mg	K	Na	CEC	ESP	Fe	Mn	Cu	Zn
0-15	0.00	0.45	0.17	0.01	0.22	0.37	0.08	0.42	0.00	0.76	0.30	0.20	0.17	0.04	0.27	0.36	0.02
15-30	0.00	0.12	0.15	0.00	0.86	0.88	0.03	0.23	0.17	0.69	0.77	0.26	0.48	0.42	0.53	0.13	0.01
30-45	0.56	0.58	0.11	0.00	0.08	0.48	0.20	0.87	0.63	0.64	0.26	0.84	0.08	0.15	0.11	0.17	0.04
45-60	0.09	0.71	0.00	0.86	0.19	0.43	0.19	0.12	0.12	0.95	0.29	0.07	0.63	0.59	0.56	0.01	0.22
60-75	0.35	0.22	0.15	0.04	0.36	0.32	0.05	0.47	0.67	0.42	0.03	0.31	0.01	0.54	0.57	0.03	0.83
75-90	0.01	0.13	0.44	0.03	0.25	0.32	0.07	0.21	0.86	0.95	0.00	0.02	0.00	0.25	0.19	0.05	0.87

*Green = * P < 0.05, blue = ** P < 0.01, yellow = *** P < 0.001, white = ns P > 0.05, (to 2 d.p.)*
EC = Electrical conductivity, SOC = Soil organic carbon, Nitrate = Nitrate N, Ammonium = Ammonium nitrogen P = Colwell phosphorus, S = Available Sulfur, Ca = Calcium, Mg = Exchangeable magnesium, K = Exchangeable potassium, Na = Exchangeable sodium, Fe = DTPA Iron, Mn = DTPA Manganese, Cu = DTPA Copper, Zn = DTPA Zinc

Appendix D – Historical Information of Sample Locations

Table 1 *- Basic History and Information of Sample Sites*

	Murrumbidgee		**Central West - Central Farm**		**Central West - Browning Family Farms**		**Narrabri**	
Sample Numbers	1 to 24	25 to 48	49-72	73-96	97-120	121-144	145-168	169-192
Land use	Dryland	Irrigation	Dryland	Irrigation	Dryland	Irrigation	Dryland	Irrigation
Soil Type	Vertosol	Vertosol	Red Chromosol	Red Chromosol	Red Chromosol - Online says it may be in a 'Vertosol-dominated landform' but appeared a red Chromosol at ground level	Red Chromosol - Online says it may be in a 'Vertosol-dominated landform' but appeared a red Chromosol at ground level	Vertosol	Vertosol
Cotton Production History (From Sampler)	[redacted]			Have a 10-20 year history of cotton irrigation		Have a 10-20 year history of cotton irrigation	[redacted]	
History (from Farmers)	Never grown cotton, in Winter 2021 Dryland Canola has been planted	2019-2020 Summer: Fallow, 2020 Winter Wheat, 2020-2021 Summer: Fallow, 2021 Winter: Canola	This field has always been a dryland field. Cotton appears to be grown much less often (potentially never!)	It is possible this field has used irrigation since 1971, but this would have been infrequent until 1996 where a groundwater bore was put in. A cotton-wheat rotation has been used since. Cotton is grown almost every year in between winter wheat, and every now and then a fallow year.	Has never had cotton produced dryland	Begun the use of irrigation in 2010 - see below		
Fertiliser Application	In-crop urea applied after soil test was taken (therefore not applicable)	2020 - in-crop wheat production, had 350kg of Urea application	Summer crop program = MAP, Sulphate of Potash and Zinc sulphate. 300 units of N at start of season and water run urea for the rest of the season	Summer crop program = MAP, Sulphate of Potash and Zinc sulphate. 300 units of N at start of season and water run urea for the rest of the season	See (Table 6)	See (Table 5)		
Other (eg. Tillage, Irrigation water type)	2021 - Field disked to 20-30cm and then graded to be levelled out		Tillage is used as required (no particular schedule). Field of sampling was levelled out in 2018	Cotton fields are cultivated by a disk tiller and then reformed into 1m hills using a listing rig	Minimum till on dryland, sowing with tyne machine.	Full cultivation before each cotton season - deep ripped/ploughed. Irrigated with river water.		

Darlington Point

Table 1 *- History of crop production and fertiliser application at Darlington Point (Irrigated)*

Irrigated			
Year	**Season**	**Crop**	**Fertiliser Application**
2019/20	Summer	Fallow	-
2020	Winter	Wheat	350kg Urea
2020/21	Summer	Fallow	-
2021	Winter	Canola	Not Provided

Table 2 *- History of crop production history Darlington Point (Dryland)*

Dryland		
Year	**Season**	**Field Information**
2021	Summer	Field was disked to 20-30cm, then graded to level
2021	Winter	Canola Crop

Narromine 'Central Farm'

Table 3 *- History of crop production and fertiliser application at Central Farm (Irrigated)*

Irrigated			
Year	**Season**	**Crop**	**Fertiliser Application**
2017/18	Summer	Cotton	130-150 kg ha^{-1} MAP 30-250 kg ha^{-1} Sulphate of Potash 5 kg/ha Zinc Sulphate 50 units of anhydrous N at the start of season 250 units of N as urea throughout the rest of the season
2018/19	Summer & Winter	Fallow	-
2019/20	Summer	Cotton	130-150 kg ha^{-1} MAP 30-250 kg ha^{-1} Sulphate of Potash 5 kg ha^{-1} Zinc Sulphate 50 units of anhydrous N at the start of season 250 units of N as urea throughout the rest of the season
2020	Winter	Wheat	100 kg ha^{-1} Urea 60 kg ha^{-1} MAP

Table 4 *- History of crop production at Central Farm (Dryland)*

Dryland		
Year	**Season**	**Crop**
2017	Winter	Canola
2018	Summer & Winter	Fallow
2019	Summer & Winter	Fallow
2020	Lupins	Wheat

Narromine 'Browning Family Farm'

Table 5 *- History of crop production and fertiliser application at 'Browning Family Farms' (Irrigated)*

Irrigated		
Year	**Crop**	**Fertiliser Application**
2012	Cotton	600 kg ha^{-1} Urea 230 kg ha^{-1} Cotton Blend
2013	Cotton	600 kg ha^{-1} Urea 230 kg ha^{-1} Cotton Blend
2014	Wheat	100 kg Urea 75 kg MAP
2015	Canola	150 kg Urea 75 kg MAP
2016	Wheat	170 kg Urea 75 kg MAP
2017	Fallow	-
2018	Cotton	600 kg ha^{-1} Urea 230 kg ha^{-1} Cotton Blend
2019	Wheat	100 kg Urea 75 kg MAP
2020	Wheat	100 kg Urea
2021	Chickpeas	50 kg MAP

Table 6 *- History of crop production and fertiliser application at 'Browning Family Farms' (Dryland)*

Dryland		
Year	**Crop**	**Fertiliser Application**
2012	Wheat	100 kg Urea 75 kg MAP
2013	Wheat	100 kg Urea 75 kg MAP
2014	Canola	200 kg Urea 50 kg MAP
2015	Wheat	100 kg Urea 75 kg MAP
2016	Chickpeas	50 kg MAP
2017	Canola	200 kg Urea 50 kg MAP
2018	Wheat	100 kg Urea 75 kg MAP
2019	Fallow	-
2020	Canola	200 kg Urea 50 kg MAP
2021	Wheat	170 kg Urea 50 kg MAP

Appendix E - Sample Location Images

Darlington Point

Figure 1 *- Darlington Point irrigated field*

Figure 2 *- Darlington Point dryland field*

Narromine 'Central Farm'

Figure 3 *- Narromine 'Central Farm' irrigated field*

Figure 4 *- Narromine 'Central Farm' dryland field*

Narromine 'Browning Family Farm'

Figure 6 *- Narromine 'Browning Family Farm' irrigated field*

Figure 7 *- Narromine 'Browning Family Farm' dryland field*

Narrabri

Figure 8 *- Narrabri irrigated field*

Figure 9 *- Narrabri irrigated field*

Appendix F - Raw data collected from experimental work

***Table 1a** - Darlington Point Raw Data*

Sample Number	Land use	Depth (cm)	Core Number	pH	EC (µS cm^{-1})	Soil Organic Carbon (%)	Nitrate N (mg kg^{-1})	Ammonium Nitrogen (mg kg^{-1})	Colwell Phosphorus (mg kg^{-1})	Available Sulfur (mg kg^{-1})
1	Dryland	0-15	1	7.25	143.7	0.52	25.1	1.8	9.3	17
2	Dryland	15-30	1	7.63	211	0.41	13.5	1.5	6	9.4
3	Dryland	30-45	1	8.39	240	0.43	13.1	1.4	4.5	8.5
4	Dryland	45-60	1	8.51	274	0.4	11.9	1.1	4	11
5	Dryland	60-75	1	8.6	314	0.3	8	1.1	3.5	14
6	Dryland	75-90	1	8.2	353	0.29	8	1.4	4.1	22
7	Dryland	0-15	2	6.89	119.1	1.2	19.8	3.1	49	15
8	Dryland	15-30	2	7.08	60	0.68	4.5	2.4	24.7	7.6
9	Dryland	30-45	2	7.76	190	0.45	3.8	1	8.8	9.5
10	Dryland	45-60	2	8.26	219	0.3	5.6	0.7	4.1	9.8
11	Dryland	60-75	2	8.57	271	0.24	6.8	0.3	4.7	11
12	Dryland	75-90	2	7.45	270	0.24	10.4	1.2	5	16
13	Dryland	0-15	3	7.04	96.2	0.93	15.9	2.9	38.8	11
14	Dryland	15-30	3	7.65	88.6	0.48	4.6	1.6	5.8	9.1
15	Dryland	30-45	3	7.74	156.6	0.37	3.2	1.2	3.5	9.6
16	Dryland	45-60	3	8.37	262	0.33	2.6	1.3	3.6	13
17	Dryland	60-75	3	8.2	364	0.25	3.4	0.9	2.8	18
18	Dryland	75-90	3	8.21	370	0.22	3	1	3.8	41
19	Dryland	0-15	4	7.29	123.4	0.94	19.6	2.8	35.4	12
20	Dryland	15-30	4	7.41	107.5	0.63	8.2	1.8	12.2	13
21	Dryland	30-45	4	7.87	226	0.48	4.5	1.2	4.1	16
22	Dryland	45-60	4	8.93	356	0.35	7.1	0.9	3.4	22
23	Dryland	60-75	4	8.47	441	0.26	7.7	0.5	3.4	35
24	Dryland	75-90	4	8.68	467	0.2	6.9	0.5	4.2	66
25	Irrigated	0-15	1	8.16	224	0.54	6	1.3	11.2	8.2

Sample Number	Land use	Depth (cm)	Core Number	pH	EC ($\mu S\ cm^{-1}$)	Soil Organic Carbon (%)	Nitrate N ($mg\ kg^{-1}$)	Ammonium Nitrogen ($mg\ kg^{-1}$)	Colwell Phosphorus ($mg\ kg^{-1}$)	Available Sulfur ($mg\ kg^{-1}$)
26	Irrigated	15-30	1	8.23	246	0.3	2.2	0.5	4.8	17
27	Irrigated	30-45	1	8.38	295	0.26	1.2	0.7	5.3	29
28	Irrigated	45-60	1	8.38	353	0.19	0.5	0.7	4	36
29	Irrigated	60-75	1	8.25	419	0.15	0.3	0.8	3.8	39
30	Irrigated	75-90	1	8	487	0.12	0.4	0.8	5	55
31	Irrigated	0-15	2	8.01	166.4	0.86	7.5	1.5	42.7	6.4
32	Irrigated	15-30	2	8	207	0.41	3.5	0.8	10.1	13
33	Irrigated	30-45	2	8.3	301	0.29	2.2	0.6	5.9	21
34	Irrigated	45-60	2	8.66	339	0.22	1.5	0.3	4.2	24
35	Irrigated	60-75	2	8.24	396	0.18	0.6	0.2	4.9	22
36	Irrigated	75-90	2	8.22	393	0.18	0.7	0.3	5.7	20
37	Irrigated	0-15	3	7.82	269	0.66	45.6	1.1	42.7	14
38	Irrigated	15-30	3	8.51	217	0.4	7.9	0.5	12.1	19
39	Irrigated	30-45	3	7.83	254	0.33	3.5	0.4	10	28
40	Irrigated	45-60	3	8.15	288	0.21	2.1	0.4	6.2	32
41	Irrigated	60-75	3	8.43	298	0.19	2.4	0.6	6.8	31
42	Irrigated	75-90	3	8.21	349	0.18	2.6	0.5	6.8	34
43	Irrigated	0-15	4	7.73	236	0.81	5.7	2	38.3	9.4
44	Irrigated	15-30	4	8.42	238	0.43	6	1.5	13.6	18
45	Irrigated	30-45	4	8.47	294	0.29	2.2	0.8	5.1	25
46	Irrigated	45-60	4	8.71	352	0.2	1.8	0.6	4	26
47	Irrigated	60-75	4	8.67	420	0.17	0.8	0.8	5.2	28
48	Irrigated	75-90	4	8.74	431	0.11	0.5	0.7	6.2	27

***Table 1b** - Darlington Point Raw Data*

Sample Number	Exchangeable Calcium ($cmol_c\ kg^{-1}$)	Exchangeable Magnesium ($cmol_c\ kg^{-1}$)	Exchangeable Potassium ($cmol_c\ kg^{-1}$)	Exchangeable Sodium ($cmol_c\ kg^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	ESP (%)	DTPA Iron ($mg\ kg^{-1}$)	DTPA Manganese ($mg\ kg^{-1}$)	DTPA Copper ($mg\ kg^{-1}$)	DTPA Zinc ($mg\ kg^{-1}$)
1	15.2	11.1	1.21	1.6	29	5.52	14	12	1.5	0.59
2	20.4	12.2	1.19	1.91	36	3.11	9.7	5	1.4	0.83
3	18	12.8	1.17	2.59	35	7.4	6.6	4.1	1.1	0.17
4	19.6	13.2	1.05	3	36.9	8.22	7.3	4.9	1.1	0.59
5	21.7	13.5	0.928	3.3	39.4	8.3	5	6	0.9	0.36
6	18.8	13.2	0.927	3.3	36.3	9.21	4.9	7.9	1	0.37
7	10.9	7.08	1.3	0.811	20	4.06	86	23	2.5	1.7
8	9.56	6.19	0.885	0.686	17	11.24	49	26	3.5	0.64
9	21.6	11.3	1.02	1.53	35	4.37	12	6.4	1.2	0.4
10	25.1	13.2	0.934	2.28	42	5.43	7.8	5.2	0.96	0.2
11	21.5	13.8	0.872	2.8	38.9	7.13	6	3.9	0.9	0.24
12	24.8	13	0.899	3.2	41.9	7.58	5.2	3.2	0.79	0.16
13	9.11	6.14	1.02	0.803	17	4.72	72	34	2.3	0.75
14	16.3	12.1	1.07	2.03	32	2.14	14	9.1	1.2	0.51
15	17.5	13.1	0.782	2.68	34	7.88	8.8	5.5	1.1	0.62
16	20.6	14	0.645	3.24	38	8.53	8.7	6	1	0.36
17	20.8	13.9	0.616	2.6	37.9	6.9	7.8	6.3	0.97	0.99
18	17.1	13.7	0.61	2.8	34.2	8.25	5.6	4.2	0.88	0.17
19	9.26	6.48	0.946	1.27	18	7.06	75	31	2.4	0.79
20	11.4	9.03	1.2	1.81	23	8.83	28	32	1.8	0.32
21	15.3	13.3	1.08	3.18	33	9.64	29	24	1.3	-
22	19.1	14.5	0.824	3.2	37.7	8.58	5.6	4.2	1.1	0.62
23	20.2	14.3	0.725	2.9	38.1	7.63	4.9	3.7	0.87	0.19
24	18.8	13.6	0.791	2.9	36.1	8.16	6.9	5.1	0.86	0.46
25	17.8	11.2	0.709	2.16	32	6.75	7.1	3.9	1.2	0.35
26	19.6	13.5	0.512	2.81	36	7.81	6.6	3.5	1.1	0.24
27	18.1	13.4	0.513	3	35	8.52	5.5	3.5	0.95	0.16

Sample Number	Exchangeable Calcium ($cmol_c$ kg^{-1})	Exchangeable Magnesium ($cmol_c$ kg^{-1})	Exchangeable Potassium ($cmol_c$ kg^{-1})	Exchangeable Sodium ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})	ESP (%)	DTPA Iron (mg kg^{-1})	DTPA Manganese (mg kg^{-1})	DTPA Copper (mg kg^{-1})	DTPA Zinc (mg kg^{-1})
28	17.4	13.5	0.562	3.1	34.5	9.04	5.2	3	0.88	0.12
29	18.3	11.2	0.56	2.6	32.7	7.85	5	2.7	0.78	0.24
30	20.4	9.78	0.582	1.8	32.6	5.62	4.4	2	0.77	0.09
31	18.2	9.29	1.54	1.23	30	4.1	16	7.1	1.7	0.99
32	20	11.7	1.12	1.91	35	5.46	8.3	4	1.2	0.33
33	19	13.6	1.05	1.9	35.6	5.43	5.3	3.5	0.87	0.19
34	16.7	15	1.15	2.3	35.1	6.47	6	4.5	0.92	0.53
35	16	13.9	1.15	2	33.1	6.14	5	2.6	0.89	0.1
36	20.6	11	1.12	1.8	34.5	5.29	4.1	2.6	0.78	0.27
37	18.6	10	1.14	1.73	31	5.58	9.9	6.6	1.4	0.82
38	20.8	11.8	1.05	1.86	35	5.31	8	4.2	1.1	0.31
39	17.5	12.9	0.927	2.2	34	6.59	7.4	3.8	1.1	0.22
40	15.7	13.3	0.923	2.3	32.2	7.01	6	3.2	0.85	0.17
41	17.1	12.1	0.94	2.5	32.6	7.69	5.6	3.1	0.84	0.4
42	21.9	9.63	0.916	2.2	34.6	6.41	6	3	0.89	0.36
43	25	9.86	1.36	1.65	38	4.34	13	7.2	1.6	0.86
44	25.4	12.3	0.924	2.15	41	5.24	8.6	2.8	1.3	0.43
45	24	15.2	0.816	2.6	42.6	6.02	7	3.5	1.2	0.21
46	23.6	15.6	0.859	3	43.1	6.98	8.2	4.8	0.92	0.26
47	24.1	13.2	0.84	3.1	41.3	7.61	6.2	3.1	1	0.51
48	27	10.1	0.723	2.8	40.6	6.88	5	1.6	0.87	0.14

Table 2a *- Narromine 'Central Farm' Raw Data*

Sample Number	Land use	Depth (cm)	Core Number	pH	EC ($\mu S\ cm^{-1}$)	Soil Organic Carbon (%)	Nitrate N ($mg\ kg^{-1}$)	Ammonium Nitrogen ($mg\ kg^{-1}$)	Colwell Phosphorus ($mg\ kg^{-1}$)	Available Sulfur ($mg\ kg^{-1}$)
49	Dryland	0-15	1	5.75	98.1	0.83	24.5	10.8	71.1	10
50	Dryland	15-30	1	7.44	32.6	0.29	6.6	1.1	15.2	5.3
51	Dryland	30-45	1	7.44	37.7	0.25	5.8	1.8	21.2	9
52	Dryland	45-60	1	7.83	35.5	0.2	3.6	2.2	15.8	9.9
53	Dryland	60-75	1	7.7	29.9	0.17	4	1.8	12.9	6.1
54	Dryland	75-90	1	7.66	48.8	0.15	5.4	1.9	11.3	6
55	Dryland	0-15	2	6.57	254	0.9	57.2	6.2	67.1	12
56	Dryland	15-30	2	6.49	120.9	0.38	9	1.3	18.6	4.8
57	Dryland	30-45	2	6.77	106.9	0.31	2.9	0.1	14.4	5.4
58	Dryland	45-60	2	6.7	122.8	0.48	3	0.2	12.1	5.1
59	Dryland	60-75	2	6.71	91.5	0.25	2.2	0.4	11.1	6.1
60	Dryland	75-90	2	6.73	119.5	0.17	2.4	0.5	11.6	4.8
61	Dryland	0-15	3	6.23	140.4	0.64	44.8	4.5	55.5	14
62	Dryland	15-30	3	7.63	86.9	0.3	31.6	0.3	16.7	8.4
63	Dryland	30-45	3	7.01	50.8	0.27	13	0.6	15.2	6.9
64	Dryland	45-60	3	6.94	61	0.22	4.5	1	18.2	8.1
65	Dryland	60-75	3	7.29	33.8	0.19	2.6	1.3	13.1	8.2
66	Dryland	75-90	3	8.07	36	0.12	2	1.7	10.2	11
67	Dryland	0-15	4	6.68	93.7	0.79	26.1	6.1	62.6	14
68	Dryland	15-30	4	7.55	44.4	0.36	6.2	0.7	9	6.8
69	Dryland	30-45	4	6.99	47.5	0.31	5.7	1.2	5.4	5.5
70	Dryland	45-60	4	7.38	47.1	0.27	3.6	2	7.7	6.2
71	Dryland	60-75	4	8.05	49.2	0.21	2.4	1.8	7.4	5.3
72	Dryland	75-90	4	7.11	87.8	0.16	1.5	1.9	6.5	5
73	Irrigated	0-15	1	6.98	164.3	0.77	32.8	1.9	41.6	8.5
74	Irrigated	15-30	1	7.72	49.8	0.25	3.7	0.8	5.5	4
75	Irrigated	30-45	1	7.82	65.4	0.24	3.2	0.8	5.8	7.2

Sample Number	Land use	Depth (cm)	Core Number	pH	EC (µS cm^{-1})	Soil Organic Carbon (%)	Nitrate N (mg kg^{-1})	Ammonium Nitrogen (mg kg^{-1})	Colwell Phosphorus (mg kg^{-1})	Available Sulfur (mg kg^{-1})
76	Irrigated	45-60	1	7.75	128.4	0.22	2.5	0.9	4.3	21
77	Irrigated	60-75	1	7.91	169.2	0.16	5.9	1	6.6	22
78	Irrigated	75-90	1	7.82	187.2	0.13	17.2	1.3	8.5	18
79	Irrigated	0-15	2	7.18	90.7	0.88	16.2	1.8	50.3	6.5
80	Irrigated	15-30	2	7.58	90.8	0.51	8.8	1	8.7	5.2
81	Irrigated	30-45	2	8.03	154	0.24	5.6	0.7	4.7	8.9
82	Irrigated	45-60	2	8.13	158.5	0.18	3	1.1	6.1	23
83	Irrigated	60-75	2	8.09	188.5	0.16	2.7	0.8	10.8	25
84	Irrigated	75-90	2	8.28	182	0.19	6.5	1.4	10.9	17
85	Irrigated	0-15	3	8.25	103.9	0.84	15.5	1.6	49.5	8.6
86	Irrigated	15-30	3	8.23	87.8	0.45	6.7	1.1	10.7	9.1
87	Irrigated	30-45	3	8.34	217	0.42	2.1	1.2	6.8	13
88	Irrigated	45-60	3	8.56	203	0.28	1.6	0.3	7.6	11
89	Irrigated	60-75	3	8.03	191.9	0.25	1.8	1.2	9.5	11
90	Irrigated	75-90	3	7.88	188.6	0.18	2.1	1.5	10.9	9.3
91	Irrigated	0-15	4	7.75	62	0.68	1.8	2.4	30.8	4
92	Irrigated	15-30	4	8.3	63.1	0.31	0.7	1.5	7.6	4.4
93	Irrigated	30-45	4	8.51	114	0.24	0.3	1.6	8.7	16
94	Irrigated	45-60	4	7.78	192.8	0.24	0.6	1.6	8.4	25
95	Irrigated	60-75	4	8.09	171.4	0.17	2.6	1.2	8.3	19
96	Irrigated	75-90	4	8.05	150.8	0.13	5.1	1.3	9	15

Table 2b *- Narromine 'Central Farm' Raw Data*

Sample Number	Exchangeable Calcium ($cmol_c\ kg^{-1}$)	Exchangeable Magnesium ($cmol_c\ kg^{-1}$)	Exchangeable Potassium ($cmol_c\ kg^{-1}$)	Exchangeable Sodium ($cmol_c\ kg^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	ESP (%)	DTPA Iron ($mg\ kg^{-1}$)	DTPA Manganese ($mg\ kg^{-1}$)	DTPA Copper ($mg\ kg^{-1}$)	DTPA Zinc ($mg\ kg^{-1}$)
49	4.36	1.14	0.826	0.044	6.4	0.69	51	86	1.6	0.66
50	5.83	1.89	0.414	0.059	8.2	0.72	29	46	1.5	0.54
51	8.51	3.71	0.409	0.079	13	0.61	25	36	1.6	0.16
52	9.92	4.86	0.402	0.139	15	0.93	34	38	1.6	0.27
53	10	4.93	0.39	0.153	15	1.02	9.3	18	1.2	0.1
54	11	5.19	0.419	0.187	17	1.1	12	12	0.94	0.3
55	11.1	1.17	1.13	0.035	13	0.27	30	72	1.5	0.79
56	20.5	1.89	1.02	0.035	23	0.15	11	16	1.1	0.22
57	17	3.45	1.07	0.035	22	0.16	4.8	8.2	1.1	0.43
58	20.2	5.34	0.98	0.035	27	0.13	7	9.1	1.2	0.18
59	13.7	6.36	0.973	0.041	21	0.2	7	7.3	0.98	0.17
60	15.7	6.51	0.923	0.047	23	0.2	10	7.4	0.84	0.17
61	4.25	1.14	0.608	0.039	6	0.65	45	120	1.7	0.83
62	6.39	2.18	0.221	0.074	8.9	0.83	27	57	1.4	0.2
63	9.25	4.06	0.294	0.155	14	1.11	18	37	1.4	0.26
64	11.3	5.27	0.384	0.231	17	1.36	18	24	1.4	0.18
65	9.78	4.76	0.363	0.248	15	1.65	13	21	1.2	0.15
66	9.13	4.4	0.341	0.263	14	1.88	8.4	13	0.89	0.14
67	4.93	1.21	0.769	0.035	6.9	0.51	48	100	1.8	0.84
68	9.56	2.54	0.378	0.053	13	0.41	18	43	1.2	0.21
69	13.4	4.33	0.386	0.098	18	0.54	17	21	1.2	0.15
70	14	4.8	0.429	0.125	19	0.66	10	11	1.2	0.21
71	12.9	4.7	0.378	0.134	18	0.74	7.3	8.4	0.89	0.12
72	13.9	4.55	0.359	0.163	19	0.86	12	8	0.8	0.16
73	5.81	2.82	0.528	0.333	9.5	3.51	20	43	0.96	3.2
74	3.85	2.06	0.147	0.524	6.6	7.94	7.2	8.3	0.65	0.39
75	6.63	3.4	0.222	1.02	11	9.27	14	14	0.92	0.39

Sample Number	Exchangeable Calcium ($cmol_c$ kg^{-1})	Exchangeable Magnesium ($cmol_c$ kg^{-1})	Exchangeable Potassium ($cmol_c$ kg^{-1})	Exchangeable Sodium ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})	ESP (%)	DTPA Iron (mg kg^{-1})	DTPA Manganese (mg kg^{-1})	DTPA Copper (mg kg^{-1})	DTPA Zinc (mg kg^{-1})
76	10.3	4.77	0.299	1.7	17	10	7.2	6.3	1.1	0.21
77	10.3	4.65	0.323	1.74	17	10.24	7.6	6.9	1	0.18
78	9.98	4.51	0.371	1.71	17	10.06	6.9	8	0.87	0.16
79	6.24	2.8	0.665	0.352	10	3.52	35	56	1.1	3.3
80	7.05	3.25	0.471	0.608	11	5.53	15	28	1.1	0.58
81	12.9	4.44	0.475	0.92	19	4.84	12	15	0.98	0.18
82	12.4	4.03	0.502	0.905	18	5.03	7.8	8	0.88	0.17
83	13.8	3.77	0.543	0.921	19	4.85	6.2	5.6	0.76	0.13
84	12.9	3.93	0.596	0.978	18	5.43	10	8.6	0.85	0.19
85	6.3	2.86	0.687	0.411	10	4.11	15	33	0.89	2.4
86	6.32	3.01	0.28	0.882	10	8.82	14	32	0.99	0.18
87	21.8	3.66	0.307	1.24	27	4.59	15	18	1.3	0.49
88	23	3.1	0.341	1.32	28	4.71	6	6.4	0.91	0.21
89	21.3	2.72	0.403	1.36	26	5.23	4.8	7.2	0.79	0.2
90	20.2	2.53	0.439	1.31	24	5.46	5.9	5.9	0.84	0.37
91	5.48	2.45	0.734	0.287	9	3.19	15	28	0.85	2
92	4.48	2.16	0.201	0.729	7.6	9.59	11	12	0.83	0.36
93	8.57	3.91	0.271	1.51	14	10.79	12	17	1.3	0.46
94	10.4	4.37	0.309	1.91	17	11.24	8.3	13	1	0.29
95	9.57	4.1	0.337	1.8	16	11.25	11	11	0.79	0.23
96	9.72	4.02	0.379	1.56	16	9.75	8	7.4	0.8	0.17

__Table 3a__ - Narromine 'Browning Family Farm' Raw Data

Sample Number	Land use	Depth (cm)	Core Number	pH	EC (µS cm^{-1})	Soil Organic Carbon (%)	Nitrate N (mg kg^{-1})	Ammonium Nitrogen (mg kg^{-1})	Colwell Phosphorus (mg kg^{-1})	Available Sulfur (mg kg^{-1})
97	Dryland	0-15	1	7.18	212	0.9	34.9	4.1	61	21
98	Dryland	15-30	1	7.3	33	0.53	4.9	2	36.1	6.9
99	Dryland	30-45	1	7.17	31	0.51	3.5	2	30	6
100	Dryland	45-60	1	7.68	27.3	0.38	2.5	2.4	48	5
101	Dryland	60-75	1	7.67	26.9	0.32	1.6	2.4	53.2	5.1
102	Dryland	75-90	1	7.49	30	0.22	1.4	1.9	48.7	6.1
103	Dryland	0-15	2	5.97	184	1.02	51.3	4.4	68.1	15
104	Dryland	15-30	2	7.5	33.3	0.72	4.4	2.4	22.5	5.4
105	Dryland	30-45	2	7.56	25.8	0.47	2.1	2.6	23.7	3.4
106	Dryland	45-60	2	7.6	26.5	0.28	1.7	2.7	37.2	4.4
107	Dryland	60-75	2	7.42	30.1	0.21	1.8	2.5	51	3.9
108	Dryland	75-90	2	7.47	30	0.16	1.6	2.1	47	3.2
109	Dryland	0-15	3	5.91	175.7	1.17	41.8	4.4	75.7	17
110	Dryland	15-30	3	6.85	53.6	0.83	8.5	1.5	33.3	7.7
111	Dryland	30-45	3	7.27	42.9	0.61	6.1	2.4	43.2	6
112	Dryland	45-60	3	7.22	34.3	0.6	4.1	2.9	50.6	4.7
113	Dryland	60-75	3	7.38	37.8	0.51	4	2.6	58.1	6.3
114	Dryland	75-90	3	8.36	38.9	0.37	3.2	2.3	43.4	4.5
115	Dryland	0-15	4	6.17	255	1.03	55.7	2.9	78.8	15
116	Dryland	15-30	4	7.11	42.1	0.61	5.5	1.3	27.2	4.6
117	Dryland	30-45	4	7.71	33.7	0.28	1.4	2.2	52.1	3.7
118	Dryland	45-60	4	7.3	34.1	0.4	1.9	2.6	37.1	2.8
119	Dryland	60-75	4	7.25	35.7	0.55	3	2.1	27.9	4.8
120	Dryland	75-90	4	8.26	31.6	0.21	1.2	2.2	57.1	4.3
121	Irrigated	0-15	1	6.13	153	1.7	73.6	6.7	117	19
122	Irrigated	15-30	1	7.94	105	1.12	11.2	2.3	42.9	14

Sample Number	Land use	Depth (cm)	Core Number	pH	EC (µS cm^{-1})	Soil Organic Carbon (%)	Nitrate N (mg kg^{-1})	Ammonium Nitrogen (mg kg^{-1})	Colwell Phosphorus (mg kg^{-1})	Available Sulfur (mg kg^{-1})
123	Irrigated	30-45	1	9.06	298	0.71	14.4	1.8	13	29
124	Irrigated	45-60	1	8.72	407	0.39	18.1	1.5	12.4	38
125	Irrigated	60-75	1	9.09	530	0.26	17.7	1.6	16.9	69
126	Irrigated	75-90	1	9.19	833	0.18	19.1	1.5	18.2	140
127	Irrigated	0-15	2	6.42	114.2	1.58	24.8	3.9	95.4	11
128	Irrigated	15-30	2	8.23	90.8	0.72	7.6	1.5	18.4	12
129	Irrigated	30-45	2	9.01	147.2	0.56	13.9	1.4	13.4	19
130	Irrigated	45-60	2	8.87	193.7	0.33	18.2	1.6	11.3	24
131	Irrigated	60-75	2	8.98	295	0.24	22.8	1.5	13.4	44
132	Irrigated	75-90	2	8.82	534	0.21	43	1.4	18.3	160
133	Irrigated	0-15	3	7.6	130.3	1.29	40.6	3.7	72	12
134	Irrigated	15-30	3	8.64	70.3	0.54	7.7	1.6	8.5	11
135	Irrigated	30-45	3	8.76	158.9	0.29	5.8	1.8	6.8	17
136	Irrigated	45-60	3	8.45	223	0.22	6.8	2	7.3	18
137	Irrigated	60-75	3	9.04	271	0.19	6.2	1.6	7.7	22
138	Irrigated	75-90	3	9.26	325	0.16	5.6	1.7	9.6	31
139	Irrigated	0-15	4	5.84	195.6	1.67	66.4	9	131.8	28
140	Irrigated	15-30	4	6.94	71.4	1.26	11.5	2.1	41.5	15
141	Irrigated	30-45	4	8.91	95.3	0.77	16.1	1.3	10.8	16
142	Irrigated	45-60	4	8.62	168.6	0.37	24.6	0.4	9.5	19
143	Irrigated	60-75	4	8.7	208	0.22	26.6	1.3	10.6	24
144	Irrigated	75-90	4	8.2	245	0.17	34.2	1.4	13	34

***Table 3b** - Narromine 'Browning Family Farm' Raw Data*

Sample Number	Exchangeable Calcium ($cmol_c\ kg^{-1}$)	Exchangeable Magnesium ($cmol_c\ kg^{-1}$)	Exchangeable Potassium ($cmol_c\ kg^{-1}$)	Exchangeable Sodium ($cmol_c\ kg^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	ESP (%)	DTPA Iron ($mg\ kg^{-1}$)	DTPA Manganese ($mg\ kg^{-1}$)	DTPA Copper ($mg\ kg^{-1}$)	DTPA Zinc ($mg\ kg^{-1}$)
97	8.53	3.56	0.503	0.147	13	1.13	64	57	2.4	0.59
98	10.9	5.25	0.359	0.122	17	0.72	56	20	3.2	0.32
99	12.6	6.51	0.407	0.187	20	0.94	41	27	2.4	0.29
100	11.1	6.05	0.395	0.21	18	1.17	27	23	2	0.14
101	10.2	5.63	0.403	0.22	16	1.38	19	22	1.6	0.2
102	9.63	5.52	0.397	0.246	16	1.54	15	19	1.2	0.22
103	10	3.5	0.492	0.104	14	0.74	59	64	2.1	0.79
104	15	5.59	0.401	0.122	21	0.58	34	27	2.2	0.25
105	14.8	5.7	0.434	0.147	21	0.7	20	25	2.2	0.16
106	12.4	5.07	0.448	0.158	18	0.88	15	20	1.9	0.11
107	11.4	4.73	0.446	0.169	17	0.99	14	14	1.5	0.2
108	10.7	4.54	0.416	0.174	16	1.09	22	15	1.1	0.18
109	8.57	3.11	0.723	0.131	13	1.01	66	62	1.7	0.67
110	12	4.52	0.387	0.112	17	0.66	43	13	2.1	0.34
111	13.2	6.23	0.423	0.172	20	0.86	46	15	2.8	0.28
112	13	6.66	0.458	0.215	20	1.08	33	27	2.5	0.18
113	12.8	6.47	0.488	0.255	20	1.28	24	26	2.2	0.18
114	11.3	5.98	0.435	0.282	18	1.57	15	18	1.6	0.13
115	9.29	2.99	0.758	0.097	13	0.75	57	63	2.1	0.72
116	12.9	4.46	0.442	0.094	18	0.52	22	20	1.8	0.2
117	11.1	5.23	0.431	0.146	17	0.86	37	29	1.7	0.16
118	13.1	5.64	0.452	0.138	19	0.73	26	23	2.1	0.18
119	14.2	5.67	0.437	0.117	20	0.59	17	20	2.2	0.2
120	10.4	5.3	0.461	0.15	16	0.94	12	13	1.2	0.12
121	9.1	5.83	1.39	0.647	17	3.81	120	69	2.6	2.7
122	11.5	9.86	0.71	2.36	24	9.83	39	25	2.1	1.1
123	13.6	11.8	0.534	3.9	29.9	13.2	17	13	1.6	0.44

Sample Number	Exchangeable Calcium (cmol$_c$ kg^{-1})	Exchangeable Magnesium (cmol$_c$ kg^{-1})	Exchangeable Potassium (cmol$_c$ kg^{-1})	Exchangeable Sodium (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	ESP (%)	DTPA Iron (mg kg^{-1})	DTPA Manganese (mg kg^{-1})	DTPA Copper (mg kg^{-1})	DTPA Zinc (mg kg^{-1})
124	13.3	11.6	0.481	4.43	29.8	14.88	7.4	6.1	1.3	0.28
125	12.1	10.6	0.5	4.75	28	16.98	8.4	6.1	1.3	0.34
126	16.1	10.1	0.493	3.5	30.2	11.58	6.7	3.6	1.1	0.34
127	9.28	5.19	1.32	0.485	16	3.03	110	42	2.4	2.6
128	10.8	8.08	0.591	1.64	21	7.81	26	6.7	1.9	0.43
129	10	8.81	0.388	3.13	22	14.23	21	9.6	2	0.48
130	9.22	9.33	0.388	4.53	23	19.7	15	10	1.6	0.45
131	8.7	9.56	0.4	5.7	24.3	23.42	9.2	5.8	1.3	0.39
132	8.6	9.6	0.409	5.34	23.9	22.32	7	4.7	1.5	0.53
133	12.7	5.2	0.987	0.556	19	2.93	50	39	1.9	1.9
134	16.1	7.83	0.433	1.19	26	4.58	17	14	1.6	0.3
135	15	8.94	0.42	1.73	26	6.65	12	8.2	1.6	0.26
136	20.8	10	0.43	2.46	34	7.24	9.4	5.8	1.7	0.44
137	19	10.6	0.385	3.57	33	10.82	7	4	1.4	0.26
138	16.4	11.3	0.437	4.5	16.3	15.73	15	6.6	1.6	0.27
139	8.08	3.87	1.38	0.416	14	2.97	120	73	2.2	2.7
140	9.3	5.12	0.673	0.51	16	3.19	98	34	2.5	1.2
141	12.2	8.65	0.442	1.14	22	5.18	17	7.5	1.6	0.36
142	12.2	9.51	0.338	1.83	24	7.63	13	8.1	1.7	0.27
143	12.1	10.2	0.311	2.84	25	11.36	14	8.6	1.6	0.25
144	11	11.1	0.318	4.25	27	15.74	14	7.7	1.6	0.53

Table 4a *- Narrabri Raw Data*

Sample Number	Land use	Depth (cm)	Core Number	pH	EC (µS cm^{-1})	Soil Organic Carbon (%)	Nitrate N (mg kg^{-1})	Ammonium Nitrogen (mg kg^{-1})	Colwell Phosphorus (mg kg^{-1})	Available Sulfur (mg kg^{-1})
145	Dryland	0-15	1	7.72	173.3	0.86	24.3	2.1	10.2	11
146	Dryland	15-30	1	8.18	230	0.61	20.2	2.2	1.8	10
147	Dryland	30-45	1	9.23	308	0.62	17.6	2.2	1.1	11
148	Dryland	45-60	1	9.19	374	0.59	11.8	2.1	1.4	11
149	Dryland	60-75	1	9.34	420	0.57	9	1.9	3.5	13
150	Dryland	75-90	1	9.48	481	0.55	11	1.7	8.1	22
151	Dryland	0-15	2	7.42	164.8	1.35	32.7	3	42.2	13
152	Dryland	15-30	2	8.32	211	0.72	22.5	1.8	6	12
153	Dryland	30-45	2	9.21	292	0.72	24.4	3.4	8.3	11
154	Dryland	45-60	2	9.44	342	0.64	17.9	3.3	5.3	12
155	Dryland	60-75	2	9.51	406	0.55	17.9	2.6	8.1	14
156	Dryland	75-90	2	9.45	476	0.51	23.2	2.2	13.8	25
157	Dryland	0-15	3	8.16	126.9	1.32	26.7	2.5	44.3	10
158	Dryland	15-30	3	8.29	192	1.12	25.6	2.5	21.6	11
159	Dryland	30-45	3	9.06	284	0.89	20.3	3.3	13.4	10
160	Dryland	45-60	3	9.32	348	0.6	12.7	1.5	2.8	11
161	Dryland	60-75	3	9.61	388	0.51	10.1	1.8	4.8	13
162	Dryland	75-90	3	9.4	498	0.53	12	1.7	12.5	23
163	Dryland	0-15	4	7.77	139.1	1.23	30.3	2.7	39.7	11
164	Dryland	15-30	4	8.77	219	0.75	23.2	2.8	10.3	10
165	Dryland	30-45	4	9.37	289	0.59	16.4	2.1	3.8	11
166	Dryland	45-60	4	9.34	349	0.61	18	2	5	11
167	Dryland	60-75	4	9.48	402	0.55	14.3	1.5	9.2	11
168	Dryland	75-90	4	9.57	468	0.48	18.7	1.4	17.3	18
169	Irrigated	0-15	1	8.62	127.2	0.83	13	2.8	34.3	9.9
170	Irrigated	15-30	1	9.09	194.6	0.56	8.2	2.2	9.6	9.3

Sample Number	Land use	Depth (cm)	Core Number	pH	EC ($\mu S\ cm^{-1}$)	Soil Organic Carbon (%)	Nitrate N ($mg\ kg^{-1}$)	Ammonium Nitrogen ($mg\ kg^{-1}$)	Colwell Phosphorus ($mg\ kg^{-1}$)	Available Sulfur ($mg\ kg^{-1}$)
171	Irrigated	30-45	1	9.35	278	0.52	7.5	2.3	4.7	10
172	Irrigated	45-60	1	9.56	332	0.49	8.9	1.9	3.8	11
173	Irrigated	60-75	1	9.47	386	0.46	13	1.8	7	15
174	Irrigated	75-90	1	9.43	487	0.49	33.3	1.8	11	28
175	Irrigated	0-15	2	8.78	151.8	0.69	7.7	2.9	18	9.7
176	Irrigated	15-30	2	9.2	204	0.56	7	1.9	6.9	9.2
177	Irrigated	30-45	2	9.45	281	0.53	10.4	1.7	4.7	11
178	Irrigated	45-60	2	9.47	351	0.53	17.8	1.3	4.7	15
179	Irrigated	60-75	2	9.52	443	0.52	39.4	1.9	7	17
180	Irrigated	75-90	2	9.4	594	0.54	66.4	1.5	13.1	29
181	Irrigated	0-15	3	8.35	143.2	0.89	22.8	2.7	27.7	10
182	Irrigated	15-30	3	9.19	193.1	0.65	10.2	2.3	7.5	9.6
183	Irrigated	30-45	3	9.03	258	0.64	7	2.1	6.1	10
184	Irrigated	45-60	3	9.35	333	0.55	8.7	1.8	6.3	11
185	Irrigated	60-75	3	9.3	436	0.53	29.7	1.6	14	19
186	Irrigated	75-90	3	9.38	512	0.53	53.7	1.4	20.5	27
187	Irrigated	0-15	4	8.91	143.3	0.76	12.5	3	22.8	10
188	Irrigated	15-30	4	8.98	200	0.67	10.4	2.7	13	8
189	Irrigated	30-45	4	9.31	322	0.58	9.5	1.6	2.8	9.9
190	Irrigated	45-60	4	9.46	438	0.51	22.3	1.5	3.5	16
191	Irrigated	60-75	4	9.34	575	0.53	36.7	1.5	7.1	28
192	Irrigated	75-90	4	9.2	749	0.6	23.3	1.3	21.1	47

Table 4b *- Narrabri Raw Data*

Sample Number	Exchangeable Calcium ($cmol_c$ kg^{-1})	Exchangeable Magnesium ($cmol_c$ kg^{-1})	Exchangeable Potassium ($cmol_c$ kg^{-1})	Exchangeable Sodium ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})	ESP (%)	DTPA Iron (mg kg^{-1})	DTPA Manganese (mg kg^{-1})	DTPA Copper (mg kg^{-1})	DTPA Zinc (mg kg^{-1})
145	30.6	14.3	0.971	1.6	47	3.4	14	6.8	1.3	0.59
146	32.4	16.3	0.679	3.37	53	6.36	26	14	1.3	0.22
147	29.7	17.9	0.695	5.07	53.37	9.5	14	5.9	1.3	0.29
148	28.3	19.2	0.738	6.47	54.71	11.83	15	5.8	1.4	0.23
149	27.2	19.3	0.796	7.37	54.67	13.49	13	5.4	1.4	0.34
150	26.2	19.2	0.858	7.61	53.87	14.12	35	22	1.4	0.33
151	27.1	13.8	1.41	1.2	43	2.79	16	13	1.4	0.59
152	31.4	16.8	0.792	2.98	52	5.73	14	5.5	1.3	0.21
153	28	17.7	0.79	4.64	51.13	9.08	33	19	1.4	0.25
154	27.3	19.1	0.806	6.52	53.73	12.14	18	7.4	1.5	0.26
155	27.2	20.1	0.87	7.87	56.04	14.05	20	8.6	1.5	0.25
156	24.3	19	0.861	7.8	51.96	15.01	43	32	1.4	0.27
157	26.7	13.7	1.73	0.609	43	1.42	17	16	1.4	0.53
158	28.8	14.7	1.12	1.53	46	3.33	13	11	1.3	0.35
159	25.6	15.9	0.812	3.94	46.25	8.52	16	12	1.3	0.34
160	27.6	17.8	0.705	6.04	52.15	11.59	15	6.9	1.4	0.18
161	25.8	17.8	0.674	7.11	51.39	13.84	9.3	5.7	1.3	0.35
162	25.9	19.1	0.906	7.42	53.33	13.91	18	11	1.4	0.4
163	27	14	1.49	0.96	44	2.18	20	19	1.3	0.43
164	32.9	16	0.844	2.63	52	5.06	15	8.3	1.3	0.2
165	30.1	17.5	0.709	4.63	52.94	8.74	48	37	1.3	0.21
166	27.4	18.7	0.739	6.39	53.23	12.01	18	8.1	1.5	0.3
167	26.7	19	0.761	7.18	53.64	13.38	14	6.2	1.5	0.39
168	26.2	19.1	0.824	7.37	53.5	13.78	29	19	1.4	0.2
169	26.8	12.9	1.47	1.23	42	2.93	14	11	1.2	0.78
170	28.9	15.2	0.81	2.83	48	5.9	22	12	1.3	0.58
171	28.2	17.5	0.711	4.81	51.2	9.4	15	6.2	1.3	0.41

Sample Number	Exchangeable Calcium ($cmol_c$ kg^{-1})	Exchangeable Magnesium ($cmol_c$ kg^{-1})	Exchangeable Potassium ($cmol_c$ kg^{-1})	Exchangeable Sodium ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})	ESP (%)	DTPA Iron (mg kg^{-1})	DTPA Manganese (mg kg^{-1})	DTPA Copper (mg kg^{-1})	DTPA Zinc (mg kg^{-1})
172	26.6	18.4	0.664	5.75	51.4	11.19	15	6.9	1.5	0.55
173	25.7	19.2	0.747	6.46	52.1	12.4	13	5	1.5	0.57
174	23.8	19.4	0.798	6.54	50.5	12.93	36	22	1.4	0.33
175	26.7	13.4	1.25	1.46	43	3.4	14	8	1.4	1
176	30.1	15.5	0.811	3	49	6.12	15	5.6	1.4	0.46
177	29.6	17.1	0.758	4.88	52.3	9.32	12	4.9	1.4	0.35
178	26.8	17.8	0.764	6.03	51.4	11.73	27	14	1.5	0.3
179	26.1	19	0.786	6.85	52.7	12.99	13	5.7	1.6	0.21
180	24.8	19.5	0.857	6.64	51.8	12.82	13	5.5	1.5	0.23
181	26.5	13	1.7	1.35	42	3.21	13	14	1.3	0.84
182	30.1	15.5	0.965	2.73	49	5.57	42	31	1.4	0.72
183	27.1	16.1	0.851	4.62	49	9.43	13	5.9	1.4	0.34
184	27.1	17.1	0.816	5.84	50.9	11.49	16	6.8	1.5	0.33
185	26.6	18	0.874	6.56	52	12.61	14	6.1	1.6	0.22
186	25.2	17.8	0.857	6.63	50.5	13.13	25	16	1.6	0.47
187	28	12.8	1.41	1.31	44	2.98	12	6.9	1.3	0.63
188	31	14.4	1.03	2.45	49	5	14	6.8	1.3	0.4
189	29.3	17.2	0.766	5.4	52.7	10.25	18	6.8	1.5	0.34
190	27.7	18.3	0.755	6.69	53.4	12.53	15	5.4	1.6	0.21
191	27.1	19	0.871	7.1	54.1	13.11	27	15	1.6	0.25
192	25.5	19.4	0.928	6.61	52.4	12.6	12	5	1.5	0.22