Soil Properties under Tree Plantations, Crops and Pastures Irrigated with Paper Mill Effluent at Albury in 2020

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June 2021

A 'commercial in confidence' report prepared by Timberlands Research Pty Ltd
for Visy Albury Pty Ltd

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1. SUMMARY

Since 1995 effluent from the paper mill at Albury has been re-used to irrigate a radiata pine plantation and irrigation was extended onto agricultural land in 2003. Annual monitoring of irrigation water and soil properties has been conducted as part of the EPA license agreement for the re-use of effluent from the paper mill at Ettamogah since the project commenced. The soil monitoring program based on site-specific protocols developed for the re-use scheme (Hopmans 2006) was reviewed in 2013 to identify soil properties most affected by effluent for an on-going monitoring program as part of a revised EPA license agreement. The revised soil monitoring program was implemented in 2013 and results for annual soil testing to 2020 are presented in this report. Irrigation with effluent from the mill continued to 2019 when paper manufacturing ceased and the mill was closed temporarily for modifications. Fresh river water was diverted to maintain water levels in the storage dam for irrigation, this reduced the salinity of irrigation water (EC from 1.2 dS/m to 0.8 dS/m).

In 2020 seasonal rainfall (612 mm) was below average and irrigation of trees (1.4 ML/ha) was low. The total hydraulic load (7.5 ML/ha) was below the range for the recent five years (8.8 to 12.4 ML/ha). Irrigation of crops and pastures was higher (3.7 ML/ha) but the total hydraulic load (9.8 ML/ha) was below the range of previous years (10.9 to 12.2 ML/ha). The salt load was lower for trees (1.3 t/ha) compared with crops and pastures (3.4 t/ha) and reflect the difference in irrigation for each land use and the lower salinity of irrigation water applied in 2020. In general soil pH and sodicity and to a lesser extent salinity and extractable S remained higher in effluent irrigated soils. The results for soil testing conducted in 2020 are summarized below:

- Soils were slightly alkaline in irrigated soil profiles under crops and pastures (pH_{Ca} 7.1 to 7.5) compared with the moderately acidic conditions of unirrigated soils (pH_{Ca} 5.6 to 6.2). Soils under irrigated trees were moderately acidic (pH_{Ca} 5.5 to 5.8) in the upper layers and slightly acidic (pH_{Ca} 6.3 to 6.5) in the sub-soils.
- Exchangeable sodium percentage (ESP) increased with depth from surface soils (4%) to sub-soils (17%) indicating sodic conditions (ESP > 6%) prevailed in soil profiles under irrigated trees. Soils of unirrigated crops and pastures under natural rainfall were non-sodic at the surface (ESP 2%) but were sodic at depth (ESP 11%). Irrigation of crops and pastures increased sodicity in surface soils (ESP 4% to 10%) and sub-soils (ESP 23%).
- Average salinity in root zones of irrigated soils under trees declined to 0.8 dS/m under a lower salt load of 1.3 t/ha in 2020. Average salinity in root zones of irrigated crops and pastures decreased to 1.0 dS/m under a salt load of 3.4 t/ha. Salinity in the root zones of trees as well as crops and pastures was below the threshold value of 4.0 dS/m as required under the EPA License.
- Extractable sulphate in irrigated soils under trees declined in surface soils (7 mg/kg) and sub-soils (49 mg/kg) reflecting the low irrigation rate and the lower concentrations of sulphate in diluted effluent in 2020. Likewise, the levels of sulphate in soil profiles under irrigated crops and pastures were low in surface soils (7 mg/kg) and sub-soils (48 mg/kg). This compared with slightly lower levels in surface soils (3 mg/kg) and sub-soils (27 mg/kg) of unirrigated soils.
- Salinity in surface soils (0 - 30 cm) has declined below the level (EC_{se} > 1 dS/m) required for these sodic soils to remain structurally stable. It is recommended to add gypsum to the irrigation water (increase EC to 1.3 dS/m) to raise soil salinity in profiles (EC_{se} > 1.0 dS/m) in order to maintain soil structure and hydraulic conductivity.

Average salinity in the root zones of trees (0.8 dS/m) and crops and pastures (1.0 dS/m) in 2020 remained below the threshold level of 4.0 dS/m for the re-use scheme under the current EPA License.

2. INTRODUCTION

Since 1995 effluent from the paper mill at Albury has been re-used to irrigate a radiata pine plantation and irrigation was extended onto adjacent agricultural land in 2003. Effluent from the mill is discharged to a large storage dam and then reticulated to irrigate the tree plantation using a drip irrigation system and agricultural crops and pastures using mobile sprinkler systems. Harvesting of the plantation commenced in 2004 and cleared areas have either been replanted with trees (radiata pine, blue gum and flooded gum) or were converted to crops and pastures. Irrigation with effluent from the mill continued to 2019 when paper manufacturing ceased and the mill was closed temporarily for modifications. Fresh river water was diverted to maintain water levels in the storage dam for the irrigation of trees, crops and pastures.

Annual monitoring of tree condition, irrigation water, and soil properties has been conducted as part of the EPA license agreement for the re-use of effluent from the paper mill at Ettamogah since the project commenced. The results of the soil monitoring program based on site-specific protocols developed for the re-use scheme (Hopmans 2006) were reviewed in 2013 to identify soil properties most affected by effluent for an on-going monitoring program as part of a revised EPA license agreement. The new soil monitoring program was implemented in 2013 and results for annual soil testing to 2020 are presented in this report.

In 2020 rainfall (612 mm) was below average for the region (710 mm) and irrigation was applied at low rates to trees (214 ha) and at intermediate rates to crops and pastures (238 ha). Soil samples were collected from the irrigated tree plantation at Ettamogah and from the areas of irrigated and unirrigated crops and pastures established on former plantation areas at Ettamogah and adjacent agricultural land at Maryvale and Rosevale. This report presents the results of soil chemical and physical testing carried out in 2020.

3. METHODS

Soil profile sampling was delayed due to COVID-19 travel restrictions in 2020 and samples were collected in November instead of September in accordance with the site-specific soil monitoring protocol (Hopmans 2006) retained in the revised EPA license agreement for the effluent re-use scheme at Ettamogah. Soil testing was limited to chemical properties most affected by irrigation with effluent including: pH, salinity, extractable sulphate and exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}).

Tree Plantation

Soil profile samples (0 - 10, 20 - 30, 50 - 60, and 80 - 90 cm) were collected from second rotation tree plantings irrigated with effluent including two monitoring plots (3.02, 3.11) in radiata pine (*Pinus radiata*), one plot (1.26) in Sydney blue gum (*Eucalyptus saligna*) and one plot (3.15) in flooded gum (*Eucalyptus grandis*).

Crops and Pastures

Soil profile samples (0 - 10, 20 - 30, and 50 - 60 cm) were collected from plots (12) in crops and pastures irrigated by mobile sprinkler systems and from plots (5) in adjacent unirrigated areas at the following locations:

- Ettamogah, former irrigated plantation areas converted to crops and pastures (irrigation resumed in 2007): irrigated (4) and unirrigated plots (2).
- Maryvale (commenced in 2003): irrigated (5) and unirrigated plots (2).
- Rosevale (commenced in 2004): irrigated (3) and one unirrigated plot (1).

Soil Chemical Tests

Soil testing was carried out at the inorganic chemistry laboratory of the Centre for Applied Sciences, Agriculture Victoria at Macleod using standard methods (Rayment and Higginson 1992) including:

- pH in water and in 0.01 M $CaCl_2$ both at a soil/water ratio of 1:5
- Electrical conductivity (EC) at a soil/water ratio of 1:5
- Extractable sulphur in 0.01M calcium phosphate
- Exchangeable cations using a compulsive exchange method (0.1M $BaCl_2$ – 0.1M NH_4Cl) after removal of soluble salts with aqueous ethanol (2 washes)

Soil Salinity

Salinity was measured as $EC_{1:5}$ (dS/m) on 1:5 soil-water extracts and EC_{se} (EC of saturation extract) was estimated using the site-specific relationship developed for soils at Ettamogah (Hopmans 2006):

$EC_{se} = 7.0 \times EC_{1:5}$ (n = 148, F = 2162, $R^2 = 0.94$)

Average salinity in root zones under trees (0 - 90 cm) and crops and pastures (0 - 60 cm) was calculated as a water-use-weighted (WUW) average EC_{se} based on weighting factors reflecting the gradient in plant water use with depth as published by Shaw (1999) and adapted for the soil monitoring protocol used at Ettamogah (Hopmans 2006).

Data Analysis

Mean values of soil properties of profile layers under irrigated trees were used to examine changes over time compared with initial values reflecting baseline conditions prior to irrigation. Monitoring of soil properties of irrigated and unirrigated crops and pastures provides a direct comparison and analysis of variance procedures were used to interpret differences in soil profiles due to irrigation with effluent (Statview 1999).

4. RESULTS AND DISCUSSION

4.1. Tree Plantation

Irrigation

Prior to clear-felling irrigation of plantation blocks ceased to reduce soil moisture and increase soil bearing strength in order to minimize disturbance and compaction of soils by harvesting equipment. Irrigation was resumed at low rates after the establishment of second rotation plantings of radiata pine and eucalypt species in 2010 and 2011.

In 2020 annual rainfall (612 mm) was below average for the location (710 mm), this was preceded by dry conditions in 2019 (462 mm) and several years of approximately average rainfall from 2014 to 2018 (Figure 1). Irrigation of trees (1.4 ML/ha) was low compared with previous years (Figure 1) reducing the total hydraulic load (rainfall plus irrigation: 7.5 ML/ha) below that of the preceding five years (range 8.8 to 12.4 ML/ha). The annual load of N, P, Zn and salts (TDS) in 2020 was estimated at 4.3, 0.4, 0.03, and 1307 kg/ha respectively (Appendix 3). The salt load in 2020 (1.3 t/ha) was lower compared with 2019 (3.9 t/ha) and was also less than the average salt load for the period 2012 to 2018 (4.7 ± 1.0 t/ha). Since 2012 lower chemical use at the mill has reduced the salinity of irrigation water (EC range 1.2 to 1.4 dS/m) and this reduced the salt load per unit of irrigation (ML/ha) applied to trees, crops and pastures. Irrigation with effluent continued to 2019 when paper manufacture ceased and the mill was closed temporarily for modifications. Fresh river water was diverted to the storage dam to maintain water levels for irrigation. This reduced the salinity of irrigation water (from 1.2 dS/m to 0.8 dS/m) and contributed to the lower salt loads in 2020.

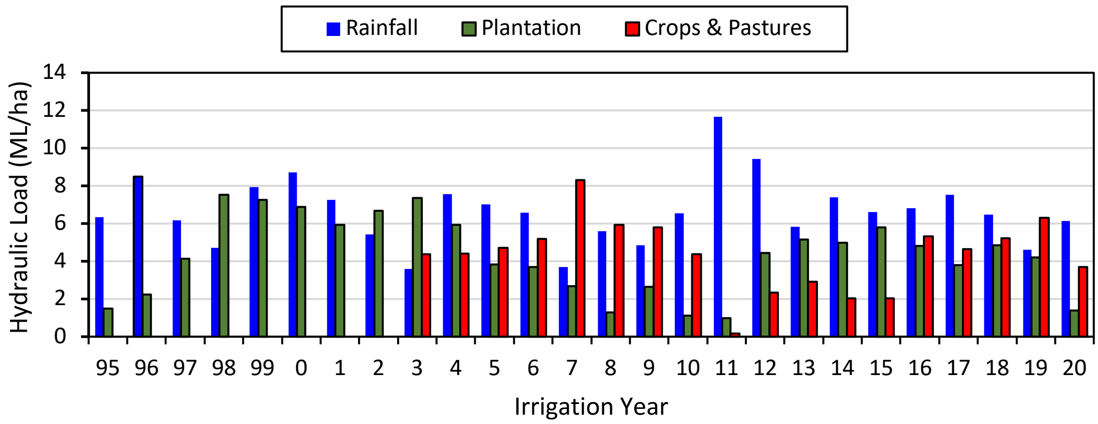

Figure 1. Seasonal rainfall (July – June) and annual irrigation (ML/ha) of the tree plantation at Ettamogah and crops and pastures at Ettamogah and Rosevale.

Chemical Properties

Soil profile samples (0 to 90 cm) were collected at four plots (1.26, 3.02, 3.11 and 3.15) under radiata pine, blue gum and flooded gum. The results of soil pH, salinity (EC), extractable S and exchangeable cations for each layer are shown in Appendix 1. Average values for irrigated soil profile layers in 2020 are presented in Table 1 and annual data for the plantation are shown in Figure 2.

- In 2020 soil pH_{Ca} was moderately acidic (5.5 to 5.8) in the upper layers (0 - 10 and 20 - 30 cm) and was slightly acidic (6.3 to 6.5) in the sub-soils (Table 1). Average soil pH_{Ca} in profiles has increased from 4.8 when irrigation commenced in 1995 to 7.0 in 2002 and remained at this level until 2010 (Figure 2) before declining to slightly acidic conditions during several wet years with low irrigation (Figure 1). In 2020 soil pH_{Ca} remained slightly acidic (Figure 2) after one year of irrigation at a low rate of 1.4 ML/ha.

- Salinity (EC_{se}) decreased to 0.6 and 0.7 dS/m in the upper layers and also declined in the subsoil to 1.1 dS/m (50 – 60 cm) and 1.3 dS/m (80 – 90 cm) compared with previous years (Figure 2 and Table 1). This showed leaching of salts to depth (> 90 cm) under low irrigation (1.4 ML/ha) and salt load (1.3 t/ha) with rainfall of 612 mm in 2020. Salinity in surface soils (0 - 30 cm) has declined below the level (EC_{se} > 1 dS/m) required for soils to remain structurally stable (Hopmans 2006).

- Exchangeable cations (Ca^{2+}, Mg^{2+} and K^{+}) in soil profiles remained at similar levels in 2020 compared with previous years (Figure 2). Ratios of exchangeable Ca/Mg for soil layers declined with depth from 5 to 2 reflecting the higher levels of exchangeable Mg^{2+} in sub-soils (Table 1).

- Exchangeable Na^{+} in soil profiles decreased to lower levels of 0.3, 0.4 and 1.1 cmolc/kg in 2020 compared with the previous year but remained moderately high (1.6 cmolc/kg) at depth (Figure 2). The decline in Na^{+} levels is consistent with the low irrigation and salt load in 2020.

- ESP (exchangeable sodium percentage) declined in the surface soil (4%) indicating non- sodic conditions (ESP < 6%) but soils remained slightly sodic (7%) at 20-30 cm (Table 1). There was little change in ESP in the sub-soils (14% and 17%) and soil profiles remained sodic at depth (Figure 2).

- Levels of extractable S declined to 7, 15, 37 and 49 mg/kg in soil profiles in 2020 (Table 1) indicating a return to sulphate levels prior to irrigation (Figure 2). The decline in extractable S in soil profiles reflects the low irrigation (1.4 ML/ha) as well as a decrease in the concentration of sulphate in effluent diluted with river water in 2020 (13 mg/L) compared with 2019 (195 mg/L).

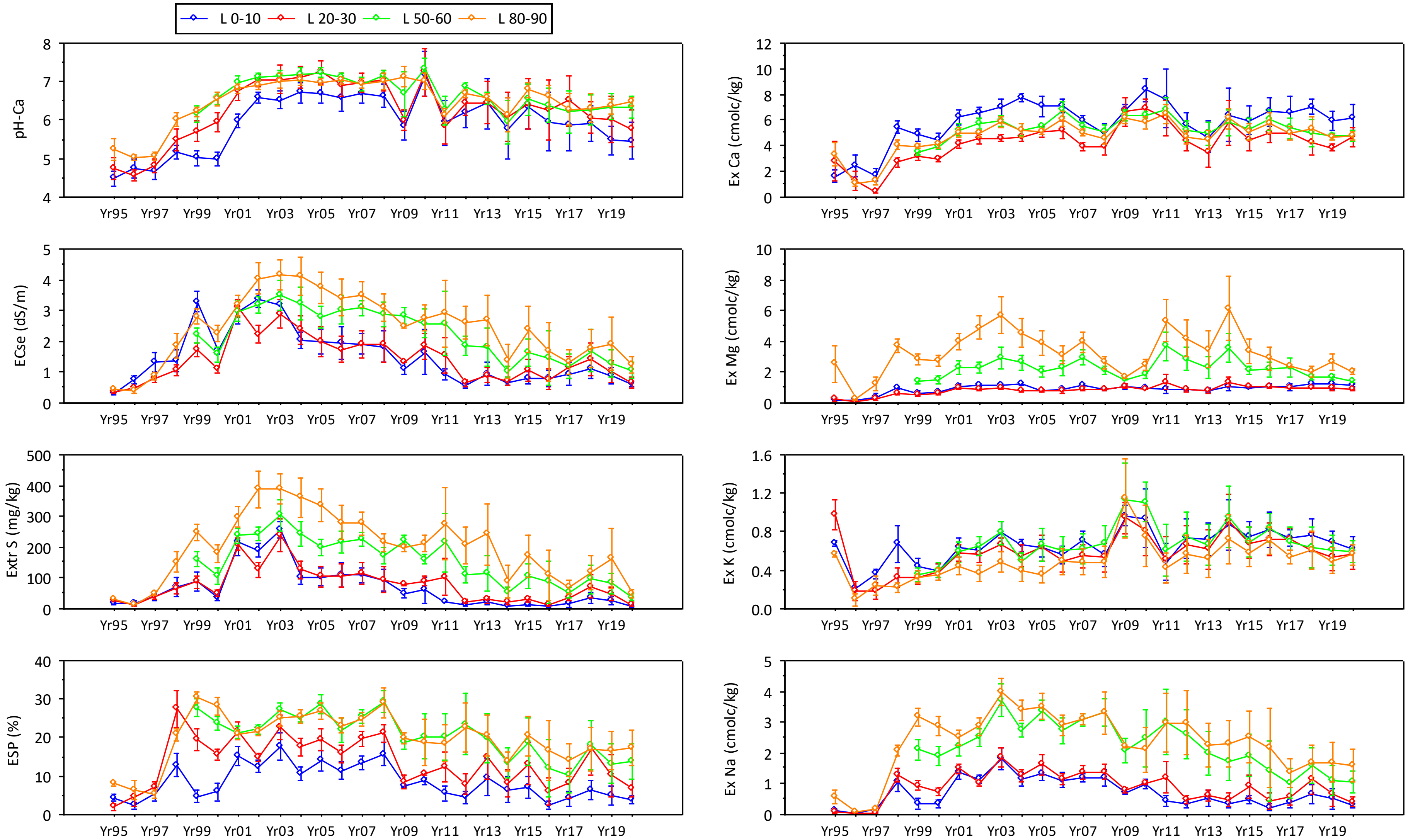

Figure 2. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in plantation soil profiles irrigated with effluent at Ettamogah since 1995 (bars indicate standard deviations). Monitoring of an additional soil profile layer (50 – 60 cm) commenced in 1999.

4.2. Crops and Pastures

Irrigation

Rainfall in 2020 (612 mm) was below average (710 mm) for the region and irrigation of crops and pastures was low at 3.7 ML/ha compared with 6.3, 5.2, 4.6 and 5.3 ML/ha in the previous four years (Figure 1). Likewise, the total hydraulic load (rainfall plus irrigation) was lower at 9.8 ML/ha in 2020 compared with 10.9, 11.7, 12.2 and 12.1 ML/ha in the previous four years. The average loads of N, P, Zn and salts (TDS) in 2020 were estimated at 9.3, 1.1, 0.07 and 3387 kg/ha respectively (Appendix 3). The salt load was lower in 2020 (3.4 t/ha) compared with loads of 5.9, 4.6, 3.9 and 4.7 t/ha in the previous four years.

Chemical Properties

Results of the chemical analysis of soil profiles under crops and pastures at Ettamogah, Maryvale and Rosevale are presented in Appendix 1. Mean values for soil pH, salinity (EC), sodicity (ESP), extractable S, exchangeable cations for profile layers are presented in Table 1; differences between irrigated and unirrigated plots that were statistically significant ($P < 0.05$) are shown in red type. Average pH_{Ca}, EC_{se}, ESP, extractable S and exchangeable cations for irrigated and non-irrigated soil profiles since 2003 (Figure 3) showed long-term changes since irrigation commenced at Maryvale (2003), Rosevale (2004) and Ettamogah where irrigation resumed in 2007 following the harvesting of radiata pine and conversion from tree plantation to crops and pastures.

Comparison of irrigated (12) and unirrigated (5) plots indicated significant differences in pH, salinity (EC_{se}), exchangeable cations, ESP and extractable S in soil profiles due to irrigation with effluent (Table 1 and Figure 3). The effects of irrigation on soil properties are summarized below:

- Soil pH_{Ca} was slightly alkaline in irrigated soil profiles (pH_{Ca} 7.1 to 7.5) in 2020 while conditions were moderately acidic (pH_{Ca} 5.6 to 6.2) in the unirrigated soil (Table 1). The long-term trend showed that pH_{Ca} has increased from acidic to slightly alkaline conditions (pH > 7.0) in irrigated soils (Figure 3). In contrast, pH_{Ca} in the unirrigated soils remained moderately acidic (5 < pH < 6).

- Salinity (EC_{se}) in irrigated surface soils decreased (0.8 and 0.9 dS/m) in 2020 and were slightly above the levels (0.5 and 0.7 dS/m) in unirrigated plots (Table 1). Likewise, salinity decreased at depth (1.3 dS/m) under irrigation in 2020 but remained higher compared with the unirrigated sub-soils (0.8 dS/m). The lower irrigation and salt load in 2020 has decreased the salinity of soil profiles compared with previous years (Figure 3). Salinity in surface soils (0 - 30 cm) has declined below the level (EC_{se} > 1 dS/m) required for soils to remain structurally stable (Hopmans 2006).

- Levels of exchangeable $Ca^{2+}$and Mg^{2+} remained higher in irrigated surface soils but were similar in irrigated and unirrigated sub-soils (Table 1). Levels of exchangeable K^{+} were similar but exchangeable Na^{+} was higher in irrigated soil profiles at lower depths compared with unirrigated soils (Table 1). Ratios of exchangeable Ca/Mg declined with depth in all soils reflecting the higher levels of exchangeable Mg^{2+} in sub-soils (Table 1).

- ESP was low in unirrigated surface soils (ESP 2%) but increased to 11% in sub-soils indicating sodic conditions (ESP > 6%) under natural rainfall (Table 1). Low Irrigation in 2020 maintained non-sodic conditions in surface soils (ESP < 6%) but sub-soils remained sodic (ESP 10% and 23%) under crops and pastures (Table 1). Sodicity in irrigated soil profiles has declined in surface soils but remained high in sub-soils (Figure 3) under lower irrigation (3.7 ML/ha) and salt load (3.4 t/ha) in 2020.

- Irrigation decreased levels of extractable S throughout the soil profile (7 to 48 mg/kg) in 2020 compared with previous years (Figure 3). The decline in extractable S in irrigated soil profiles reflects the decrease in concentration of sulphate in effluent diluted with river water in 2020. Extractable S was low (3 to 27 mg/kg) in unirrigated soil profiles (Table 1).

Table 1. Average pH, salinity (EC), extractable S and exchangeable cations in soil profiles under trees, crops and pastures in 2020.

Site	Treatment	Layer cm	pH-w	pH-Ca	$EC_{1:5}$ dS/m	EC_{se} dS/m	Extr S mg/kg	Exch Ca cmolc/kg	Exch Mg cmolc/kg	Exch K cmolc/kg	Exch Na cmolc/kg	Sum Cations cmolc/kg	ESP %	Exch Ca/Mg
Tree Plantation	Effluent	0-10	6.5	5.5	0.09	0.6	7	6.2	1.1	0.6	0.3	8.3	4	5.6
Ettamogah	Effluent	20-30	6.8	5.8	0.10	0.7	15	4.7	0.9	0.6	0.4	6.5	7	5.5
	Effluent	50-60	7.4	6.3	0.15	1.1	37	4.7	1.4	0.6	1.1	7.8	14	3.3
	Effluent	80-90	7.6	6.5	0.18	1.3	49	4.8	2.1	0.6	1.6	9.0	17	2.4
Crops & Pastures	Nil	0-10	6.7	5.6	0.10	0.7	3	3.7	0.6	0.8	0.1	5.1	2	6.6
Ettamogah, Maryvale	Nil	20-30	7.0	5.9	0.06	0.5	7	3.3	1.4	0.4	0.2	5.3	5	3.7
& Rosevale	Nil	50-60	7.3	6.2	0.12	0.8	27	4.1	4.0	0.3	1.1	9.6	11	1.4
	Effluent#	0-10	8.3	7.5	0.13	0.9	7	8.1	1.0	0.6	0.4	10.0	4	8.9
	Effluent	20-30	8.6	7.5	0.12	0.8	10	5.5	0.9	0.4	0.8	7.6	10	6.3
	Effluent	50-60	8.3	7.1	0.19	1.3	48	5.0	2.6	0.4	2.4	10.4	23	2.2

Values in red type indicate statistically significant differences (*P*<0.05) compared with the value for the corresponding unirrigated soil layer.

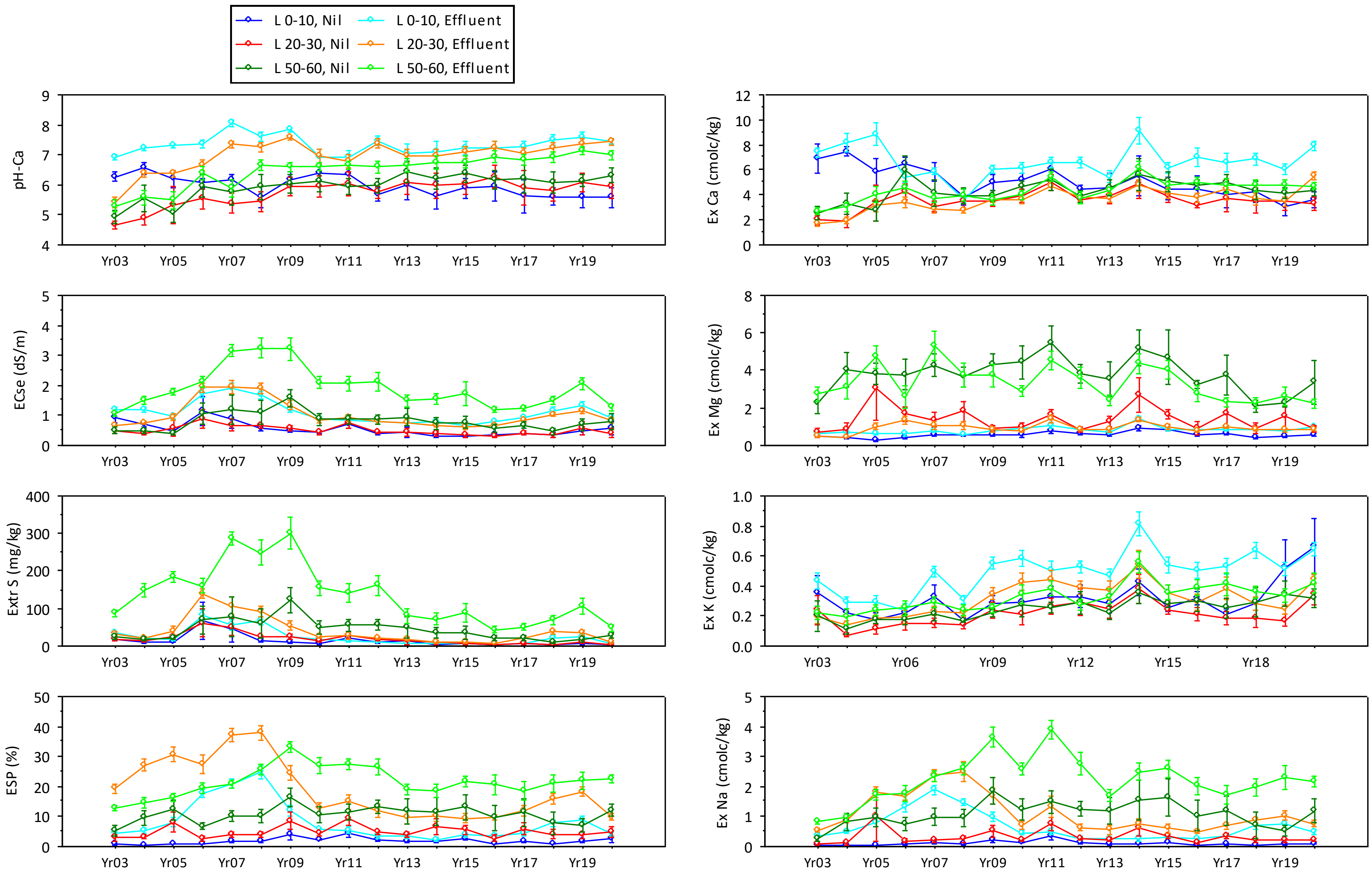

Figure 3. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in soil profiles of crops and pastures under irrigation with effluent and non-irrigated (natural rainfall) since 2003 (bars indicate standard deviations).

4.3. Salinity in Root Zones of Trees, Crops and Pastures

Average water-use weighted salinity (WUW EC_{se}) in soil profiles of trees and crops and pastures were calculated in accordance with the soil monitoring protocol for the effluent re-use scheme (Appendix 2). Average salinity in the root zones of irrigated trees and irrigated and unirrigated agricultural crops and pastures have been summarized in Table 2.

- Average salinity in the root zones of trees in 2020 was estimated at 0.8 ± 0.3 dS/m (Table 2) and was below the salinity threshold level of 4.0 dS/m as required under the current EPA License. Annual monitoring of the effluent irrigated tree plantation showed that root zone salinity in recent years has declined from 1.4 dS/m in 2018 to the present level of 0.8 dS/m (Figure 4).

- Average salinity in the root zones of crops and pastures irrigated with effluent at Ettamogah, Maryvale and Rosevale in 2020 was estimated at 1.0 ± 0.2 dS/m (Table 2) and was below the threshold value of 4.0 dS/m. Reduced irrigation and salt load in 2020 has decreased average root zone salinity from 1.5 ± 0.5 dS/m in 2019 to 1.0 ± 0.2 dS/m at present (Figure 4).

- Average salinity in the root zones of unirrigated crops and pastures at Ettamogah, Maryvale and Rosevale was estimated at 0.6 ± 0.4 dS/m (Table 2).

Table 2. Average water-use weighted salinity (WUW EC_{se}) in root zones under trees, crops and pastures irrigated with paper mill effluent in 2020.

Site	Irrigated (yrs)	WUW EC_{se} (dS/m) Average	Std Dev#	Plots (n)	CoVar† (%)
Tree Plantation					
Ettamogah – Pine & Eucalypt	25	**0.8**	**0.3**	4	40
Irrigated Crops & Pastures					
Ettamogah, Maryvale & Rosevale	17	**1.0**	**0.2**	12	24
Unirrigated Crops & Pastures		**0.6**	**0.4**	5	63

Std Dev: standard deviation

† CoVar: coefficient of variation

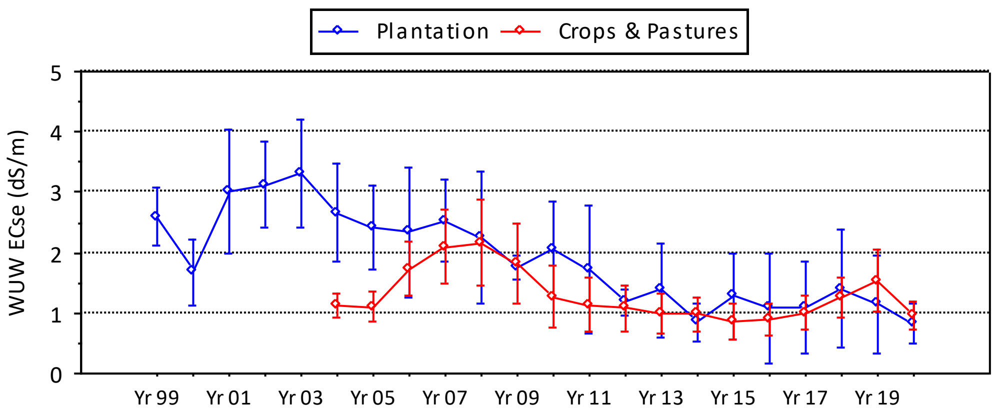

Figure 4. Average salinity (WUW EC_{se}) in the root zones of trees (0 – 90 cm) and crops and pastures (0 – 60 cm) irrigated with paper mill effluent. Bars indicate standard deviations.

5. CONCLUSIONS

In 2020 soil testing was carried out as part of the environmental monitoring program for the effluent re-use scheme at Ettamogah to determine the effects of irrigation on soil properties in the root zones of trees, crops and pastures. Past monitoring has shown that irrigation with effluent increased pH, salinity, sodicity and sulphate in soil profiles while the effects on other properties have been relatively minor. Soil testing has been confined to properties most affected by effluent since the re-use scheme was reviewed in 2013. Irrigation with effluent from the mill continued to 2019 when paper manufacturing ceased and the mill was closed temporarily for modifications. Fresh river water was diverted to maintain water levels in the storage dam for the irrigation of trees, agricultural crops and pastures. This reduced the salinity of irrigation water (EC from 1.2 dS/m to 0.8 dS/m) and contributed to the lower salt loads in 2020.

Salinity of irrigation water in 2020 was low and soil EC_{se} has declined below the level (TEC > 1 dS/m) required for the sodic soils at Ettamogah to stay flocculated and remain structurally stable (Hopmans 2006). Soil physical testing conducted in 2019 showed that irrigated soils readily dispersed in fresh water indicating a collapse of fine structure and porosity. In contrast, dispersion tests in effluent (EC 1.3 dS/m) showed that the fine structure of soils remained stable (no clay dispersion) for a wide range of sodicity in soil profiles. Therefore the EC of irrigation water needs to be increased by adding gypsum to raise soil salinity (EC_{se} > 1.0 dS/m) and maintain the structural stability and hydraulic conductivity of these sodic soils under irrigation with fresh water and natural rainfall.

In 2020 seasonal rainfall (612 mm) was below average and irrigation of trees (1.4 ML/ha) was low. The total hydraulic load (7.5 ML/ha) was below the range for the previous five years (8.8 to 12.4 ML/ha). Crops and pastures were irrigated at a higher rate (3.7 ML/ha) and the total hydraulic load (9.8 ML/ha) was below the range for previous years (10.9 to 12.2 ML/ha). The salt load was lower for trees (1.3 t/ha) compared with crops and pastures (3.4 t/ha) and reflects the difference in irrigation for each land use. In general soil pH, sodicity and to a lesser extent salinity and extractable S remained higher in effluent irrigated soils in 2020. The results for soil testing are summarized below:

- Soils were slightly alkaline in irrigated soil profiles under crops and pastures (pH_{Ca} 7.1 to 7.5) compared with the moderately acidic conditions of unirrigated soils (pH_{Ca} 5.6 to 6.2). Soils under irrigated trees were moderately acidic (pH_{Ca} 5.5 to 5.8) in the upper layers and slightly acidic (pH_{Ca} 6.3 to 6.5) in the sub-soils.
- Exchangeable sodium percentage (ESP) increased with depth from surface soils (4%) to sub-soils (17%) indicating sodic conditions (ESP > 6%) prevailed in soil profiles under irrigated trees. Soils of unirrigated crops and pastures under natural rainfall were non-sodic at the surface (ESP 2%) but were sodic at depth (ESP 11%). Irrigation of crops and pastures increased sodicity in surface soils (ESP 4% to 10%) and sub-soils (ESP 23%).
- Average salinity in root zones of irrigated soils under trees declined to 0.8 dS/m under a lower salt load of 1.3 t/ha in 2020. Average salinity in root zones of irrigated crops and pastures decreased to 1.0 dS/m under a salt load of 3.4 t/ha. Salinity in the root zones of trees as well as crops and pastures was below the threshold value of 4.0 dS/m as required under the EPA License.
- Extractable sulphate in irrigated soils under trees declined in surface soils (7 mg/kg) and sub-soils (49 mg/kg) reflecting the low irrigation rate and the lower concentrations of sulphate in diluted effluent in 2020. Likewise, the levels of sulphate in soil profiles under irrigated crops and pastures declined in surface soils (7 mg/kg) and sub-soils (48 mg/kg). This compared with slightly lower levels in surface soils (3 mg/kg) and sub-soils (27 mg/kg) of unirrigated soils.
- Salinity in surface soils (0 - 30 cm) has declined below the level (EC_{se} > 1 dS/m) required for these sodic soils to remain structurally stable. It is recommended to add gypsum to the irrigation water (increase EC to 1.3 dS/m) to raise soil salinity in profiles (EC_{se} > 1.0 dS/m) in order to maintain soil structure and hydraulic conductivity.

Average salinity in the root zones of trees (0.8 dS/m) and crops and pastures (1.0 dS/m) in 2020 remained below the threshold level of 4.0 dS/m for the re-use scheme under the current EPA License.

6. REFERENCES

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Appendix 1. Results of chemical analysis of soils of the tree plantation at Ettamogah and crops and pastures at Ettamogah, Maryvale and Rosevale in 2020.

Plantation at Ettamogah

Species & Plot	Treatment	Depth (cm)	pH-Ca	pH-W	$EC_{1:5}$ (dS/m)	Extr S (mg/kg)	Exch Ca (cmolc/kg)	Exch Mg (cmolc/kg)	Exch K (cmolc/kg)	Exch Na (cmolc/kg)
Blue gum										
1.26	Irrigated	0-10	6.8	7.6	0.10	4	7.1	1.0	0.3	0.3
1.26	Irrigated	20-30	7.0	8.0	0.12	10	4.6	0.8	0.3	0.6
1.26	Irrigated	50-60	6.6	8.0	0.19	42	4.1	1.6	0.4	1.8
1.26	Irrigated	80-90	6.7	8.0	0.25	64	4.6	2.6	0.5	3.0
Radiata pine										
3.02	Irrigated	0-10	5.5	6.5	0.08	4	8.3	1.2	0.8	0.2
3.02	Irrigated	20-30	5.7	6.5	0.05	2	6.6	0.9	0.8	0.1
3.02	Irrigated	50-60	6.3	7.2	0.08	14	6.0	1.5	0.9	0.3
3.02	Irrigated	80-90	6.5	7.4	0.11	28	5.8	2.0	0.9	0.6
3.11	Irrigated	0-10	4.6	5.9	0.06	7	3.5	0.9	0.9	0.2
3.11	Irrigated	20-30	4.6	5.7	0.06	10	3.1	0.9	0.8	0.3
3.11	Irrigated	50-60	5.6	6.6	0.10	25	4.2	1.4	0.6	0.6
3.11	Irrigated	80-90	6.2	7.3	0.11	28	4.4	1.9	0.6	1.0
Flooded gum										
3.15	Irrigated	0-10	4.9	6.0	0.11	13	5.9	1.4	0.4	0.5
3.15	Irrigated	20-30	5.9	6.9	0.16	36	4.3	0.8	0.3	0.7
3.15	Irrigated	50-60	6.8	7.9	0.23	68	4.6	1.2	0.4	1.5
3.15	Irrigated	80-90	6.5	7.7	0.24	74	4.3	1.8	0.4	1.7

Crops and Pastures

Plot	Treatment	Depth (cm)	pH-Ca	pH-W	EC1:5 (dS/m)	Extr S (mg/kg)	Exch Ca (cmolc/kg)	Exch Mg (cmolc/kg)	Exch K (cmolc/kg)	Exch Na (cmolc/kg)
Ettamogah										
1.03	Irrigated	0-10	7.7	8.5	0.20	7	9.6	1.5	0.8	0.9
1.03	Irrigated	20-30	7.6	8.8	0.16	23	5.6	1.1	0.5	0.9
1.03	Irrigated	50-60	7.1	8.3	0.23	61	4.1	2.0	0.8	2.5
MVP5-2.03	Irrigated	0-10	7.6	8.4	0.14	12	8.3	1.0	0.7	0.3
MVP5-2.03	Irrigated	20-30	7.7	8.6	0.14	12	5.6	0.8	0.5	0.7
MVP5-2.03	Irrigated	50-60	7.4	8.6	0.24	66	5.9	2.3	0.5	2.5
MVP5	Irrigated	0-10	6.9	7.7	0.14	10	6.6	1.1	0.9	0.4
MVP5	Irrigated	20-30	6.7	8.0	0.08	7	3.3	0.7	0.3	0.5
MVP5	Irrigated	50-60	6.0	7.3	0.13	37	3.1	2.0	0.3	1.3
MVC5	Unirrigated	0-10	5.6	6.8	0.04	1	3.5	0.6	0.5	0.0
MVC5	Unirrigated	20-30	6.3	7.6	0.04	1	3.0	0.7	0.3	0.2
MVC5	Unirrigated	50-60	6.6	7.9	0.08	22	4.7	1.9	0.5	1.3
MVP4-2.13	Irrigated	0-10	7.4	8.4	0.13	9	7.6	1.2	0.6	0.9
MVP4-2.13	Irrigated	20-30	7.2	8.4	0.14	21	5.6	1.2	0.4	1.4
MVP4-2.13	Irrigated	50-60	6.8	8.1	0.25	96	5.1	3.4	0.3	2.6
MVC4-2.15	Unirrigated	0-10	5.1	6.2	0.09	4	5.0	0.4	1.1	0.1
MVC4-2.15	Unirrigated	20-30	5.8	6.7	0.04	4	3.4	0.4	0.3	0.1
MVC4-2.15	Unirrigated	50-60	6.4	7.3	0.12	41	5.1	2.6	0.3	0.7
Rosevale										
RVP1.1.1	Irrigated	0-10	7.6	8.2	0.14	5	10.2	0.9	0.4	0.2
RVP1.1.1	Irrigated	20-30	8.0	9.0	0.16	6	5.4	1.2	0.1	1.4
RVP1.1.1	Irrigated	50-60	7.6	8.8	0.27	54	7.0	3.8	0.2	3.6
RVP1.2.1	Irrigated	0-10	7.5	8.1	0.11	5	8.0	0.7	0.4	0.1
RVP1.2.1	Irrigated	20-30	7.6	8.6	0.12	5	5.5	1.0	0.2	0.8
RVP1.2.1	Irrigated	50-60	7.1	8.2	0.21	41	5.7	3.9	0.2	3.2
RVP2.1.1	Irrigated	0-10	7.2	7.8	0.08	3	7.5	0.9	0.4	0.1
RVP2.1.1	Irrigated	20-30	7.3	8.4	0.08	4	5.2	0.9	0.2	0.6
RVP2.1.1	Irrigated	50-60	6.8	8.0	0.18	53	5.0	3.3	0.2	2.8
RVP2.1.2	Unirrigated	0-10	5.5	6.5	0.16	4	3.8	0.7	1.2	0.1
RVP2.1.2	Unirrigated	20-30	5.6	6.6	0.09	15	3.2	3.4	0.5	0.4
RVP2.1.2	Unirrigated	50-60	5.8	6.7	0.13	22	3.2	6.4	0.3	0.8

Crops and Pastures

Plot	Treatment	Depth (cm)	pH-Ca	pH-W	$EC_{1:5}$ (dS/m)	Extr S (mg/kg)	Exch Ca (cmolc/kg)	Exch Mg (cmolc/kg)	Exch K (cmolc/kg)	Exch Na (cmolc/kg)
Maryvale										
MVP2a.1	Irrigated	0 - 10	7.3	8.1	0.11	2	9.3	1.0	0.7	0.2
MVP2a.1	Irrigated	20 - 30	7.5	8.6	0.10	1	6.0	0.7	0.6	0.4
MVP2a.1	Irrigated	50 - 60	7.3	8.7	0.12	9	5.5	1.1	0.7	1.2
MVP2b.1	Irrigated	0 - 10	7.4	8.2	0.08	2	7.0	0.8	0.5	0.1
MVP2b.1	Irrigated	20 - 30	7.2	8.5	0.08	5	5.4	0.8	0.4	0.7
MVP2b.1	Irrigated	50 - 60	7.2	8.5	0.16	37	5.1	1.9	0.4	2.1
MVP2c.2	Irrigated	0 - 10	7.8	8.7	0.16	14	8.5	1.0	0.5	0.8
MVP2c.2	Irrigated	20 - 30	8.0	8.8	0.17	17	6.8	0.9	0.4	1.1
MVP2c.2	Irrigated	50 - 60	7.6	8.9	0.21	49	5.0	1.7	0.3	2.7
MVP3a.1	Irrigated	0 - 10	7.6	8.3	0.11	3	7.5	0.8	0.7	0.3
MVP3a.1	Irrigated	20 - 30	7.5	8.5	0.10	3	6.3	0.8	0.5	0.5
MVP3a.1	Irrigated	50 - 60	6.9	8.4	0.12	23	4.3	2.3	0.3	2.0
MVP3b.1	Irrigated	0 - 10	7.5	8.4	0.13	11	7.1	0.7	0.5	0.4
MVP3b.1	Irrigated	20 - 30	7.5	8.5	0.11	13	5.0	0.8	0.3	0.6
MVP3b.1	Irrigated	50 - 60	6.7	7.9	0.18	55	4.3	3.5	0.3	2.5
MVC2a	Unirrigated	0 - 10	6.5	7.2	0.17	3	4.0	0.5	0.8	0.1
MVC2a	Unirrigated	20 - 30	6.7	7.6	0.13	6	4.7	1.4	0.6	0.3
MVC2a	Unirrigated	50 - 60	6.7	7.7	0.21	41	4.6	6.8	0.3	2.3
MVC3c	Unirrigated	0 - 10	5.1	6.6	0.02	2	2.1	0.9	0.3	0.2
MVC3c	Unirrigated	20 - 30	4.9	6.4	0.03	6	2.1	1.0	0.2	0.3
MVC3c	Unirrigated	50 - 60	5.6	7.0	0.04	10	3.0	2.2	0.2	0.5

Appendix 2. Salinity in root zones of trees, crops and pastures in 2020.

Ettamogah Plantation

Site	Soil Unit	Plot	Treatment	Layer	$EC_{1:5}$	EC_{se}	WU	WUW EC_{se} (dS/m)	
				(cm)	(dS/m)	(dS/m)	Factor	Layer	Profile
Ettamogah	Unit 4	1.26	Effluent	0-10	0.104	0.73	0.41	0.30	
Ettamogah	Unit 4	1.26	Effluent	20-30	0.115	0.81	0.21	0.17	
Ettamogah	Unit 4	1.26	Effluent	50-60	0.194	1.36	0.25	0.34	
Ettamogah	Unit 4	1.26	Effluent	80-90	0.250	1.75	0.13	0.23	1.03
Ettamogah	Unit 1	3.02	Effluent	0-10	0.078	0.55	0.41	0.22	
Ettamogah	Unit 1	3.02	Effluent	20-30	0.053	0.37	0.21	0.08	
Ettamogah	Unit 1	3.02	Effluent	50-60	0.081	0.57	0.25	0.14	
Ettamogah	Unit 1	3.02	Effluent	80-90	0.113	0.79	0.13	0.10	0.55
Ettamogah	Unit 2	3.11	Effluent	0-10	0.059	0.41	0.41	0.17	
Ettamogah	Unit 2	3.11	Effluent	20-30	0.061	0.43	0.21	0.09	
Ettamogah	Unit 2	3.11	Effluent	50-60	0.096	0.67	0.25	0.17	
Ettamogah	Unit 2	3.11	Effluent	80-90	0.113	0.79	0.13	0.10	0.53
Ettamogah	Unit 4	3.15	Effluent	0-10	0.109	0.76	0.41	0.31	
Ettamogah	Unit 4	3.15	Effluent	20-30	0.157	1.10	0.21	0.23	
Ettamogah	Unit 4	3.15	Effluent	50-60	0.233	1.63	0.25	0.41	
Ettamogah	Unit 4	3.15	Effluent	80-90	0.239	1.68	0.13	0.22	1.17
								Average	**0.82**
								Std Dev	**0.33**
								Covar%	**40**

Ettamogah, Maryvale and Rosevale Crops and Pasture: Irrigated Plots

Site	Soil Unit	Plot	Treatment	Layer	$EC_{1:5}$	EC_{se}	WU	WUW EC_{se} (dS/m)	
				(cm)	(dS/m)	(dS/m)	Factor	Layer	Profile
Ettamogah	Unit 3	1.03	Effluent	0-10	0.201	1.41	0.53	0.75	
Ettamogah	Unit 3	1.03	Effluent	20-30	0.157	1.10	0.28	0.31	
Ettamogah	Unit 3	1.03	Effluent	50-60	0.225	1.58	0.19	0.30	1.35
Ettamogah	Unit 2	MVP5-2.03	Effluent	0-10	0.140	0.98	0.53	0.52	
Ettamogah	Unit 2	MVP5-2.03	Effluent	20-30	0.138	0.96	0.28	0.27	
Ettamogah	Unit 2	MVP5-2.03	Effluent	50-60	0.244	1.71	0.19	0.32	1.11
Ettamogah	Unit 2	MVP5	Effluent	0-10	0.142	0.99	0.53	0.53	
Ettamogah	Unit 2	MVP5	Effluent	20-30	0.079	0.55	0.28	0.16	
Ettamogah	Unit 2	MVP5	Effluent	50-60	0.130	0.91	0.19	0.17	0.85
Ettamogah	Unit 3	MVP4-2.13	Effluent	0-10	0.131	0.92	0.53	0.49	
Ettamogah	Unit 3	MVP4-2.13	Effluent	20-30	0.144	1.01	0.28	0.28	
Ettamogah	Unit 3	MVP4-2.13	Effluent	50-60	0.248	1.74	0.19	0.33	1.10
Maryvale	Unit 2	MVP2a.1	Effluent	0-10	0.107	0.75	0.53	0.40	
Maryvale	Unit 2	MVP2a.1	Effluent	20-30	0.101	0.70	0.28	0.20	
Maryvale	Unit 2	MVP2a.1	Effluent	50-60	0.123	0.86	0.19	0.16	0.76
Maryvale	Unit 2	MVP2b.1	Effluent	0-10	0.083	0.58	0.53	0.31	
Maryvale	Unit 2	MVP2b.1	Effluent	20-30	0.084	0.59	0.28	0.16	
Maryvale	Unit 2	MVP2b.1	Effluent	50-60	0.159	1.12	0.19	0.21	0.68
Maryvale	Unit 4	MVP2c.2	Effluent	0-10	0.158	1.10	0.53	0.59	
Maryvale	Unit 4	MVP2c.2	Effluent	20-30	0.173	1.21	0.28	0.34	
Maryvale	Unit 4	MVP2c.2	Effluent	50-60	0.212	1.49	0.19	0.28	1.21
Maryvale	Unit 4	MVP3a.1	Effluent	0-10	0.107	0.75	0.53	0.40	
Maryvale	Unit 4	MVP3a.1	Effluent	20-30	0.096	0.67	0.28	0.19	
Maryvale	Unit 4	MVP3a.1	Effluent	50-60	0.118	0.82	0.19	0.16	0.74
Maryvale	Unit 4	MVP3b.1	Effluent	0-10	0.126	0.88	0.53	0.47	
Maryvale	Unit 4	MVP3b.1	Effluent	20-30	0.112	0.78	0.28	0.22	
Maryvale	Unit 4	MVP3b.1	Effluent	50-60	0.175	1.23	0.19	0.23	0.92
Rosevale	Unit 3	RVP1.1.1	Effluent	0-10	0.137	0.96	0.53	0.51	
Rosevale	Unit 3	RVP1.1.1	Effluent	20-30	0.159	1.11	0.28	0.31	
Rosevale	Unit 3	RVP1.1.1	Effluent	50-60	0.272	1.91	0.19	0.36	1.18
Rosevale	Unit 3	RVP1.2.1	Effluent	0-10	0.110	0.77	0.53	0.41	
Rosevale	Unit 3	RVP1.2.1	Effluent	20-30	0.122	0.85	0.28	0.24	
Rosevale	Unit 3	RVP1.2.1	Effluent	50-60	0.207	1.45	0.19	0.28	0.92
Rosevale	Unit 4	RVP2.1.1	Effluent	0-10	0.077	0.54	0.53	0.28	
Rosevale	Unit 4	RVP2.1.1	Effluent	20-30	0.082	0.58	0.28	0.16	
Rosevale	Unit 4	RVP2.1.1	Effluent	50-60	0.180	1.26	0.19	0.24	0.68
								Average	**0.96**
								SDEV	**0.23**
								COVAR%	**23.6**

Ettamogah, Maryvale and Rosevale Crops and Pasture: Unirrigated Plots

Site	Soil Unit	Plot	Treatment	Layer	$EC_{1:5}$	EC_{se}	WU	WUW EC_{se} (dS/m)	
				(cm)	(dS/m)	(dS/m)	Factor	Layer	Profile
Ettamogah	Unit 4	MVC5	Nil	0-10	0.037	0.26	0.53	0.14	
Ettamogah	Unit 4	MVC5	Nil	20-30	0.035	0.25	0.28	0.07	
Ettamogah	Unit 4	MVC5	Nil	50-60	0.084	0.59	0.19	0.11	0.32
Ettamogah	Unit 4	MVC4-2.15	Nil	0-10	0.095	0.66	0.53	0.35	
Ettamogah	Unit 4	MVC4-2.15	Nil	20-30	0.044	0.31	0.28	0.09	
Ettamogah	Unit 4	MVC4-2.15	Nil	50-60	0.121	0.84	0.19	0.16	0.60
Maryvale	Unit 2	MVC2a	Nil	0-10	0.166	1.16	0.53	0.62	
Maryvale	Unit 2	MVC2a	Nil	20-30	0.127	0.89	0.28	0.25	
Maryvale	Unit 2	MVC2a	Nil	50-60	0.212	1.48	0.19	0.28	1.15
Maryvale	Unit 4	MVC3c	Nil	0-10	0.025	0.17	0.53	0.09	
Maryvale	Unit 4	MVC3c	Nil	20-30	0.029	0.20	0.28	0.06	
Maryvale	Unit 4	MVC3c	Nil	50-60	0.038	0.27	0.19	0.05	0.20
Rosevale	Unit 4	RVP2.1.2	Nil	0-10	0.164	1.15	0.53	0.61	
Rosevale	Unit 4	RVP2.1.2	Nil	20-30	0.086	0.60	0.28	0.17	
Rosevale	Unit 4	RVP2.1.2	Nil	50-60	0.130	0.91	0.19	0.17	0.95
								Average	**0.64**
								SDEV	**0.40**
								COVAR%	**62.7**

Appendix 3. Annual rainfall, pan evaporation, irrigation and loads of nitrogen, phosphorus, zinc and total dissolved solids (TDS) in effluent applied from 1st July 2019 to 30th June 2020 to tree plantations, crops and pastures.

Irrigation year	Rainfall	Evaporation	Rainfall	Irrigation:	Total hydraulic	Irrigation:	Total hydraulic	N		P		Zn		TDS	
1 July - 30 June				trees	load: trees	pasture	load: pasture	trees	pasture	trees	pasture	trees	pasture	trees	pasture
	(mm)	(mm)	(ML/ha)	(ML/ha)	(ML/ha)	(ML/ha)	(ML/ha)	(kg/ha)		(kg/ha)		(kg/ha)		(kg/ha)	
2019 - 2020	612	1398	6.1	1.4	7.5	3.7	9.8	4.3	9.3	0.40	1.10	0.03	0.07	1307	3387