Performance of perennial tropical grasses in different Mediterranean environments in southern Italy

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Abstract

A 3-year trial at 3 different locations in southern Italy was conducted to assess winter survival, forage yield and quality and seed production of 23 accessions of C_4 perennial grasses native to Africa and America and a C_3 species native to Italy (*Festuca arundinacea*), which was used as a control. Thirteen C_4 grasses [*Sorghum almum*, *S.* spp. *hybrids* (Silk sorghum), *Panicum maximum*, *Eragrostis curvula*, *Chloris gayana*, *Panicum coloratum*, *Panicum virgatum*, *Paspalum dilatatum*, *Bouteloua curtipendula*, *Sorghastrum nutans*, *Sporobolus airoides*, *Buchloe dactyloides*] along with *F. arundinacea* showed good winter survival at all 3 locations. *S. almum* and Silk sorghum gave the highest DM yields (mean 39.1 and 35.0 t/ha, respectively), while *E. curvula*, *P. maximum* and *C. gayana* yielded between 19.1 and 17.3 t/ha. *F. arundinacea* yielded 8.6 t/ha. *P. dilatatum* and *S. airoides* had the highest CP concentration (10.6 and 10.5%, respectively) and the lowest NDF (62 and 66%, respectively) and ADF (31%). Seed yields ranged between 100 and 900 kg/ha, with *S. almum*, Silk sorghum, *B. dactyloides*, *F. arundinacea* and *P. coloratum* yielding between 900 and 600 kg/ha.

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Introduction

During the low rainfall spring-summer period in Mediterranean areas there is an increasing water deficit, which peaks in July-August (Corleto 1985). Hence, the possibility of having green forage in summer under dry farming conditions is related to the use of forage shrubs such as *Medicago arborea*, *Atriplex halimus* and *Coronilla emerus*, or trees like *Robinia pseudoacacia* felled in late winter to allow luxuriant re-growth in summer (Papanastasis 1985; Le Houèrou 1991; Corleto *et al.* 1994).

Another opportunity to extend green forage supply in summer is through the use of tropical perennial grasses. However, tropical grasses have poor cold tolerance and temperatures are often below 0°C in Mediterranean environments during the winter.

Preliminary investigations with tropical grasses in Apulia and Basilicata (southern Italy) have produced interesting results. In relation to winter survival, *Sorghum almum*, *Chloris gayana*, *Panicum maximum*, *Eragrostis curvula*, *Panicum virgatum*, *Buchloe dactyloides*, *Bouteloua curtipendula* and *Sorghastrum nutans* showed good cold tolerance in a range of environments in middle and southern Italy, ranging from sea level to an elevation of 250 masl (Corleto *et al.* 1990; Pazzi *et al.* 1990; De Franchi *et al.* 1995; Maiorana *et al.* 2002; Gherbin *et al.* 2007).

These grasses are responsive to N fertiliser. Applying 150 kg/ha N to *S. almum* increased DM yield from 12 t/ha to 24.8 t/ha, and applying 225 kg/ha N to *C. gayana* increased yield from 8.4 t/ha to 23.3 t/ha. However, only a moderate increase in dry biomass was observed in *S. almum* and *C. gayana* with seasonal irrigation of 240 and 720 mm (Corleto and Cazzato 1990).

The aim of the present research was to compare, under different soil and climatic Mediterranean conditions, 23 tropical perennial grasses in terms of total and seasonal dry matter yields and other features such as cold tolerance, forage quality and seed yield.

Materials and methods

Trial sites

Trials were conducted in 1995–1997 at Cassibile in Sicily (40 masl; 37° 5′N, 15° 17′E) and Gaudiano di Lavello in Basilicata (180 masl; 41° 3′N, 15° 48′E) and in 1996–1998 at Rutigliano in Apulia (122 masl; 40° 56′N, 16° 54′E). All locations experience a Mediterranean climate with mild, rainy winters and rainfall deficits in spring-summer, with peak dryness in July-August. The mean rainfall (1976–1988) (Table 1) was around 480 mm at Cassibile, 540 mm at Rutigliano and 580 mm at Gaudiano di Lavello. During the 3-year test period, total rainfall was always above average at Rutigliano and varied at Cassibile and Gaudiano di Lavello, with 1 year below average, 1 year about average and the third above average.

Annual mean temperatures were below the medium-term mean (1976–1988) values for all sites, with Cassibile about 2.2°C warmer than the other 2 sites (Table 2). However, Cassibile had a narrower temperature range with lower absolute maximum and higher absolute minimum temperatures than the other 2 sites. Cassibile was virtually frost-free, while both Rutigliano and Gaudiano di L. recorded a significant number of frosts, especially during the first 2 years.

The soils were a clay loam (Cassibile), sandy clay (Gaudiano di L.) and mostly clay (Rutigliano) (Table 3). The soil at Cassibile contained a moderate amount of gravel (20%), whereas the soil at Rutigliano was moderately thick (30–40 cm) and laid over fissured carbonatic rock. Soil pH ranged between 7.4 and 8.0, while total N levels were low.

Table 1. Annual and seasonal rainfall and number of rainy days over 3 years at 3 sites.

Parameter	Location								
	Cassibile			Gaudiano di L.			Rutigliano		
	95	96	97	95	96	97	96	97	98
Annual rainfall (mm)	452	921	575	719	603	487	627	617	667
Rainy days (No)	50	76	33	81	85	61	140	71	88
Autumn rainfall (mm)	238	219	327	127	196	244	133	460	304
Rainy days (No)	9	26	14	18	28	23	46	24	35
Winter rainfall (mm)	101	523	196	169	244	79	293	57	174
Rainy days (No)	4	9	4	22	30	13	44	16	19
Spring rainfall (mm)	17	50	41	134	99	66	116	76	77
Rainy days (No)	12	12	3	17	14	10	32	23	22
Summer rainfall (mm)	95	129	11	289	64	98	85	25	110
Rainy days (No)	25	29	12	24	13	15	18	8	12

Table 2. Temperature during the study.

Parameter	Location								
	Cassibile			Gaudiano di L.			Rutigliano		
	95	96	97	95	96	97	96	97	98
	(°C)								
Annual mean temperature	17.8	17.8	17.6	15.2	15.2	16.0	14.6	15.5	16.5
Maximum annual mean temperature	21.8	21.5	21.8	19.3	20.1	20.3	19.3	20.4	21.4
Minimum annual mean temperature	13.7	14.1	13.5	11.2	11.1	11.8	10.0	10.7	11.6
Absolute minimum temperature	3.0	5.5	0.6	–0.9	–3.3	–0.5	–4.0	–1.0	0.0
Month with absolute minimum temperature	Jan	Jan	Jan	Jan	Dec	Apr	Mar	Dec	Dec
Absolute maximum temperature	36.2	37.3	37.0	36.8	39.4	39.7	37.4	39.6	39.8
Month with absolute maximum temperature	Jul	Jun	Jul	Jul	Jul	Jul	Jul	Jul	Jul
Days with daily mean temperature <2°C	0	0	0	8	10	0	3	0	0
Days with frost (= <0°C)	0	0	1	9	17	1	14	5	2

Table 3. Physico–hydrological and chemical soil characteristics.

Parameter	Location		
	Cassibile	Gaudiano di L.	Rutigliano
Coarse soil (%)	19.8	2.0	4.2
Fine soil (%)	80.2	98.0	95.8
Clay (%)	24.0	27.0	51.2
Silt (%)	41.0	7.9	20.6
Sand (%)	35.0	65.1	28.2
Organic matter (%)	1.2	1.2	1.7
pH	8.0	7.5	7.4
Total N (%)	0.5	1.0	1.3
Available P (ppm)	4.6	56.0	25.1
Water–soluble K (ppm)	171	516	593
Limestone (%)	23.1	0.1	7.9
Field capacity (%)	25.4	24.1	30.7
Wilting point (%)	15.2	13.3	18.3

Treatments and experimental design

Twenty-four perennial grass species and cultivars were compared at Gaudiano di Lavello and 23 at Cassibile and Rutigliano (Table 4). These included 23 C_4 accessions native to Africa and America and a single C_3 species native to Italy (*Festuca arundinacea* cv. Penna), which showed good adaptation and production in the Mediterranean environment (Corleto *et al*. 1978) (Table 4). *Sorghum* spp. hybrid cv. Silk (Silk sorghum) is a hybrid derived from a cross between *S. halepense* x *S. roxburghii* cv. Krish (2n=20) and *S. arundinaceum* (2n=20) (CSIRO 1978).

A randomised block design was used with 3 replicates and a plot area of 6 m^2 at Cassibile and 4 m^2 at Gaudiano di Lavello and Rutigliano. The last 2 sites were resown because of poor emergence following the first sowing. At Cassibile and Gaudiano di L., 2 additional replicates were sown to observe phenology and, in the case of Gaudiano di L., seed-producing ability. Seed was sown by hand in furrows 1–2 cm deep (20 rows 20 cm apart) on May 15, 1995 at Cassibile, August 7, 1995 at Gaudiano di L. and June 5, 1996 at Rutigliano, the one-year delay at Rutigliano being caused by establishment failure in the previous year. Owing to variation in 1000-seed weights (from 0.25 g for *C. gayana* to 7–9 g for the 2 sorghums) and germination rates (12% for *C. ciliaris* to 90% for *P. clandestinum*) and, considering the size of plants at full flowering, sowing rates varied: 20 kg/ha for the species with a 1000-seed weight between 0.2 and 1.5 g and a 30% maximum germinability (*C. gayana*, *S. sphacelata*, *P. maximum*, *P. coloratum, P. dilatatum*, *U. mosambicensis*); 30 kg/ha for the remaining trop-

Table 4. Species included in study.[1]

Species scientific name	Cultivar	Common name	Origin
Andropogon gerardi	Cimarron	big bluestem	USA and Canada
Andropogon gerardi	Kaw	big bluestem	USA and Canada
Bothriochloa insculpta	Hatch	creeping bluegrass	Tropical Asia and Africa
Bothriochloa pertusa	Keppel	Indian bluegrass	South and South–east Asia
Bouteloua curtipendula	El reno	side–oats grama	USA
Buchloe dactyloides	Not registered	buffalo grass	USA
Cenchrus ciliaris	Gayndah	buffel grass	Tropical Africa and Asia
Cenchrus setigerus	Not registered	birdwood grass	Tropical Africa and Asia
Chloris gayana	Callide	rhodes grass	Africa
Chloris gayana	Pioneer	rhodes grass	Africa
Eragrostis curvula	Not registered	weeping lovegrass	Tanzania
Festuca arundinacea	Penna	tall fescue	Europe, Asia, N. Africa
Panicum coloratum	Bambatsi	kline grass	Tropical Africa
Panicum maximum	Gatton	guinea grass	Tropical Africa
Panicum virgatum	Blackwell	switch grass	Central–eastern USA
Paspalum dilatatum	Not registered	dallis grass	Humid zone subtropical Brasil and Argentina
Pennisetum clandestinum	Not registered	kikuyu grass	Zaire, Kenya
Setaria sphacelata	Narok	African bristlegrass	Africa
Setaria sphacelata	Solander	African bristlegrass	Africa
Sorghastrum nutans	Cheyenne	Indian grass	USA
Sorghum almum	Not registered	columbus grass	Argentina
Sorghum spp. hybrids *(S. halepense x S. roxburghii)*	Silk	Silk sorghum	Developed in Australia
Sporobolus airoides	Not registered	alkali sacaton	USA
Urochloa mosambicensis	Nixon	sabi grass	Southern and East Africa

[1] The information reported hereby has been deduced from: Skerman and Riveros (1989); Baldoni *et al*. (1974). htpp://plants.usda.gov

ical species; and 40 kg/ha for *F. arundinacea*, the rate most commonly used in southern Italy. At planting (the successful one) at Gaudiano di L. and Rutigliano, peat was applied at the bottom of the furrow to ensure better moisture retention. At all locations, the soil was rolled following seeding and sprinkler irrigated till full seedling emergence. Subsequently, irrigation levels during the 3 trial years were 300 mm at Cassibile during April-September, 125 mm at Gaudiano di L. in June-August and 80 mm at Rutigliano in July-August. In the first year, fertiliser applications were 44 kg/ha P at all sites, with 200 kg/ha N at Cassibile, 100 kg/ha N at Gaudiano di L. and 50 kg/ha N at Rutigliano. These applications of fertiliser were repeated in the second and third years. Phosphorus was applied at planting and at the end of each growing season, whereas nitrogen was applied at the beginning of vegetative growth in a single application at Rutigliano and as split dressings after each cut at the other locations. The plots were kept free of weeds by frequent soil hoeing.

Soil cover (0–100%) was estimated visually at the end of emergence and at the beginning of vegetative growth in each year. The green biomass was cut by a mower at 3 cm above ground level at the beginning of flowering (10% of plants flowering) at Cassibile and Gaudiano di L. and at 100% flowering at Rutigliano. There were usually 2 or 3 cuts a year. Whole plots were cut at Cassibile, while 4 and 6 central rows were sampled at Gaudiano di L. and Rutigliano, respectively. Mean plant height (including the inflorescence) was measured with a measuring stick before cutting at 5 random points in the plot. Forage quality was determined only at Cassibile. A 500 g green sample was dried in a forced-draught oven at 65 °C at the first cut in 1995 and 1996 and analysed for N (Kjeldahl method), NDF (neutral-detergent fibre) and ADF (acid-detergent fibre), using the methodology of Goering and van Soest (1970). The seed production of all species was tested at Gaudiano di L. on 2 additional replicates, at the second cut (September 29, 1997) in the third year, with germinability (%) and mean germination time also assessed. The germination test was performed in April 1998 by placing 4 Petri dishes containing 50 seeds for each species in a growth chamber at 20/30°C with 12 sunlight hours. Mean germination time (MGT), which is an index of the seed germinating energy, was calculated as $MGT = \sum(n \times D)/\sum n$ where n is the number of germinated seeds on a given day; D is the sequence number of the day on which counting was made; and $\sum n$ is the total number of germinated seeds (Giardini 1992). This index is important because the more quickly the seed germinates the better the crop can survive this critical phase.

As not all species were perennial, the statistical analyses for DM yield/ha were applied separately for the first year, with a second analysis including years and test locations for species that persisted throughout the study. The statistical analysis was applied to data following square root transformation (yield data) or in angular values (percent data). Differences among mean values were tested by the LSD test. ANOVA was performed using the Costat software v. 6. 2003 (Cohort Software).

Results

Species behaviour and morpho-physiological traits

Seedling establishment. Many species, in particular those with a 1000-seed weight below 1 g, showed serious emergence difficulties at the initial sowing, caused mostly by soil moisture deficit but also by inadequate seed-bed preparation. Applying peat at the bottom of the furrow at Gaudiano di L. and Rutigliano in the second sowing, but not at Cassibile, where this was not necessary, resulted in good emergence and establishment for most species. Emergence was completed about 1 month after sowing, when *U. mosambicensis* and *B. pertusa* at Rutigliano and *A. gerardi* at Gaudiano di L. produced ground cover below 50%. This was considered inadequate for good establishment of the crop.

Species persistence. The following 13 species persisted well at all 3 locations: *B. dactyloides*, *B. curtipendula*, *C. gayana* cv. Pioneer, *E. curvula*, *F. arundinacea*, *P. coloratum* cv. Bambatsi, *P. maximum* cv. Gatton, *P. virgatum* cv. Blackwell, *P. dilatatum*, *S. nutans* cv. Cheyenne, *S. almum*, Silk sorghum and *S. airoides*. *A. gerardi* cv. Kaw was not sown at Cassibile, while *A. gerardi* cv. Cimarron was not sown at Rutigliano. Both cultivars tolerated the winter's low temperatures. *B. pertusa* cv. Keppel persisted for 2 years at Gaudiano di L. and died after the first year at the other locations. *B. insculpta* cv. Hatch, *C. ciliaris* cv. Gayndah and *P. clandestinum* did not survive the second winter, while *S. sphacelata* cvv. Narok and Solander did not survive the first winter at Gaudiano di L. *C. gayana* cv. Callide, *C. setigerus* and *U. mosambicensis* cv. Nixon showed good persistence at Cassibile but died after 1 or 2 years at the other 2 locations. This behaviour could be in part related to minimum temperatures experienced at Gaudiano di L. and Rutigliano (see Table 2), while the annual behaviour of *B. pertusa* cv. Keppel at Cassibile is not clear but would be unrelated to winter temperature.

Plant height. Table 5 includes only species that produced significant biomass yields in the 3 years at all test locations. Species height, averaged for all locations, showed a wide range from about 90 cm for the 2 sorghums to about 20 cm for *B. dactyloides*. The mean values for each location were 43 cm (Cassibile), 45 cm (Gaudiano di L.) and 62 cm (Rutigliano), where cuts were effected at a later stage (full flowering) than at the other locations.

Number of cuts performed on perennial species. The total number of cuts effected in the 3 years ranged, averaged over all locations, from 9.7 in *E. curvula* to 5.0 in *S. nutans* cv. Cheyenne and *P. virgatum* cv. Blackwell.

Biomass production

Dry matter yield in the first year. Dry matter yields in the first year (Table 6), averaged over the 3 sites, varied between 29.5 t/ha (*S. almum*) and 1.0 t/ha (*A. gerardi* cv. Cimarron). Mean yield varied between sites: 11.3 t/ha (Cassibile), 6.7 t/ha (Gaudiano di L.) and 14.3 t/ha (Rutigliano), which could be a function of the later sowing time at Gaudiano di L. (August 7) compared with the other locations. Only *S. almum* and Silk sorghum yielded well in the first year (mean 29 t/ha) and they were the top-ranked species at all 3 locations with dry matter yields ranging between 22.3 and 35.9 t/ha.

Dry matter yield of perennial species over 3 years. The mean yields, averaged over the 3 years at each site (Table 7), ranged between 39.1 t/ha for *S. almum* and 4.8 t/ha for *S. airoides*. *S. almum* (38.7 t/ha) and Silk sorghum (34.9 t/ha) yielded almost twice that of *E. curvula*, *P. maximum* cv. Gatton and *C. gayana* cv. Pioneer, that ranked 3rd, 4th and 5th with DM yields between 19.1 and 17.3 t/ha. The mean yield (Table 7) was higher at Gaudiano di L. (17.9 t/ha) than at Cassibile (12.7 t/ha) and Rutigliano (14.1 t/ha). In the first year, mean yield was 9.5 t/ha DM (Table 7) with only *S. almum* (29.3 t/ha), Silk sorghum (28.0 t/ha), *P. maximum* cv. Gatton (20.0 t/ha) and *C. gayana* cv. Pioneer (15.7 t/ha) being significantly above average. In the second year, mean yield increased to 19.8 t/ha and the most productive species were *S. almum* (50.1 t/ha) and Silk sorghum (45.9 t/ha). In the third year, mean yield

Table 5. Mean plant height of the perennial species during the study.[1]

Species	Location			
	Cassibile	Gaudiano di L.	Rutigliano	Mean
		(cm)		
B. curtipendula cv. El reno	50	23	39	37
B. dactyloides	15	14	28	19
C. gayana cv. Pioneer	50	47	64	54
E. curvula	60	42	70	57
F. arundinacea cv. Penna	35	40	60	45
P. coloratum cv. Bambatsi	55	43	59	52
P. maximum cv. Gatton	60	47	76	61
P. virgatum cv. Blackwell	50	35	58	47
P. dilatatum	25	31	59	38
S. almum	60	113	92	88
S. nutans cv. Cheyenne	25	26	56	36
S. spp. hybrids cv. Silk	60	114	98	90
S. airoides	15	20	43	26
Mean	43	46	62	50

[1] Includes only species that showed perennial behaviour and valuable biomass yield at the 3 locations.

Table 6. Dry matter yields of the species in the first year.

Species	Location[1]			
	Cassibile	Gaudiano di L.	Rutigliano	Mean
		(t/ha)		
A. gerardi cv. Cimarron	0.5	1.4	Not sown	1.0
A. gerardi cv. Kaw	Not sown	0.2	3.0	1.6
B. curtipendula cv. El reno	2.5	1.7	3.5	2.6
B. insculpta cv. Hatch	11.1	3.8	5.0	6.6
B. pertusa cv. Keppel	9.2	5.0	3.7	6.0
B. dactyloides	0.6	0.5	4.9	2.0
C.ciliaris cv. Gayndah	12.6	10.2	12.9	11.9
C. setigerus	14.0	6.0	15.1	11.7
C. gayana cv. Callide	27.4	11.1	39.6	26.1
C. gayana cv. Pioneer	14.4	10.0	24.3	16.2
E. curvula	6.0	4.8	14.2	8.3
F. arundinacea cv. Penna	0.5	0.8	2.2	1.2
P. coloratum cv. Bambatsi	11.5	6.5	9.6	9.2
P. maximum cv. Gatton	23.6	11.9	26.1	20.6
P. virgatum cv. Blackwell	2.4	3.9	5.5	3.9
P. dilatatum	2.3	0.9	2.4	1.9
P. clandestinum	20.9	8.7	25.2	18.2
S. sphacelata cv. Narok	11.0	6.4	19.5	12.3
S. sphacelata cv. Solander	18.1	7.7	13.5	13.1
S. nutans cv. Cheyenne	0.9	1.7	1.6	1.4
S. almum	32.1	22.5	33.8	29.5
S. spp. hybrid cv. Silk	26.7	22.3	35.9	28.3
S. airoides	0.7	0.3	2.2	1.1
U. mosambicensis cv. Nixon	11.7	12.3	24.5	16.2
Mean	11.3	6.7	14.3	10.4
LSD (P<0.01)	0.76	0.54	0.60	

[1]The statistical analysis was conducted separately for each location.

Table 7. Dry matter yield of the perennial species over locations and time.[1]

Species	Location			Year			Mean
	Cassibile	Gaudiano di L.	Rutigliano	1	2	3	
				(t/ha)			
B. curtipendula cv. El reno	6.0	10.9	4.3	2.6	11.1	8.4	7.1
B. dactyloides	3.2	8.6	4.6	2.0	8.8	7.0	5.4
C. gayana cv. Pioneer	15.4	13.2	23.3	16.2	16.4	19.0	17.3
E. curvula	11.2	28.3	17.9	8.3	26.8	24.2	19.1
F. arundinacea cv. Penna	3.0	17.7	5.0	1.2	14.5	11.2	8.6
P. coloratum cv. Bambatsi	11.4	9.0	11.3	9.2	10.0	12.8	10.6
P. maximum cv. Gatton	24.5	10.0	20.5	20.6	16.1	17.3	18.4
P. virgatum cv. Blackwell	10.3	12.6	6.3	3.9	15.8	11.2	9.8
P. dilatatum	7.9	15.2	9.5	1.9	20.1	15.6	10.9
S. airoides	2.5	7.5	4.2	1.1	6.5	8.3	4.8
S. nutans cv. Cheyenne	7.5	11.2	4.7	1.4	14.8	10.5	7.8
S. almum	32.6	49.5	35.2	29.5	50.1	38.2	39.1
S. spp. hybrid cv. Silk	29.7	39.4	36.0	28.3	45.9	32.0	35.0
Mean	12.7	17.9	14.1	9.7	19.8	16.6	14.9

[1] Includes only species that showed perennial behaviour and valuable biomass yield at the 3 locations.
LSD (P<0.01): species effect = 3.54; location effect = 1.70; location x species effect = 6.13; year effect = 1.40; year x species effect = 5.05.

Table 8. Dry matter yield distribution (%) between seasons (Mean of 2nd and 3rd years).

Species	Date of 1st cutting	Spring	Summer	Autumn
B. curtipendula cv. El reno	29/06	32.0	53.9	14.2
B. dactyloides	5/06	51.8	34.7	13.5
C. gayana cv. Pioneer	8/07	16.5	53.8	29.7
E. curvula	22/05	42.5	40.9	16.7
F. arundinacea cv. Penna	14/05	67.7	22.4	9.9
P. coloratum cv. Bambatsi	25/06	19.0	55.8	25.2
P. maximum cv. Gatton	15/07	3.5	70.4	26.1
P. virgatum cv. Blackwell	30/06	33.3	56.2	10.5
P. dilatatum	8/06	37.4	38.1	24.6
S. nutans cv. Cheyenne	12/07	11.2	72.3	16.5
S. almum	15/06	31.0	42.7	26.3
S. spp. hybrid cv. Silk	15/06	31.8	42.3	26.0
S. airoides	12/06	44.3	48.7	7.0
Mean	18/06	32.5	48.6	18.9

Table 9. Forage qualitative characteristics determined at Cassibile.

Species	CP	NDF	ADF
		(%DM)	
B. curtipendula cv. El reno	9.0	69.0	38.0
B. dactyloides	7.5	71.0	33.0
C. gayana cv. Pioneer	8.3	69.0	37.0
E. curvula	7.6	73.0	35.0
F. arundinacea cv. Penna	7.5	55.0	33.0
P. coloratum cv. Bambatsi	6.3	64.0	30.0
P. maximum cv. Gatton	7.4	66.0	38.0
P. virgatum cv. Blackwell	4.7	73.0	40.0
P. dilatatum	10.6	62.0	31.0
S. nutans cv. Cheyenne	4.0	71.0	41.0
S. almum	6.0	67.0	41.0
S. spp. hybrid cv. Silk	6.6	68.0	38.0
S. airoides	10.5	66.0	31.0
Mean	7.4	67.2	35.8
LSD (P<0.05)	1.8	8.1	12.1

Table 10. Seed production, germinability and mean germination time (MGT) of the species evaluated in 1997 at Gaudiano di Lavello.

Species	Seed production (kg/ha)	Germinability (%)	MGT (d)
A. gerardi cv. Cimarron	220	16.0	5.9
A. gerardi cv. Kaw	140	14.5	7.5
B. insculpta cv. Hatch	*[1]	–	–
B. pertusa cv. Keppel	*	–	–
B. curtipendula cv. El reno	280	19.5	6.5
B. dactyloides	605	***[3]	–
C. ciliaris cv. Gayndah	240	21.0	7.4
C. setigerus	*	–	–
C. gayana cv. Callide	*	–	–
C. gayana cv. Pioneer	270	53.0	6.2
E. curvula	430	98.5	4.0
F. arundinacea cv. Penna	610	38.0	7.7
P. coloratum cv. Bambatsi	600	72.5	5.4
P. maximum cv. Gatton	545	46.0	6.6
P. virgatum cv. Blackwell	515	74.0	6.7
P. dilatatum	420	11.5	7.4
P. clandestinum	**[2]	–	–
S. sphacelata cv. Narok	*	–	–
S. sphacelata cv. Solander	*	–	–
S. nutans cv. Cheyenne	340	4.5	7.3
S. almum	920	48.5	7.7
S. spp. hybrid cv. Silk	825	58.0	7.3
S.airoides	420	30.0	5.6
U. mosambicensis cv. Nixon	*	–	–

[1]Species which did not persist.
[2]Species with no valuable seed production.
[3]Species with no viable seeds.

was only 16.6 t/ha, but *S. almum* (38.2 t/ha) and Silk (32.0 t/ha) still produced the highest yields.

Seasonal distribution of DM. S. nutans and *P. maximum* produced more than 70% of their yield in summer, while the other C_4 species produced between 56% (*P. virgatum*) and 35% (*B. dactyloides*) in summer. In contrast, *F. arundinacea* produced the highest percentage in spring (68%) (Table 8).

Forage quality

Forage quality (CP, NDF, ADF) was investigated only for the first cut in the first (1995) and second (1996) years at Cassibile. Protein % ranged from 10.6% in *P. dilatatum* and *S. airoides* to 4.0% in *S. nutans,* while *F. arundinacea* showed a mean CP of 7.5% (Table 9). The lowest NDF value was observed in *F. arundinacea* (55%). Among C_4 species, the highest values (71–73%) were found in *S. nutans*, *B. dactyloides*, *E. curvula* and *P. virgatum* and the lowest in *P. dilatatum* (62%). The highest ADF values were in *S. almum* and *S.*

nutans (both 41%), whereas the lowest value was found in *P. coloratum* (30%).

Seed production

Seed production was measured at Gaudiano di L. in 1997, only on accessions still persisting, and varied between 100 and 900 kg/ha (Table 10). The two perennial sorghums, with a high unit seed weight, gave the highest yields (800 and 900 kg/ha). *E. curvula* had the highest germination percentage and shortest mean germination time.

Discussion

Survival

The results obtained in this research have demonstrated wide variation in adaptation of the 24 species to the Mediterranean environment. *S. almum*, Silk sorghum, *P. maximum* cv. Gatton, *C. gayana* cv. Pioneer and *E. curvula* demonstrated a high yield potential at latitudes between 37 and 41° N. It is interesting that only *B. pertusa* did not survive the winter of the first year under milder winter conditions (Cassibile, Sicily), but this species survived for 2 years at Gaudiano di L., where 17 days of frost were recorded in the winter of 1996. Other species such as *P. clandestinum*, *C. setigerus*, *C. ciliaris*, *U. mosambicensis*, *S. sphacelata* and *C. gayana* cv. Callide disappeared after 1 or 2 years and it has not been possible to identify the causes. Callide rhodes grass was shown to be perennial only at Cassibile, whereas Pioneer rhodes, which produced lower yields than Callide in the first year, persisted for 3 years at all 3 locations. Low winter temperatures and an inappropriate cutting regime may have had some influence on the results. A cutting height of 12–15 cm is recommended to ensure survival. Cutting closer to the soil surface (in our trials mostly 3–4 cm) can remove both the buds responsible for the growth of new stalks and the plant organs rich in storage substances (carbohydrates), with a subsequent reduction of cold-tolerance (Bartholomew *et al*. 1995). Species longevity is also related to plant habit: species with an upright habit (bunch or clump-forming grasses) show a lower cold tolerance than rhizomatous running grasses (Moore *et al*. 2006).

Plant establishment

All species compared, except the perennial sorghums, experienced emergence problems and established slowly, as observed with C_4 grasses in Ohio (Bartholomew *et al*. 1995) and eastern Montana (Holzworth 2006). To facilitate a rapid establishment of these species for the northern hemisphere and in the presence of mild winter temperatures, autumn sowing was proposed; in eastern Montana (Holzworth 2006), *P. virgatum* established successfully in spring when sown in the previous autumn. At Gaudiano di L. (Italy), *E. curvula* sown in October showed excellent establishment in autumn and good winter growth (A. Corleto and E. Cazzato, unpublished data). In Florida (USA), *E. curvula* is sown for pasture improvement and is utilised in winter (Skerman and Riveros 1989). However, in Australia, *E. curvula* is regarded at best as undesirable, and at worst as a nasty weed (Parsons and Cuthbertson 1992). In our research, warm season grasses could be sown successfully during May-August, preferably after adequate manuring in a fine seed-bed. However, sowing C_4 grasses with small seeds into clay soils low in organic matter will generally be unsuccessful.

Yield potential

The potential to produce dry matter, expressed as an average for the 3 years and 3 locations, was impressive for some C_4 species. In particular, very high yields (35–39 t/ha) were observed for the perennial sorghums, *S. almum* and Silk sorghum, followed by *E. curvula*, *P. maximum* cv. Gatton and *C. gayana* cv. Pioneer with values between 17 and 18 t/ha. All other species showed much lower yield potential (<11 t/ha DM). It should be noted that these yields were obtained from small experimental plots, which were well maintained and kept free of weeds, but were cut very close to the soil surface. How well the yields obtained reflect what could be obtained with commercial stands is a matter for debate. However, in Mediterranean environments under irrigation on fertile soils, annual DM yields of 25 t/ha have been obtained from annual sorghums like Sudan grass, as the sum of two cuts effected at flowering (Baldoni and Giardini 2002). Moreover, the performance of the summer grasses could be greatly reduced through winter-spring competition from invading native/naturalised species and their use of soil moisture, which would not be available for use in later months.

Nearly all species showed substantial yield variation across sites. *S. almum* showed the maximum yield (49.5 t/ha) at Gaudiano di L., under the best overall soil fertility conditions, with lower yields (32.6 and 35.2 t/ha) at the other sites. A similar trend was displayed by other species, *e.g. E. curvula*, *P. dilatatum*, *F. arundinacea*, *S. nutans*, *B. curtipendula*, *B. dactyloides*, *S. airoides* and *P. virgatum*. However, other species, *e.g.* Silk sorghum and *P. coloratum* cv. Bambatsi, showed similar yields at all sites.

It was significant that these species produced adequate DM yields not only in summer but also in spring and autumn, when daily mean temperatures were much lower and would be expected to limit growth.

Seed yield

All species that persisted at Gaudiano di L. (17 out of 24) produced seed except *P. clandestinum*. The seed of *P. clandestinum* used in our experiment was not from an Australian registered cultivar and could derive from Kenyan ecotypes described by Edwards (1937), characterised by male sterility and anthers not exserted and therefore not visible outside the leaf-sheath during the flowering stage. The wide variation in germination percentages of the seed indicates the importance of obtaining germination test results when purchasing seed.

Forage quality

While forage quality was affected by cutting time and environmental conditions that influenced forage growth and leafiness, some C_4 grasses (*P. dilatatum*, *S. airoides*, *B. curtipendula*) expressed significantly higher CP values (9–10% DM) than *F. arundinacea* (7.5%), although the latter showed the lowest NDF (55.0%). As was to be expected with the warm season grasses, the NDF was higher and ranged between 62% (*P. dilatatum)* and 73% (*E. curvula* and *P. virgatum)*. Since forage quality measurements mainly reflect differences in leaf:stem ratios, the results presented here and even the ranking of accessions, might not apply to other situations with different defoliation regimes, N levels, etc. Furthermore, under grazing conditions, cattle select for leaf, especially in forage sorghums, and the thicker stems are not consumed, yet these are included in the samples analysed in this study.

Application

The tested species are suited to a range of situations, depending on the type of forage produced and the requirements for particular applications. The two sorghums and *E. curvula,* partly owing to their high resistance to drought and salinity (Skerman and Riveros 1989), are suitable for hay or silage production or even, in the case of *E. curvula*, for pasture. The same uses may be envisaged for *P. maximum*, *C. gayana* (very resistant to salinity, Russel and Webb 1976) and *P. dilatatum* (requires good soil fertility, Skerman and Riveros 1989). However, Silk sorghum seems the most promising species for hay-making or grazing in Mediterranean environments and future research seems warranted to clarify its response in terms of biomass yield and forage quality to different regimes of irrigation and N fertilisation. Australian research will provide good indications of the likely outcomes. The high yields of fibre-rich biomass produced by the sorghums, *E. curvula* and *P. maximum* suggest that these species could be valuable sources of energy for non-food uses, *e.g*. biogas production. Similarly, *B. dactyloides* and *B. curtipendula* might be used as cover crops in orchards and for the protection of sloping land from water erosion, because of their ability to produce a dense, short groundcover. While caution is always recommended, indications from this research are that some warm season grasses should be introduced into the Mediterranean environment, taking account of the objectives to be pursued, and being mindful that some might have the potential to become environmental weeds, which could be difficult to eradicate (Stevens 1975). Regular monitoring of sites of introduction would be essential.

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