Tolerance of Macrophytes and Grasses to Sodium and Chemical Oxygen Demand in Winery Wastewater

N.S. Zingelwa* and J. Wooldridge†

(1) ARC Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, Republic of South Africa. Zingelwan@arc.agric.za
(2) ARC Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, Republic of South Africa. Wooldridgej@arc.agric.za

Submitted for publication: June 2009
Accepted for publication: July 2009

Key words: chemical oxygen demand, Juncus acutus, Pennisetum clandestinum, Scirpus maritimus, sodium, Typha latifolia, Vetiveria zizanioides, winery wastewater

Winery wastewater often contains elevated concentrations of sodium (Na), and has a high chemical oxygen demand (COD). In constructed wetlands, Na may be removed through phytoremediation by such macrophytic plants as Typha latifolia, Juncus acutus and Scirpus maritimus. The relative abilities of these plants to absorb Na, and to tolerate high COD wastewaters was determined in a glasshouse pot trial. Also tested were Pennisetum clandestinum (Kikuyu) and Vetiveria zizanioides (Vetiver) grass, which are used on wastewater disposal sites. Treatments consisted of factorial combinations of Na and COD. Toxicity symptoms were not apparent below 16.2 μM Na/L < 5 000 mg COD L, but were marked at ≥ 40 μM Na/L and ≥ 15 000 mg COD/L. Of the macrophytes, J. acutus was the least affected by high Na and COD levels. Averaged across the Na and COD treatments, total plant dry mass (DM) in the macrophytes peaked at 40 μM Na/L, as did ability to tolerate COD. The total Na in the top growth was greatest in J. acutus from which 61.4 mg Na/plant (767 mg/m²) could potentially be harvested after six months. Equivalent figures for T. latifolia and S. maritimus were 38.8 and 25.0 g/plant, respectively. Of the grasses, P. clandestinum produced 35% more total DM than V. zizanioides. Top-growth Na contents were, respectively, 1427 and 29.1 mg/plant. To maximise Na uptake in harvestable plant components, J. acutus should be planted in wetlands, and P. clandestinum in pastures used for wastewater disposal.

Wastewaters from wineries contain elevated concentrations of mineral elements, notably sodium (Na) (Van Schoor & Rossouw, 2004). This is largely derived from cleaning and sterilising agents such as sodium hydroxide, sodium metasilicate and sodium carbonate (Papini, 2000). Winery wastewater also contains organic material (Shepherd, 1995), which confines high levels of chemical oxygen demand (COD) (Van Schoor, 2000). The disposal onto land or into streams of wastewater characterised by high Na concentrations and high COD values is regulated by the National Water Act (1998). Compliance invariably necessitates implementation of measures which reduce element concentrations and COD to acceptable levels before disposal. A method that has proved cost effective in South Africa (Mulidzi, 2008) and internationally (Bulc et al., 1997) is the treatment of wastewater in constructed wetlands. In such wetlands mineral elements are taken up by macrophytes (plants that grow in water but whose shoots project above the water surface) (Moshiri, 1993), a process known as phytoremediation (McCUTCHEON & Schnoor, 2003). Some of the mineral elements taken up from water, sediment or soil (Moshiri, 1993; Salt et al., 1998), usually by the roots, are translocated to the shoots and reproductive structures (WAINIO et al., 2003), together with which they may be removed by periodic harvesting. In addition to the removal of nutrient elements, macrophytes contribute to water purification by providing substrates and habitats where organic compounds may be broken down (Gale et al., 1994), reducing COD. Such breakdown is mainly brought about by microbes associated with the macrophyte root systems (Brix & Carter, 1986).

Regardless of whether winery wastewaters undergo treatment or not, the water must be reused or disposed of. A common method is that of pasture irrigation (MILLS et al., 2005). However, this practise may lead to increased soil salinity and sodicity, structural degradation, and the onset of anaerobic conditions in the subsoil (Van Schoor, 2000). A mitigating factor in such pastures is that plants may intercept and adsorb some of the minerals before they enter the soil (McCUTCHEON & Schnoor, 2003). In constructed wetlands and disposal pastures effective phytoremediation necessitates the use of plants that are able to function in environments that may be acidic, nutritionally unbalanced, brackish and contain organic materials that contribute to high COD levels (SALT et al., 1998; BATTY et al., 2002). Some plants reportedly flourish under these conditions, finding the wastewater a rich source of nutrients (KARPISCAC et al., 1999). Others may lack adequately developed tolerance mechanisms and not flourish in such conditions (MARSCHNER, 1995). Identification of suitable plants is therefore a necessity. Typha latifolia, an emergent wetland macrophyte (QUICK, 1987), has already been used in wastewater treatment wetland trials (HE & MANKIN, 1989; MOSHIRI, 1993; ZINGELWA & WOODRIDGE, 2009). Other potentially usable macrophytes are Scirpus maritimus and Juncus acutus. Typha species are found in a variety of often saline habitats throughout the world, and may have evolved a genetic potential to

Corresponding author: e-mail: Zingelwan@arc.agric.za
Acknowledgements: Funding for this project was provided by Winetech and by the Agricultural Research Council. The authors wish to thank Mr F. Calitz for carrying out the statistical analysis, and the staff of the Soil and Water Science Division at ARC Infruitec-Nietvoorbij for technical assistance.

tolerate such conditions (Von Oertzen & Finlayson, 1984). *Juncus acutus* and *S. maritimus*, however, are salt-marsh macrophytes. Both have been used in salt-tolerance studies (Coul tas & Hsieh, 1997). *Scirpus maritimus* is a facultative halophyte. It lacks morphological adaptations to salt tolerance, but is nevertheless able to accumulate Na (Kan trud, 1996). *Scirpus maritimus* ranked highly in sodium tolerance studies, and shows positive growth responses to NaCl (Ungar, 1991).

Since wastewater salt concentrations do not decrease appreciably during passage through constructed wetlands (Zingelwa & Wooldridge, 2009), the plants used in disposal areas must, like those in artificial wetlands, be tolerant of poor water quality and able to take up minerals. *Vetiveria zizanioides* (vetiver grass) is widely used in hedges to alleviate erosion and improve soil structures in degraded land (Greenfield, 2002). *Vetiveria zizanioides* is tolerant of soil salinity, sodicity, and high heavy metal concentrations over a wide pH range (Greenfield, 2002), and tolerates up to 15% NaCl (Nanakorn et al., 2005), whereas most plants have a threshold of 1% NaCl. When supplied with municipal effluent spiked with NaCl, *V. zizanioides* plants thrived, due to the nutrients provided by the wastewater (Kloijke & Nitisoravit, 2005). Another grass, *Pennisetum clandestinum* (kikuyu grass) is a common pasture crop that has been used in experiments to investigate tolerance and accumulation of salts (Mulidzi et al., 2002). In a study by Mills et al. (2005), *P. clandestinum* pastures irrigated with saline wastewater showed exceptional tolerance to salinity. Information concerning the tolerance of *P. clandestinum* to high COD levels is nevertheless sparse.

The objective of this work was to determine the relative abilities of certain macrophytes and grasses to survive, generate dry mass (DM), and accumulate mineral elements in environments containing a range of Na and COD concentrations.

**MATERIALS AND METHODS**

Cuttings of the macrophytes *T. latifolia*, *J. acutus* and *S. maritimus*, and of the grasses *P. clandestinum* and *V. zizanioides* were established in coarse sand in 40 x 20 x 20 cm cement troughs. These were arranged in a glasshouse using a design that made provision for a fully randomised trial in which each plant x quality treatment was represented in two blocks. Each treatment received two L of a simulated winery wastewater twice each week. Wastewater treatments consisted of five concentrations of Na (0, 16, 40, 162 and 400 µM/L), as in salinity tolerance trials by Marschner (1995), in factorial combination with five levels of Na and COD concentrations of 0, 5 000, 10 000, 15 000 and 20 000 mg/L. The Na was derived from NaCl, and the COD from distilled wine. The treated plants were allowed to grow for a six month period, by the end of which some of the shoots showed physiological responses to the treatments. Response severity was graded on a 4-point scale (0, dead; 1, weak shoots; 2, shoots showing toxicity symptoms, die-back and necrosis apparent; 3, all shoots green and apparently healthy). After grading, each plant was removed from the sand, quickly washed and divided into components (shoots, rhizomes [*T. latifolia* only] and roots). These were dried to constant mass (± 1%) in a fan oven at 70°C, weighed to determine DM and passed through a Wiley mill. A 0.40 g sample of each component was digested using a mixture of sulphuric acid and hydrogen peroxide (Allen, 1989). Concentrations of calcium (Ca), Na, magnesium (Mg) and potassium (K) in the volumetric solutions were then determined using a Pye Solaar Atomic Absorption Spectrophotometer. Phosphorus (P) was determined by the method of Murphy and Riley (Olsen & Sommers, 1982), using a Shimadzu spectrophotometer. Kjeldahl distillation and titration (Bremner & Mulvaney, 1982) were used to quantify the nitrogen (N) contents. The DM and analytical data were subjected to an analysis of variance using SAS (SAS, 2003). Least significant difference (LSD) values were calculated at the 5% probability level to facilitate comparison between treatment means. Treatments which differed at P = 0.05 were regarded as significantly different. Co-efficients of determination ($r^2$) (Rees, 2001) were calculated to enable tissue element concentrations and DM’s to be related to the concentrations of Na and COD in the treatment solutions.

**RESULTS AND DISCUSSION**

**Macrophytes**

**Physiological responses and survival**

From Table 1, it is apparent that there is a broad diagonal relationship such that the macrophyte shoots remained healthy where both Na and COD were low (≤ 16 mM/L Na; ≤ 5 000 mg COD/L), whereas at high Na and COD concentrations (≥ 40 mM/L Na, ≥ 15 000 mg COD/L), most of the macrophyte plants died. In treatment combinations between these extremes, macrophyte shoot growth was generally weak or characterized by toxicity symptoms. This observation agrees with Xu et al. (2006), who found that high COD can cause shoot burning or even plant death, and with Marschner (1995) who commented that excess Na can stunt growth or even kill, either through its osmotic effect or through antagonism with essential mineral nutrients such as K and Ca. Dead *S. maritimus*, *T. latifolia* or *J. acutus* plants were observed in eight, four and three treatments, respectively. If the number of dead plants is regarded as an indication of ability to tolerate Na and COD in wetlands, then potential suitability for wetland use is likely to decrease in the sequence: *J. acutus* > *T. latifolia* > *S. maritimus*. At all levels of COD, *T. latifolia* and *J. acutus* tolerated higher concentrations of Na than *S. maritimus*.

**TABLE 1**

Effect of sodium (Na) concentration and chemical oxygen demand (COD) on growth and survival of *Typha latifolia*, *Scirpus maritimus* and *Juncus acutus*. Visually evaluated after six months using the scale: 0, dead; 1, weak shoots; 2, shoots showing toxicity symptoms; 3, healthy shoots.

<table>
<thead>
<tr>
<th>COD mg/L (x 10$^3$)</th>
<th>Species</th>
<th>Na (µM/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td><em>S. maritimus</em></td>
<td>3 3 2 2 1</td>
</tr>
<tr>
<td>5 000</td>
<td><em>J. acutus</em></td>
<td>3 3 2 2 2</td>
</tr>
<tr>
<td>10 000</td>
<td><em>S. maritimus</em></td>
<td>2 2 2 1 1</td>
</tr>
<tr>
<td>15 000</td>
<td><em>J. acutus</em></td>
<td>2 2 2 1 1</td>
</tr>
<tr>
<td>20 000</td>
<td><em>S. maritimus</em></td>
<td>1 0 0 0 0</td>
</tr>
<tr>
<td></td>
<td><em>T. latifolia</em></td>
<td>3 2 1 0 0</td>
</tr>
<tr>
<td></td>
<td><em>J. acutus</em></td>
<td>2 2 1 1 0</td>
</tr>
</tbody>
</table>

The effects of Na and COD on DM in the individual macrophytes were inconsistent. Where the macrophytes were most abundant in S. maritimus, whereas P and K contents did not differ between species. Total plant Na peaked at 162 μM Na/L, and K, Ca and Mg contents were greatest in T. latifolia. Whereas the Ca and Mg contents were lower in S. maritimus, whereas the Ca and Mg contents were lowest at zero mg COD/L, tending to increase over the range from 5 000 to 20 000 mg COD/L.

Whole plant DM production at 40 μM Na/L was lowest at zero mg COD/L, tending to increase over the range from 5 000 to 20 000 mg COD/L. Sodium decrease. Whole plant DM production at 40 μM Na/L then increased with Na to a maximum at 40 μM/L, then decreased. Whole plant DM production at 40 μM Na/L then increased with Na to a maximum at 40 μM/L, then decreased. Whole plant DM production at 40 μM Na/L then increased with Na to a maximum at 40 μM/L, then decreased.

The effects of Na and COD on DM in the individual macrophytes were inconsistent. Where the macrophytes were most abundant in S. maritimus, whereas the Ca and Mg contents were highest at zero mg COD/L, tending to increase over the range from 5 000 to 20 000 mg COD/L.

Whole plant DM production at 40 μM Na/L was lowest at zero mg COD/L, tending to increase over the range from 5 000 to 20 000 mg COD/L.

Dry mass production

### TABLE 2

<table>
<thead>
<tr>
<th>Species</th>
<th>Leaf</th>
<th>Stem</th>
<th>Rhizome</th>
<th>Root</th>
<th>Shoot</th>
<th>Whole Plant</th>
<th>Leaf</th>
<th>Stem</th>
<th>Rhizome</th>
<th>Root</th>
<th>Shoot</th>
<th>Whole Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. acutus</td>
<td>123</td>
<td>154</td>
<td>112</td>
<td>93</td>
<td>146</td>
<td>405</td>
<td>123</td>
<td>154</td>
<td>112</td>
<td>93</td>
<td>146</td>
<td>405</td>
</tr>
<tr>
<td>T. latifolia</td>
<td>123</td>
<td>154</td>
<td>112</td>
<td>93</td>
<td>146</td>
<td>405</td>
<td>123</td>
<td>154</td>
<td>112</td>
<td>93</td>
<td>146</td>
<td>405</td>
</tr>
<tr>
<td>S. maritimus</td>
<td>123</td>
<td>154</td>
<td>112</td>
<td>93</td>
<td>146</td>
<td>405</td>
<td>123</td>
<td>154</td>
<td>112</td>
<td>93</td>
<td>146</td>
<td>405</td>
</tr>
</tbody>
</table>

Values in the same row and in the same block of data that are followed by the same letter do not differ at P = 0.05.
and COD concentrations in wetlands where such macrophytes are likely to perform best as agents of phytoremediation. The effects of Na on tissue element concentrations were either not significant or inconsistent, as were the effects of COD. The exception was tissue Na, which was highest in the zero μM Na/L treatment, and which tended to increase with increasing COD. Coefficients of determination exceeded 0.5 (50%) in the cases of Na in J. acutus and T. latifolia ($r^2 = 0.54$ in both), and total Na in S. maritimus ($r^2 = 0.50$) (data not shown). Magnesium also correlated with the Na and COD treatments in S. maritimus ($r^2 = 0.69$). No other element was significantly related to the Na and COD treatments, implying the absence of a direct suppressive effect of the treatments on these elements, contradicting Marschner (1995).

Juncus acutus, with its combination of high shoot DM, reasonably high tolerance of Na and COD, and high shoot N, P, K and Na concentrations, relative to the roots; plus its high total shoot Na (61.4 mg/L) as compared with 25.0 mg/plant in S. maritimus and 38.8 mg/plant in T. latifolia (data not shown) was the best suited of the three macrophytes for use as a phytoremediant in wetlands. At a density of 12.5 plants/m², full harvesting of the top growth would result in the removal of 0.77, 0.31 and 0.49 g Na/m² of wetland per harvest by J. acutus, S. maritimus and T. latifolia, respectively. These masses are small relative to the amount of Na that could enter a wetland, which explains why wetlands are not usually effective in removing Na (Zingelwa & Wooldridge, 2009). A further drawback to harvesting top growth in wetlands is that any dead plant material that remains behind will decompose, promoting eutrophication (Quick, 1987).

Grasses

Physical responses and survival
Neither of the grass species showed visible signs of physiological stress nor did the plants die (data not shown). Both P. clandestinum and V. zizanioides were therefore able to function across the range of Na concentrations, from zero to 400 μM Na/L, and from zero to 20 000 mg COD/L (data not shown).

Dry mass production

Pennisetum clandestinum produced 35% more total plant DM (roots, rhizomes and shoots) than V. zizanioides (Table 4). Root DM in both grasses exceeded shoot DM. However, P. clandestinum exhibited a higher ratio of shoot DM to root DM (1:1.739) than V. zizanioides (1:1.391), which accords with the observation by Greenfield (2002) that V. zizanioides has a relatively well developed root system. In the grasses, total DM’s tended to decrease with increasing solution Na concentration, in accordance with Marschner (1995). According to Chapman (1974), excess Na may affect the Ca regime in the plant, thereby inhibiting cell wall formation and membrane integrity, resulting in reduced growth. Total plant DM increased with both COD and Na over the respective ranges zero to 20 000 mg COD/L and zero to 40 mg Na/L. At higher Na concentrations DM was suppressed in the higher COD treatments (Table 5). Coefficients of determination ($r^2$) between total plant DM and the combined effects of Na and COD were not significant for either grass species (data not shown).

Tissue element concentrations

Concentrations of N, P, Ca, Mg and Na, but not K, were significantly greater in P. clandestinum than V. zizanioides (Table 4). In P. clandestinum the concentrations of N, P, K, Mg and Na in the shoots exceeded those in the roots whereas, in V. zizanioides the root N, Ca and Na concentrations exceeded those in the shoots (Table 4). As with COD, the tissue N, P, K, Ca and Mg concentrations were lower at 162 and 400 μM Na/L than in the zero (mg/L) Na, which agrees with Marschner (1995) and Chapman (1974). In contrast, tissue Na concentrations increased with increasing solution Na concentration. Chemical oxygen demand

### TABLE 3

Effect of sodium (Na) concentration and chemical oxygen demand (COD) on dry mass production (g DM/plant) by Typha latifolia, Juncus acutus and Scirpus maritimus (data for the three species pooled).

<table>
<thead>
<tr>
<th>COD mg/L × 10³</th>
<th>Na (μM/L)</th>
<th>0</th>
<th>16</th>
<th>40</th>
<th>162</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>13.63a</td>
<td>6.08c</td>
<td>6.53b</td>
<td>9.08ab</td>
<td>12.7a</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>6.97c</td>
<td>7.18bc</td>
<td>6.75b</td>
<td>7.79bc</td>
<td>5.48c</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8.96bc</td>
<td>10.84a</td>
<td>6.86b</td>
<td>12.07a</td>
<td>6.16bc</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>8.33bc</td>
<td>9.54ab</td>
<td>15.50a</td>
<td>8.38bc</td>
<td>7.04b</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>10.34b</td>
<td>6.53bc</td>
<td>5.71b</td>
<td>5.53c</td>
<td>8.69</td>
<td></td>
</tr>
</tbody>
</table>

Values in the same column, which are followed by the same letter, do not differ at P < 0.05

### TABLE 5

Parameter estimates and standard errors for regression relationships between dry mass (DM), tissue sodium (Na) concentration and total plant Na, in the shoots of Pennisetum clandestinum as functions of solution Na concentration (mM/L) and solution chemical oxygen demand (COD) (mg/L). Model described by the relationship: DM, Na conc., Total Na = a + b(Na conc.) + c(Na conc.)² + d(COD) + e(COD)² + f(Na conc. × COD).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>a (Intercept)</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>P</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM (g/plant)</td>
<td>Par. est.</td>
<td>21.138</td>
<td>0.031</td>
<td>-1.183x10⁻⁴</td>
<td>-1.796x10⁻⁴</td>
<td>2.343x10⁻⁴</td>
<td>6.646x10⁻⁷</td>
<td>0.010</td>
</tr>
<tr>
<td>Std error</td>
<td>2.371</td>
<td>0.027</td>
<td>6.145x10⁻⁴</td>
<td>4.521x10⁻⁴</td>
<td>2.111x10⁻⁴</td>
<td>8.354x10⁻⁷</td>
<td>&lt;0.01</td>
<td>80.6%</td>
</tr>
<tr>
<td>Na concentration</td>
<td>Par. est.</td>
<td>26.461</td>
<td>0.557</td>
<td>6.132x10⁻⁴</td>
<td>8.274x10⁻⁴</td>
<td>5.543x10⁻⁴</td>
<td>-6.010x10⁻⁴</td>
<td>0.050</td>
</tr>
<tr>
<td>(mg/kg⁻¹)</td>
<td>Std error</td>
<td>7.772</td>
<td>0.088</td>
<td>2.014x10⁻⁴</td>
<td>1.480x10⁻⁴</td>
<td>6.918x10⁻⁴</td>
<td>2.740x10⁻⁴</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Total Na in plant</td>
<td>Par. est.</td>
<td>415.663</td>
<td>15.840</td>
<td>-0.028</td>
<td>-0.018</td>
<td>1.930x10⁻⁶</td>
<td>1.360x10⁻⁶</td>
<td>0.050</td>
</tr>
<tr>
<td>(mg/plant)</td>
<td>Std error</td>
<td>162.234</td>
<td>2.966</td>
<td>6.800x10⁻³</td>
<td>0.050</td>
<td>2.330x10⁻⁶</td>
<td>9.239x10⁻⁸</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

but are likely to stop if the concentration is too high. Cattle consume salt liberally if given the choice, this trial can probably be used as fodder for cattle. wastewaters over the range of compositions used in removed from pastures used for the disposal of zizanioides and Pennisetum clandestinum Na (at 12.5 plants/m²), the removal of one ha of shoot removes 178.4 g of whereas the removal of P. clandestinum produces more shoot DM (grazeable areas receiving winery wastewaters, mainly because be better suited than P. clandestinum or harvestable top growth) than P. clandestinum. The effects of solution Na and COD (data not shown). Total elements in plants and plant components showed no such significant relationships, implying that it is more likely to be compared and 2.44 t/ha, respectively, by extrapolation). Total P, Ca, Mg and Na, but not N, were greater in P. clandestinum than in the shoots. The concentrations of K, Mg and Na tended to drift irregularly downward with increasing solution Na concentration. The observed general tendency for P. clandestinum to contain lower masses of mineral elements than V. zizanioides whereas total root N, Ca and Na exceeded that in the shoots in V. zizanioides. The total P, Ca, Mg and Na, but not N and K, were significantly lower in the case of tissue concentration, total Ca and Ca concentration to be increase with solution Na. The effects of COD, where the COD treatment, in which it was lower at high solution Na concentrations supports Chapman's (1974) contention that Na suppresses Ca uptake and DM production. In addition to Ca, total N, P and Mg were significantly lower in the 400 than in the zero μM Na treatment. As in the 20 μM Na treatment, in which it was lower at high solution Na concentrations supports Chapman's (1974) contention that Na suppresses Ca uptake and DM production. In addition to Ca, total N, P and Mg were significantly lower in the 400 than in the zero μM Na treatment. As in the COD. Total N, P, K, and Mg followed no specific sequence with increasing COD. Contrary to Chapman (1974), the Na concentration was low at zero mg COD/L relative to the higher COD treatments. Tissue P peaked in the 1000 mg COD/L treatment, in which it was lower than in the zero and 20 000 mg COD/L treatments. Nitrogen concentrations did not differ over the range from zero to 10 000 mg COD/L, but declined at higher COD's. In P. clandestinum, the COD showed no significant correlations (r²). Of the grasses tested, Vetiver zizanioides appears to be better suited than P. clandestinum or harvestable top growth. Where Na is a problem, the use of V. zizanioides or V. clandestinum to remediate winery wastewaters has merit.
(C. Muller, personal communication, 2009). Grazing cattle on the pasture itself would result in Na being returned to the pasture in excreted material.

**Effects of Na and COD**

In *P. clandestinum*, shoot DM, shoot Na concentration and total shoot Na content were significantly affected by the Na concentration and COD treatments (Table 5). The relationships between shoot Na concentration and total shoot Na were characterised by higher r² values than was shoot DM. The Na and COD treatments had no significant effects on root DM, root mineral concentrations or total root Na in *P. clandestinum*, or on shoot or root DM and mineral contents in *V. zizanioides* (data not shown). Potential Na removal in harvested top growth can therefore be calculated from a bivariate second order polynomial function for *P. clandestinum* (presented in Table 5), but not for *V. zizanioides*, where the wastewater Na concentration and level of COD are known.

**CONCLUSIONS**

This trial was carried out in a glasshouse using simulated winery wastewater. The results must therefore be verified under field conditions. It is nevertheless apparent from the trial results that the macrophyte *J. acutus* is, potentially, a better alternative to *T. latifolia* for use in wetlands, and even more suitable than *S. maritimus*. However, none of the macrophytes tested removed appreciable amounts of Na, or other elements, from the simulated winery wastewater. Post wetland disposal sites will therefore continue to receive mineral elements, notably Na, though in slightly lower concentrations than would be the case if passage through a wetland were omitted. Since total plant DM production by wetland macrophytes varies with both Na concentration and level of COD in the environment, the efficiency of a wetland containing these macrophytes will vary with wastewater quality, and probably also with temperature and season. Collectively, these factors increase the need for pasture plants in disposal areas as second lines of defence against Na entry into the soil. *Pennisetum clandestinum* accumulates considerably more Na in the top growth, is more tolerant of high Na concentrations and high COD treatment levels than *V. zizanioides*, and may be a better alternative for use in areas receiving winery wastewater than *V. zizanioides*, as well as providing feed for cattle. It must nevertheless be emphasised that the combination of macrophytes in wetlands and grasses in disposal pastures is unlikely to take up more than a limited percentage of the Na in the wastewater. Further, after harvest, the Na-containing plant tissues must be disposed of in such a way that the Na will not contribute to increased sodicity elsewhere. It is better not to allow Na to enter the system in the first place. For this reason every effort should be made to substitute Na-free products for those that contain Na. Lowering COD levels, as by reducing the amounts of solids that enter the wastewater treatment system, may also minimise future problems with the treatment process, either in constructed wetlands or in post constructed wetland systems.

**LITERATURE CITED**


Plant tolerance of Na and COD in winery wastewaters


