Evaluation of deficit irrigation for efficient sheep production from permanent sown pastures in a dry continental climate

S. Ates[a,b,*], S. Isik[a], G. Keles[a,c], A.H. Aktas[a], M. Louhaichi[b] and V. Nangia[b]

a. Bahri Dagdas International Agricultural Research Institute, Konya, Turkey
b. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syrian Arab Republic
c. Faculty of Agriculture, Adnan Menderes University, 09100 Aydin, Turkey

Abstract

Deficit irrigation can be a useful management tool to increase water productivity of forage and sheep production from pastures in water deprived areas of the world. A three year study compared sheep production from permanent sown pastures on clay–loam soil in a dry continental climate that were irrigated at four levels in Konya, Central Anatolia Region of Turkey. Pastures were established in 2007 with red fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) and irrigated with 100 (optimum irrigation), 75, 50 or 25% of their full irrigation requirement. Established pastures were grazed rotationally by flocks of weaned lambs between 2008 and 2010. Liveweight gain was approximately 2 kg ha^{-1} d^{-1} from the 100 and 75% irrigation treatments. However, lower levels of irrigation caused reductions ($P < 0.01$) in liveweight gains with animals gaining less than 1 kg ha^{-1} d^{-1} in the 25% irrigation treatment. Average total annual animal liveweight production was 498, 445, 380 and 198 kg ha^{-1} for 100, 75, 50 and 25% irrigation treatments, respectively. The water productivity of the full irrigation treatment per unit of dry matter and meat produced was low, particularly during the summer months, and it increased with deficit irrigation. Deficit irrigation between 50 and 75% of the full requirements during late spring and summer, prior to de–stocking, can provide efficient use of water when water resources are limited. The level of irrigation can be reduced further during the late summer and autumn when stocking rates and the demand for feed or energy from pastures are lower.

*Corresponding author. Tel.: +962 6 553 1237.
E-mail address: s.ates@cgiar.org (S. Ates)
Current address: International Center for Agricultural Research in the Dry Areas (ICARDA)
P.O. Box 950764, Amman 11195, Jordan

Keywords: Forage production, Grazing management, Lamb production, Liveweight gain, Water productivity, Water scarcity

1. Introduction

Sheep production is an integral part of crop–livestock farming in the Central Anatolia region of Turkey like in many other dry areas of the world. Animal meat production is in great demand due to the vast increases in the human population of these areas (Hopfenberg and Pimentel, 2001; IFPRI, 2000; Tan et al., 2000). However, poor productivity from overgrazed rangelands does not enable the sustainable intensification of sheep production that is necessary to meet this demand. Rehabilitation of degraded rangelands is not a feasible short–term remedy since it is expensive and may take a long time depending upon the degree of disturbance (Allen, 1995). Alternatively, forages and sown pastures grown on arable land can provide high quality feed to improve animal production (Aganga and Tshwenyane, 2003; Gokkus et al., 2005) and complement rangeland grazing (Bowman and Sowell, 2003).

The erratic and low precipitation often causes feed shortages, and annual and seasonal variations in forage production in most dry areas (Ates et al., 2010; Mills et al., 2008). Supplemental irrigation can extend the growing season, increase reliability and pasture persistence to help attain desirable pasture and animal production (Jensen et al., 2001). However, animal production that relies on irrigated pastures is subject to water scarcity, the same as irrigated field crops in dry areas of the world. Irrigated agricultural production is already under pressure due to declining water resources that force farmers to grow more with less water (Oweis and Hachum, 2008; Postel, 1998). It is, therefore, inevitable that the scarcity of water will require a proper management of the irrigation resources to improve the water productivity in arable lands (McBride, 1994; Oweis and Hachum, 2008). This becomes even more crucial with declining precipitation (IPCC, 2007) and a degradation of environmental quality due to excessive irrigation abstraction in the region (Yilmaz, 2010).

The highest water requirement for optimal crop production has been recorded in Egypt, India, Iraq, Pakistan, Turkey, and Uzbekistan, reflecting the ineffective use of irrigation in hot, arid areas (Doell and Siebert, 2002). The negative impact of this inefficient use of scarce water resources on agricultural production and the environment is projected to be exacerbated by climate change and recurrent droughts (IPCC, 2007). It is likely that the scarcity of water will impact forage production to a larger degree than field crops, which have priority for irrigation resources because of their role in providing food security in most dry areas of the world (Carruthers et al., 1997; Lobell et al., 2008). This situation will put more pressure on animal production systems that rely on irrigated forages and pastures to support meat production in these areas. Thus, the emphasis of irrigation management needs to be focused on maximizing forage and animal production per unit of water consumed. Deficit irrigation, which is defined as water application at a level below full crop requirement, has been promoted as one of the primary means of maintaining productivity and coping with scarce water supplies (Fereres and Soriano, 2006; Oweis and Hachum, 2008).

Several studies have investigated the effects of irrigation on the plant physiology and productivity of pasture and forage plants in small plots (Aranjuelo et al., 2011; Assuero et al., 2002; Justes et al., 2002; Suarez et al., 2003; Vignolio et al., 2002) and have reported a linear relationship between yield and evapotranspiration for a given forage species, which varies between regions and years. In studies where losses from runoff and drainage were negligible, there has generally been a decline in water productivity in response to decreasing water application below optimum irrigation (Farre and Faci, 2006; Kiziloglu et al., 2006). However, little published data is available on the effect of deficit irrigation on sheep production from permanent sown pastures in the dry areas of the world. It is likely that different levels of irrigation will have an impact on pasture dynamics and, therefore, on sheep production. It is important to define the best deficit irrigation strategy for an efficient low–cost sheep production from permanent sown pastures in these areas. The adaptation of water application strategy that sustains environmental quality and improves animal productivity will be directly linked to the sustainability of irrigated pastures. Thus, the aim of this study was to evaluate the impact of deficit irrigation on forage and animal production, and water productivity (units of water to produce a unit of forage or liveweight) in permanent pastures.

2. Material and methods

2.1. Site

The study was conducted within a 1.34 ha paddock at Bahri Dagdas International Agricultural Research Institute (37° 51’ N, 32° 33’ E, 1008 m a.s.l.), Konya, Central Anatolia region of Turkey from September 2008 to November 2010. The site has a clay–loam soil with slightly alkaline characteristics. Soil tests taken on 4 April 2007 gave: pH (in water) 7.8, soluble salt 0.05%, organic matter 3.7%, available phosphorous (P) 250 kg ha^{-1}, calcium (Ca) 426 kg ha^{-1} and potassium (K) 250 kg ha^{-1}.

2.2. Pasture establishment and experimental design

A pasture seed mixture of white clover (*Trifolium repens* L., 3 kg ha^{-1}), birdsfoot trefoil (*Lotus corniculatus* L., 3 kg ha^{-1}), red fescue (*Festuca rubra* L., 9 kg ha^{-1}), Kentucky bluegrass (*Poa pratensis* L., 5 kg ha^{-1}) and perennial ryegrass (*Lolium perenne* L., 6 kg ha^{-1}) was sown in 0.2 m row spacing on 4 April 2007. Based on soil test results, a total of 217 kg/ha fertilizer (18% N and 46% P_2O_5) was applied at sowing and repeated in October 2008 and 2009. Following the establishment year (2007), the paddock was fenced and divided into three blocks, each containing four individually fenced plots (45 × 25 m) opening onto adjoining laneways in March 2008. Each of these blocks represented one replicate of four individually grazed pasture treatments. Within each block the four irrigation treatments were applied, providing 100, 75, 50 or 25% of the pastures full irrigation requirement at each irrigation event. This gave a completely randomized block design with three replicates of four irrigation treatments.

2.3. Irrigation treatments and scheduling

All plots received full irrigation during the establishment year to enable good establishment of the pasture. Each pasture plot was irrigated uniformly as needed to return the soil to field capacity with a line source sprinkler irrigation system. Each plot had its own irrigation system and water meter so different amounts could be applied to each plot. The irrigation system had sprinkler heads with nozzle sizes of 4.5 x 4.8 mm that were located 5.0 m apart on the lateral. Irrigation treatments began in April 2008. No irrigation was applied during the late autumn–winter periods. The irrigation schedule was based around daily monitoring of nested soil tensiometers placed to 30 and 60 cm depths and gravimetric soil moisture measurements in the 100% irrigation plots. Based on the laboratory soil analyses using pressure plate apparatus, the field capacity was 33.3% in the top 30 cm and 33.8% at the 30–60 cm depth. Irrigation was applied to all treatments each time the soil water content of the 100% treatments fell to half of field capacity. Sufficient water was applied to the 100% treatment to return the soil water content to field capacity and 75, 50 and 25% of this amount was applied to the corresponding treatments at the same time. Winter rains had returned all treatments to 100% of field capacity at the beginning of the grazing season. Two water productivity indices (forage yield/water received and meat production/water received) were calculated on either seasonal or annual basis. The water productivity for total water received (rainfall + irrigation) was defined as the DM yield of each pasture treatment or total meat production divided by total water received. Total precipitation and supplementary irrigation throughout the experimental period are given in Table 1.

2.4. Grazing management

Konya merino weaned lambs were classified according to their liveweight (mean LW = 41 ± 2.6 kg in 2008, 43 ± 1.8 kg in 2009 and 39 ± 1.3 kg in 2010) and allocated randomly to treatments on the basis of their liveweight. The grazing management was designed to maximise stock production from each treatment by applying optimal grazing management (i.e. stocking rate, duration of grazing, etc.). All treatments were rotationally grazed with a flock of sheep of each treatment grazing one plot while the other two plots were spelled. Each treatment had a core group of 5–12 weaned lambs (testers) with spare lambs (regulators) used in a put–and–take grazing system (Bransby, 1989) to match feed demand with changing supply. The rotation length was approximately 30 days with an average grazing duration of 8–12 days in each plot. The average grazing intensity in the 100, 75, 50 and 25% treatments was 107, 89, 62 and 45 weaned lambs/ha, respectively, in each year. Grazing began on 24 April each year for all irrigation treatments and was continued until 20 October giving a total yearly grazing period of 193 days. The number of grazing days (number of sheep × duration of grazing) are given in Table 2.

2.5. Meteorological data

Rainfall and air temperatures at the trial site during the experimental period (2008–2010) are given in Table 3. Total annual rainfall was 254 mm in 2008, 410 mm in 2009 and 286 mm in 2010 which was 68 mm lower, 88 higher, and 35 mm lower, respectively, than the long–term average. In most cases, mean monthly air temperature in 2008 and 2009 followed a trend similar to the long–term mean. The exceptions were that the mean temperature was 3.2 and 3.9°C lower during January and February 2008, respectively and 4 and 3.1°C higher in March and April 2008 respectively. Overall, the mean monthly air temperature was higher during each month of 2010 with the exception of February which was 9.7 °C lower.

2.6. Measurements

Dry matter production and mean daily growth rates of the four irrigation treatments were measured by using quadrat cuts inside 1 m^2 grazing exclosure cages at approximately 30 day (range 28-32 days) intervals during active growth in spring, summer and autumn. No samples were collected during the winter period as the pasture growth was halted due to low temperature. Pasture growth was measured from a quadrat cut with electric shears to a stubble height of 20 mm. Cages were placed over a pasture area pre–trimmed to 20 mm stubble height at the start of each new growth period. After cutting, cages were relocated to new pre–trimmed sites in each pasture treatment. All herbage from the quadrat cuts was dried in an oven (65 °C) until constant weight. Mean daily growth rates (kg DM ha^{-1} d^{-1}) were calculated at each harvest by dividing total DM production (kg DM ha^{-1}) by the duration of re–growth since the previous harvest. Pre–grazing pasture mass was used as an indicator of the availability of herbage on offer prior to each grazing. This was measured by quadrat cuts taken from each plot. A total of three randomly placed 0.2 m^2 quadrats were cut to 20 mm residual height with electric shears prior to grazing of the plots. Quadrat cuts were sub–sampled for sorting into botanical fractions (Cayley and Bird 1996) before they were dried in an oven (65 °C) until constant weight. Crude protein content of sub–samples was determined by the Kjeldahl method (AOAC, 1990). Liveweight gain was determined by weighing the core animals prior to and following each grazing period (30 day intervals) throughout each year. Lambs were held overnight and weighed "empty" the following morning. Liveweight gain per head of tester lambs was calculated from the change in weight between each liveweight measurement date. Liveweight gain (kg ha^{-1} d^{-1}) was calculated by multiplying liveweight gain per head of tester lambs by the number of tester plus regulator lambs per hectare. Total seasonal liveweight gain per hectare was calculated by multiplying liveweight gain per hectare (kg ha^{-1}) by the total number of calendar days that the plot was grazed.

2.7. Statistical analyses

Dry matter production (kg DM ha^{-1}), liveweight production (LWP kg ha^{-1} d^{-1}), pre–grazing herbage mass (kg DM ha^{-1}), legume content (%) and crude protein content (%) were analyzed by the analysis of variance (ANOVA) with three replicates for each measurement period as a randomized complete block design. However, the liveweight gain (LWG, g $head^{-1}$ d^{-1}) was analysed using a completely randomized design model. The data were analyzed by an ANOVA of unbalanced design (due to differences in the number of animals per treatment) with repeated measures for each liveweight gain measurement period. This was due to the fact that blocks were not segregated since they were rotationally grazed with the same flock. In this case, it was assumed that the pooled data from the three blocks (replicates) were random samples within the same population of sheep grazing under a given irrigation level. Further, the interaction between irrigation level and grazing period was analyzed using repeated measures under a completely randomized design model. Significant differences among treatment means were compared by Fisher's protected LSD at α = 0.05. All analyses were undertaken using Genstat version 8.1 (GenStat, 2005).

3. Results

3.1. Pasture dry matter production

Total accumulated DM production (kg ha^{-1} y^{-1}) of pastures irrigated at four levels from 2008 to 2010 is given in Fig. 1. The total annual accumulated DM production ranged from 4070 kg ha^{-1} in pastures irrigated at 25% of full requirement to 9800 kg ha^{-1} y^{-1} for fully irrigated pastures over the three year period. Dry matter production decreased ($P < 0.01$) with each decreasing level of irrigation with the 25% treatment having 50% lower production than the 100% treatment. The only exception was that the total accumulated dry matter production from the 75% treatment was similar to the 100% treatment in 2009.

Mean daily growth rate (kg DM ha^{-1} d^{-1}) was consistently higher ($P < 0.05$) for pastures irrigated with the 100 and 75% treatments compared to the pastures irrigated with 50 and 25% of the full requirement, except during the winter–early spring period of 2008 and 2010 when all pastures had similar growth rates (Fig. 2). The mean daily growth rates (kg DM ha^{-1} d^{-1}) were the highest during the spring months. The growth rates gradually decreased in summer months before increasing again in autumn. The reduction of the mean daily growth rates during the summer months was the greatest ($P < 0.05$) in the lowest irrigation treatment.

3.2. Livestock production

Liveweight gain per animal (g $head^{-1}$ d^{-1}) in each measurement period did not differ ($P = 0.35$) among irrigation treatments in 2008 and 2010 (Fig. 3a, c). However, a significant interaction ($P < 0.01$) was detected between the irrigation treatments and measurement periods for the liveweight gains of the lambs in 2009 (Fig. 3b). The liveweight gain per animal (g $head^{-1}$ d^{-1}) from the 25 and 100% treatments was higher than from the 50 and 75% treatments in May, while the lambs in the 25% treatments had lower liveweight gains than the rest of the lambs in the other treatments in the next measurement period in June. Averaged over the entire grazing period, lambs grew at 64.3, 67.3 and 74.1 g $head^{-1}$ d^{-1} in 2008, 2009 and 2010, respectively. However, the liveweight gains of animals were affected ($P < 0.01$) by the measurement period in each year of the study. The fastest growth rates were obtained in May, followed by a rapid decline toward summer months before they increased again in September and October. Overall, the average liveweight gains ranged from 30 to 125 g $head^{-1}$ d^{-1} throughout the grazing seasons during the three year experimental period.

Unlike individual lamb liveweight gain per head, the irrigation treatments affected ($P < 0.01$) total animal liveweight production (Fig. 4). Liveweight gain per hectare of the 100% treatment was over 2 kg ha^{-1} d^{-1} in each of the three years. This was similar to the liveweight gain per hectare obtained from the 75% treatment that ranged between 1.9 and 2.3 kg ha^{-1} d^{-1}. However, the lower levels of irrigation resulted in a reduction ($P < 0.01$) in liveweight gains. The reduction in total liveweight gains per hectare was due to lower stocking rate applied to treatments with lower levels of irrigation. The lowest ($P < 0.01$) liveweight gain per hectare was less than 1 kg ha^{-1} d^{-1} from the pastures irrigated with 25% of the full requirement.

The total monthly liveweight production (kg ha^{-1}) during the grazing periods (2008, 2009 and 2010) is presented in Fig. 5. No statistical analysis was performed on this dataset because animals and flocks per treatment were not replicated. Averaged across three years, total annual animal liveweight production was 198, 380, 445 and 498 kg ha^{-1} for the 25, 50, 75 and 100% treatments, respectively. Over three years, liveweight production was the most consistent in spring and early summer (May and June) and averaged over treatments and years, these months accounted for 51% of total annual liveweight production.

3.2.1. Herbage on offer to lambs

As an indicator of the availability and the quality of pasture prior to each grazing, herbage on offer to lambs was presented in Fig. 6. Pre–grazing herbage mass in pastures ranged from 1075 to 2215 kg DM ha^{-1} in spring 2008, with a general increase from late April to mid May, followed by a decline as the season progressed (Fig. 6a). Differences ($P < 0.05$) among irrigation treatments occurred on most occasions throughout the 2008 grazing year, with the exception of 24 April and 2 October. Pre–grazing herbage mass in the spring 2009 was over 3500 kg DM ha^{-1} and exceeded 4500 kg DM ha^{-1} in the pastures that received full irrigation (100%). This was followed by a sharp decline towards June. Pastures that received 100 or 75% of their irrigation requirement had a higher ($P < 0.05$) pre–grazing herbage mass compared to pastures irrigated with 50 and 25% of their requirement. Pre–grazing herbage mass in the spring of 2010 followed a similar trend to that of the spring 2009 ranging from 2500 kg DM ha^{-1} in 25% treatments to 4000 kg DM ha^{-1} in the 100% treatments (Fig 6b, c). However, the difference in herbage mass among irrigation treatments was not different ($P = 0.13$) prior to June 2010. Herbage mass in the summer of each year ranged from 500 to 1500 kg DM ha^{-1} and this did not change during the autumn period with the exception of the herbage mass in the autumn 2008 which had an increasing trend until the spell of pastures on 10 October.

Over the three year grazing experiment, legume content of pasture on offer ranged from negligible to 65% of total biomass (Fig. 6d, e, f). In general, legume content of pasture on offer increased towards summer months before declining in autumn. On several occasions, pastures receiving the

100 or 75% irrigation treatments had a higher ($P < 0.05$) legume content than the lower irrigation treatments and the difference appeared to be greater during the summer months, particularly in 2009 and 2010. The legume content was only different ($P < 0.05$) on three occasions in 2008. The crude protein content of pastures on offer fluctuated between 12 and 22% in 2008 and 2009 (Fig. 6g, h, i). On occasions, the difference between the treatments for crude protein content was significant ($P < 0.05$) but no particular treatment or season had any superiority over others.

4. Discussion

The study aimed to evaluate whether deficit irrigation would be a useful management strategy to improve the efficiency of sheep production from irrigated pastures in dry areas where water scarcity is a common event. Table 4 compares the average total dry matter and meat production, total water received (rainfall + irrigation) and water productivity under the four treatments. The highest dry matter as well as meat production was observed under the full irrigation (100%) treatment but at a low level of water productivity (Table 4 and Fig. 7). The water productivity of the 75% irrigation treatment improved by 12 and 9% for dry matter and meat, respectively, (compared to 100% treatment) but there was 8% loss of dry matter and 11% loss of meat production. So an 18% saving of water led to only 8% reduction in dry matter production and an 11% reduction in meat production. Similarly, water productivity further increased when water application was reduced from 75 to 50%. Water productivity started to fall when water application was further reduced from 50 to 25%. These changes in the level of animal productivity by varying irrigation suggest that full irrigation was not as effective in producing liveweight as lower irrigation rates. Thus, proper use of irrigation water on permanent pastures in dry areas is important to achieve high water productivity. This study represents a compelling case to suggest that deficit irrigation between 50 and 75% of the full requirement be used only in spring when evapotranspiration rates are lowest. However, this experiment imposed the same degree of irrigation deficit to treatments throughout the year, thus there may be further scope for manipulation of dry matter and meat production by imposing different levels of water deficit during different periods of the growing season.

Irrigation during the summer and autumn months (even full irrigation) could not maintain the liveweight gains of weaned lambs that were observed in the spring (Fig. 3), This was probably due to the slower growth of the new plant tissues (Fig 2) and the lower nutritive values of these grasses which typically occurs at high air and soil temperatures (Cosgrove and Edwards, 2007; Waghorn and Clark, 2004). In addition, water productivity (units of water to produce a unit of forage and a unit of liveweight) was reduced dramatically during summer months (Fig. 7a, b, c and d). This situation questions the benefit of applying high amounts of water to pastures in dry areas during the summer months when the productive use of irrigation water is low (Moot et al., 2008).

From these findings it becomes clear that the emphasis on maximizing sheep production from sown pastures should be during the spring season when plant growth is not restricted by either moisture or temperature. This is relevant for the Central Anatolia region of Turkey and for similar areas where crop–livestock farming is a common practice. Thus, the focus of production should be on lamb fattening in spring while managing pastures for the maintenance of dry ewes during the summer period. Application of a lower amount of water to pastures during summer may be a valid strategy for more efficient water use, as water productivity of plants is low (Brown et al., 2006; Rihawi et al. 2010; Korte et al., 1987) due to higher soil evaporation and temperature (Moot et al., 2008). Alternatively, irrigation of summer crops with higher water productivity during dry seasons may provide a higher overall benefit for farms (Oweis and Hachum, 2008).

Results on herbage on offer indicated that pastures which received 100 or 75% of the full irrigation requirement had similar amounts of pre–grazing pasture mass (Fig. 6a, b, c) and higher liveweight production (Fig. 5a, b, c) compared to the lower irrigation levels. As would be expected, decreasing the amount of irrigation had the effect of reducing the number of available grazing days (Table 2) and the overall carrying capacity of the pasture, and in the end resulted in lower animal production (Figs. 4 and 5). Applying deficit irrigation with 25% of full requirement reduced the pasture mass and animal production dramatically, primarily due to lower dry matter production and, thus, less available forage for grazing sheep on these pastures. These results are consistent with the findings of Aranjuelo et al. (2011), Assuero et al. (2002), McBride (1994) and Vignolio et al. (2002).

Animal liveweight gains (g head^{-1}d^{-1}) from pastures under different irrigation levels were not affected by changing pasture conditions such as pre–grazing herbage mass or legume content of pasture on offer. This was mainly due to the animals having a similar amount of pasture allowance at different stocking rates within each treatment (Cosgrove and Edwards, 2007). Thus, their forage intake may have been similar throughout the whole grazing season in each year.

Legume proportion is one of the most important factors governing the forage intake of ruminants (Waghorn and Clark, 2004). Many studies confirm that a high legume content of a pasture on offer leads to increased liveweight gain in sheep (Ates et al., 2008; Hyslop et al., 2000; Litherland and Lambert, 2007). However, the difference in legume content which occurred, on occasion, among the pasture treatments in this study was not reflected in the animal liveweight gains. Of note, in this study, was the fact that the difference in legume content mainly occurred during the summer period when the overall pasture mass was low. Thus, the amount of legumes in the diet may not have been high enough to influence the actual forage intake of the animals and the higher legume content of the pastures during the summer months did not increase the overall crude protein content of pasture on offer. This was reported by Ates (2009) who indicated that increased clover content generated by higher than normal summer rainfall in the dryland pastures of New Zealand did not increase lamb growth rates due to the decreased metabolisable energy content of the pasture on offer during that summer. On occasion, the crude protein content of pastures on offer differed ($P < 0.05$), but no superior pasture treatment, or season, was identified throughout the three year grazing experiment, despite crude protein contents of the pastures on offer fluctuating between 12 and 22% in 2008 and 2009. These crude protein contents of the pastures were comparable with levels reported by Ates et al. (2010) and Waghorn and Clark (2004) for permanent sown pastures in temperate climates.

Although not evaluated in this study, an important strategy to improve the efficiency of sheep production may be achieved through the inclusion of annual legumes to permanent pastures. A number of studies (Ates et al., 2008; Muir et al., 2003) suggest that annual legumes in permanent dryland pastures can promote high lamb growth rates in early spring when they have high dry matter production due to their lower temperature requirements compared with perennial legumes (Mills et al., 2008; Moot et al., 2003). Thus, including annual legumes that commence growth earlier in spring than perennial legumes to pasture combinations in Central Anatolia may provide higher growth rates for lambs in the early spring. This was earlier reported in Australia where the total water use of pastures containing annual clovers was substantially lower than for perennial pastures as irrigation was not applied during the summer months when evaporation was high, although overall production was lower than for pastures established with perennial species (Stockdale, 1983).

The findings of this study suggest that the adaptation of proper irrigation management in permanent sown pastures is crucial in Konya and in similar environments where crop–livestock farming is practiced. Irrigating permanent pastures that consist of annual clovers with their full irrigation requirement in the early spring – when response of plants to additional water and response of stock to additional feed is highest – will help to maximize the water productivity of lamb production. Deficit irrigation between 50 and 75% of the full requirements for the rest of the spring – when evaporative losses is increasing and transpiration efficiency is decreasing – prior to de–stocking the pastures in the summer may be a valuable practice when limited water is available. An important consideration for this practice should be the seasonal and annual changes in the number of animals on farms when scheduling the irrigation for sustainable pasture management. The level of irrigation can be compromised during the periods of lower stocking rates (i.e. following lamb sales) when the demand for feed or energy from pastures is lower. However, persistence and competitive relations among species in the pasture at different soil–water conditions should be taken into account when making the decision to irrigate.

Another important point is that the decision to begin grazing, for this study, was based on standard recommendations for the onset of the grazing season for the rangelands in this region. However, this generally resulted in a high early pre–grazing pasture mass, particularly in 2009 and 2010 (Fig. 6b, c). This was followed by fast reductions in the availability of herbage on offer which caused difficulties when arranging the number of sheep required for each grazing period. Thus, it is recommended that the grazing of permanently sown pastures in the region should begin earlier to exploit the high pasture production rates and the high pasture quality in the early spring.

5. Conclusions

- Permanent sown pastures can provide satisfactory animal production (~500 kg ha^{-1} y^{-1}) when 75 to 100% of the full irrigation requirement is applied in the Central Anatolia Region of Turkey.
- Animal production from pastures irrigated at 75% of the full requirement was similar to that from pastures which received full irrigation but reducing irrigation to 50% of the full requirement caused substantial reduction in the animal production potential.
- Liveweight production (kg ha^{-1}) in spring and early summer was the most consistent and, thus, the focus in Central Anatolia, and in similar environments, should be on fattening lambs during these periods.
- The water productivity of the full irrigation per unit of meat production was low, particularly during the summer months, and water productivity for each unit of dry matter and meat produced increased with deficit irrigation.
- Fully irrigating permanent pastures that consist of annual clovers in the early spring may maximize the water productivity of lamb production. Deficit irrigation between 50 and 75% of the full requirement for the rest of the spring prior to de-stocking the pastures in the summer may be a valuable practice when water resources are limited. The level of irrigation can be compromised during the periods of lower stocking rates when the demand for feed or energy from pastures is lower.

- The cost–benefit and impact on the environment need to be considered in both irrigation management (level and frequency) and animal production of permanent sown pastures in dry areas.

Acknowledgements

The authors thank Drs. Derrick Moot, David Feindel and Hamish Brown for reviewing the manuscript and Dr. Murari Singh for providing advice on statistical analyses. Funding for this project was provided by Turkish Ministry of Food, Agriculture and Livestock.

References

Aganga, A.A., Tshwenyane, S.O., 2003. Lucerne, Lablab and *Leucaena leucocephala* forages: Production and utilization for livestock production. Pakistan Journal of Nutrition. 2, 46–53.

Allen, E.B., 1995. Restoration ecology: limits and possibilities in arid and semiarid lands. p. 7–15. In: B.A. Roundy, E.D. McArthur, J.S. Haley and D.K. Mann (comps.) Proceedings of wildland shrub and arid land restoration symposium. Gen. Tech. Rep. INT-GTR-315. USDA For. Serv. Int. Res. Sta. Ogden, Utah.

AOAC., 1990. Official methods of analysis 15th ed. Association of Analytical Chemists, Washington DC.

Aranjuelo, I., Molero, G., Erice, G., Avice, J.C., Nogues, S., 2011. Plant physiology and proteomics reveals the leaf response to drought in alfalfa (*Medicago sativa* L.). Journal of Experimental Botany. 62, 111–123.

Assuero, S., Kemp, P., Barker, D. J., 2002. Effects of water deficit on Mediterranean and temperate cultivars of tall fescue. Australian journal of agricultural research. 53, 29-40.

Ates, S., Lucas, R.J., Edwards, G.R., 2008. Pasture production and liveweight gain from cocksfoot-subterranean clover pastures grazed at two stocking rates and closed at different times during spring. Proceedings of the New Zealand Grassland Association. 70, 225-232**.**

Ates, S., 2009. Grazing management of subterranean clover (*Trifolium subterraneum* L.) in South Island (New Zealand) summer dry pastures. *PhD* thesis, Lincoln University, Canterbury, New Zealand 189 pp.

Ates, S., Tongel, M.O., Moot D.J., 2010. Annual herbage production increased when subterranean clover overdrilled into grass-dominant dryland pastures. Proceedings of the New Zealand Grassland Association. 72, 3-10**.**

Bowman, J.G.P., Sowell, B.F., 2003. Technology to complement forage-based beef production systems in the West, Journal of Animal Science. 81, 18-26.

Bransby, D.I., 1989. Compromises in the design and conduct of grazing experiment. In: Marten, G.C., (Ed.), Grazing research: design, methodology and analyses. CSSA special publication: no 16 pp. 53-69. Madison, Wisconsin, USA.

Brown, H.E., Moot, D.J., Lucas, R.J., Smith, M.C., 2006. Sub clover, cocksfoot and lucerne combine to improve stock production. Proceedings of New Zealand Grassland Association. 68, 109-117.

Carruthers, I., Rosegrant, M.W., Seckler, D., 1997. Irrigation and food security in the 21st century, Irrigation and drainage systems. 11, 83-101.

Cayley, J.W.D., Bird, P.R., 1996. Techniques for measuring pastures (2nd Ed). Hamilton, Vic.: Pastoral and Veterinary Institute, 51.

Cosgrove, G.P., Edwards, G.R., 2007. Control of grazing intake. In P. V. Rattray, Brookes, I.M., Nicol, A.M (Ed.), Pasture and supplements for grazing animals (pp. 61-81). Christchurch: New Zealand Society of Animal Production.

Doell, P., Siebert, S., 2002. Global modelling of irrigation water requirements. Water Resources Research. 38, 1010-38.

Farre, I., Faci, J.M., 2006. Comparative response of maize (Zea mays L.) and sorghum (*Sorghum bicolor* L. Moench) to deficit irrigation in a Mediterranean environment. Journal of Agricultural Water Management. 83, 135-143.

Fereres E., Soriano M.A., 2006. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany. 58, 147-59.

GenStat., 2005. The Guide to GenStat Release 8.1 Part 2: Statistics. In: Payne, R.W. (Ed.). Lawes Agricultural Trust (Rothamsted Experimental Station). VSN International, Oxford.

Gokkus, A., Hakyemez, B. H., Yurtman, I.Y., Savas, T., 2005. The Effects of Different Stocking Rates on Pasture Hay Yield and Milk Yield of Goats in Different Types of Pastures , Akdeniz University, Journal of Agricultural Faculty, 18, 207-21.

Hopfenberg, R., Pimentel, D., 2001. Human population numbers as a function of food supplies. Environment, Development and Sustainability. 3, 1-15.

Hyslop, M. G., Fraser, T.J., Smith, D.R., Knight, T.L, Slay, M.W.A., Moffat, C.A., 2000. Liveweight gain of young sheep grazing tall fescue or perennial ryegrass swards of different white clover content. Proceedings of the New Zealand Society of Animal Production. 60, 51-54.

IFPRI (International Food Policy Research Institute), 2000. A vision of water for food and rural development. World Water Vision Report. Washington, D. C.

IPCC, 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report.

Jensen, K.B., Asay, K.H., Waldron, B.L., 2001. Dry matter production of orchardgrass and perennial ryegrass at five irrigation levels. Journal of Crop Science. 41, 479–487.

Justes, E., Thiebeau, P., Avice, J.C., Lemaire, G., Volenec, J.J., Ourry, A., 2002. Influence of summer sowing dates, N fertilization and irrigation on autumn VSP accumulation and dynamics of spring regrowth in alfalfa (*Medicago sativa* L.) Journal of Experimental Botany. 53, 111-121.

Kiziloglu, F.M., Sahin, U., Tune, T., Diler, S., 2006. The effect of deficit irrigation on potato evepotranspiration and tuber yield under cool season and semiarid climatic conditions. Journal of Agronomy. 5, 284–288.

Korte, C.J., Chu, A.C.P., Field, T.R.O., 1987. Pasture production. In: Nicol, A.M., (Ed.), Livestock feeding on pasture New Zealand Society of Animal Production Occasional Publication No. 10.

Litherland, A.J., Lambert, M.G., 2007. Factors affecting the quality of pastures and supplements produced on farms. In: Rattray, P.V., Brookes, I.M., Nicol, A.M (Ed.), Pasture and supplements for grazing animals (pp. 81-95). Christchurch: New Zealand Society of Animal Production.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., Naylor, R.L., 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. Science 319, 607-610.

McBride, S.D., 1994. Pasture yield responses to irrigation in Canterbury. Proceedings of the New Zealand Grassland Association. 56, 165-168.

Mills, A., Smith, M.C., Lucas R.J., Moot, D.J., 2008. Dryland pasture yields and botanical composition over 5 years under sheep grazing in Canterbury. Proceedings of the New Zealand Grassland Association. 70, 37-44.

Moot, D.J., Black, A.D., Scott, W.R., Richardon, J., 2003. Leaf development and dry matter production of subterranean clover cultivars in relation to autumn sward management. In: Moot, D.J., (Ed.), Legumes for dryland pastures. Proceedings of a New Zealand Grassland Association (Inc). Symposium held at Lincoln University, New Zealand. Grassland research and practice series No.11. (pp. 193-200).

Moot, D.J., Brown, H.E., Pollock, K., Mills, A., 2008. Yield and water use of temperate pastures in summer dry conditions. Proceedings of New Zealand Grassland Association. 70, 51-59.

Muir, P.D.; Smith, N.B.; Lane, J.C., 2003. Maximising lamb growth rate – just what is possible in a high performance system. Proceedings of the New Zealand Grassland Association. 65, 61-63.

Oweis, T., Hachum, A., 2008. Optimizing supplemental Irrigation: Tradeoffs between profitability and sustainability. Journal of Agricultural Water Management. 96, 511-516.

Postel, S., 1998. Water for Food Production: Will There Be Enough in 2025? Bioscience. 48, 629-637.

Rihawi, S., Iniguez, L., Knaus, W.F., Zaklouta, M., Wurzinger, M., Soelkner, J., Larbi, A., Bomfim, M.A.D., 2010. Fattening performance of lambs of different Awassi genotypes, fed under cost-reducing diets and contrasting housing conditions. Journal of Small Ruminant Research. 94, 38-44.

Stockdale, C.R., 1983. Irrigated pasture productivity and its variability in the Shepparton region of northern Victoria. Australian Journal of Experimental Agriculture and Animal Husbandry. 23, 131-139.

Suarez, D.L., Grieve, C.M., Poss, J.A., 2003. Irrigation method affects selenium accumulation in forage Brassica species. Journal of Plant Nutrition. 26, 191-201.

Tan, E., Avcioglu, R., Munzur, M., Demiroglu, G., 2000. Grassland and forage crop cultivation in Turkish agriculture, Anadolu Journal of AARI. 12, 100-109.

Waghorn, G.C., Clark, D.A., 2004. Feeding value of pastures for ruminants. New Zealand Veterinary Journal. 52, 320-331.

Yilmaz, M., 2010. Environmental problems caused by ground water level changes around Karapinar, Ankara Üniversitesi Çevrebilimleri Dergisi. 2, 145-163.

Vignolio, O.R., Biel, C., de Herralde, F., Araujo-Alves, J.P.L., Save, R., 2002. Growth of *Lotus creticus creticus* and *Cynodon dactylon* under two levels of irrigation. Australian Journal of Agricultural Research. 53, 1375-1381.

Tables and Figs

Table 1. The amount of water received (precipitation + irrigation) and supplementary irrigation applied in four pastures irrigated with 100, 75, 50 and 25% of the full irrigation requirement in 2008, 2009 and 2010.

Level of irrigation	Supplementary irrigation (mm)			Total water received (mm) (precipitation + irrigation)		
	2008	2009	2010	2008	2009	2010
100%	867	760	816	1122	1170	1102
75%	650	570	612	905	980	898
50%	433	380	408	688	790	694
25%	217	190	204	472	600	490

Table 2. The total number of grazing days (number of grazing animals x duration of grazing) of pastures grazed with weaned lambs in 2008, 2009 and 2010.

Level of irrigation	2008	2009	2010
100%	2148	2148	2388
75%	1969	1969	2189
50%	1611	1611	1791
25%	895	895	995

Table 3. Monthly rainfall and mean daily air temperatures at Bahri Dagdas International Agricultural Research Institute, Konya, Turkey during the experimental period (2008-2010).

Months	Air temperature (^oC)				Rainfall (mm)			
	2008	2009	2010	LTM*	2008	2009	2010	LTM*
January	-3.5	1.8	3	-0.3	23	60.1	44.2	32.9
February	-2.7	3.4	-8.5	1.2	21.2	44.8	28.1	24.5
March	9.8	5.0	8.6	5.8	39.2	24.4	12.6	25.6

April	14.1	10.5	11.1	11.0	6.3	45.7	41.4	37.4
May	15.7	15.2	17.5	15.8	10.7	55.8	18.8	40.5
June	22.0	21.6	20.9	20.3	4.1	2.7	39.8	22.9
July	24.6	23.6	26.2	23.6	4.6	11.7	2.4	8.2
August	26.0	22.6	27.6	23.1	0	0	0.7	7.7
September	20.2	18.1	21.8	18.7	41.0	21	0.8	11.8
October	12.7	15.5	12.9	12.6	22.4	12.7	9.2	33.3
November	8.2	6.6	10.1	5.9	22.8	56.7	2.8	35.3
December	0.5	4.8	5.2	1.3	59.3	74.6	85.2	41.8

LTM*: Long term means of air temperature and rainfall are for the period 1975-2010. Data were collected from the meteorological station located nearby the experimental site.

Table 4. Average yearly total dry matter and meat production, water received and water productivity for the four irrigation treatments.

Treatment	Dry matter (ton)	DM loss (%)	Meat production (ton)	Meat loss (%)	Water received (mm)	Water saved (%)	WP_{DM} (kg mm^{-1})	WP_{meat} (kg mm^{-1})
100%	9.59	NA	4.98	NA	1131	NA	8.48	4.40
75%	8.79	8	4.45	11	927	18	9.48	4.80
50%	7.21	25	3.80	24	724	36	9.96	5.25
25%	4.86	49	1.98	60	520	54	9.68	3.94

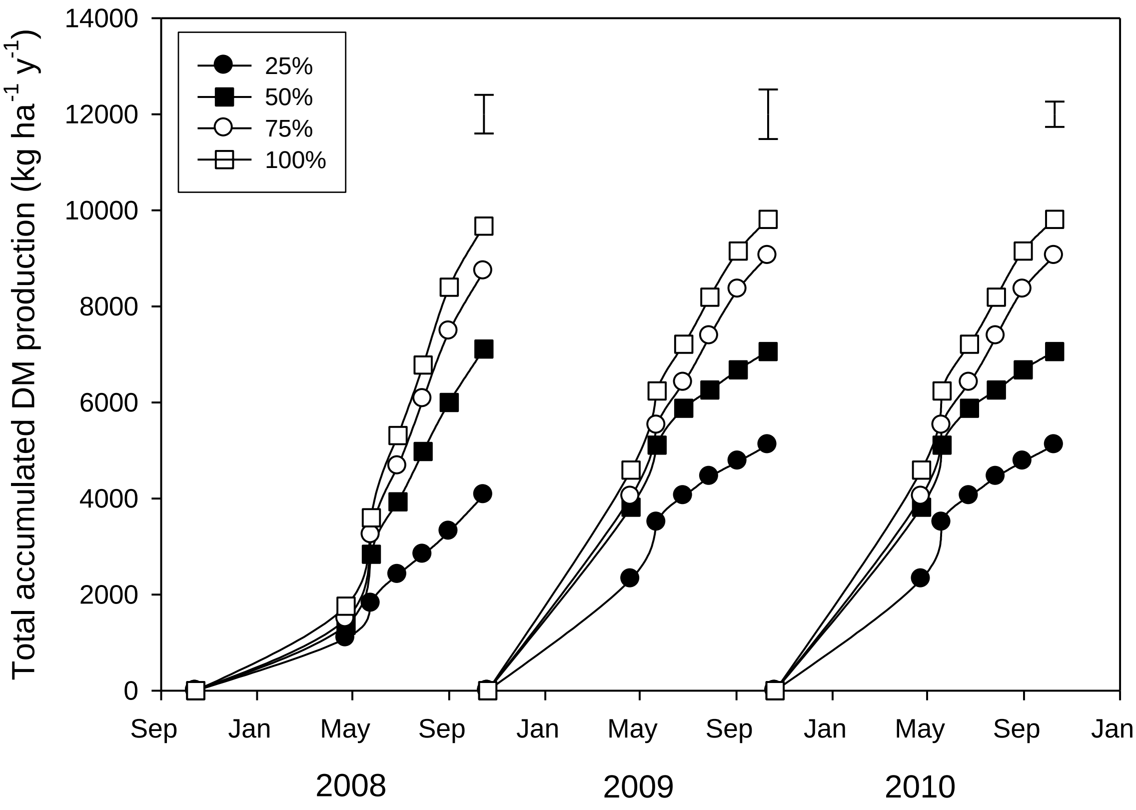

Fig 1. Total yearly accumulated dry matter (DM) production in kg ha^{-1} y^{-1} for the four pasture treatments from 2008 to 2010. Bars represent least significant difference (LSD).

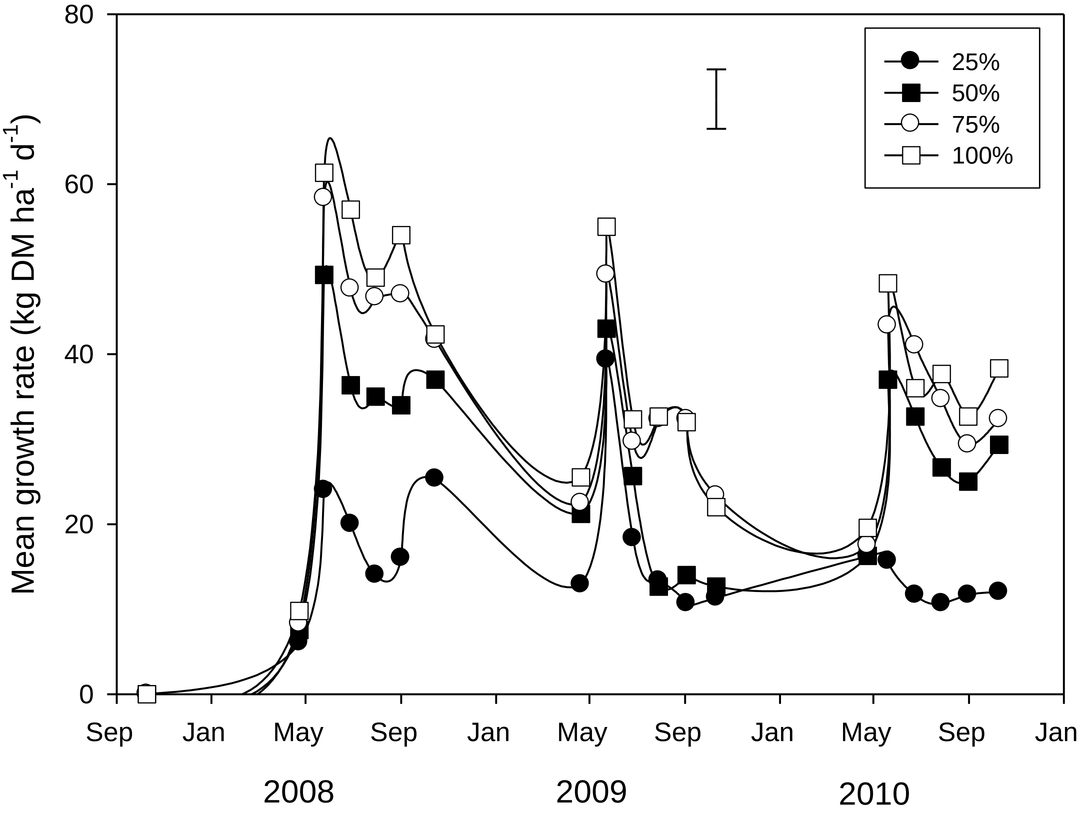

Fig 2. Mean daily growth rates (kg DM ha^{-1} d^{-1}) for four pasture treatments from 2008 to 2010. Bar represent maximum standard error of mean (SEM).

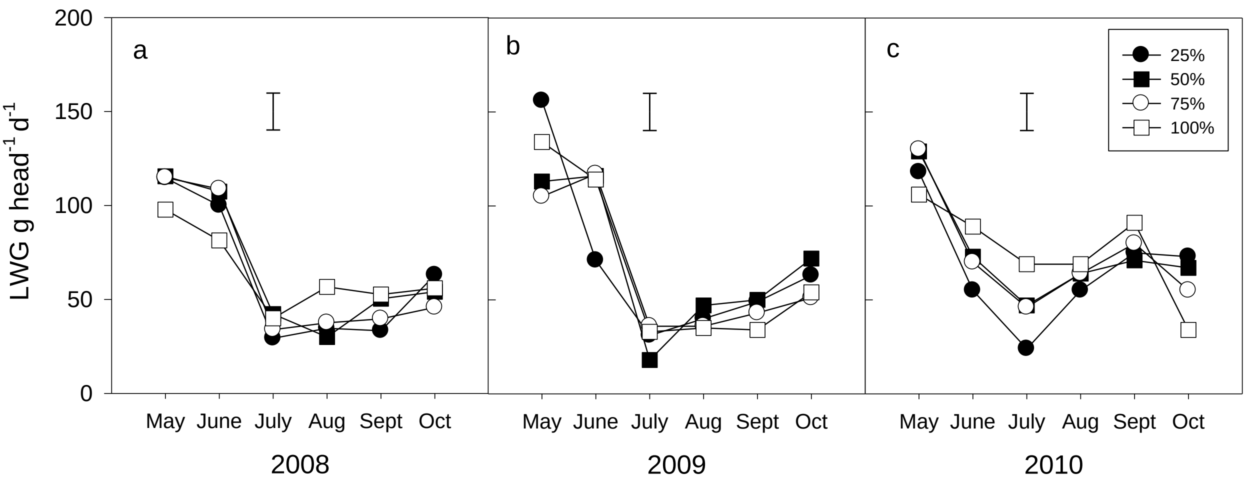

Fig 3. Daily liveweight gains (g $head^{-1}$ d^{-1}) of lambs grown on pasture receiving different percentages of full irrigation requirement in (a) 2008, (b) 2009 and (c) 2010. Bars represent SEM.

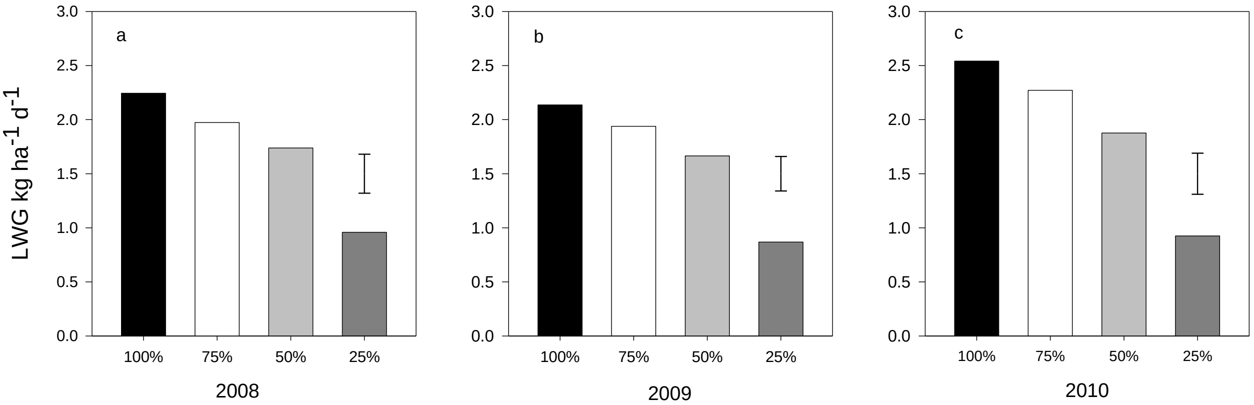

Fig 4. Mean liveweight production (kg ha^{-1} d^{-1}) of lambs grown on pasture receiving different percentages of full irrigation requirement in (a) 2008, (b) 2009 and (c) 2010. Bars represent LSD.

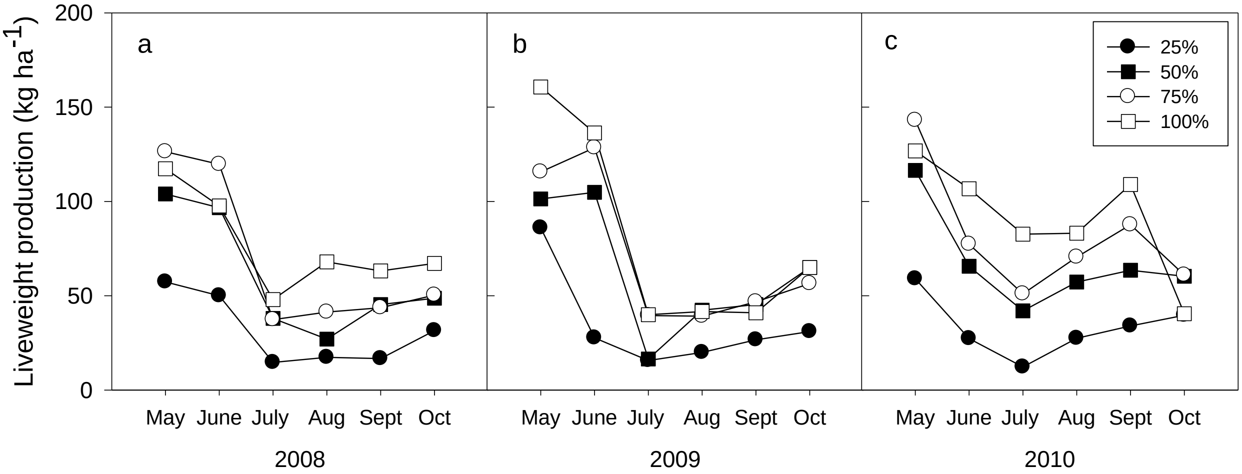

Fig 5. Monthly liveweight production of lambs (kg ha^{-1}) grown on pasture receiving different percentages of full irrigation requirement in (a) 2008, (b) 2009 and (c) 2010.

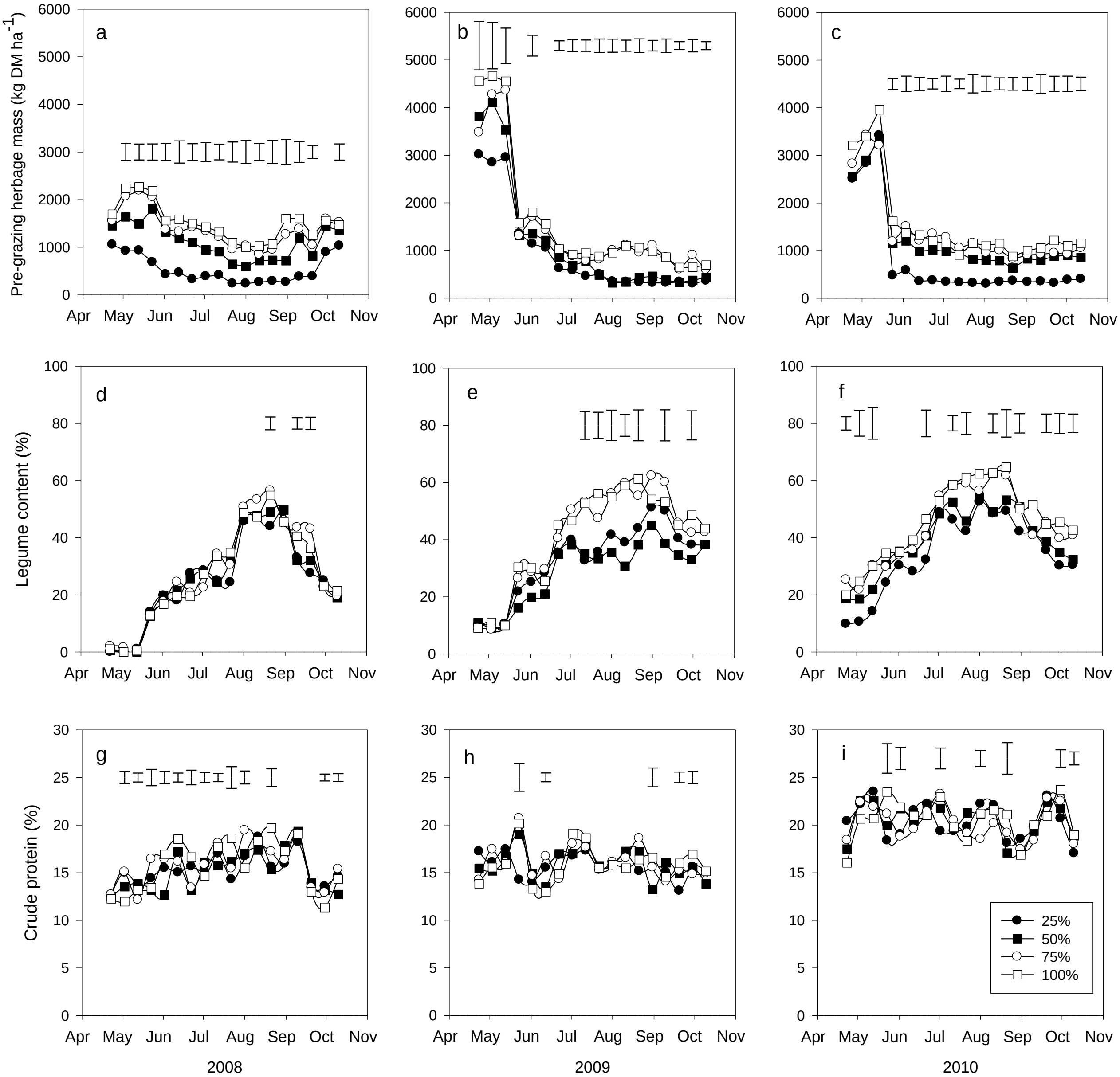

Fig 6. Monthly average pre–grazing herbage mass (kg DM ha^{-1}), (a, b, c), legume content (%), (d, e, f) and crude protein content (%) (g, h, i), of herbage on offer from pastures receiving different percentages of full irrigation requirement. Bars represent LSD above the period that ANOVA was significant (P < 0.05).

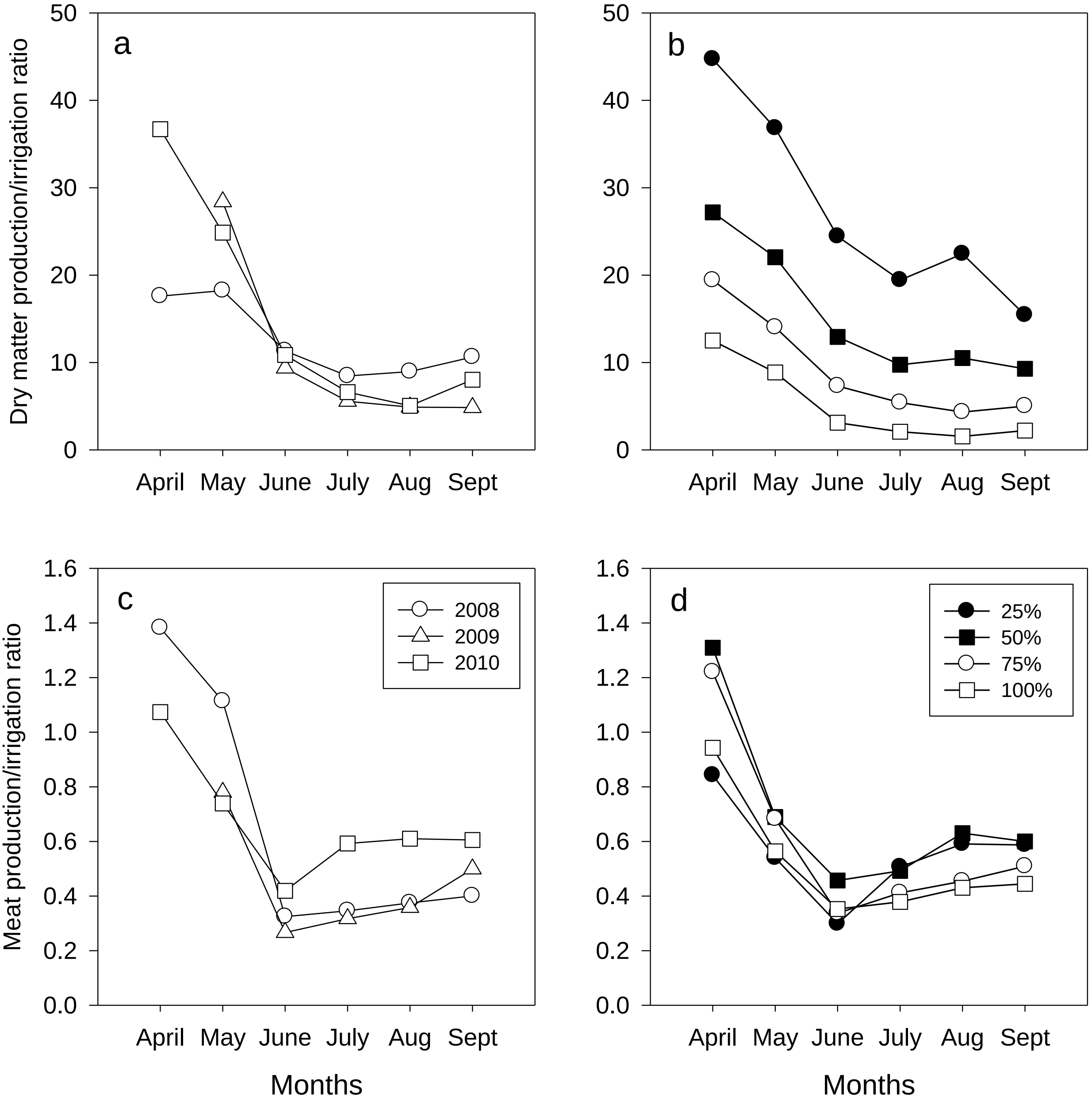

Fig 7. The water productivity per unit of dry matter (a, b) (kg ha^{-1} mm^{-1}) and meat produced (c, d) (kg ha^{-1} mm^{-1}) from pasture receiving different percentages of full irrigation requirement.