

## Supplementary Material

### **Some soil factors constraining buffel grass (*Cenchrus ciliaris* L.) seedling growth rate across a range of acid red Kandosols in Queensland, Australia**

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Supplementary data tables S1 and S2

**Table S1. Correlations between seedling growth rates and soil parameters.** Strong correlations (>0.80) in bold font.

|                    | <i>F.C. (%)</i> | <i>A.D. wtr (%)</i> | <i>pH wtr</i> | <i>pH 1 M KCl</i> | <i>E.C. (mS/cm)</i> | <i>Cl (ppm)</i> | <i>Acid P (ppm)</i> | <i>Bicarb P (ppm)</i> | <i>Eff. C.E.C. (me%)</i> | <i>Exch. Ca<sup>2+</sup> (me/100g)</i> | <i>Exch. Mg<sup>2+</sup> (me/100g)</i> | <i>Exch. Ca<sup>2+</sup> + Exch. Mg<sup>2+</sup> (me/100g)</i> |
|--------------------|-----------------|---------------------|---------------|-------------------|---------------------|-----------------|---------------------|-----------------------|--------------------------|--|--|--|
| Sow to emerge -P   | 0.30            | 0.39                | 0.13          | 0.10              | 0.09                | 0.06            | -0.21               | -0.14                 | 0.36                     | 0.39                                   | 0.28                                   | 0.35   |
| Sow to emerge +P   | 0.41            | 0.47                | -0.01         | -0.12             | 0.23                | 0.28            | -0.17               | -0.09                 | 0.37                     | 0.33                                   | 0.27                                   | 0.31   |
| Sow to emerge Δ    | 0.06            | 0.01                | -0.17         | -0.26             | 0.13                | 0.24            | 0.09                | 0.07                  | -0.06                    | -0.14                                  | -0.07                                  | -0.12  |
| Sow to L3 appce -P | -0.35           | -0.32               | -0.37         | -0.50             | -0.33               | -0.18           | -0.67               | -0.66                 | -0.35                    | -0.48                                  | -0.21                                  | -0.38  |
| Sow to L3 appce +P | -0.14           | -0.01               | -0.31         | -0.47             | -0.20               | -0.08           | -0.44               | -0.39                 | -0.13                    | -0.23                                  | -0.04                                  | -0.16  |
| Sow to L3 appce Δ  | -0.40           | -0.42               | -0.34         | -0.45             | -0.34               | -0.20           | -0.69               | -0.69                 | -0.41                    | -0.52                                  | -0.27                                  | -0.43  |
| Sow to L4 F/exp -P | -0.53           | -0.42               | -0.27         | -0.37             | -0.27               | -0.15           | -0.53               | -0.58                 | -0.40                    | -0.49                                  | -0.22                                  | -0.39  |
| Sow to L4 F/exp +P | -0.32           | -0.20               | -0.33         | -0.40             | -0.21               | -0.20           | -0.36               | -0.35                 | -0.28                    | -0.36                                  | -0.15                                  | -0.28  |
| Sow to L4 F/exp Δ  | -0.54           | -0.44               | -0.25         | -0.35             | -0.27               | -0.13           | -0.53               | -0.59                 | -0.40                    | -0.49                                  | -0.22                                  | -0.39  |
| Length Leaf 4 -P   | 0.27            | 0.17                | 0.33          | 0.43              | 0.14                | -0.04           | <b>0.86</b>         | <b>0.85</b>           | 0.20                     | 0.31                                   | 0.10                                   | 0.23   |
| Length Leaf 4 +P   | 0.14            | 0.02                | 0.04          | 0.09              | 0.01                | -0.03           | 0.56                | 0.57                  | 0.00                     | 0.06                                   | -0.09                                  | 0.00   |

|                       |       |       |       |       |       |       |       |       |       |       |       |       |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Length Leaf 4 Δ       | -0.23 | -0.21 | -0.40 | -0.49 | -0.17 | 0.02  | -0.65 | -0.63 | -0.26 | -0.35 | -0.22 | -0.31 |
| Emerge to L3 app -P   | -0.43 | -0.42 | -0.39 | -0.51 | -0.34 | -0.19 | -0.57 | -0.59 | -0.45 | -0.57 | -0.29 | -0.47 |
| Emerge to L3 app +P   | -0.48 | -0.39 | -0.32 | -0.39 | -0.39 | -0.31 | -0.32 | -0.33 | -0.44 | -0.51 | -0.26 | -0.42 |
| Emerge to L3 app Δ    | -0.37 | -0.40 | -0.38 | -0.52 | -0.29 | -0.12 | -0.64 | -0.65 | -0.42 | -0.55 | -0.28 | -0.45 |
| L3 app to L4 F/Exp -P | -0.55 | -0.44 | -0.25 | -0.34 | -0.26 | -0.14 | -0.49 | -0.56 | -0.40 | -0.48 | -0.22 | -0.39 |
| L3 app to L4 F/Exp +P | -0.38 | -0.27 | -0.31 | -0.34 | -0.20 | -0.23 | -0.29 | -0.30 | -0.32 | -0.38 | -0.19 | -0.31 |
| L3 app to L4 F/Exp Δ  | -0.55 | -0.44 | -0.23 | -0.33 | -0.25 | -0.12 | -0.50 | -0.57 | -0.40 | -0.48 | -0.21 | -0.38 |
| Emerge to L4 F/Exp -P | -0.54 | -0.44 | -0.28 | -0.37 | -0.27 | -0.15 | -0.51 | -0.57 | -0.42 | -0.51 | -0.23 | -0.41 |
| Emerge to L4 F/Exp +P | -0.42 | -0.31 | -0.32 | -0.36 | -0.26 | -0.26 | -0.31 | -0.32 | -0.36 | -0.43 | -0.21 | -0.35 |
| Emerg to L4 F/Exp Δ   | -0.54 | -0.44 | -0.26 | -0.36 | -0.26 | -0.12 | -0.53 | -0.59 | -0.41 | -0.50 | -0.23 | -0.40 |

**Table S1 continued**

|                  | <i>Exch. Na<sup>+</sup></i><br><i>(me/100g)</i> | <i>Exch. K<sup>+</sup></i><br><i>(me/100g)</i> | <i>Exch.</i><br><i>Acidity</i><br><i>(me/100g)</i> | <i>Exch. Al<sup>3+</sup></i><br><i>(me/100g)</i> | <i>% Al</i><br><i>satn</i> | <i>Exch.</i><br><i>Al<sup>3+</sup> /</i><br><i>Exch.</i><br><i>Ca<sup>2+</sup></i> | <i>Exch.</i><br><i>Al<sup>3+</sup> /</i><br><i>Ca<sup>2+</sup> +</i><br><i>Mg<sup>2+</sup></i> | <i>ESP =</i><br><i>100*Na<sup>+</sup></i><br><i>/C.E.C.</i> | <i>Base</i><br><i>saturation</i><br><i>(%)</i> | <i>Exch.</i><br><i>Ca<sup>2+</sup> /</i><br><i>C.E.C.</i><br><i>(%)</i> |
|------------------|---|--|--|--|----------------------------|--|--|---|--|---|
| Sow to emerge -P | -0.06   | 0.27   | -0.09  | -0.15  | -0.37                      | -0.34  | -0.42  | -0.50   | 0.33   | 0.23  |

|                       |       |       |       |       |             |             |       |       |              |              |
|-----------------------|-------|-------|-------|-------|-------------|-------------|-------|-------|--------------|--------------|
| Sow to emerge +P      | 0.07  | 0.37  | 0.13  | 0.09  | -0.22       | -0.32       | -0.33 | -0.53 | 0.21         | 0.05         |
| Sow to emerge Δ       | 0.15  | 0.05  | 0.27  | 0.30  | 0.24        | 0.09        | 0.19  | 0.06  | -0.20        | -0.25        |
| Sow to L3 appce -P    | -0.34 | -0.42 | 0.47  | 0.48  | 0.72        | 0.72        | 0.67  | 0.03  | -0.73        | <b>-0.82</b> |
| Sow to L3 appce +P    | -0.17 | -0.26 | 0.38  | 0.37  | 0.42        | 0.60        | 0.30  | -0.17 | -0.42        | -0.62        |
| Sow to L3 appce Δ     | -0.37 | -0.44 | 0.45  | 0.47  | 0.77        | 0.67        | 0.74  | 0.12  | -0.77        | <b>-0.80</b> |
| Sow to L4 F/exp -P    | -0.34 | -0.54 | 0.33  | 0.35  | 0.65        | 0.70        | 0.58  | 0.16  | -0.65        | -0.71        |
| Sow to L4 F/exp +P    | -0.21 | -0.39 | 0.31  | 0.32  | 0.48        | <b>0.86</b> | 0.41  | 0.01  | -0.47        | -0.63        |
| Sow to L4 F/exp Δ     | -0.35 | -0.54 | 0.31  | 0.34  | 0.65        | 0.64        | 0.59  | 0.18  | -0.65        | -0.69        |
| Length Leaf 4 -P      | 0.28  | 0.21  | -0.38 | -0.37 | -0.56       | -0.47       | -0.51 | 0.11  | 0.58         | 0.69         |
| Length Leaf 4 +P      | 0.08  | 0.09  | -0.03 | -0.05 | -0.21       | -0.61       | -0.16 | 0.15  | 0.19         | 0.41         |
| Length Leaf 4 Δ       | -0.31 | -0.20 | 0.47  | 0.45  | 0.57        | 0.10        | 0.54  | -0.02 | -0.61        | -0.56        |
| Emerge to L3 app -P   | -0.30 | -0.49 | 0.47  | 0.51  | <b>0.80</b> | 0.79        | 0.76  | 0.18  | <b>-0.80</b> | <b>-0.85</b> |
| Emerge to L3 app +P   | -0.23 | -0.57 | 0.28  | 0.31  | 0.62        | <b>0.88</b> | 0.58  | 0.26  | -0.61        | -0.68        |
| Emerge to L3 app Δ    | -0.31 | -0.41 | 0.52  | 0.55  | <b>0.82</b> | 0.68        | 0.78  | 0.14  | <b>-0.81</b> | <b>-0.86</b> |
| L3 app to L4 F/Exp -P | -0.34 | -0.55 | 0.30  | 0.32  | 0.63        | 0.69        | 0.56  | 0.18  | -0.63        | -0.68        |
| L3 app to L4 F/Exp +P | -0.20 | -0.42 | 0.25  | 0.27  | 0.47        | <b>0.90</b> | 0.42  | 0.09  | -0.45        | -0.58        |
| L3 app to L4 F/Exp Δ  | -0.35 | -0.55 | 0.29  | 0.32  | 0.62        | 0.62        | 0.56  | 0.19  | -0.62        | -0.67        |

|                       |       |       |      |      |      |             |      |      |       |       |
|-----------------------|-------|-------|------|------|------|-------------|------|------|-------|-------|
| Emerge to L4 F/Exp -P | -0.34 | -0.55 | 0.33 | 0.36 | 0.66 | 0.72        | 0.60 | 0.18 | -0.66 | -0.72 |
| Emerge to L4 F/Exp +P | -0.22 | -0.47 | 0.26 | 0.29 | 0.52 | <b>0.91</b> | 0.48 | 0.14 | -0.51 | -0.62 |
| Emerge to L4 F/Exp Δ  | -0.35 | -0.54 | 0.33 | 0.36 | 0.66 | 0.64        | 0.60 | 0.18 | -0.66 | -0.70 |

**Table S2. Correlations amongst the various buffel grass seedling growth rate measures between sowing time and the full expansion of the 4<sup>th</sup> leaf.**

| Parameters          | Sow to           |                  |               |                    |                    |                    | Length    |           | Emerge       |              | L3 app         | L3 app         | Emerge         | Emerge         | Δ   |
|---------------------|------------------|------------------|---------------|--------------------|--------------------|--------------------|-----------|-----------|--------------|--------------|----------------|----------------|----------------|----------------|---|
|                     | Sow to emerge -P | Sow to emerge +P | L3 appce -P   | Sow to L3 appce +P | Sow to L4 F/exp -P | Sow to L4 F/exp +P | Leaf 4 -P | Leaf 4 +P | to L3 app -P | to L3 app +P | to L4 F/Exp -P | to L4 F/Exp +P | to L4 F/Exp -P | to L4 F/Exp +P | Emerg to L4 F/Exp   |
| Sow to emerge -P    | 1                |                  |               |                    |                    |                    |           |           |              |              |                |                |                |                |   |
| Sow to emerge +P    | 0.672            | 1                |               |                    |                    |                    |           |           |              |              |                |                |                |                | V strong correln betw Time to L3 appnce & later plant size & growth rate -P & size of fert P response |
| Sow to L3 appce -P  | -0.003           | 0.017            | 1             |                    |                    |                    |           |           |              |              |                |                |                |                | Strong correln between Time to L3 appearce & time to L4 FE when P fert added                          |
| Sow to L3 appce +P  | 0.224            | 0.439            | 0.792         | 1                  |                    |                    |           |           |              |              |                |                |                |                | Strong correln between time to L4 FE & time to L3 appearance -P                                       |
| Sow to L4 F/exp -P  | -0.073           | -0.087           | <b>0.952</b>  | 0.753              | 1                  |                    |           |           |              |              |                |                |                |                | V strong correln between Time to L4 FE -P & growth rate for all early stages                          |
| Sow to L4 F/exp +P  | -0.073           | -0.014           | 0.777         | <b>0.857</b>       | 0.784              | 1                  |           |           |              |              |                |                |                |                | V strong correln betw Time to L4 FE +P & earlier growth rate  |
| Length Leaf 4 -P    | -0.121           | -0.188           | <b>-0.895</b> | -0.697             | -0.825             | -0.581             | 1         |           |              |              |                |                |                |                |   |
| Length Leaf 4 +P    | -0.160           | -0.058           | -0.718        | -0.726             | -0.748             | -0.812             | 0.658     | 1         |              |              |                |                |                |                |   |
| Emerge to L3 app -P | -0.312           | -0.191           | <b>0.951</b>  | 0.684              | <b>0.927</b>       | 0.761              | -0.813    | -0.633    | 1            |              |                |                |                |                |   |

|                             |        |        |              |       |              |              |        |        |              |              |              |              |              |       |   |
|-----------------------------|--------|--------|--------------|-------|--------------|--------------|--------|--------|--------------|--------------|--------------|--------------|--------------|-------|---|
| Emerge to L3 app +P         | -0.319 | -0.365 | 0.807        | 0.676 | <b>0.851</b> | <b>0.900</b> | -0.568 | -0.705 | <b>0.865</b> | 1            |              |              |              |       |   |
| L3 app to L4 F/Exp -P       | -0.085 | -0.105 | <b>0.933</b> | 0.738 | <b>0.998</b> | 0.776        | -0.803 | -0.746 | <b>0.913</b> | <b>0.851</b> | 1            |              |              |       |   |
| L3 app to L4 F/Exp +P       | -0.201 | -0.218 | 0.698        | 0.714 | 0.725        | <b>0.972</b> | -0.475 | -0.776 | 0.725        | <b>0.918</b> | 0.722        | 1            |              |       |   |
| Emerge to L4 F/Exp -P       | -0.124 | -0.121 | <b>0.947</b> | 0.738 | <b>0.999</b> | 0.783        | -0.815 | -0.736 | <b>0.938</b> | <b>0.864</b> | <b>0.998</b> | 0.732        | 1            |       |   |
| Emerge to L4 F/Exp +P       | -0.241 | -0.267 | 0.744        | 0.715 | 0.777        | <b>0.967</b> | -0.513 | -0.768 | 0.782        | <b>0.960</b> | 0.775        | <b>0.992</b> | 0.786        | 1     |   |
| Emerge to L4 F/Exp $\Delta$ | -0.095 | -0.086 | <b>0.940</b> | 0.705 | <b>0.993</b> | 0.708        | -0.834 | -0.693 | <b>0.923</b> | 0.801        | <b>0.992</b> | 0.644        | <b>0.992</b> | 0.704 | 1 |

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Strong correlation between Time from emergence to L3 appearance +/- P & later growth rate -P & magnitude of P fertiliser response

Strong correlation between Time from emergence to L3 appearance with P fertiliser & subsequent growth rate +/- P fertiliser

Extremely strong correlations between time from L3 appearance to L4 FE -P & magnitude of P fertiliser response and also emergence to L4 FE -P

Extremely strong correlation between L3 appearance to L4 FE time interval with added P & time from emergence to L4 full expansion

Extremely strong correlation between time from coleoptile emergence to L4 FE growth stage -P & magnitude of the P fertiliser response by a given soil