# Impact of waterlogging on growth of perennial ryegrass

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**Report for NIWA**

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# 1. Executive Summary

The purpose of this review was to consider the published and grey literature for information on the impact of waterlogging on growth of perennial ryegrass to inform work on the impacts of sea level rise (through water table depth). This included the impact of duration of waterlogging, the depth of the water table, plant/pasture age and, if possible, quantification of impacts. Impacts of salinity on perennial ryegrass were also of interest, including any interactions between waterlogging and salinity.

In general:

- Although the searches found numerous papers on waterlogging in perennial ryegrass, only a small number of them quantified impacts on yield that were relevant for the purpose of this review.
    - This was consistent with several recent papers, including a review paper that quantified the impact of waterlogging in forage grasses, both of which only included a small number of studies for perennial ryegrass.
- Other studies could not be included as they did not contain information useful for this review as they:
    - Did not present numerical information quantifying impacts – that is data were presented in graphs, not tables from which percentage changes could be calculated, at least not without extracting values from these graphs. Percentage changes were not described in the text or only quantitatively e.g. “minimal”.
    - Did not provide sufficient information describing the waterlogging treatment.
    - Did not provide information describing the plant material used.
- Experimental conditions in the studies were very variable including plant age, depth of waterlogging/waterlogging treatment, duration of waterlogging, plant material (seed versus vegetative tillers, different cultivars or genotypes), inclusion of recovery time, etc.
- Most studies were pot trials and there was very little information from field studies.
- Due to the low number of studies and variable conditions it was therefore not possible to group the studies into ranges of impact under different waterlogging conditions.
    - In general, the changes in yield presented in this report ranged from -59% to +34%, including some studies with no (or at least not statistically significant) impacts.
- Therefore, it was not possible to definitively answer questions from the project scope around duration of waterlogging, depth of waterlogging, and influence of plant age.

    - It is likely that the impact of waterlogging will vary with plant maturity, but this review could not separate impact by plant age.
        - From the literature there are also indications that plant size, leaf stage, and the presence of different root types (seedling versus adventitious) could also be relevant factors.
    - The results from pot studies may have some relevance to the impact of increasing water tables on waterlogging to the soil surface (or groundwater emergence) but not where there is waterlogging at depth.
    - Pot studies will also not include the damaging effects of grazing on waterlogged soils.
    - There was very little balanced data on the depth of the water table in field situations.
        - The general results in different field studies were not always the same, showing both decreases and increases in yield with shallower water tables. This could be due to local soil or water table conditions.
        - It is possible that waterlogging could be tolerated to relatively shallow depths as most perennial ryegrass roots are in the top 10-20 cm of the soil profile. However, as noted above, shallow water tables could have other negative impacts through soil structure and treading damage.
        - Plants may also adapt to waterlogging by decreasing roots at depth and increasing surface rooting to avoid waterlogged layers, and by changes to root type and anatomy.
        - Some authors also commented on oxygen concentrations in surface soil versus deeper layers under waterlogging.
    - Although available data was also not sufficient to determine impact ranges for duration of waterlogging, a paper by Donohue *et al*. (1984) suggested that there is a critical waterlogging threshold (such as from longer periods. of waterlogging) above which impacts don’t increase. There were indications of this in this review, but figures were confounded by other factors such as plant age.
        - As above, plants may adapt over time to longer periods of waterlogging, for example by changing root types and anatomy, as well as root depth distribution.
- Although there were more search results for salinity and perennial ryegrass than for waterlogging, there were still relatively few relevant for this review.

    - As with waterlogging, these were mostly pot studies with very little data from the field, and there was variability or some limitation in the experimental conditions.
    - A number of sources cited salinity tolerance ranges for perennial ryegrass although these (and units used) varied slightly – e.g. 6-8 mS/cm, 4-8 dS/m, 6-10 dS/m (mS = milliSiemens, dS = deciSiemens).
    - The range of impact for salinity on plant yield was narrower than for waterlogging (generally 30-40% and up to 48% in one study) but the highest salinity treatments were several times higher in concentration than the reported tolerance ranges.
    - No data was found for the impact of differing durations of salinity stress on forage types of perennial ryegrass.
- For both waterlogging and salinity there is variation in tolerance within perennial ryegrass. It's possible that impacts for New Zealand bred cultivars could differ to those reported, but few studies included recent New Zealand cultivars.
- Search results for this report found very few papers on combined waterlogging and salinity stress in perennial ryegrass, and those were for turf types.
    - As for the individual stresses, there was therefore insufficient data to provide even envelopes of impact.
    - Note also that data from controlled studies using artificial growing media may not accurately represent field conditions as they do not replicate the impacts from ion toxicity created by waterlogging in soil or include the additional damage caused by grazing on waterlogged soils.
    - Combined stresses, including that of waterlogging and salinity, were mentioned in a recent review as an area in need of future work in forage grasses generally.

# 2. Background

"The purpose in the review is to inform the relationship between ground water table levels and pasture health and productivity."

This is aimed at informing the impact of increasing groundwater levels from sea level rise.

The scope of the review covered a number of points if information on these was available:

- Where possible, reported freshwater impacts:
    - Distil information on the tolerance of ryegrass to freshwater saturation in general.

    - Make observations, from the literature, on how long perennial ryegrass pasture can be submerged in freshwater before there is an impact on productivity.
        - How long root zone saturation can be tolerated before impacts occur.
        - Observe the range of impacts depending on age of the plants – e.g. whether younger plants with shallower root systems are more or less vulnerable to harm.
        - Identify where practical the origin of the heuristic “that 3 days of submergence kills the perennial ryegrass pasture” (from Litherland 2004).
    - Any impacts on productivity or operating costs from saturation/inundation of the root zone to different depths.
- Advise (where possible) reported salinity impacts:
    - Distil information of the tolerance of perennial ryegrass to salinity generally.
    - Make observations from the literature about how long perennial ryegrass pasture can be subjected to different levels of salinity before there are impacts on productivity.
- And comment on potential impacts of combined saturation and salinity.

# 3. Method

A review of published and grey literature was conducted using online resources (Scopus, Medline, Google Scholar, Google, CAB Abstracts).

Initial literature searches looked for resources related to “waterlogging”, “salinity” and “perennial ryegrass”. This produced 37 results related to waterlogging (including total submergence) and 89 results related to salinity. A few publications considered combined waterlogging and salinity stress.

After reviewing the search results a second search was conducted incorporating “water table” to try and find more results from field-based studies.

The number of search results of relevance to this study was small. Although the scope of the project was perennial ryegrass an additional search was conducted to determine if there was more information on waterlogging in other temperate grass species, particularly those relevant to New Zealand pastoral systems such as tall fescue and cocksfoot.

At the request of the project team, data from the relevant sources was summarised by citation, age of plants, depth/degree/description of waterlogging, duration of waterlogging, impact, and other variables such as source of plant material, experimental conditions, recovery periods etc.

A table grouping impacts by degree and depth of waterlogging would have been valuable for the project team, however it was not possible to assemble a robust summary due to the relatively small number of results, and the variable experimental conditions, for studies including perennial ryegrass.

# 4. Results and Discussion

## 4.1 Freshwater impacts

### 4.1.1 Search results – available data

A key paper was a recent review by Di Bella *et al*. (2022) on waterlogging in forage grasses. The authors considered their paper, along with that by Striker and Colmer (2017), to have reviewed all the available literature on waterlogging in both forage grasses and legumes.

After conducting a literature search, Di Bella *et al*. (2022) filtered the results based on their criteria which included excluding papers on full submergence and non-agronomic studies.

There were 45 papers with data to calculate waterlogging tolerance and/or compare root porosity/aerenchyma for 15 perennial forage grass species, including perennial ryegrass. Thirty-eight of the papers included data on the effect of waterlogging on plant biomass.

However, only four papers met their criteria for perennial ryegrass.

From the literature search conducted for this report only a few additional papers were found that contained numerical data on yields under waterlogging for perennial ryegrass, with sufficient experimental detail to describe waterlogging treatments.

A very recent paper by Braun and Patton (2024) included perennial ryegrass amongst 11 temperate grass species, although these all seem to be turf types of perennial ryegrass rather than forage cultivars. The citations in that paper related to perennial ryegrass were also found by the current searches suggesting that the existing literature has been well captured.

Relevant citations are shown in Table 1.

In general, the literature on impacts of waterlogging on perennial ryegrass yields is relatively limited, with high variability among studies in experimental conditions and waterlogging treatments (see Table 1). This includes:

- Type of study (pots, field, hydroponics) – and size/depth of containers.
- Growing media (soil, sand, nutrient solutions).
- Depth of waterlogging.

- Duration of waterlogging.
- Age of plants.
- Origin of experimental plants (seed vs clonal propagation of tillers).

Some papers only included qualitative descriptions of the impact (e.g. “minimal”), or data were presented in figures without numerical data on yields or quantification of the size of the impact. Others included some quantification of impact but poor description of experimental conditions.

### 4.1.2 Variable experimental conditions

In the 38 papers reviewed by Di Bella *et al*. (2022) that included data on the effect of waterlogging on biomass of forage grasses:

- 89% were in pots (34 studies, n = 110 samples).
- 8% were in nutrient solutions (3 studies, n = 9).
- only 3% were in the field (1 study, n=22 – 2 for one species and 22 for another).

This reflects the general findings of the literature searches from the current review, that most waterlogging studies on perennial ryegrass are from pot trials and so may not accurately reflect the impact of waterlogging under field conditions.

Depth of waterlogging in the 38 studies in Di Bella *et al*. (2022), across species, ranged from:

- at the soil surface (24% of experiments).
- to 10 cm above the surface (varying degrees of partial submergence; 76%).

This also reflects the general findings of this review that many of the studies in pots have involved waterlogging of the whole root zone or flooding/partial submergence of the shoots.

In the four papers reviewed by Di Bella *et al*. (2022) which included perennial ryegrass:

- The “depth” of the waterlogging included:
    - 1 cm above the soil surface.
    - 5 mm below the brim of the pot.
    - at the soil surface.
    - watered to field capacity of the soil type.
- Duration of waterlogging ranged from 7-163 days (only one paper included recovery).
- Growing media in three of the studies used sand, and one used soil.

| Citation | Plant source | Plant material | Age of plants | Growing conditions | Waterlogging conditions | Duration | Recovery | Individual cultivar, genotype, or experiment | Change in shoot DW relative to control (%) | Change in root DW relative to control (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Yin et al. (2017)[1] | Seed | Two cultivars | 4 months | Sand? | At the soil surface | 7 days | n/a | Inspired | 0 | - 30 |
| | | | | | | | | Catalina | - 6 | +29 |
| McFarlane *et al*. (2003)[1] | One clonal tiller | Four genotypes (from one cultivar and three accessions) | 4 weeks | Pots, sand | 1 cm above surface | 28 days | n/a | Nth African 6 | -20 | -38 |
| | | | | | | | | 2182 | -33 | -64 |
| | | | | | | | | 2178 | -59 | -62 |
| | | | | | | | | Aurora 6 | +20 | -27 |
| Staines *et al*. (2012) | Seed? | | 2 years<br>Harvests done at 3-leaf stage | Pots 40cm high, sandy soil | < 40cm below ground level (BGL), fluctuating to replicate local water table movements, mean was 15 cm BGL | After 49 days | | | No significant difference | |
| | | | | | | After 95 days | | | Data only presented in a figure, estimate just over a 20% decrease from this[2] | |
| | | | | | | | 55 days | | No significant differences. | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | And no differences over whole 233 days | |
| Hesse *et al*. (2005)[1] | Four clonal tillers | Two genotypes | 5 weeks | Pots, sand | 5 mm below the brim | 49 days | 21 days | Genotype B | +34 | |
| | | | | | | | | Genotype M | -4 | |
| Leddin *et al*. (2003) | Seed | Eight cultivars | "seedlings" at 3-4 leaf stage | Not described | Not described | 53 days | n/a | | -52 on average[3] | -48[4] |
| Braun and Patton (2024) | Seed | One cultivar (Apple 3GL), two experiments | 9 weeks | Pots, sand | At the surface | 55 days | n/a | Expt. 1 | -28 | -3 |
| | | | | | | | | Expt. 2 | -43 | -9 |
| Laidlaw (2009)[1] | Seed (87 seed/pot) | One cultivar (Tivoli) | 1 year | Pots, loam soil | 1.25 times field capacity | 163 days | n/a | | -15 | |
| Donohue *et al*. (1984) | Seed | One cultivar (Nui) | 18 months | Field | Flood irrigation, ponding for 0, 24 or 48 hours at 8-day intervals | Approx. 4.5 months | n/a | | -25 | |

[1] Details from Di Bella *et al*. (2022).
[2] Note this harvest date included 6 days of recovery time.
[3] The negative effect occurred somewhere between 28-42 days.
[4] The negative effect occurred somewhere between 7-14 days.

*Table 1: Summary of studies on waterlogging and perennial ryegrass, where sufficient detail was available on plant material, experimental conditions, and quantified impacts on shoot yield (in order of waterlogging duration). DW = dry weight. Where citations contain data for multiple cultivars, genotypes or experiments the individual values are given for changes in shoot and root yield.*

| Citation | Plant source | Plant material | Age of plants | Growing conditions | Waterlogging conditions | Duration | Recovery | Individual cultivar or genotype | Change in shoot yield relative to control (%) | Change in root DW relative to control (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Menon-Martinez *et al*. (2021)[1] | | 7 cultivars | 46 days | Agar nutrient solution | Deoxygenated the growing media | 14 days | 14 days | Barverde | -24 | -66 |
| | | | | | | | | Bar 2025 | -18 | -30 |
| | | | | | | | | Baralta | -0 | -5 |
| | | | | | | | | Royal Q100 | -13 | -21 |
| | | | | | | | | Tunisia | -2 | -10 |
| | | | | | | | | Aprilia | -10 | -34 |
| | | | | | | | | Cajun II | -27 | -32 |
| Ploschuk *et al*. (2017)[1] | Seed | One cultivar (Malma) | 42 days | 20 cm deep pots, sand:soil | 1 cm above surface | 15 days | 15 days | | +5 | -47 |
| Jansen *et al*. (2005)[1] | | One cultivar (Dovey) | | Pots, sand and compost | At the surface | 21 days | n/a | | -5 | -26 |
| Liu *et al*. (2017)[1] | | One cultivar (Rebel XLR) | Plants with 4 leaves | Pots, potting soil | At the surface | 28 days | n/a | | -24 | -43 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Zhang *et al*. (2013)[1] | | One cultivar (Stonewall) | 4 months old | Pots, sand and topsoil | At the surface | 28 days | n/a | | +161 | -20 |
| Braun and Patton (2024) | Seed | One cultivar (Bonfire), two experiments | 9 weeks old | Pots, sand | At the surface | 55 days | n/a | Expt. 1 | -16 | -32 |
| | | | | | | | | Expt. 2 | -26 | -13 |

[1] Data on shoot and root yield relative to control from Di Bella et al. (2022).

*Table 2: Summary of studies on waterlogging and tall fescue, where sufficient detail was available on plant material, experimental conditions, and quantified impacts on shoot yield (in order of waterlogging duration). DW = dry weight. Where citations contain data for multiple cultivars, genotypes or experiments the individual values are given for changes in shoot and root yield.*

| Citation | Plant source | Plant material | Age of plants | Growing conditions | Waterlogging conditions | Duration | Recovery | Individual cultivar or genotype | Change in shoot yield relative to control (%) | Change in root DW relative to control (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ploschuk *et al*. (2017)[1] | Seed | One cultivar (Omea) | 42 days old | Pots, soil:sand mix | 1 cm above the surface | 15 days | 15 days |  | -6 | -35 |
| Klaas *et al*. (2019)[1] |  | One cultivar (Sparta) | 8 weeks old | Pots, soil | "water level of 5-8cm" | 15 days | n/a |  | -33 | n/a |
| Etherington (1984)[1] | Clonal tillers | Two clones |  | Pots, soil | 1 cm above the surface | 84 days | n/a | Clone A<br>Clone L | -59<br>-45 | -58<br>-53 |
| Etherington and Thomas (1986)[1] | Clonal tillers | Two clones (same as Etherington 1984) |  | Pots, peat-soil mix | 1 cm above the surface | 97 days | n/a | Clone A<br>Clone L | -6<br>-3 | n/a |

[1] Data on shoot and root yield relative to control from Di Bella et al. (2022).

*Table 3: Summary of studies on waterlogging and cocksfoot, where sufficient detail was available on plant material, experimental conditions, and quantified impacts on shoot yield (in order of waterlogging duration). DW = dry weight. Where citations contain data for multiple cultivars, genotypes or experiments the individual values are given for changes in shoot and root yield.*

- In two studies, plants were grown from seed, and experimental plants were:
    - 4 months old, or
    - 1 year old.
- In two studies, plants were propagated from tillers and experimental plants were:
    - 4 weeks old (grown from one tiller), or
    - 5 weeks old (grown from four tillers).

Given the depth (and range) of waterlogging in these four studies, results might have relevance for situations where water table rise causes waterlogging right to the soil surface, or groundwater emergence, but may not provide data relevant for waterlogging at depth with lower or "normal" soil moisture nearer the surface. Whether partial submergence has an additive effect on top of waterlogging is unclear. As mentioned above, data from pot studies will also not have incorporated the additional impact of animal grazing on waterlogged soils.

### 4.1.3 The tolerance of ryegrass to freshwater saturation

Di Bella *et al*. (2022) used shoot growth relative to controls (not waterlogged) to classify waterlogging tolerance (sensitive = median < 50% of controls; intermediate = median 50-75% of controls; tolerant = 75-100% of controls; very tolerant = median is 100% of controls). Note that all 15 species were classed as intermediate to tolerant.

Perennial ryegrass was described as one of the more tolerant species. Median relative shoot growth was only 6% lower than the control (see Table 4). However, keep in mind the wide variability in experimental conditions.

Braun and Patton (2024) classified perennial ryegrass as being of fair to medium tolerance.

| | **Shoot biomass** | | | **Root biomass** | | |
|---|---|---|---|---|---|---|
| | Median relative to control (%) | Q1 (%) | Q3 (%) | Median relative to control (%) | Q1 (%) | Q3 (%) |
| Perennial ryegrass | 94 a | 73 | 110 | 67 a | 44 | 87 |
| Tall fescue | 87 a | 76 | 100 | 70 b | 57 | 80 |
| Cocksfoot | 80 b | 52 | 95 | 47 na | 42 | 65 |

*Table 4: Data from Di Bella et al.* (2022) *for median and quartile values (relative to control) for shoot and root biomass under waterlogging across studies for perennial ryegrass, cocksfoot and tall fescue. a = median not different to the control (100%), b = 75% < median < 100%, na = not enough data for analysis (using Wilcoxon signed rank tests).*

Table 4 also includes the data from Di Bella *et al*. 2022 for tall fescue and cocksfoot, two other common perennial grass species used in New Zealand which are considered more tolerant of drought and dry conditions than perennial ryegrass. In that study cocksfoot was one of the least tolerant $C_3$ species to waterlogging, which may be consistent with its tolerance of dry conditions though tall fescue is also a species adapted to dry conditions.

This is consistent with several other studies which also found cocksfoot to be more sensitive to waterlogging than other grass species that it was compared to, such as Rogers and Davies (1973) (compared with four grass species, including perennial ryegrass and tall fescue) and Nguyen (2022) (compared to tall fescue).

### 4.1.4 Duration of saturation

It was difficult to draw conclusions on the duration of waterlogging which impacts perennial ryegrass productivity from the published data due to the small number of studies and variability in plant ages and experimental conditions.

Although it might be tempting to see some trends of increasing impact with increasing duration in Table 1, these could be confounded by plant age. For example, 0-6% decreases in yield with 7 days of waterlogging in 4-month-old plants (Yin *et al*. 2017) compared with 52% for 53 days of waterlogging but in “seedlings” (Leddin *et al*. 2003).

Even at similar durations the impacts were variable, for example two studies in Table 1 which included durations of 49 days. In one, using 2-year-old plants, there was no difference in yield between waterlogged and control plants. In the other, using 5-week-old plants propagated from tillers, the yields increased by 34% for one genotype and decreased by 4% for another. The latter also illustrates the variability in responses among different cultivars or genotypes.

In field studies on ponding from irrigation, even short periods of “waterlogging” had an impact on yields. Donohue *et al*. (1984) studied the effect of different durations of ponding on a pure ryegrass sward, from flood irrigation applied every eight days for approximately four and a half months (late November to early April in Victoria, Australia). Both 24 and 48 hours of ponding decreased yields by 25% - so increasing ponding to 48 hours had no additional effect. This was despite the 48-hour ponding treatment experiencing longer times below the optimal soil oxygen levels.

Dunbabin *et al*. (1997) conducted a similar field experiment, in New South Wales, with different durations of surface ponding (4, 12 or 24 hours) at different frequencies of irrigation. They also concluded that, with frequent irrigation, increasing ponding from 12 to 24 hours had no additional impacts on yield. Measurement of soil oxygen found short periods of ponding (4 hours) would increase waterlogging stress but, as with Donohue *et al*. (1984), increasing ponding to 24 hours had a small impact. However, Donohue *et al*. (1984) found the number of days below a critical soil oxygen concentration, per irrigation cycle, increased with ponding duration in both the 0-0.1 m and 0.1-0.2 m soil layers.

With tall fescue and cocksfoot, Nguyen (2022) noted that waterlogging started to have negative effects on root traits after 14 to 21 days, and tiller development after 21 days. Leddin *et al*. (2003) noted that negative impacts occurred between 28-42 days. However, Donohue *et al*. (1984) speculated that with repeated waterlogging perennial ryegrass may reach a critical level above which there is no additional impact and cited several papers they felt supported this (in this case longer durations were also potentially important). For example, Rogers and Davies (1973) where mean yields reduced by 25%, though not statistically, in plants that had experienced 112 days of waterlogging compared with well drained plants. Donohue *et al.* (1984) concluded that, in their study, plants were adapting to low oxygen levels caused by 24 and 48 hours of ponding by producing new roots, and that this was triggered by a critical waterlogging level.

It may be worth noting that both Rogers and Davies (1973) and Donohue *et al*. (1984), in studies running for relatively longer periods of time (112 days in pots and repeated waterlogging for 4.5 months in the field, respectively), as well as a modelling study by Grieve *et al*. (1986) based on the Murray Valley region of NSW, all found 25% decreases in ryegrass or ryegrass/white clover sward yields.

**Recovery**

Di Bella *et al*. (2022) suggested recovery from waterlogging is not often measured - only one of the four perennial ryegrass studies included in their review measured this. There is probably little data available on recovery to incorporate into models.

In their paper, Di Bella *et al*. (2022) gave some examples where different conclusions about a species' performance would be made based on data during waterlogging versus recovery. Some species which performed well under waterlogging in their review had low growth compared to the controls (not waterlogged) during recovery, and some which had poor growth under waterlogging performed as well as the controls during recovery.

A similar situation could be reflected in the data shown in Staines *et al*. (2012) where there were significant decreases in perennial ryegrass yield after 95 days of waterlogging, but no differences between waterlogged and control treatments after 55 days of recovery (and no differences overall for the 233 days of the experiment).

### 4.1.5 Origin of the heuristic that "ryegrass pastures don't survive 3 days of submergence".

Litherland (2004) specifically states that "Pastures that have been under water for 2-3 days will probably recover, but those under water for a week or more in warm summer conditions will be dead".

It seems that Boswell (1979) is likely the source of much of the information in Litherland (2004) based on similarities in their summaries about the conditions under which flooding will have the worst effects (see Table 5).

Boswell stated that the duration of flooding that grass species used in New Zealand could tolerate was not well documented and considered them "relatively intolerant particularly perennial ryegrass". But also stated that "Perennial ryegrass can be expected to survive continued flooding for 7-8 days before mortality occurs". Note that ryegrass genetics will have changed since that time.

| Boswell (1979) | Litherland (2004) |
|---|---|
| In late spring when soil temperatures have risen | If flooding occurs when soil temperatures are warm |
| Following soon after hard grazing | A pasture has been hard grazed |
| If the floods are deep enough to submerge all parts of the plants | (In the text states that pastures with leaf tips above water will survive) |
| If flooding is prolonged | Flooding is prolonged |
| If flooding is accompanied by at least 5 cm of silt | Pastures are covered by at least 5 mm of silt (given other similarities with Boswell this could possibly be a typographical error?) |

*Table 5: Summaries from Boswell (1979) and Litherland (2004) regarding when the worst effects of flooding in pastures will occur.*

Flooding or submergence impacts plants through decreases in light levels and gas exchange – both of which affect photosynthesis and ultimately plant growth – as well as stresses which cause physiological damage. Silt in flood waters will also exacerbate impacts of low light conditions.

Colmer and Voesenek (2009) and Striker and Colmer (2017) summarise two main plant strategies to cope with submergence:

- Escape – where growth, particularly elongation of shoots, continues in order to get shoots above the surface of the water (and access light and $CO_2$).

- Quiescence – where growth stops, to either conserve energy for physiological processes that enable the plants to survive submergence stress, or for recovery of growth once water has receded. Submergence induces the production of compounds called radical oxygen species which damage plant tissues, requiring the production of protective antioxidants.

The comments in Litherland (2004) and Boswell (1979) that pasture with shoots above the water will survive flooding may reflect the escape strategy. However, different species may use different strategies. Strategies could also vary within a species, depending on both conditions and plant genetics.

For example, the forage legume *Lotus tenuis* exhibits an escape strategy during partial submergence and quiescence during full submergence (Manzur *et al*. 2009). Yu *et al*. (2012) also found both quiescent and escape types among 99 populations of perennial ryegrass with 7 days of total submergence followed by recovery.

### 4.1.6 Plant maturity

It is likely that plant age will affect the impact of waterlogging, but again it was not possible to quantify this due to the limited number of studies and variable conditions. Essentially there were not enough papers to group combinations of plant age and severity of waterlogging.

In the four studies in Di Bella *et al*. (2022) which included perennial ryegrass some experiments were sown from seed and some were vegetatively propagated using tillers. Plant age included 4 months (from seed), 1 year (from seed), and 4-week-old or 5-week-old clonal plants grown from one or four tillers respectively.

Depth of roots in younger plants may not be the only factor to consider. Di Bella *et al*. (2022) specifically mentioned plant size when discussing the highly variable impacts seen for shoot biomass in two studies with tall fescue. The study with the highest values – 161% increase in shoot yield – used 4-month-old plants, whereas plants in other studies were much younger (e.g. 46 days old).

Di Bella *et al*. (2022) also suggested plant developmental stage is important. In the same cultivar of tall wheat grass (*Thinopyrum ponticum*), waterlogging in plants of relatively similar ages at different leaf stages had quite different impacts – an approximately 50% decrease in shoot biomass for 33-day-old plants at the 3-leaf stage compared with an approximately 50% increase for 48-day-old plants at the 5-leaf stage.

Donohue *et al*. (1984) commented that seminal (seedling) roots may "cease to function" within 24 to 48 hours of anaerobic conditions whereas adventitious roots or roots adapted to low oxygen conditions can still develop in saturated soil. Both seminal and adventitious roots from the tiller bases are present in relatively young grass plants.

Nguyen (2022) speculated that the differences observed between two experiments in their study with tall fescue and cocksfoot could be due to the formation of aerenchyma (air spaces) in primary (seminal) versus adventitious roots in the different aged plants used (6 weeks old v 14 weeks old). However, they only measured aerenchyma in adventitious roots.

Plant age and developmental stage relative to time of year and agronomic practices will also be important. For example, temperate species are normally sown in autumn, so the impact of autumn and winter waterlogging could be greater for newly sown pastures compared with well-established ones. Di Bella *et al.* (2022) suggested the impact of autumn and winter waterlogging needs to be further studied and understood.

### 4.1.7 Depth of saturation

As mentioned in Section 4.1.2 there were very few field studies in general, let alone balanced quantitative data, meaning it is even more difficult to make any definite conclusions about the impact of water table depth.

Some qualitative conclusions from several papers for forages grasses were also contradictory. For example, Warda *et al*. (2008) noted decreases in perennial ryegrass yields with shallower water tables over a 10-year period in field plots (under grazing). Panov and Shishkov (1974) made similar observations for annual ryegrass and timothy yields in 1-2 m tall lysimeters over 3 years (under manual cutting), where yields generally increased with deeper mean water table depths (ranging from approx. 60-150 cm).

This contrasts with Mueller *et al*. (2005) who concluded that grasses grew well at shallow water tables in field plots and lysimeters in lowland north-eastern Germany. Across different plant types, yields decreased with deeper water tables (<40 cm to 160 cm) which was attributed to shallow root systems and low capillary flow in local soil profiles. This may reflect the potential effect of local soil conditions on the impact of water table depth.

In general, most perennial ryegrass root mass is in the top 10-20 cm of the soil profile both in the field and controlled conditions (Houlbrooke 1996; Crush *et al*. 2010). Plants may also increase surface root mass, and decrease roots at depth, to avoid waterlogging in deeper soil layers (Blaikie *et al*. 1988; Waddington and Zimmerman 1972), which could also contribute to adaptation over time (Section 4.1.4). Both these factors could enable ryegrass to tolerate waterlogging to relatively shallow depths, taking into account previous points about soil oxygen in the 0-10 cm layer, but this requires further investigation. However, shallower root systems could also have further negative impacts on nutrient uptake, grazing damage from treading and pulling, and drought stress.

## 4.2 Salinity impacts

### 4.2.1 Search results – available data

Compared with waterlogging, there were a lot more search results for salinity and perennial ryegrass. However, many of these were about impacts on seed germination, the effect of applying treatments to ameliorate salinity (particularly on germination), gene expression or physiology etc. – generally these were excluded from consideration unless they contained some quantitative yield data.

Many of the remaining studies were on perennial ryegrasses for turf rather than forage types or did not specify in the title or abstract whether the focus was on turf or forage types. Some searching was done to try and identify the cultivars mentioned in the methods to focus on studies that included forage cultivars. For the scope of this review, studies exclusively on turfgrasses were excluded, and the citations presented in Table 6 involve forage cultivars or genetically diverse collections.

As the main focus of this review was on waterlogging, less time was spent distilling the information on salinity. However, given the search results and filtering described above, there were still relatively few relevant papers despite there being more results overall than for waterlogging.

Note that many salinity studies would involve irrigation water or soil water with a different ionic composition to that from sea water intrusion. Salinity in these cases being dissolved salts rather than “salt water” (predominantly Na and Cl) per se. Measures of salinity using electrical conductivity will not necessarily take into consideration the ionic composition.

Similar comments to those about waterlogging, can be made about the work on salinity:

- Many of the scientific studies were conducted in pots in the glasshouse, very few were from the field.

- As with waterlogging these pot studies may be relevant for salinity in the root zone, as would occur with irrigation using saline water, but less so for salinity at depth from increasing water tables.

- Pot studies were usually in sand rather than soil as this would allow total concentrations of ions to be controlled.

    - These were watered with solutions of sodium chloride (NaCl), so different experiments are perhaps more comparable than for waterlogging as treatments are expressed in concentrations of NaCl (usually in mM).

- Units of salinity treatments in field studies differed to pot studies - total dissolved solids (TDS), or electrical conductivity (EC) in dS/m (deciSiemens) or mS/cm (milliSiemens) - although dS/m equivalents to the mM treatments were provided by some authors.

    - In field situations, salinity treatments were also applied through irrigation as this was usually the issue being investigated rather than increasing salinity in the water table.

    - Note as above, that "salinity" in these studies is not necessarily comparable to salinity from sea water intrusion, whereas NaCl applied in pot studies may be more relevant (while taking into consideration concentration levels as below, and other differences between controlled and field conditions).

    - Table 6 contains no studies from New Zealand and perhaps only two, very old, New Zealand bred cultivars. Tang *et al*. (2013b) grouped ryegrass accessions according to salinity tolerance and found that genetically related accessions had similar tolerance levels - therefore it is possible that New Zealand cultivars could differ to those from other genetic backgrounds.

- Several authors commented that the plant germplasm, concentration and duration of salinity, and growth system used will affect variation in either growth or concentrations of salinity used for screening tolerance.

### 4.2.2 Impacts on yield

Perennial ryegrass is described in various sources as tolerant or moderately tolerant to salinity though growth stage is also noted as being of importance, with yield being reduced in seedlings (e.g. Liddicoat and McFarlane (2007), McLaren and Cameron (1996)).

Tolerance ranges of electrical conductivity (EC) cited in different sources vary slightly, though as noted by Snow *et al*. (1998) thresholds will vary with soil conditions, climate, management practices, cultivar etc.:

- McLaren and Cameron (1996) – 6-8 mS/cm ($EC_e$) ("tolerant").

- Tang *et al*. (2013) – "moderate in salinity tolerance for commercial cultivars, tolerating soil $EC_e$…ranging from 4-8 dS/m".

- Koch *et al*. (2017) – "moderately salt tolerant up to salinity levels of 6-10 dS/m".

- Note Tang *et al.* and Koch *et al*. cite different EC ranges, from the same source.

- Snow *et al*. (1998) describe ryegrass as having medium salinity tolerance (for all dissolved salts), with a critical EC of 5.6 dS/m or 3,584 mg/L.

- Government of Western Australia, Department of Primary Industries and Regional Development website includes perennial ryegrass in a list of species tolerant of moderately saline sites (400-800 mS/m or 4-8 dS/m).

- Rogers, Noble and Pederick (1996) also describe perennial ryegrass as being moderately tolerant.

A figure that appeared several times in guidelines and technical reports from Australia indicates that perennial ryegrass begins to be affected by soil salinity at about 6 dS/m, with yield reduced by 50% at just over 12 dS/m (Liddicoat and McFarlane 2007, Coorong District Council, Turner unknown).

Table 6 also summarises scientific citations with relevant data and information.

In some studies, only one relatively high salinity treatment was applied in addition to the control, most likely due to the purpose those studies (e.g. to study gene expression or look for tolerant accessions). In those and other studies the maximum treatment was 300 mM NaCl, which the authors describe as equivalent to approximately 25 dS/m – four to eight times higher than the tolerance ranges listed above.

Compared with the waterlogging studies in Table 1, decreases in yield under salinity covered a much narrower range (mostly in the range of 30-40%, and up to 48% in one case). However, as noted, the maximum salinity treatments used were considerably higher than the tolerance ranges reported for the species.

The results of Tang *et al*. (2013a) where there was no effect of salinity up to 100 mM NaCl or ≈8.4 dS/m (and decreases in yield above that) are consistent with the tolerance ranges reported above for perennial ryegrass. Several studies reported increases in yield at salinity levels that were considerably lower than those used in other studies e.g. Liu *et al*. (2018) and Mehanni and West (1992).

Rogers (2007) found relatively small (10-15%) decreases in yield averaged across four species, including perennial ryegrass, at 4.5 dS/m - which is at or below the range of reported tolerance. However these results were from the field, which may have some confounding factors compared to pot studies.

As with waterlogging, variability in salinity tolerance was recorded within the species (Tang *et al*. 2013a, Tang *et al*. 2013b, Song *et al*. 2017). Very few New Zealand bred cultivars were included - it’s possible that impacts could differ to those reported here.

Also similar to waterlogging, it’s likely that factors such as plant age and duration of salinity treatments may affect the impacts of salinity on perennial ryegrass, but it isn’t possible to comment on this from the data found for this review. Plants in pot trials were relatively young (2-12 weeks old). Swards in the field studies were older, however results were either for mixed swards (where contribution of legumes may be important) or impacts could not be quantified for perennial ryegrass specifically.

| **Citation** | **Plant source** | **Plant material** | **Age of plants** | **Growing conditions** | **Duration** | **Salinity treatment** | **Equivalent conductivity reported by authors (dS/m)** | **Change in shoot yield relative to the control (%)** |
|---|---|---|---|---|---|---|---|---|
| Mehanni and West (1992) | Seed | One cultivar (Nui) | Approx. 2 weeks? Three leaf stage | Pots with sand and vermiculite | Increase in concentration over 4 days, then approx. 12 weeks treatment | 100, 750, 1500, 3000 mg/L NaCl[1]<br>Plus nitrogen treatments | | Yield was higher at 750 than 100 mg/L, then decreased with increasing salinity above 750 mg/L |
| | Presume seed | Perennial ryegrass/white clover pasture | Existing pasture (refers to a trial established 10 years previously on 15-year-old pasture) | Field | Two years | 100, 700, 1500 and 3000 mg/L TDS[2].<br>Plus nitrogen treatments | | Mean -32% from 100 to 3000 mg/L with no added nitrogen<br>-20% with 150 kg N/ha. |
| Rogers (2007) | Seed | Four species, including perennial ryegrass (cultivar Victorian) | One year old | Field | Irrigated over for 3-6 months of the year for 4 years. | 1.6, 2.5 and 4.5 dS/m | | No difference in relative tolerance of the 4 species |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 10-15% decrease at 4.5 dS/m |
| Tang *et al*. (2013a)[3] | Grown from 9-10 tillers | 10 diverse accessions | 24 days | Pots with sand | Gradual increase then 20 days | 0<br>50<br>100<br>150<br>200<br>300 mM in solution | ≈ 1.5<br>≈4.2<br>≈8.4<br>≈12.6<br>≈16.8<br>≈25.2 | No effect up to 100 mM<br>-30%<br>-36%<br>-48% |
| Tang *et al*. (2013b)[4] | Seed? | 56 diverse accessions | 35 days | Pots with sandy loam soil | Gradual increase then 10 days at 300 mM | 0 and 300 mM NaCl in solution | ≈1.5<br>≈25.2 | -30% on average<br>For 3 genetic groups<br>G1 -30%<br>G2[5] -33%<br>G3 -39% |
| Song *et al*. (2017)[6] | Tillers | 8 accessions | 10 weeks old, with 5 or 6 tillers | Pots with sand | Gradual increase over 7 days, then 10 days at 300 mM | 0<br>300 mM NaCl in solution | ≈ 25 | -37% on average<br>No difference among groups of accessions with differing tolerance |
| Liu *et al*. (2018) | Seed | One tolerant and one sensitive accession | 12 weeks | Pots with sand | Increase in concentration over three days, then 14 days at 75 mM | 0 and 75 mM Na Cl in solution | ≈8.5 | +33% on average<br>Height not affected in the |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | tolerant accession, -16% in the sensitive one |
| Peng *et al*. (2019) | Seed | Not stated | 60 days | Pots with soil and sand | 7 days | 100 mM<br>200 mM<br>NaCl | | -34%<br>-30%<br>(annual ryegrass was -46%) |

*Table 6: Summary of studies on salinity and perennial ryegrass where sufficient detail was available on plant material and experimental conditions and, quantifiable impacts on shoot yield (in chronological order of publication).*

[1] Equivalent mM concentrations calculated are 1.7, 12.8, 25.7, and 51 mM

[2] Mixing 6000 mg TDS (total dissolved solids)/L saline groundwater with 100 mg TDS/L water

[3] Accessions include cultivars, plus accessions of wild, cultivated and unknown origin.

[4] Accessions include cultivars, plus accessions of wild, cultivated and unknown origin.

[5] Group 2 included the three New Zealand accessions.

[6] Accessions include cultivars, plus accessions of wild and unknown origin.

## 4.3 Combined waterlogging and salinity

Waterlogging and salinity were an example given by Di Bella *et al*. (2022) for combined stresses needing further study in forage grasses. The searches of the scientific literature for this report located a few papers on the topic in perennial ryegrass but both were in turf types.

Generally, the combined effect is expected to be greater than either stress on their own, for example as seen in barley by Zeng *et al*. (2013). Menon-Martinez *et al*. (2021) also reported that tall fescue had higher tolerance to waterlogging than to salinity or to combined waterlogging and salinity.

In turf cultivars of perennial ryegrass Iswieri *et al*. (2020) also concluded that the effect of waterlogging and salinity together was greater than salinity or waterlogging alone, although there was some variation among cultivars (Table 7). In contrast, Yin *et al*. (2017) found that salinity and the combined stresses had similar effects on growth, however these results could be influenced by the fact that only two cultivars were studied (see the variation found by Iswieri *et al*. (2020) in Table 7). In their study, Yin *et al*. (2017) suggested that salinity stress was responsible for most of the negative effects in the combined treatment.

As with the individual stresses there is probably variation within perennial ryegrass for tolerance or responses to combined waterlogging and salinity (see Table 7). This has been observed in other species e.g. barley (Zeng *et al*. 2013) and tall fescue (Menon-Martinez *et al*. 2021).

Note that the decreases in shoot production under salinity stress reported by Isweiri *et al*. (2020) were higher than those found in the limited results for salinity stress in perennial ryegrass (Table 6). This could be due to differences in experimental conditions, but it is also not known if turf and forage types of perennial ryegrass differ in their response to this or other stresses (and was outside the scope of this review).

Also note that Zeng *et al*. (2013) reported differences in the severity of the combined stress for barley in soil versus vermiculite and discussed the potential influence of ion toxicity from waterlogging in the soil treatment. They commented on the common use of artificial growing media for studies on waterlogging and salinity and stressed the importance of screening plants in soil. Similarly, the limited data quantifying the impacts of combined waterlogging and salinity in perennial ryegrass should be treated with caution.

Barrett-Lennard (2003) noted in a general review on the interaction between waterlogging and salinity in plants that there was very little data from field conditions, and that such trials would be difficult to establish. Instead, multivariate analyses of plant performance and physiology across natural variation in field sites was suggested.

Liddicoat and McFarlane (2007) provided some guidelines for selecting forage species in Australia according to rainfall, salinity and waterlogging. This placed perennial ryegrass in the categories for low-moderate salinity with the soil saturated to the surface for 1-3 weeks each year, and low-moderate salinity with the soil saturated to the surface for 1-3 months each year.

| | Decrease in total shoot DW relative to control treatment (%) | | |
|---|---|---|---|
| **Cultivar** | **Waterlogging** | **Salinity** | **Waterlogging + salinity** |
| Top Hat | -21 | -64 | -71 |
| Palmer | -25 | -67 | -58 |
| Brightstar | -6 | -60 | -80 |
| Paragon | -28 | -43 | -60 |
| 10.0815 | -26 | -57 | -57 |
| 10.0824 | -4 | -35 | -41 |
| 10.0825 | +70 | -46 | -63 |
| 10.0876 | -28 | -60 | -62 |
| 10.0798 | -39 | -59 | -86 |

*Table 7: Decreases in total shoot clipping dry weights (DW) for turf cultivars of perennial ryegrass under waterlogging, salinity, and combined waterlogging and salinity as reported by Isweiri et al. (2020). Salinity treatments increased in electrical conductivity over time to 6, 9 and 12 dS/m, lasting for 4 weeks each time.*

## 4.4 Knowledge gaps

There appear to be a number of gaps in knowledge on the impacts of both waterlogging and salinity on perennial ryegrass.

For the scope of this review, information which was lacking to enable practical evaluation of the impacts of waterlogging and salinity included:

- Impact of water table depth.
- Data from New Zealand, especially from recent studies.
- Studies using recent New Zealand cultivars.
- Studies under field conditions – this is difficult to impose particularly for waterlogging – and particularly studies with changes in water table depth (usually treatments for both waterlogging and salinity are applied by irrigation).
    - This also results in an absence of data under grazing which could have additional negative impacts on yield.
- More robust data on the impact of duration of both waterlogging and salinity stress.
- Information on how plant adaption to waterlogging may affect overall impacts on yield.
- Little information on the impact on feed quality (particularly for waterlogging).

Di Bella *et al*. (2022) listed four priorities for further investigation for waterlogging tolerance in forage grasses generally (some of which are also relevant to the purpose of this review):

- More studies in general on $C_3$ perennial grasses.
- Traits and responses for recovery from waterlogging as well as for tolerance during the stress.
- Plant developmental stage (e.g. adult versus young plants).
- Combined and successive stresses (e.g. combined waterlogging and salinity, or waterlogging followed by drought).

# 5. Conclusions

Overall, the number of studies with relevant data to quantify impacts of both waterlogging and salinity on perennial ryegrass appear to be relatively small. Most of the studies collated for this review and others were conducted in pot trials and involved waterlogging up to or just above the soil surface, or irrigation with saline water (NaCl). These may have some relevance where similar conditions occur in the field but may not be directly comparable for waterlogging or salinity at depth.

Experimental conditions for pot experiments on waterlogging were very variable including duration, “depth” of waterlogging, plant age, the genetic material used (different cultivars/genotypes/accessions), and growing media. In some studies plants were established from seed and in others from tillers.

It was not possible to robustly define envelopes of impact for different ranges of waterlogging duration and severity due to the low number of studies and the variability of the experimental conditions, nor further define this by plant maturity. A modelling exercise, for example using the pasture model APSIM, could provide more robust estimates of the impact of waterlogging under more uniform conditions.

Pot studies on salinity were slightly more comparable as treatments are applied as concentrations, although units used were not always directly comparable. Factors such as plant age and duration of treatment also varied although to a lesser degree than for waterlogging – plants were of relatively young ages, but the few field experiments included were on established pastures. However, the ionic composition of saline water or soils in field studies may not necessarily be comparable to salinity from sea water intrusion.

Several sources cite conductivity ranges for salinity tolerance in perennial ryegrass. A New Zealand soil science textbook puts this at 6-8 mS/cm with similar but slightly different ranges in several other sources (4-8 and 6-10 dS/m - 1 mS/cm being equivalent to 1 dS/m). One commonly used Australian diagram puts the electrical conductivity level above which yield is affected at about 6 dS/m, with a 50% decrease at just over 12 dS/m. The maximum salinity concentrations used in the collated pot studies were many times higher than the reported tolerance limits, though some reported reductions in yield occurred at levels consistent with these.

Search results included very few studies on combined waterlogging and salinity in perennial ryegrass, and these were in turf types. Generally, the combined stress is considered to have a greater impact than either stress on their own. The review by Di Bella *et al*. (2022) included waterlogging and salinity as an example of combined stresses which require further study in forage grasses.

For both waterlogging and salinity, as best as could be determined, very few New Zealand bred cultivars were included. As variation for tolerance was reported within perennial ryegrass for both stresses, this could be an important knowledge gap.

Other factors not in scope for this review could also impact pasture or economic performance. For example, the impacts of waterlogging and salinity on feed quality could affect animal productivity (through product yield and quality) and farm profit.

Also note that perennial ryegrass is usually sown in mixtures with legumes, but the scope of this review focussed only on the ryegrass component. Field studies which measure the total yield of the mixed sward may not distinguish the relative impact on the grass versus the legume. Several authors note that legumes are less tolerant of both waterlogging and salinity compared to grasses (e.g. Grieve *et al*. 1986).

On its own, a decrease in the legume component could have an important impact on total productivity due to the contribution of legumes to nitrogen fixation and feed quality. A requirement for nitrogen fertiliser or resowing of legumes could impact financial performance, even if there is no impact on the yield of the grass component of the sward.

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