

EFFECTS OF FROSTING ON SUB-TROPICAL GRASSES

B. J. Forde and L. J. Davies
Grasslands and Plant Physiology Divisions, D.S.I.R.,
Private Bag, Palmerston North.

ABSTRACT

Grasses of sub-tropical or tropical origin are being tested for use as perennial forage plants in New Zealand because of their comparatively high summer yield and resistance to drought. A major disadvantage of sub-tropical species is their intolerance of frost or sustained periods of cool temperatures typical of the New Zealand winter, though a few species are frost hardy. Many sub-tropical grasses are sensitive to reductions of 1-2°C in the temperature range 0 to -5°C. Field experiments at Kaitaia and Palmerston North have measured rates of survival ranging from complete kill for *Panicum maximum* var. *trichoglume* 'Petrie' through partial kill, e.g. lines of *Setaria anceps*, and *Digitaria* spp., to 100% survival - *Paspalum dilatatum* and *Cynodon dactylon*. Within lines of out-crossing species such as *Setaria anceps* there is considerable variability in rates of winter survival.

Factors which influence the extent of frost kill of the leaves or other organs are discussed. These include frost hardening ability, duration and intensity of cold temperatures, atmospheric humidity, fertiliser levels, and plant water status.

INTRODUCTION

There are two main groups of grasses used for forage production around the world. The festucoid species of temperate origin, e.g. ryegrass (*Lolium* spp) have an optimum temperature for growth in the range 17-25°C and can grow at temperatures as low as 5°C (McWilliam, 1978). The panicoid species of tropical or sub-tropical origin, e.g. *Paspalum dilatatum*, grow most rapidly within the temperature range 25-35°C, and generally fail to grow at temperatures below 15°C (McWilliam, 1978).

The panicoid grasses are of potential agronomic importance in New Zealand because of their relatively high summer/autumn yield and drought tolerance. Maximum growth of the temperate species occurs in spring whereas the tropical grasses are able to make more effective use of favourable irradiance and temperature conditions of summer.

The potential of some tropical grasses is indicated in Table 1 which presents the yields from small plots at Palmerston North and Kaitaia (Forde *et al.*, 1976a; Taylor *et al.*, 1976a, b). The lower yields at Kaitaia were probably related to the sandy soil at the site since summer moisture stress was more severe there than on the Manawatu fine sandy loam at Palmerston North. Superior yields of the tropical species relative to those of the temperate species were not necessarily obtained at the expense of forage digestibility when comparisons were made of tissue harvested at the same time (Forde *et al.*, 1976b).

While annual grasses of tropical origin such as maize and sorghum can be used to increase forage production in summer, the frost tolerant perennial species could also fill this role in the warmer areas of the North Island where moisture deficit in summer may impose a severe limitation upon the growth of temperate grasses (Forde *et al.*, 1976a; Sithampanathan, 1979, Taylor *et al.*, 1976a, b).

TABLE 1: Yield of plots in the second warm season after establishment under dryland conditions expressed as kg DM/ha. (Forde *et al.*, 1976a; Taylor *et al.*, 1976a, b)

	Palm. Nth. (Lat. 40°) 13/10/73 - 20/4/74	Kaitaia (Lat. 35°) 21/11/73 -8/5/74
<i>Tropical grasses</i>		
<i>Cynodon dactylon</i> Cy6 135	16 620	9 110 ^a
<i>Digitaria decumbens</i>	18 290	8 760
<i>Digitaria smutsii</i> CPI 38869	16 530	10 850
<i>Paspalum dilatatum</i> Aust. comm.	17 230	5 360
<i>Pennisetum clandestinum</i> KS 233	14 870	8 630
<i>Setaria anceps</i> 'Narok'	15 410	13 830 ^a
<i>Setaria splendida</i> CPI 15899	16 540	16 970 ^a
<i>Setaria trinervia</i> CPI 33453	13 240	12 940
<i>Temperate grasses</i>		
<i>Phalaris tuberosa</i> 'General Select'	12 370	7 710
<i>Lolium perenne</i> 'Grasslands Nui'	5 250	1 370

^a From warm season 1974/5.

THE FROST PROBLEM

A major limitation to the more extensive use of tropical grasses in New Zealand is their relative intolerance of frosts. In the Australian sub-tropics also, frosts and cool winter temperatures are recognised as a major limitation to the usefulness and distribution of tropical pasture species (Coleman, 1964). Frosts can kill susceptible species and retard the growth of surviving plants, in addition to reducing herbage quality.

The photosynthetic rate of surviving leaf tissue of buffel grass (*Cenchrus ciliaris*) may be depressed for

several days after frosting (Ludlow and Taylor, 1974) and a similar effect has been reported for the temperate cereal wheat (Marcellos, 1977).

Jones (1969) recorded the survival of a number of grasses frosted during the winter following late summer/early autumn planting in an Australian sub-tropical environment (Table 2). Terrestrial minimum temperatures (25–50 mm above ground level) as low as -8°C were recorded in this trial. Survival rates were proportional to plant size. Plants which survived one winter were killed if close grazed prior to or during their second winter.

TABLE 2: Percentage survival of tropical grasses on the eastern Darling Downs in Queensland in the winter following sowing (Jones, 1969).

Species	Percentage survival
<i>Chloris gayana</i> 'Pioneer'	97
<i>Paspalum notatum</i> CPI 9073	90
<i>Panicum coloratum</i> 'Burnett'	61
<i>Setaria anceps</i> 'Nandi'	23
<i>Cenchrus ciliaris</i> 'Gayndah'	23
<i>Panicum maximum</i> var. <i>trichoglume</i> 'Petre'	6
<i>Paspalum plicatum</i> 'Rodds Bay'	3

In Northland, New Zealand, Lambert *et al.* (1973) found the performance of four lines of *Setaria sphacelata* to be related to the severity of frosting (-3 or -7°C) at two experimental sites.

Survival rates for a number of tropical grasses grown in small monoculture plots at Palmerston North ranged from complete kill to complete survival (Table 3). During the winter following establishment there were 37 occasions when the grass minimum reading was -1°C or less, two occasions when the reading was -4°C or less and the minimum temperature for the winter was -5°C .

TABLE 3: Percentage survival of plants at Palmerston North in early December 1977 following overwintering.

Species	Percentage survival
<i>Cynodon dactylon</i> 'Coastcross'	100
<i>Hemarthria altissima</i> PI 299995	100
<i>Paspalum dilatatum</i> 'G 15'	100
<i>Pennisetum clandestinum</i> KS 233	100
<i>Digitaria pentzii</i> x <i>setivalva</i> A3/13	98
<i>Setaria neglecta</i>	98
<i>Digitaria smutsii</i> CPI 38869	90
<i>Setaria splendida</i> CPI 15899	86
<i>Digitaria decumbens</i>	79
<i>Setaria anceps</i> 'Narok'	52
<i>Digitaria pentzii</i> '17761B'	3
<i>Panicum maximum</i> var. <i>trichoglume</i> 'Petrie'	0

Although frost damage to susceptible species may be the most obvious cause of poor winter survival it is not the only factor. Many tropical grasses are unable to grow and may show specific damage symptoms in the range $0-15^{\circ}\text{C}$ (McWilliam, 1978). Also, although

there is little published information, controlled environment studies suggest that continued exposure to cool temperatures, in the absence of frost, may have a debilitating effect on the plant which ultimately results in its death (Davies and Forde, unpublished data.).

Strategies for winter survival

The tropical grasses can be placed in three groups on the basis of their reaction to frost.

- (i) Those which are killed by frost, e.g. *Panicum maximum* at Palmerston North.
- (ii) Species which tolerate frost with little or no leaf death, e.g. *Paspalum dilatatum* and *Eragrostis curvula* whose leaves can tolerate frost temperatures as low as -6° (Rowley *et al.*, 1975).
- iii Grasses whose leaves are readily killed by frost but avoid frost kill by possessing stolons or rhizomes which are partially or wholly protected by the soil, e.g. *Cynodon dactylon*, *Digitaria scalarum*, *Pennisetum clandestinum*. In *Setaria anceps* some crowns survive, presumably because of their close proximity to the soil. Though the limited frost tolerance of the leaves of these species is of little relevance to their survival, it does reduce their value for herbage production.

THE FREEZING PROCESS

As air temperatures around the leaf decline below 0°C , supercooling of the cell contents can occur. The extent of supercooling before ice formation commences in the tissue appears to be inversely proportional to the amount of free water on the leaf surface (Steponkus, 1978). Freezing occurs first in the extracellular solutions which have a lower solute concentration and more effective icenucleators than the intracellular components of the cell. Generally, extracellular ice formation is not lethal though it can cause damage because of the rapid formation of ice masses which can even split the tissue, and it can cause desiccation damage to the cell through the withdrawal of water. Intracellular ice formation is usually lethal to the cell (Steponkus, 1978). The physical manifestation of freezing damage includes a water-soaked appearance of the leaves upon thawing and consequent upon "leaking" of the membranes. A loss of electrolytes from the cells can be measured after freezing damage and the technique is used as the basis of some quantitative estimations of frost damage.

Because freezing is a physical process the severity of damage, especially to leaves of tropical grasses, may increase markedly with a decrease in temperature of only one or two degrees (Hacker *et al.* 1974; Ludlow and Taylor, 1974).

FACTORS AFFECTING FROST DAMAGE

Physical factors which are known to affect the degree of freezing damage to tropical grasses include the duration and severity of cold, the degree of supercooling of the cell contents, the rate of freezing and thawing, the number of frosting cycles, and the moisture content of the ambient air. Plant factors which influence frost damage include plant habit, the amount of plant tissue at frosting, the frost hardening (if any), and tissue moisture content.

Frost hardening

The leaves of temperate grasses can be 'hardened' to frost by exposure of the plant to low but above-freezing temperatures (Lorenzetti *et al.*, 1971), high light intensities (Lawrence *et al.*, 1973), and long days (Laidlaw and Berrie, 1977). In contrast, many tropical grasses have a limited ability for frost hardening of the leaves. Rowley (1976) determined the temperature at which severe freezing injury occurred in leaves from plants grown outside through the year at Palmerston North, and the results from seven species are presented in Table 4. The data indicate a basic difference between the first five species in which the leaves were killed by slight frost and there was no capacity to harden the leaves, and *Eragrostis* and *Paspalum* where the leaves hardened to frost as the season became cooler.

TABLE 4: Temperature (°C) at which severe frosting injury occurred for leaves taken from the field on various dates (Rowley, 1976).

Species	10 March	29 April	5 June	14 July
<i>Digitaria pentzii</i> 'Slenderstem'	-1.5	-1.4	-1.3	dead
<i>Acroceras macrum</i> 'Cedara special'	-1.3	-1.3	-1.2	dead
<i>Setaria anceps</i> 'Narok'	-2.0	-1.8	-1.8	dead
<i>Cynodon dactylon</i> Cy6 135	-2.1	-3.0	-	dead
<i>Pennisetum clandestinum</i> KS 233	-2.2	-2.0	-2.3	dead
<i>Eragrostis curvula</i>	-4.9	-6.3	-7.3	-7.5
<i>Paspalum dilatatum</i>	-3.7	-6.1	-7.5	-9.1
Grass min. temperature (°C)	10.7	8.5	3.0	-1.1

Generally, prehardening of tropical grass plants has only a slight effect in lowering the temperature at which a given severity of frost damage occurs. For example when plants of centipedegrass (*Eremochloa ophiuroides*) were grown at day/night temperatures of either 31/25° or 22/4° for 21 days and exposed to temperatures in the range 0 to -10°C, the temperature at which a given severity of leaf damage was lowered by 1-2° as a result of the cooler conditions of growth (Johnston and Dickens, 1977).

While the leaves of *Cynodon dactylon* have little or no ability to harden (Rowley *et al.*, 1975), the rhizomes can harden to resist freezing temperatures of -8°C (Davis and Gilbert, 1970).

Usually a temperature of 10°C or lower is required for maximum frost hardening of tropical grasses. Ivory and Whiteman (1978a) showed the effect of 8 days of different night temperatures on the severity of foliar damage (ratio of dead to live dry-weight expressed as percentage) when plants of *Setaria anceps* 'Narok' or *Panicum maximum* var. *trichoglume* 'Petrie' were exposed to two frost levels (Table 5). All plants were in 20°C day temperatures during the 8-day period. The table shows that the two lower night temperatures during preconditioning have a similar effect. The narrow range of

temperatures over which damage increases dramatically is clearly shown. In general, susceptible species are not damaged by frost at -1°C under controlled climate conditions but suffer considerable damage at -2 or -3°C.

TABLE 5: Effect of preconditioning night temperature on percentage foliar damage in *Setaria* and *Panicum* (Ivory and Whiteman, 1978a)

Species	Frost temp. °C	Frost damage%*			No pre- conditioning 29/19°C
		Night temp. 5 °C	10 °C	15 °C	
<i>Setaria</i>	-2	2.4	2.2	6.2	3.4
	-3	14.5	14.5	39.0	55.7
<i>Panicum</i>	-2	0.8	1.2	4.9	64.4
	-3	66.3	65.7	92.7	95.8

* Ratio of dead to live dry weight expressed as a percentage.

Maximum foliar hardening is achieved in centipedegrass after about 10 days of preconditioning at day/night temperatures of 16/4°C (Johnston and Dickens, 1976) though the cold hardness could be lost very rapidly. Two days of warm growing conditions dehardened plants so that their sensitivity to frosting was similar to that of non-hardened plants. In *Setaria* and *Panicum* frost hardening was achieved in 8 days (Ivory and Whiteman, 1978a). *Cynodon dactylon* also showed enhanced frost resistance after a few days preconditioning at cool temperatures (Reeves *et al.*, 1970).

Rate of cooling

A rapid rate of cooling of plants from temperatures under which they were grown to frosting conditions appears to be less injurious to the leaves than a slower rate of cooling. Hacker *et al.* (1974) observed less foliar damage when the temperature was reduced from 15° to 0°C in one hour compared with eight hours. They expressed foliar damage as the percentage of the leaf dry matter which was >90% dead. Ivory and Whiteman (1978a) noted that cooling rates of 2.0 and 6.0°C/hr from ambient resulted in less leaf damage during frosting of *Setaria* and *Panicum* than cooling at 0.5°/hr.

Duration of freezing temperature

Damage to leaf tissue increases with duration of exposure to frost conditions though the relationship is not necessarily linear with time. For 20 lines of tropical grasses the mean leaf damage was 18% after one hour frosting at -1.7°C whereas 35% of the leaf tissue was damaged after a four-hour exposure (Hacker *et al.*, 1974). As frosting time of *Setaria* increased from 0.5 to 2.0 to 4.0 hours, foliar damage increased from 8.5% to 24.7% to 37.3%; the damage to *Panicum* leaves over the same intervals was 23.5, 49.8 and 63.0% respectively (Ivory and Whiteman, 1978a). Centipedegrass exhibits a similar trend with a 25% topkill after exposure of the plant to -9.7°C for 1.5 hours but a 100% kill after nine hours exposure (Johnston and Dickens, 1977).

TABLE 6: Effect of relative humidity on percent foliar damage upon frosting (Ivory and Whiteman, 1978a)

	RH %	Frost temperature °C		
		-1	-3	-5
<i>Setaria</i>	99	2.3	51.4	95.4
	79	8.3	2.8	7.3
<i>Panicum</i>	99	0.2	76.2	99.8
	79	0.0	11.3	20.1

Atmospheric humidity

Several studies have shown that tropical grasses are affected more severely when frosted at higher humidities compared with low humidity, apparently because under high humidity free water may be present on the leaf surface thus encouraging freezing within the tissue. Table 6 compares the effect of humidity and temperature on frost damage of *Setaria* and *Panicum* (Ivory and Whiteman, 1978a) and indicates the severe effect of high humidity upon foliar damage. The adverse effect of reducing the temperature particularly at high humidity is also shown.

Ludlow and Taylor (1974) observed complete kill of buffel grass at -1°C and 100% relative humidity whereas under their low humidity environment there was no leaf damage at temperatures above -5°C and complete kill was not observed until -10°C was attained. Hacker *et al.* (1974) observed a lowered leaf kill when plants were exposed to -2.5°C at 3mb VPD (40% RH) compared with Omb VPD (100% RH).

The wide variation in foliar damage dependent upon relative humidity of the atmosphere may partially explain in the wide range of temperature sensitivities reported in the literature for the same line or cultivar.

Fertiliser application

Plant nitrogen concentration affects frost susceptibility of tropical grasses (Gilbert and Davis, 1971) with increased nitrogen level resulting in greater sensitivity of *Setaria* and *Panicum* (Ivory and Whiteman, 1978a). Improved frost hardiness in *Cynodon dactylon* can result from application of potassium and phosphorus fertilisers (Gilbert and Davis, 1971).

Plant water status

Plant moisture content also affects the frost susceptibility of tropical grasses, water stressed plants of *Setaria* and *Panicum*, being less damaged at a given frost level than well watered plants (Ivory and Whiteman, 1978a).

Genetic variation

Variation in frost tolerance exists among ecotypes or cultivars of several tropical grasses and may permit selection of cultivars with improved frost tolerance for use in New Zealand conditions. Within the genera *Chloris*, *Digitaria*, *Paspalum*, and *Setaria* there is a wide variation in the frost tolerance of leaf tissue (Hacker *et al.*, 1974; Ivory and Whiteman,

1978b). In *Cynodon dactylon* genetic variation exists for both frost tolerance and avoidance as there is a variation in tolerance of the rhizomes (Ahring and Irving, 1969) and in the amount of rhizomes and stolons produced (Dunn and Nelson, 1974).

The comparison (Table 7) of foliar kill among lines and cultivars of *Setaria anceps* at a given frosting temperature (Ivory and Whiteman, 1978b) indicates the variation in frost tolerance present within this species which might be exploited in a selection programme.

TABLE 7: Foliar kill (%) of a number of *Setaria anceps* lines at five frost temperatures (Ivory and Whiteman, 1978b)

Line of cultivar	Frosting Temperature °C				
	-1	-2.5	-3.25	-4.0	-4.75
'Nandi'	1.2	85.9	99.2	99.8	—
'Narok'	1.2	49.1	83.7	94.6	—
CPI 33453	0.0	5.0	88.8	99.4	—
CPI 32728	—	—	0.0	32.8	72.3

SCREENING FOR FROST TOLERANCE

Because tropical grass species or lines may differ in their frost tolerance by only $1-2^{\circ}\text{C}$, and because it is difficult or impossible to obtain reproducible frost conditions in the field, there has been considerable interest in screening for frost tolerance under controlled environment conditions. Such conditions allow control of intensity and duration of frosting, atmospheric humidity and plant pre-history which is not possible in the field. By the use of laboratory methods we are better able to understand the physiology of frost tolerance or sensitivity with a view to selection of improved lines.

However the relevance of laboratory methods depends on the relationship between field and laboratory assessments. Fortunately there has been a good agreement between field and laboratory assessments of frost tolerance of tropical grasses (Hacker *et al.*, 1974; Rowley *et al.*, 1975; Johnston and Dickens, 1977) and it would seem that laboratory screening can be used effectively in association with a field programme to accelerate screening for plants which can withstand that major limiting factor of the environment—frost.

REFERENCES

- Ahring, R. M., Irving, R. M. 1969. A laboratory method of determining cold hardiness in Bermudagrass, *Cynodon dactylon* (L.) Pers. *Crop Science* 9: 615-618.
- Coleman, R. G. 1964. Frosts and low night temperatures as limitations to pasture development in subtropical eastern Australia. *Division of Tropical Pastures Technical Paper No. 3* CSIRO. 8pp.
- Davis, D. L., Gilbert, W. B. 1970. Winter hardiness and changes in soluble protein fractions of Bermuda grass. *Crop Science* 10: 7-9.
- Dunn, J. H., Nelson, C. J. 1974. Chemical changes occurring in three Bermudagrass turf cultivars in relation to cold

- hardiness. *Agronomy Journal* 66: 28-31.
- Forde, B. J., Slack, C. R., Roughan, P. G., Whitehead, H. C. M. 1976a. Growth of tropical and temperate grasses at Palmerston North. I. Warm-season yields with and without irrigation. *N.Z. Journal of Agricultural Research* 19: 135-142.
- Ford, B. J., Slack, C. R., Roughan, P. G., Haselmore, R. M., McLeod, M. N. 1976b. Growth of tropical grasses at Palmerston North. II. Total nitrogen, soluble sugar, starch, and *in vitro* digestibility determinations. *Ibid* 19: 489-498.
- Gilbert, W. B., Davis, D. L. 1971. Influence of fertility ratios on winter hardiness of Bermudagrass. *Agronomy Journal* 63: 591-593.
- Hacker, J. B. Forde, B. J., Gow, J. M. 1974. Simulated frosting of tropical grasses. *Australian Journal of Agricultural Research* 25: 45-57.
- Ivory D. A., Whiteman P. C. 1978a. Effects of environmental and plant factors on foliar freezing resistance in tropical grasses. I. Precondition factors and conditions during freezing. *Australian Journal of Agricultural Research* 29: 243-259.
- Ivory, D. A., Whiteman, P. C. 1978b. Effects of environment and plant factors on foliar freezing resistance in tropical grasses. II. Comparison of frost resistance between cultivars of *Cenchrus ciliaris*, *Chloris gayana* and *Setaria anceps*. *Australian Journal of Agricultural Research* 29: 261-266.
- Johnston, W. J., Dickens, R. 1976. Centripedegrass cold tolerance as affected by environmental factors. *Agronomy Journal* 68: 83-85.
- Johnston, W. J., Dickens, R. 1977. Cold tolerance evaluation of several centripedegrass selections. *Agronomy Journal* 69: 100-103.
- Jones, R. M., 1969. Mortality of some tropical grasses and legumes following frosting in the first winter after sowing. *Tropical Grasslands* 3: 57-63.
- Laidlaw, A. S., Berrie, A. M. M. 1977. The relative hardening of roots and shoots and the influence of day-length during hardening in perennial ryegrass. *Annals of Applied Biology* 87: 443-450.
- Lambert J. P., Boyd, A. F., Harris, W. 1973. Comparison of seasonal growth pattern frost tolerance, and cutting response of *Setaria sphacelata sensu lato* varieties with cocksfoot and ryegrass. *N.Z. Journal of Experimental Agriculture* 1: 15-22.
- Lawrence, T., Cooper, J. P. Breese, E. L. 1973. Cold tolerance and winter hardiness in *Lolium perenne* II. Influence of light and temperature during growth and hardening. *Journal of Agricultural Science, Cambridge* 80: 341-348.
- Lorenzetti, F., Tyler, B. F., Cooper, J. P., Breese, E. L. 1971. Cold tolerance and winter hardiness in *Lolium perenne*. I. Development of screening techniques for cold tolerance and survey of geographical variation. *Ibid* 76: 199-209.
- Ludlow, M. M., Taylor, A. O. 1974. Effect of sub-zero temperatures on the gas exchange of Buffel grass. "Mechanisms of Regulation of Plant Growth". ed. Bialeski, R. L., Ferguson, A. R., and Cresswell, M. M. *Bulletin* 12. The Royal Society of New Zealand. Wellington, 513-518.
- McWilliam, J. R., 1978. Response of pasture plants to temperature. "Plant Relations in Pastures" Ed. Wilson, J. R., CSIRO, Melbourne. 17-34.
- Marcellos, H. 1977. Wheat frost injury – freezing stress and photosynthesis. *Australian Journal of Agricultural Research* 28: 557-564.
- Reeves, S. A., McBee, G. G., Bloodworth, M. E. 1970. Effect of N, P, and K tissue levels and late fall fertilization on the cold hardiness of Tifgreen Bermudagrass (*Cynodon dactylon* X *C. transvaalensis*). *Agronomy Journal* 62: 659-662.
- Rowley, J. A. 1976. Development of freezing tolerance in leaves of C⁴ grasses. *Australian Journal of Plant Physiology* 3: 597-603.
- Rowley, J. A., Tunnicliffe, C. G., Taylor, A. O. 1975. Freezing sensitivity of leaf tissue of C⁴ grasses. *Australian Journal of Plant Physiology* 2: 447-451.
- Sithamparanathan, J. 1979. Seasonal growth patterns of herbage species on high rainfall hill country in northern North Island. II. Legumes and sub-tropical grasses. *N.Z. Journal of Experimental Agriculture* 7: 163-167.
- Steponkus, P. L. 1978. Cold hardiness and freezing injury of agronomic crops. *Advances in Agronomy* 30: 51-98.
- Taylor, A. O., Rowley, J. A., Hunt, B. J. 1976a. Potential of new summer grasses in Northland. I. Warm-season yields under dryland and irrigation. *N.Z. Journal of Agricultural Research* 19: 127-133.
- Taylor, A. O., Rowley, J. A., Hunt, B. J. 1976b. Potential of new summer grasses in Northland. II. A further range of grasses. *Ibid* 19: 477-481.