Cutting and water deficit effect on water use efficiency of forage species

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Abstract

Water use efficiency (WUE) is a widely used concept connecting different processes directly or indirectly related to biomass production and water used. The different ratios of WUE proposed in the literature are based on agronomical, ecophysiological approaches or combination of them. Water deficit influences plants by closing the stomata, indirectly reducing photosynthesis, leaf extension and growth. Moreover the reduction of transpiration due to stomatal closure is greater than photosynthesis. Furthermore, water deficit changes root growth and distribution, therefore modifying the plant ability to extract water from the soil. The relationship between water deficit and WUE is controversial. Many researchers report higher WUE under water deficit, while others lower. On the other hand, cutting parameters, such as timing, frequency and intensity affect the values of WUE, as they affect the harvestable biomass and evapotranspiration. Nevertheless, the absolute values of WUE vary markedly depending on plant, soil, climatic factors and management practices. Regardless of the method used, WUE could still be considered as a useful selection criterion for superior performance, particularly, in a dry environment.

Key words: cutting, drought, grassland, stomatal closure, water use efficiency

Introduction

Worldwide, water availability for agriculture is steadily reducing, because of overuse and observed decline in annual precipitation and increase in the annual mean temperatures. Under these conditions, the use of less water to achieve high yield is a major objective of the modern agriculture (Tambussi *et al*. 2007, Moreno *et al*. 2008).

Water use efficiency (WUE) is an index generally used to describe the relationship between the agriculture product (output) and the water used (input) (Fairweather et al. 2008). Improving the efficiency of water use, under given climate and soil conditions, may result from better managing of several factors, including water availability, fertility, pests and diseases, crop or pasture species variety, cutting intensity, planting date, soil water conditions at planting, plant density and row spacing. Therefore, improving water use efficiency requires an understanding of the whole system and should not focus solely on managing irrigation water (Cox et al. 1988, Ritchie and Basso 2007, Fairweather et al. 2008). Ritchie and Basso (2007) have used extensive literature data to demonstrate that, under most circumstances, increases in yield resulting from crop management also result in increases in WUE. This occurs because management usually has little influence on the duration of an annual crop growth cycle and evapotranspiration (ET) but may have a large influence on yield. Although cutting is a common practice for forages there are few publications concerning its relation with the WUE concept.

Generally, WUE is considered as a crucial parameter, where water is scarce, although the aspect that it is an elusive ratio, regardless the estimation method used, was expressed as well (Tambussi *et al*. 2007, Blum 2009). Nevertheless, the selection of forage species for dry areas should not be based on WUE alone. Yield and nutritive value need also to be considered (Neal *et al*. 2011). This review focuses on water availability and cutting management effect on the WUE of forages species.

Definition of WUE

The relationship between plant biomass accumulation (W) and plant water loss through transpiration (TR) quantified by de Wit since 1958 as water use efficiency (WUE), given by the ratio WUE=W/TR. Nowadays, there are many acceptable definitions that can be used to describe WUE. The resulting forms are sometimes overlapping and confounded. The values derived from all these different concepts are not always directly associated, resulting to conclusion export inability (Anyia and Herzog 2003). For these reasons, in each particular study the concept of WUE should be accurately defined. The agronomic approach, which is at the interest of farmers and agronomists, refers to plant WUE and focuses in concepts based on harvestable biomass and the amount of irrigation applied in the field. The ecophysiological approach, at the interest of plant physiologists and biochemists, refers to concepts of leaf gas exchange, based on analysis, at a given instant, of the relationship between photosynthesis and transpiration (Instantaneous WUE) or stomatal conductance (Intrinsic WUE) per unit of leaf area and trying to explain the mechanism at the level of the plant tissue (Passioura 2006, Lelievre et al. 2011). Combinations of the agronomic and ecophysiological approach are based mainly on yield and transpiration (Lazaridou and Noitsakis, 2003). In forage crops, WUE is based on seasonal or annual above ground dry biomass. It should be taken into account that the major quantity of the water applied to perennial forages is used for transpiration (85%), only 10% for evaporation, while 5% is lost as drainage below the root zone (Greenwood et al. 2008).

Different forms of the WUE concept, developed the last century, have been discussed by Fairweather et al. (2008), Blum (2009), Tambussi et al. (2007), Moreno et al. (2008) and others.

WUE under water deficit

Water use efficiency is often considered an important determinant of yield under stress and even as a component of crop drought resistance. It has been used to imply the production of rainfed plants per unit water used, resulting in ‘’more crop per drop’’ (Greenwood et al. 2009).

Plants under water deficit close their stomata, indirectly reducing photosynthesis, leaf extension rate and growth, while the reduction of transpiration due to stomatal closure is greater than the reduction of photosynthesis. In addition, stomatal conductance to water loss under water deficit is not completely eliminated, and water continues to be lost. Furthermore, several species growing under water deficit increase the root to shoot ratio, as root growth is stimulated to increase water uptake at the expense of shoot growth, changing the root depth and density. It should be noted that the ability to increase water extraction from the soil is an important mechanism for drought tolerance and avoidance (Moreno et al. 2008, Lelièvre et al. 2011, Neals et al. 2011).

There is evidence that drought tolerant species increases WUE with increasing drought stress and reduced water supply (Blum 2009, Moreno et al. 2008). However, there are variations both among and within species (Karatassiou et al 1998, Neals et al. 2011). Neal et al. (2011) indicated that the yield difference between species, rather than the water use, was the primary determinant of WUE_t (defined as Dry Matter yield for total water used in a year). These researchers studied fifteen species in annual basis and found that perennial forages have a greater yield potential and WUE_t in a given environment. Therefore, for any forage species, strategies that maximize yield potential, rather than strategies that try to reduce water use, will have greater potential to increase annual WUE_t. Moreover, the evaluated C_4 species had higher annual WUE_t, than C_3 species. Deficit water supply led to a significant decline in annual WUE_t for all species except alfalfa.

Studying ten grass species, under three soil moisture levels, Bahrani et al. (2010) found that water deficit negatively affects the water use efficiency (shoot dry weight/total water use). Nonetheless, contradictory results have been reported for alfalfa, the most studied forage species, under water deficit. Higher WUE is reported by Lazaridou and Noitsakis (2003), Lindenmayer et al. (2008) and Ismail and Almarshadi (2011), while a decrease of WUE of alfalfa has been reported by Carter and Sheaffer (1983) and no effect by Neals et al. (2011). The differences in the results concerning the same species could be attributed either in the method of estimating WUE or to irrigation quantity and timing (Moreno et al. 2008).

WUE under cutting

Cutting, which can be described in terms of timing, frequency and intensity (amount of leaf and stem removed) may reduce water use either directly (leaf area reduction) or indirectly (negative effects on root growth and distribution). The effect of cutting on yield is well documented (Cox et al. 1988, Snyman 2005). However, although effects of cutting on WUE are expected, these are not thoroughly studied.

Asseng and Hsiao (2000) calculated WUE (CO_2 assimilation rate per unit land area/ET) just before last cutting, after cutting, during regrowth, and during the initial senescence phase of alfalfa. Before cutting, WUE of the alfalfa normalized, it declined dramatically after cutting, but steadily increased following the canopy regrowth. Late in autumn, under less favorable growing conditions, WUE declined again.

In the perennial ryegrass (*Lolium perenne*) frequent cutting (once every 2 weeks from April to September) and low height (20mm) reduced water use in the first year only. In later years, infrequent cutting (twice a year) led to higher yields and higher water-use efficiencies, but did not affect total water use (Cox et al. 1988). WUE of the species *Cleistogenes squarrosa, Agropyron cristatum and Potentilla acaulis,* subjected to four grazing intensities, increased significantly from non-grazed plots to moderately grazed plots, then decreased in high-grazed plots. However, *Artemisia frigida* responded differently (Peng et al. 2007).

In moderately species-rich temperate grassland, increasing the mowing frequency from 1 to 3 cuttings per year had no significant effect on WUE. In addition, timing of cutting influenced the WUE of alfalfa. When alfalfa was harvested during the period from pre-bud to the bud initiation stages, the WUE was higher than when harvest was performed at a later stage. The post-bud growth period also coincides with higher ET, as the plant stand reaches full canopy cover and remains at or near full canopy cover until the bloom stage. In contrast, cutting early in the season (in advance of pre-bud) will reduce the potential for highest biomass yields. This same strategy will result in decreased stand longevity, which offsets the benefits of increased WUE by harvesting at an earlier growth stage (Bauder et al. 2011). Li et al. (2011) have shown that the forage yield and WUE of Siberian wildrye (*Elymus sibiricus* L.) were the lowest at early heading stage harvest, while the highest at flowering stage regardless of the water regime. Water use efficiency (biomass retained / total water use) of three tree legumes (*Leucaena leucocephala* cv. *Tarramba,* L. *pallida x L. leucocephala* (KX2) *and Gliricidia sepium*), was higher for the April and June (mid dry season) cuttings but not for the earlier cutting (wet season) or when being left uncut. Moreover, the peak of this effect depended on species (Butisantoso et al. 2004).

Nevertheless, higher WUE values are not always associated to increased biomass. Although the different aspects of WUE render comparison of results of different studies rather challenging, WUE is still an important index and a useful selection criterion for superior performance, particularly, in a dry environment.

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