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Water use efficiency in a mild season and water cost of summer survival of perennial forage grasses in Mediterranean areas

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SUMMARY – Sixteen Mediterranean cultivars (cvs) of cocksfoot, tall fescue and phalaris were compared for water use, yield and water use efficiency (WUE) for three years in a field trial covered by rainout shelters in Montpellier (France). From October to May, all cvs were watered at the same water supply amounting to 70-80% of potential evapotranspiration. From June to September, no water was supplied and growth ceased during three months. For each cv and each growth cycle, yield and water balance were established. Pluri-annual production and interest of cvs in such semi-arid conditions ranged according to their perenniality (summer drought survival) and their average WUE during the autumn to spring growth period, which depends on growth potential at low temperatures. Unproductive water loss imposed by the climate during the survival period was not significantly different between cvs and years (83±18 mm). This water cost of summer survival amounted to 15-20% of annual rainfall.

Keywords: Perennial grass, Mediterranean climates, drought, perenniality, water use efficiency.

RESUME – *"Efficience de l'utilisation de l'eau pendant la saison tempérée et coût hydrique de la survie estivale des graminées pérennes en régions méditerranéennes". Seize cultivars (cvs) de dactyle, fétuque élevée et phalaris ont été comparés pour la production et l'efficience d'utilisation de l'eau (WUE) pendant trois ans dans un essai au champ sous abri anti-pluie à Montpellier (France). D'octobre à mai, les apports d'eau couvraient 70 à 80% de l'évapotranspiration potentielle. De juin à septembre, une sécheresse complète était appliquée, bloquant la croissance pendant trois mois. Les mesures ont permis de faire un bilan hydrique pour chaque cycle de croissance de chaque cv. La production fourragère pluriannuelle des cvs dépend de leur tolérance à la sécheresse et de WUE moyenne de la période active, laquelle dépend de la capacité de croissance des cvs aux basses températures de novembre à mars. La perte d'eau non productive pendant la survie estivale a été de 83 ± 18 mm, sans différence significative entre cvs ou entre années. Ce coût hydrique de la survie représente* 17 ± 4 *% de la pluviométrie annuelle dans cette situation.*

Mots-clés : *Graminée pérenne, climat méditerranéen, sécheresse, pérennité, efficience de l'eau.*

Introduction

Genetic improvement and agronomical optimisation of harvested yields HY (g DM m^{-2}) depend on maximisation of the three terms in the equation proposed by Passioura (2002):

(1) $HY = T \times WUE \times HI$ (with $DMT = T \times WUE$)

where T (gH_2O/m^2) is the crop transpiration, WUE the average water use efficiency (gDM/kgH_2O) for the crop cycle; HI the harvest index, and DMT (gDM m^{-2}) the total dry matter yield. Considering ET and E respectively as crop evapotranspiration and soil evaporation (in g H_2O m^{-2}), T = ET – E. Since in field studies it is difficult to measure root biomass, only aerial biomass (DMF) is often taken into account. Then, the yield of a forage crop is the aerial biomass (HY= DMF, HI=1), and equation (1) is simplified:

(2) $DMF = T \times WUE$ or $DMF = (ET-E) \times WUE$

This can be considered for any period like one growth cycle, one year, or more. When DMF_a, WUE_a ET_a, E_a, and T_a are the annual values of already defined parameters, equation (2) is for a year:

(2a) $DMF_a = T_a \times WUE_a$ or $DMF_a = (ET_a - E_a) \times WUE_a$

Pluriannual yield for n years is $DMF_n = \Sigma_n(DMF_a)$. Therefore, to improve forage yields implies: (i) to maximise plant water uptake (T_a); and (ii) to maximise water transformation into biomass through WUE. Objectives differ between temperate and Mediterranean areas.

In temperate areas, where annual rainfall (P_a) generally exceeds potential evapotranspiration (ET_{pa}), to maximise (T_a) of forage crops implies the following relationship: $T_a \leq ET_a \leq ET_{pa}$ ($\leq P_a$). The limit of T_a is ET_{pa}, which can be assessed when all over the year daily $T \approx ET \approx ET_p$ (E not significant). It involves high plant density, continuous plant soil cover, long and active growth during the growing season. Unproductive periods are rainy cold winters, which have no water cost (E, T and ET very low, P largely in excess). In summer, growth is maintained. Drought resistance is defined as the ability to maintain optimal growth under moderate water deficits, which depends mainly on root depth.

In Mediterranean environments, where annual ET_{pa} exceeds annual rainfalls P_a and where E_a is always significant, maximisation of T_a implies the following relationship: $T_a < ET_a < P_a$ ($< ET_{pa}$). In Mediterranean areas, a year is composed of two contrasting periods: a wet mild growing season followed by a dry hot season of several weeks or months without any growth of forage plants. Annual yield DMF_a is produced during the growing period (characterised by cumulated T_g and ET_g, and average WUE_g) following the equation:

(3) $DMF_a = [(1 - K_r - K_d - K_e - K_s) \times P_a] \times WUE_g$

where K_r, K_d, K_e, are the fractions of annual rainfall P_a lost respectively by run-off, deep drainage, soil evaporation during the growing period, and K_s is the fraction of P_a lost during summer. During this survival period, high evaporative conditions impose unproductive water loss (ET_s), through conservative transpiration and soil evaporation, which need to be evaluated for different plant material.

The objective of the present study was to analyse the repartition of use of annual rainfall between two seasons (productive/conservative) by perennial forage grasses (*Dactylis glomerata*, *Festuca arundinacea, Phalaris arundinacea)* in semi-arid Mediterranean environments. The study is carried out within an Euro-Mediterranean multi-site network analysing drought resistance, perenniality and pluriannual yield in cool-season perennial grasses (PERMED, www.montpellier.inra.fr/permed/).

Material and methods

Sixteen cultivars (cvs) representing six types of cool-season grasses (cocksfoot, tall fescue, phalaris) bred for sub-humid and semi-arid Mediterranean environments were tested in pure stands:

- five Mediterranean non summer dormant dactylis: cvs Medly (France), Currie (Australia), Jana (Italia), Delta 1 (Portugal) and the Sardinian ecotype Ottava (Italia);

- a Mediterranean cocksfoot with complete summer dormancy, cv Kasbah (Australia/Morocco);

- a temperate oceanic cocksfoot, cv Porto (Australia/GB/Portugal);

- five cvs of Mediterranean tall fescues with incomplete summer dormancy: Centurion (France), Tanit (Italy), Flecha-N (Argentina), Flecha-E (Argentina-New-Zealand), Fraydo (Australia);

- two intermediate Mediterranean-temperate cvs of tall fescue : Lutine (France) and Sisa (Italy);

- two summer dormant phalaris : cvs Australian (Australia) and Atlas PG (Australia/Morocco).

The trial was a complete randomised block design with four replicates, set on a deep loamy clay alluvial soil (> 2 m) in the Montpellier-Mauguio area, southern France. It was sown on 21/10/2004 at seed rates of 2 to 2.5 g m^{-2}, in plots of 2.5 m² of 8 rows, interline 0.17 m. Plants received 80-80 kg ha^{-1} P_2O_5-K_2O in autumn each year. N supply was 120 kg ha^{-1} per year (40 in early autumn; 40 around 10 February at end of winter rest; 40 around mid-March at onset of stem elongation and hay cycle).

The trial was covered by rainout shelters and watered from mid September to early June through dripping at 70-75% of potential ET_p in order to have no surface run-off and no drainage. Water supply (P_a) was 495 mm in 2004-05, 496 mm in 2005-06, 460 mm in 2006-07. From June to September, no irrigation was provided during 106 days (648 mm of cumulated ET_p) in 2005, 100 d (640 mm) in 2006, and 129 d (735 mm) in 2007, corresponding to average semi-arid climates of southern Italy or Spain.

Each of the 64 plots was equipped of a 2.0 m depth tube to measure water profiles with a neutron probe at beginning and end of each growth cycle from June 2005 to October 2007. Considering the absence of run-off and drainage, accurate measurements of water supplies and soil water reserve variations allowed to calculate water balance of each plot at each cycle to obtain its ET (ET = reserve variation + irrigation) and WUE (WUE = DMF/ET). During summer drought, soil moisture was measured several times to assess evapotranspiration ET_s (term $K_s.P_a$ in equation 3).

Linear density rate (LDR) of living plants was assessed visually (scale 0-100) at the beginning of each regrowth after rehydrations and cuts. Yields (DMF) were measured by moving all plots:

- Autumn DMF (from rehydration to winter rest) was the sum of two cuts (around 20 October and 15 December); when grass height was insufficient, only the second cut was performed.

- Winter DMF was measured by one cut around 22 March (spiklets at 2-3 cm height for the earlier cv, Medly); the contribution of the first and colder part (15 December-31 January) was not significant.

- Spring DMF was measured by cumulating hay cut at heading (between 20 April and 10 May depending of earliness of cvs) and a late spring cut (between 5 and 10 June for all cvs). The date of this last cut was a function of the date of the last water supply to obtain a limited regrowth (less than one leaf per tiller in average) before growth cessation under water stress.

Results

Plant density evolution and persistence

Linear density rates (LDR) were almost stable during wet periods but varied greatly under summer droughts. Consequently, average LDR for each growing season gives a synthetic result of density variations and perenniality (Fig. 1). Mediterranean tall fescues (Flecha to Fraydo) maintained the highest LDR (80-90% in fourth year). Mediterranean dactylis including the summer dormant one (Medly to Kasbah) lost slightly more density but maintained LDR at high levels (70-80% in fourth year), except Ottava ecotype which had uncomplete emergence because of seeds deficiency. Negative impacts of droughts were more important on the three other groups of cultivars. Intermediate tall fescues (Sisa, Lutine) lost density each summer, but partially compensated by the extension of remaining plants in big clumps. Plant densities of phalaris and oceanic dactylis decreased drastically during summers, but surviving plants of phalaris showed high capacity to recolonise soil surface by underground stolons in autumn, what did not occur for dactylis Porto.

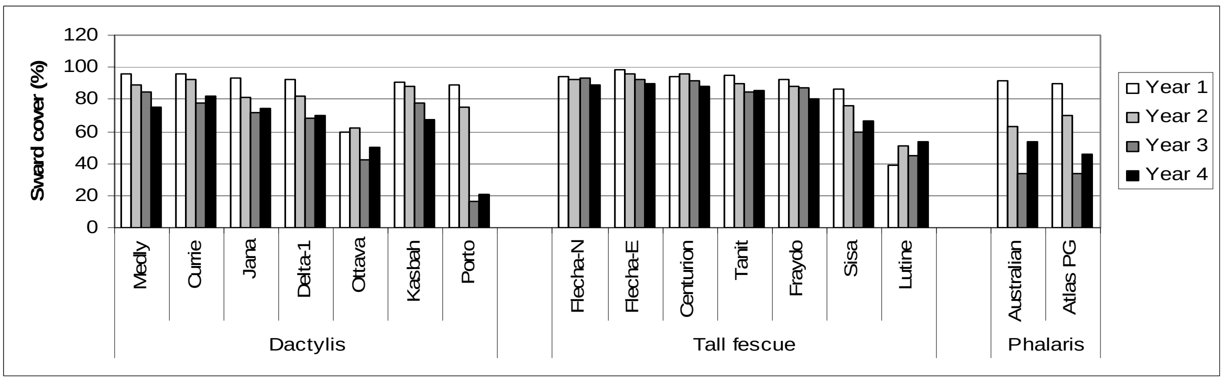

Fig. 1. Plant density (linear density rate, %) evolution of 16 cultivars of cool-season perennial grasses during four years, under rainout shelters imposing severe summer droughts in Montpellier.

Water use and water cost of summer droughts

Actual evapotranspiration during the non growing period (ET_s) was measured during summer droughts in 2006 and 2007. The thirty-two values (16 cvs x 2 years) were all in the interval 83 ± 18 mm, without significant difference between cvs and years. This is due to a similar water use by all cvs during the growing period : ET_g represented 83 ± 3 % and 82 ± 2 % of the annual water supply in both years. At the beginning of drought, complete cessation of growth occurred at very close dates and soil water profiles between cvs, when remaining extractible water in the soil was around 90 mm, except the dormant cv Kasbah which stopped earlier. Two thirds of this remaining water was used in next 25-30 days, when plants were still green. The last part (20-30 mm) was used slowly during the following 70-90 days, at ET rates decreasing progressively from 10% to 3-4% of ET_p (from 0.6 to 0.1 mm/day). Mortality of tillers increased when ET fluxes decreased under 5% of $ET_{p.}$ This "water cost" of summer survival' amounted to a large part of annual water supply (K_s of 0.17 and 0.18 for the two years). Even though the soil water depletion was slightly different between groups of cvs, higher in the first soil layers by non dormant Mediterranean dactylis, larger at depth by Mediterranean fescues and phalaris, it resulted in limited and non significant differences in $ET_{s,}$.

Yield, water use, and water-use efficiency during growth period (autumn to late spring)

Annual yields (DMF_a) were low in the first growing season (1.5 to 3 t ha^{-1} per year). They varied between 8.5 and 4 t ha^{-1} per year in years 2 and 3, with the same ranking between cvs (r = 0.93*** between yields of both years). Except the dormant dactylis, cultivars having the highest persistence (LDR > 60% along time) exhibited the highest yields. At the end of the third growing season, their cumulated yields ranged from 18 t ha^{-1} /3y (Centurion, Flecha) to 14.3 t ha^{-1} /3y (Fraydo, Delta). All cvs with low initial densities or low persistence (Ottava, Porto, Lutine, Australlian, Atlas PG) had lower yields (12.5 to 11.2 t ha^{-1} /3y). The summer dormant Kasbah is particular, being persistent but weakly productive (8.7 t ha^{-1} /3y). Because ET_g was almost constant between cvs, no correlation was found between annual yields and corresponding water use in the growing seasons 2005-06 and 06-07.

Since there was no run-off and drainage and the soil was in general well covered , WUE per growth cycle was assessed by the ratio DMF/ET, and WUE_g for the whole growing period by DMF_a/ET_g (total of 4 cycles in 2005-06 and five in 2006-07). Results of both years being similar, only 2006-07 is presented (Fig. 2). ET_g being almost constant, WUE_g and DMF_a are linearly linked (r^2=0.95***). WUE_g varied from 2.2 g DM $kg^{-1}H_2O$ (Centurion and Flecha) to 1.0 (Kasbah). WUE are much more variable between cvs in winter and autumn than in spring, which highly determines annual yields and WUEg variations. It depends of growth potential at low temperatures, higher in Mediterranean tall fescues (Flecha, Centurion, Tanit) than in Mediterranean dactylis.

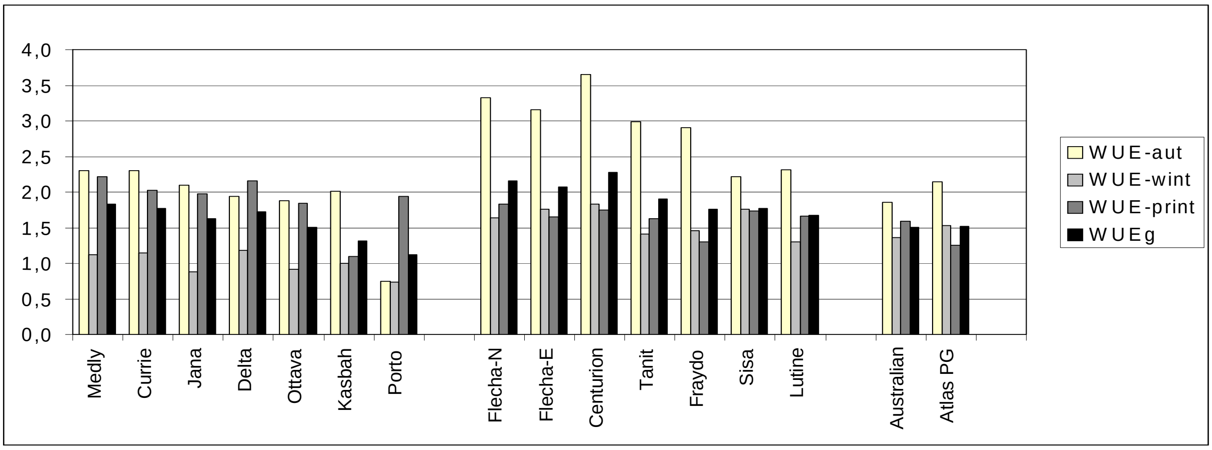

Fig. 2. Water use efficiency (g DM/kg H_2O) in winter 2005-2006 and spring 2006 at Montpellier-Mauguio, for 16 cultivars of grasses (lsd are 0.58 and 0.97 for the 2 periods respectively).

Discussion and conclusions

In Mediterranean climates where annual rainfall is at least 400-500 mm, rainfed perennial pastures are possible using adapted tall fescues and cocksfoots. They must cumulate high growth rates and high WUE in mild and cold seasons with high drought tolerance (survival) across dry summers (Volaire *et al.*, 2005). In deep soils, the best cvs can tolerate 100-120 days of complete drought and cumulated water deficits of 600-700 mm, without important damage to plant density. Their rapid recovery allows first grazing 20-30 days after the first significant autumn rainfalls. To maximise use of annual rainfall for production needs to minimise the coefficients in equation (3). K_r is generally small (0.00-0.10), K_d may be more important (0.00-0.20), but decreases with soil and root depth (Angus *et al.,* 2001; Batchelor *et al.,* 2002; Passioura, 2004). In wheat, Richards *et al.,* (2002) showed that soil evaporation during the growing season ranges between 50 and 160 mm (K_e from 0.10 to 0.30), depending on rapid establishment of the canopy and soil shading along crop cycle (early vigour, plant density, nitrogen nutrition). The lowest values of K_e could be applied to grass crops. However, unproductive water loss in summer (60-100 mm, Ks of 0.15-0.21 here) is important and unavoidable.

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