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ANIMAL RESEARCH PAPER

Performance of indigenous and exotic × indigenous sheep breeds fed different diets in spring and the efficiency of feeding system in crop–livestock farming

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SUMMARY

Genetic variation in feed efficiency may have a significant impact on sheep production in integrated crop livestock farming systems in dry areas, where the shortage and poor quality of feed is widespread. Thus, the present study was carried out to investigate the effects of sheep genotype and feed source on liveweight gain, feed conversion efficiency and dry matter (DM) intake in feedlot lambs finished on diets based on low-cost forages or a high-cost concentrated feed as a means of assessing the efficiency of this feeding system. Early weaned lambs of the purebred fat-tailed Akkaraman breed were compared with synthetic Anatolian Merino (0·80 German Mutton Merino × 0·20 Native Akkaraman) breed. The lambs were kept in individual pens for 8 weeks and fed four diets: daily harvested forages of triticale (T), Hungarian vetch (HV), a triticale-Hungarian vetch mixture (T + HV), and a concentrate-based feed (CF). Lamb liveweight gain (LWG) was monitored during the early (18 April–16 May) and late (17 May–13 June) spring periods. Diet × period and diet × breed interactions were detected in LWG of the lambs. Lambs from both genotypes on the concentrate-based diet had higher liveweight gains, DM intakes and better feed conversion ratios compared with lambs finished on the forage-based diets. The LWG of lambs offered triticale forage decreased from 177 g/head/day in the early spring to 95 g/head/day in the late spring period, as plant maturity increased. Liveweight gains did not change for the other forage rations during the same period. The LWG of Akkaraman lambs were similar for both the early (189 g/head/day) and the late (183 g/head/day) spring periods, whereas Anatolian Merino lambs gained 41 g/head/day less LW and had 3·8 higher feed conversion rate for the late spring period compared with the early spring period. The present study showed that fat-tailed Akkaraman lambs were better able to utilize forages with low nutritive value compared to Anatolian Merino lambs, and may be better suited to semi-arid areas, where crop and livestock are highly integrated in the farming system.

INTRODUCTION

Animal products are in great demand in the West Asia North Africa (WANA) region due to increases in per capita real income, urbanization and population growth (Delgado *et al*. 1999; Aw-Hassan *et al*. 2010). However, undue pressure on natural resources and deteriorating feed availability for livestock are challenging the growing opportunities for livestock production (Ates & Louhaichi 2012). Pessimistic predictions on the impact of population growth, climate change and unsustainable resource management indicate that the constraints on land and food supply will become increasingly evident in mixed crop–livestock and grazing systems in the region (World Bank 2008). There is a general consensus that competition for grains between humans and livestock, diminishing feed supplies from overexploited

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rangelands and trade-offs between crop stubbles for animal feed, soil fertility and biofuels are likely to increase the pressure on small ruminant production in both high and low-input systems (Nefzaoui & Ben Salem 1999; Aw-Hassan *et al*. 2010; Smith *et al*. 2013).

Appropriate management practices to address worsening feed shortage with simple and cost-effective feeding techniques is becoming more critical for the sustainability of small ruminant production and rangeland ecosystems (Ben Salem & Nefzaoui 2003; Ben Salem *et al*. 2005; Rihawi *et al*. 2010). Currently, one-third of total agricultural water and over one-third of the entire world's grain production are used in livestock production (Correal *et al*. 2006; Smith *et al*. 2013). The role of annual forage legumes and cereal crops that can be produced with relatively low cost in the region's dryland agriculture for improving the feeding management for ruminants is crucial, particularly with dwindling water supplies in the region. Forage legumes can contribute to sustainable use of land resources (Christiansen *et al*. 2000; Yau *et al*. 2003; Abd El Moneim & Ryan 2004) and have significant potential to reduce the need for supplementary feeding of livestock with grains in dry areas (Rihawi *et al*. 2010). Although it has been customary to use legume and cereal forage mixes for hay or silage, satisfactory liveweight gains can also be obtained from direct grazing of the green forages in spring (Dove 2006; Larbi *et al*. 2008; Rihawi *et al*. 2010). The high feeding value of cereal forages in the early stage of maturity can also be synchronous with the most productive period of ruminants, and can be comparable with concentrate feeding (Dove *et al*. 2002; Coblentz & Walgenbach 2010). Rihawi *et al*. (2010) suggested that direct vetch grazing could be an alternative option for reducing high feed costs for sheep production in the WANA region.

One of the primary objectives of sustainable animal production in mixed farming is successful matching of suitable genotypes with local environmental and feeding conditions. Optimizing the available feed resources with an appropriate class or breed of livestock that can utilize the feed efficiently within the prevailing production systems is crucial for crop–livestock farmers in developing countries (Ørskov 1999). Indigenous breeds of small ruminants such as Awassi, Akkaraman, Barbarine or Barbados Blackbelly sheep evolved under low-input management conditions and are highly adaptable in dry and harsh environments (Atti *et al*. 2004; Ben Salem *et al*. 2005; Wildeus *et al*. 2005; Aktas *et al*. 2014). These sheep breeds utilize the low-quality fodders efficiently compared to improved breeds and they may have a specific production niche under forage-based systems (Wildeus *et al*. 2005). Despite the fact that the growth rates of indigenous sheep breeds are generally lower than those of improved sheep breeds, they may be as productive as improved breeds even in high-input feeding systems (Fletcher *et al*. 1985; Kebede 2000).

Studies that compared the performance of sheep genotypes revealed significant differences between and within breeds (Fletcher *et al*. 1985; Lourenco *et al*. 2000; Tibbo 2006; Fraser *et al*. 2009). There is however, little information available on genotypic variation in utilizing different feed resources with varying nutritive values and their effects on animal performance in the context of integrated crop–livestock production systems in dry areas. Therefore, in the present study, the performance of fat-tailed indigenous Akkaraman and improved Anatolian Merino lambs fed either a high-cost, concentrated feed, or low-cost, green forage diets of varying quality was compared, focusing on the efficiency of meat production with specific reference to financial outcomes.

MATERIALS AND METHODS

Site, establishment and experimental design for forage production

The present study was conducted at Bahri Dagdas International Agricultural Research Institute (37°51′N, 32°33′E, 1008 m a.s.l.), Konya, Turkey in 2010–2011. Triticale (*Triticosecale* Wittmack, cv. tatlicak) and Hungarian vetch (*Vicia pannonica* cv. tarm beyazi) were chosen as a low-cost feeding system commonly grown for livestock in the Central Anatolia Region. Triticale, Hungarian vetch and a mixture of the two (0·20 : 0·80 seeding ratio) were sown in 16 × 78 m plots using a commercial seed drill with 0·2 m row spacing on 9 November 2010. Forage seeds were sown at rates typical for the region, which were 200 kg/ha for triticale, 100 kg/ha vetch and 80 kg/ha vetch + 20 kg/ha triticale for the mixture. Treatments were arranged in a completely randomized block design with three replicates. The field experiment site was on a clay–loam soil with slightly alkaline characteristics. Soil tests indicated that the site had 24 g/kg organic matter, available phosphorous of 107 kg/ha, calcium of 277 kg/ha and potassium 150 kg/ha, soluble salt 0·78 dS/m, and that the soil pH (in water) was 7·7.

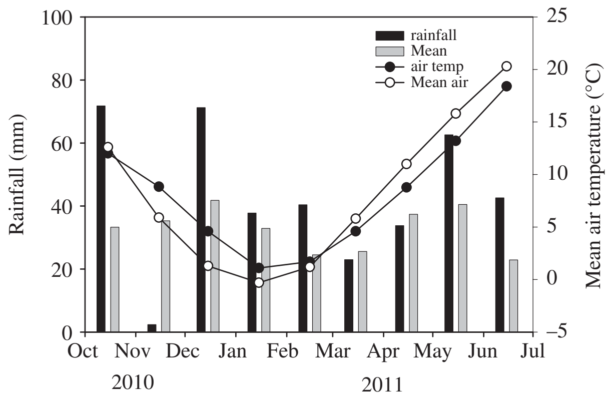

Fig. 1. Monthly rainfall and mean daily air temperatures during the experimental period (2010/11). LTM: Long-term means of air temperature and rainfall are for the period 1975–2010.

Based on soil test results, a total of 100 kg/ha fertilizer [180 g nitrogen (N)/kg and 460 phophorus pentoxide (P_2O_5)] was applied at sowing. No additional fertilizer was applied at any later date during the trial.

Climate

Average mean temperature and monthly rainfall during the growing season (October 2010–July 2011) are shown in Fig. 1. Total rainfall during the growing season was 396 mm. Of note was that the rainfall in Konya during spring 2011 was greater than the long-term mean and evenly distributed through the spring period, providing favourable conditions for plant growth. The mean air temperature was higher in autumn and winter and lower in spring and summer than the long-term average.

Pen feeding trial

A pen feeding trial was conducted with a total of 32 weaned, male fat-tailed Akkaraman (20 ± 1·2 kg) and Anatolian Merino lambs (0·80 German Mutton Merino × 0·20 Native Akkaraman) (20 ± 1·8 kg) for a period of 8 weeks from 18 April to 13 June in 2011. Equally balanced by genotype, 2-month-old Akkaraman and Anatolian Merino lambs (16 lambs per genotype) were assigned randomly to individual pens (1·7 × 1·5 m) equipped with feeders and water buckets in a four replication 4 × 2 factorial arrangement consisting of four diets and two genotypes. Prior to the feeding trial, the lambs were allowed to adapt to their diet for a 12-day period. Lambs had *ad libitum* access to daily harvested fresh forages of either triticale, Hungarian vetch or a mixture of the two and received 100 g/day concentrate supplement formulated mainly to meet mineral and vitamin requirements during the trial (Table 1). Another group of lambs, from both breeds, were fed *ad libitum* a concentrate-based feed with 200 g alfalfa hay per lamb/day to compare the forage-based low-cost feeding system with the concentrate-based high-cost feeding system. The formulations and chemical compositions of concentrate offered to lambs on feedlot and concentrate supplement offered to lambs consuming fresh forage are given in Table 1.

Table 1. *Formulation and chemical composition (dry matter (DM) basis) of concentrated feed and concentrate supplement*

Item	Concentrate	Supplement
Ingredient (g/kg)		
Cracked maize grain	813	530
Soy meal, solvent, 0·49	163	250
Magnesium sulphate	9	80
Vitamin–mineral premix*	1	10
Calcium carbonate	7	60
Dicalcium phosphate	5	50
Salt	2	20
Chemical composition, g/kg DM unless stated otherwise		
Metabolizable energy (MJ/kg DM)	12·9	10·4
Crude protein	158	175
Neutral detergent fibre	102	88
Acid detergent fibre	439	43
Calcium	4·7	36
Phosphorus	4·5	13
Magnesium (mg/kg)	2·2	9·2

* Each kilogram contains: 1·300·000 IU vitamin A, 260·000 IU vitamin D3, 3·000 mg vitamin E, 120·000 mg niacin, 5·000 mg magnesium, 5·000 mg iron, 5·000 mg zinc, 1·000 mg copper, 15 mg cobalt, 80 mg iodine, 15 mg selenium.

Feeding costs and cost–benefit ratio

The total feeding cost for the low-cost forage-based diets included land rent, seeds, fertilizer, sowing, cultivation and the harvest costs based on the daily harvested forage production. Concentrated feed costs applied in the calculations were based on the current market prices for the ingredients. For the cost–benefit ratio, daily and total feeding costs per lamb were calculated taking into consideration the production cost for each feed component. Meat production per

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lamb (kg/head) was calculated by multiplying average daily liveweight gain (LWG) of lambs (g/head/day) by the duration (56 days) of the feeding experiment. Total meat production revenue was calculated from the market price of lamb meat in Turkey. The cost–benefit ratio was calculated by dividing the total feeding cost per lamb (US$) to the value of total meat production per lamb (US$) during the fattening trial period.

Measurements

Forage dry matter production

Forage dry matter (DM) production was measured from three quadrat cuts in each plot with electric shears to a stubble height of 50 mm from ground level at weekly intervals from 18 April to 13 June. All freshly cut plant material was weighed immediately on a platform scale and sub-samples of each forage crop were dried to constant weight at 60 °C for 48 h to determine the proportion of DM. Sub-samples of the T + HV mixture group were also subjected to botanical composition and each component was oven dried at 60 °C for 48 h. Mean daily growth rates (kg DM ha/day) were calculated at each harvest by dividing total DM production (kg/ha) by the duration of growth since the previous harvest date.

Animal performance

Lamb LWG and dry matter intake (DMI) were monitored during the early (18 April–16 May) and late (17 May–13 June) spring periods. Lamb weights were recorded at the beginning of the trial and at 28 day intervals thereafter, following a 12 h fast. The feed conversion ratio (FCR) was calculated by dividing daily DMI by daily LWG. Crude protein (CP) intake was calculated by multiplying daily DMI by average CP content of the feed for the early and the late spring periods. Forage samples and unconsumed feed from each group were taken three times each week for DM determination. All lambs were fed once daily and the unconsumed feed was collected and weighed prior to morning feeding to determine feed consumption per lamb. The unconsumed feed represented 0·20–0·25 of feed offered to lambs. Sub-samples of leftover feed from the T + HV treatments were taken for the determination of the botanical composition on a dry weight basis three times a week to detect the feed preference of the lambs for each genotype.

Two hours after the feeding on 27 April, 24 May and 10 June blood samples (5 ml) were taken through jugular vein puncture from each lamb for serum biochemical analysis (Coles 1986). The samples were centrifuged (1800 ***g***, 10 min) for separation of the sera that were then stored at −20 °C. Blood constituents of urea-N, calcium, inorganic phosphorus and magnesium levels were assessed calorimetrically with an auto-analyser (GEM Premier 3000, Instrumentation Laboratory, USA).

Analytical procedures

Forage samples were collected at weekly intervals to determine their nutritive value and monitor the changes in nutritive quality throughout the spring season. Samples were dried at 60 °C in an air-forced oven for 48 h and ground to pass through a 1·0 mm screen in a Retsch mill (SM 100) (Retsch GmbH, Haan, Germany). Ground samples were analysed for DM, ash and CP by AOAC methods (AOAC 2003). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin was assayed according to Van Soest *et al*. (1991). The NDF was analysed with the inclusion of a heat-stable amylase and sodium sulphite, but both NDF and ADF were expressed inclusive of residual ash. Neutral and acid detergent insoluble CP that was necessary for calculating metabolizable energy (ME) was determined on the samples obtained from ADF and NDF residues. The ME (MJ/kg DM) was calculated according to tabular value of NRC (2001). *In vitro* true DM digestibility (DMD) was determined with the ANCOM Daisy[11] incubator (Daisy II, ANKOM Technology, Fairport, NY). Ruminal fluid used for DMD was collected from a non-pregnant, dry cow fed an alfalfa pellet and concentrate (0·60 : 0·40).

Statistical analysis

Total accumulated DM production (kg/ha/year) of forage crops was analysed by analysis of variance (ANOVA) with three replicates as a randomized complete block design. Mean daily growth rate (kg DM ha/day) and nutritive value of forages were analysed by ANOVA using 8 × 3 factorial model that accounted for the main effects of time and forage crop. When the F value was significant ($P < 0{\cdot}05$), the interaction between crop and time was further portioned into orthogonal polynomial contrast to identify linear, quadratic and cubic time effects. Liveweight gain (g/head/day), DMI (g/head/day), crude protein intake (CPI, g/head/day), FCR, carrying capacity

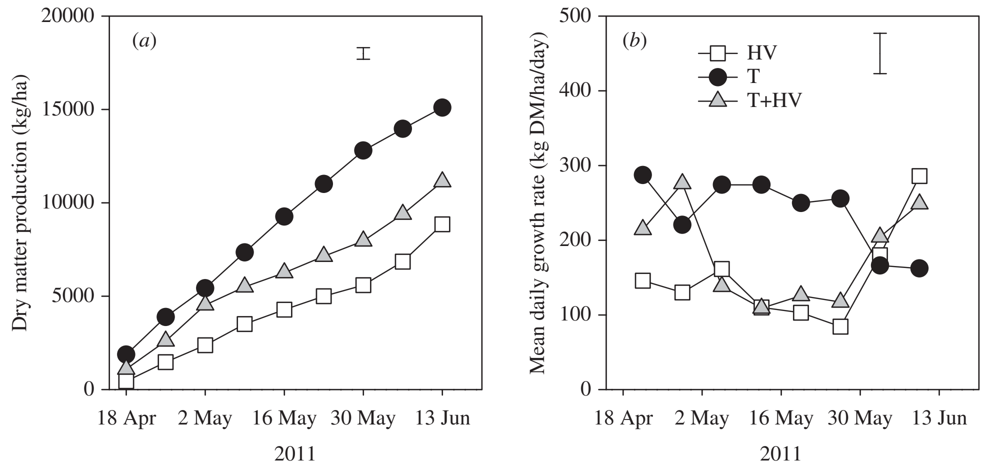

Fig. 2. Total accumulated dry matter production (kg DM ha/year) (*a*) and mean daily growth rates (kg DM ha/day) (*b*) for Hungarian vetch (HV), triticale (T) and triticale + Hungarian vetch mixture (T + HV) in spring 2011. Bars represent S.E. for forage × period interaction.

(number of lambs/ha) and total estimated meat production (kg/ha/day) were analysed by ANOVA based on a 2 × 4 × 2 factorial model that accounted for the main effects of genotype, diet and period in a completely randomized design. The weekly botanical composition of triticale + Hungarian vetch diet was analysed by ANOVA with three replicates in a randomized block design. The unconsumed component of T + HV diet was analysed by ANOVA based on a split–split plot design where genotype was the main factor, feed component was sub-plot and week was the sub–sub-plot factors. Plasma metabolite concentrations were analysed by one-way ANOVA with repeated measures for each sampling dates. Where ANOVA was significant, comparisons between treatments were made using the least significant difference procedure.

RESULTS

Forage dry matter production and nutritive value

Total annual forage DM production of Hungarian vetch, triticale and the mixture of two is presented in Fig. 2(*a*). Overall, the triticale monoculture had the highest ($P<0{\cdot}01$) total annual DM production (15·09 t/ha), whereas Hungarian vetch monoculture had the lowest (8·85 t/ha) and the T + HV mixture was in the middle (11·13 t/ha). There was a forage production × period interaction ($P<0{\cdot}01$) as the DM production of Hungarian vetch, T + HV mixture on 16 May did not differ from the DM production on 30 May, while the triticale monoculture had a steady increase in DM production as the season progressed.

Mean daily growth rate of forages ranged from 30 to 320 kg DM/ha/day during spring 2011(Fig. 2(*b*)). A forage × period interaction ($P<0{\cdot}01$) was detected for mean daily growth rates of the forages. Triticale monoculture had higher mean daily growth rates than the other forages until mid-May but Hungarian vetch monoculture and T + HV mixture had higher growth rates than triticale monocultures during late May–early June. The growth rate of triticale decreased from 287 kg DM/ha/day in early May to 162 kg DM/ha/day in early June. The growth rates of Hungarian vetch and T + HV mixture showed a decreasing trend until late May after which their growth rates started to increase in early June, exceeding 250 kg DM/ha/day.

The ash content of forages decreased ($P<0{\cdot}001$) from 131 g/kg on 18 April to 81 g/kg on 6 June (Fig. 3(*a*)). Hungarian vetch always had the highest ($P<0{\cdot}001$) ash content, whereas triticale had the lowest throughout the spring season. There was a forage × period interaction ($P<0{\cdot}01$) for the CP content of the forages (Fig. 3(*b*)). Crude protein decreased from 233 to 116 g/kg as the season progressed, but the reduction was greater in triticale than Hungarian vetch and T + HV. The CP contents of forages responded cubically ($P<0{\cdot}001$) across the season.

Significant interactions were detected ($P<0{\cdot}05$) between forage and period for NDF (Fig. 3(*c*)) and DMD (Fig. 3(*e*)) contents of the forages. The decrease in NDF and DMD contents of triticale with advancing maturity was more pronounced than Hungarian vetch and T + HV forages. The DMD contents of forages responded linearly ($P<0{\cdot}001$), whereas CP and NDF contents responded cubically ($P<0{\cdot}001$) across the

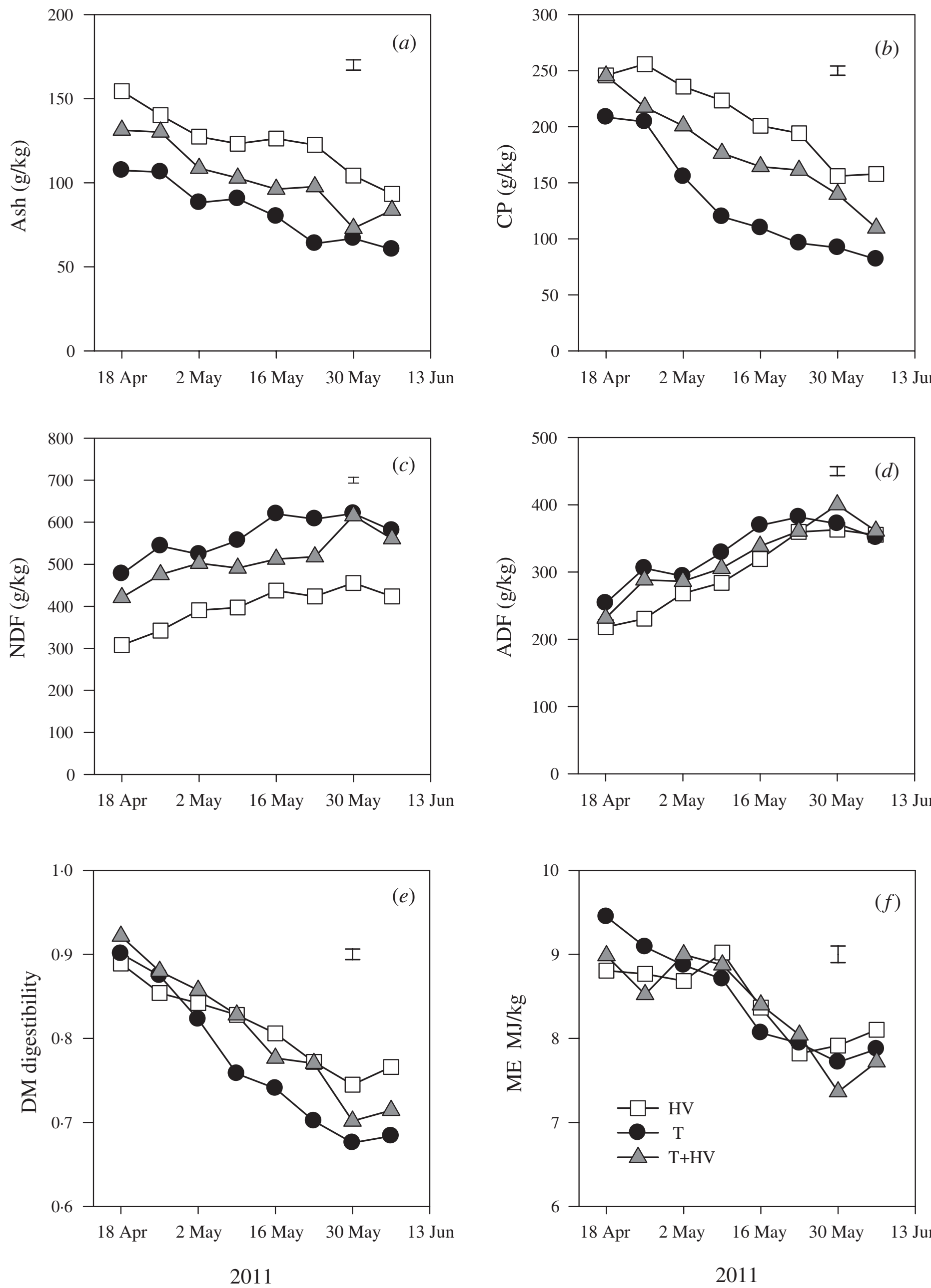

Fig. 3. Nutritive value of Hungarian vetch (HV), triticale (T) and triticale + Hungarian vetch mixture (T + HV). Bars represent s.e. for the forage × period interaction.

season. There were significant ($P < 0{\cdot}05$) differences between the ADF content of the plants with a diverging trend ($P < 0{\cdot}05$) as the season progressed (Fig. 3(*d*)). Overall, Hungarian vetch monoculture had the lowest ADF and NDF contents, whereas triticale monoculture had the highest values. The DMD values of the forages decreased ($P < 0{\cdot}05$) with maturity and the decline was faster in the triticale monoculture. The ME content of forages decreased ($P < 0{\cdot}001$) from 9·1 MJ ME/kg DM on 18 April to 7·7 MJ ME/kg DM on 13 June 2011 (Fig. 3(*f*)). There was no interaction between forage and period for the ME content of forages.

Liveweight gain, feed intake and feed conversion efficiency

Both lamb genotypes had similar LWG at the early (18 April–16 May) and late (17 May–13 June) spring periods (Table 2). However, a diet × period interaction ($P < 0{\cdot}05$) in the LWG of the lambs was

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Table 2. *Daily liveweight gain (g/head/day) of Akkaraman and Anatolian merino lambs that were fed either concentrated feed, Hungarian vetch, triticale or a mixture of the two (HV+T)*

		LWG g/head/day		
Genotype	Diet	0–28 days	28–56 days	Mean
Akkaraman	Vetch	160	167	163
	Triticale	176	111	143
	HV+T	153	149	151
	Concentrate	267	306	286
A. Merino	Vetch	153	164	159
	Triticale	179	80	129
	HV+T	163	113	138
	Concentrate	308	280	294
P_{Diet}			0·001	
$P_{Genotype}$			0·510	
P_{Period}			0·033	
$P_{Diet \times Genotype}$			0·832	
$P_{Diet \times Period}$			0·010	
$P_{Genotype \times Period}$			0·059	
$P_{Diet \times Genotype \times Period}$			0·591	
S.E.$_{Diet \times Genotype \times Period}$			18·6	

detected. The LWG of lambs fed triticale decreased ($P<0·05$) from 178 g/head/day in the early spring to 95 g/head/day in the late spring period. LWG of the lambs on the other forage diets and the concentrated feed did not change during the same period. There was a tendency for an interaction between genotype × period ($P=0·06$) as the decrease in LWG of Anatolian Merino lambs in the late spring period (28–56 days) appeared to be sharper than the Akkaraman lambs. Lambs fed the concentrated diet had higher ($P<0·05$) liveweight gains compared to those fed forages during both periods, and were 6·5–8·1 kg heavier ($P<0·01$) at the end of the experiment. The final liveweights of the lambs fed the three forage-based feeds were not significantly different from each other.

The mean DMI of lambs was 830 and 1088 g/head/day for the early and late spring periods, respectively (Table 3). There was a diet × period interaction ($P<0·01$) as the increase in DMI was greater in the concentrated feed treatment, whereas the increase in intake in the late compared to the early spring period for the lambs on all three forage-based diets were similar. Anatolian Merino lambs consumed 35 g/head/day more ($P<0·05$) feed DM compared to Akkaraman lambs. Diet × period and diet × breed interactions in the FCR were significant ($P<0·05$). Mean FCR increased from 4·7 in the early spring period to 7·6 in the late spring period. The increase in FCR was significantly different ($P<0·05$) for the lambs fed triticale and T + HV forages, whereas FCR of the lambs that were offered Hungarian vetch or the concentrated feed did not change. Both breeds had poorer ($P<0·05$) FCR for the late spring period compared to the early spring period, but the reduction in FCR was more pronounced in Merino than Akkaraman lambs.

From a low-cost feeding system context, Table 4 compares the estimated meat production (kg/ha/day) and calculated carrying capacity/ha of triticale, Hungarian vetch and Hungarian vetch + triticale plots for Akkaraman and Anatolian Merino lambs. Significant interactions were detected ($P<0·001$) between diet and period for total estimated meat production and carrying capacity of the forage treatments. Triticale had higher lamb-carrying capacity than Hungarian vetch and Hungarian vetch + triticale mixture in both the early and the late spring periods. Carrying capacity of all forage groups was lower in the late than early spring periods with the decrease being more profound for triticale than other groups. Despite the fact that triticale provided poorer ($P<0·001$) average lamb LWG, the total calculated meat production from triticale was superior to Hungarian vetch or their mixture due to its higher total DM production. Of note was that Hungarian vetch provided similar meat production potential in both spring periods. The total meat production from Hungarian vetch did not change as the season progressed, whereas triticale and HV + T

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Table 3. *Dry matter intakes (DMI, g/head/day) and feed conversion ratio (FCR) of Akkaraman and Merino lambs that were fed either concentrated feed, Hungarian vetch, triticale a mixture of two (HV+T)*

		DMI g/head/day			FCR		
Genotype	Diet	0–28 days	28–56 days	Mean	0–28 days	28–56 days	Mean
Akkaraman	Vetch	763	966	865	4·9	5·8	5·4
	Triticale	758	1000	879	4·4	9·7	7·0
	HV+T	840	1041	940	5·9	7·3	6·6
	Concentrate	889	1273	1081	3·4	4·3	3·9
A. Merino	Vetch	766	1016	891	5·6	6·3	6·0
	Triticale	819	988	903	4·8	12·7	8·9
	HV+T	838	1097	968	5·2	10·2	7·1
	Concentrate	964	1319	1142	3·1	4·8	4·0
P_{Diet}			0·001			0·001	
$P_{Genotype}$			0·050			0·010	
P_{Period}			0·001			0·001	
$P_{Diet \times Genotype}$			0·833			0·484	
$P_{Diet \times Period}$			0·010			0·001	
$P_{Genotype \times Period}$			0·992			0·010	
$P_{Diet \times Genotype \times Period}$			0·420			0·274	
$S.E._{Diet \times Genotype \times Period}$			32·1			0·74	

had a lower meat production potential in the late than early spring periods. Total meat production potential from triticale, Hungarian vetch and their mixture for Akkaraman was 60·1, 99·6 and 65·6 kg/ha/day, respectively, whereas for Anatolian Merino the production potential was 57·0, 88·7 and 61·3 kg/ha/day, respectively.

Feed preference

Averaged across the spring period, the T+HV diet consisted of 0·51 triticale, 0·49 Hungarian vetch and 0·01 annual and broad-leaved weeds, and this did not change during the feeding experiment ($P>0·05$, Fig. 4(*a*)). The composition of unconsumed T+HV diet collected from the feeders revealed significant differences ($P<0·05$) in the diet preference of Akkaraman and Merino lambs (Fig. 4(*b*)). Genotype × week interaction ($P<0·05$) was detected for the preference of Hungarian vetch and triticale plants in diet. Overall the proportion of unconsumed triticale in the diet increased from 0·25 in the first week of feeding trial to 0·61 in the final week, whereas the unconsumed Hungarian vetch decreased from 0·68 in the first week to 0·22 at the end of the trial. Hungarian vetch comprised 0·8 of uneaten feed for Anatolian Merino lambs but only 0·6 for Akkaraman lambs in the first two weeks of the trial. In contrast, Anatolian Merino lambs rejected a higher proportion of triticale in their diet compared to Akkaraman lambs in the last 2 weeks of the trial. There was no effect of genotype on the preference to broad-leaf weeds.

Crude protein intake and plasma metabolites

A diet × period interaction ($P<0·001$) was detected for the CPI of the lambs across the diets employed in the present study (Table 5). The CPI of lambs on the concentrated feed was 23–91 g/head/day lower than those fed forage-based diets in the early spring period. This was in contrast to the late spring period when the CPI of the lambs on the concentrated diet was 30–110 g/head/day higher than the lambs fed the forage diets (including 17·5 g/head/day CP coming from the mineral supplement). Mean daily CPI of Anatolian Merino lambs were 7 g/head/day higher ($P<0·05$) than Akkaraman lambs. Significant genotype and diet differences ($P<0·05$) were detected for the plasma metabolites concentrations of the lambs sampled on 27 April, 24 May and 10 June (Tables 5 and 6). The mean plasma urea N (PUN) concentrations of the lambs ranged from 15·1 mg/dl on 10 June to 24·8 mg/dl on 27 April (Table 5). There were diet × period and genotype × period interactions ($P<0·05$) for PUN. The lambs fed with Hungarian vetch had the highest ($P<0·01$) PUN concentrations at each sampling date despite the PUN levels of the lambs that were on forage-based diets were lower on 24 May and 10 June than on 27 April. The lambs fed the concentrated diet had the lowest PUN with a mean

Table 4. *Carrying capacity of triticale, Hungarian vetch and triticale + Hungarian vetch plots and total estimated meat production of Akkaraman and Anatolian Merino lambs in the early and late spring periods*

Genotype	Period	Fodder	Carrying capacity (head/ha)*	Meat production (kg/ha/day)†
Akkaraman	Early	Hungarian vetch	200	31·9
		Triticale	435	76·5
		HV + T	267	40·7
	Late	Hungarian vetch	169	28·2
		Triticale	209	23·1
		HV + T	167	24·9
A. Merino	Early	Hungarian vetch	200	30·6
		Triticale	403	71·9
		HV + T	267	43·3
	Late	Hungarian vetch	160	26·4
		Triticale	212	16·8
		HV + T	159	18·0
P_{Diet}			0·001	0·001
$P_{Genotype}$			0·095	0·255
P_{Period}			0·001	0·001
$P_{Diet \times Genotype}$			0·649	0·819
$P_{Diet \times Period}$			0·001	0·001
$P_{Genotype \times Period}$			0·576	0·424
$P_{Diet \times Genotype \times Period}$			0·114	0·739
$S.E._{Diet \times Genotype \times Period}$			8·6	4·65

* Estimated carrying capacity (number of lambs per ha) was calculated by dividing DM growth rate of forages (kg/ha/day) by DM intake of lambs (kg/head/day) for each period.
† Meat production was calculated by multiplying estimated carrying capacity of each fodder plots by average daily liveweight gain of lambs.

14·7 mg/dl on 27 April, but together with Hungarian vetch had the highest PUN levels during 24 May and 10 June. PUN concentrations of Anatolian Merino lambs was 2·7 mg/dl higher ($P < 0·05$) than Akkaraman lambs at the beginning of the experiment but both Anatolian Merino and Akkaraman lambs had similar ($P > 0·05$) PUN concentrations on 24 May and 10 June.

The plasma calcium (Ca) concentrates of Akkaraman and Anatolian Merino lambs were not affected ($P > 0·05$) by the diet or genotype or the period (Table 6). There were diet × period and genotype × period interactions ($P < 0·05$) for the plasma magnesium (Mg) concentrates of lambs. The lambs fed T + HV diet had identical plasma Mg concentrates of 1·7 mg/dl at each sampling dates while the rest of the treatments had a varying range of decrease in their plasma Mg levels. Plasma Mg concentrates of lambs that were on concentrated feed did not change with sampling date. However, the plasma Mg concentrates of the lambs that were fed with forage-based diets were lower ($P < 0·05$) in the second and the third samplings compared to the first sampling dates. The plasma phosphorus (P) concentrates of the lambs were not affected by diet and did not change with time, but Akkaraman lambs had significantly higher ($P < 0·05$) plasma P and Ca concentrates than Anatolian Merino lambs.

Economic profitability analyses

A cost–benefit analysis was performed to assess the profitability under both low-cost forage-based and high-cost concentrated feeding systems (Table 7). The empirical findings of the economic profitability analyses revealed that total feeding cost for the fattening of Anatolian Merino lambs is higher than Akkaraman lambs across the diets employed in the present study for the 56-day-trial period. The results indicated that the cost–benefit ratios vary with the feeding regime and genotype. The cost–benefit ratios are lower for the fattening of Akkaraman lambs both at high- and low-cost feeding systems, which indicates higher profitability.

DISCUSSION

The present study aimed to evaluate the efficiency of high- and low-cost feeding options by comparing the

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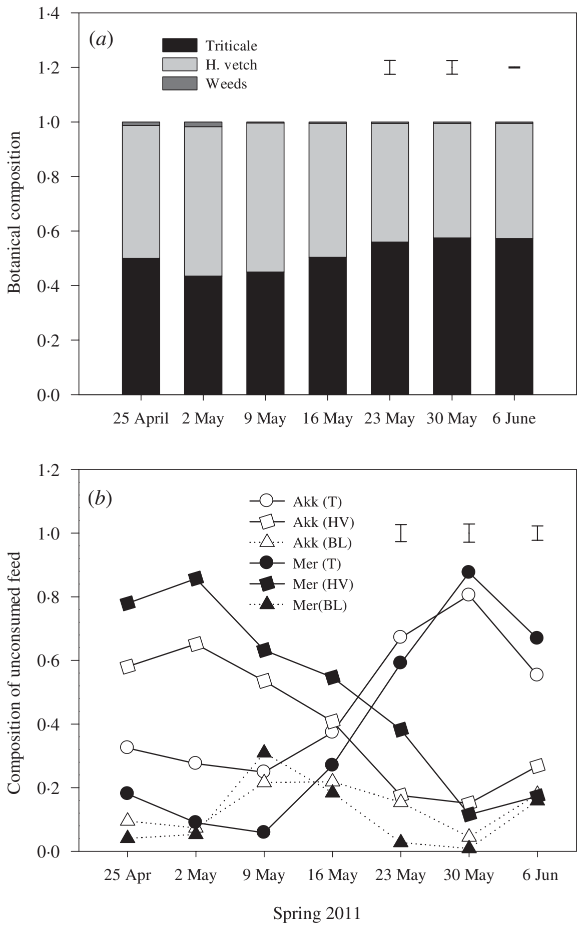

Fig. 4. Botanical composition (*a*) of triticale-Hungarian vetch (T+HV) diets of Akkaraman (Akk) and Anatolian Merino (Mer) lambs and the content (*b*) of unconsumed triticale (T), Hungarian vetch (HV) and broad leaf weeds (BL). Bars represent S.E. for (*a*) for the forage, period and the forage × period interaction for (*a*) and S.E. for the forage × period, genotype × period and forage × genotype × period interactions for (*b*).

responses of indigenous and improved sheep breeds to different feed resources during the early and the late spring periods, in an attempt to simulate a feedlot or cut-and-carry feeding approach in the crop/livestock farming systems of the Central Anatolia Region.

Triticale and Hungarian vetch monocultures and a mixture of the two (T + HV) provided highly nutritious feed for lambs with high DMI (841–904 g/kg), ME (8·7–9·4 MJ/kg) and CP contents (197–233 g/kg) in their early stages of maturity. High DMD of cereal forages at early vegetative stage exceeding 0·90 were also reported by Coblentz & Walgenbach (2010). The nutritive value of all fodder crops decreased with advancing maturity, especially after the switch from vegetative to reproductive growth, which typically occurs in temperate pasture and forage crops (Lambert & Litherland 2000; Waghorn & Clark 2004). Increased maturity in all forage groups resulted in decreased concentration of CP and digestibility but increased concentration of ADF and NDF. The decline in quality with tissue age was lower in Hungarian vetch, as evidenced by lower reductions in CP level and NDF value (424 g/kg) compared to triticale (581 g/kg) and the mixture of both (561 g/kg) on 13 June. The slight increase in DMD contents of the plants in the final week of the trial was probably due to the filling of grain in the triticale and pod formation in the Hungarian vetch. The changes in nutritive quality parameters in the present study were in line with the results of Brown & Moot (2004), who reported that ME in the palatable fraction of the legumes generally remains constant as the plants grow and herbage is accumulated compared to cereal crops and grass species, which generally have dramatic reductions in their nutritive value with increasing DM production and development.

The results showed clear evidence of significant differences between indigenous fat-tailed Akkaraman and improved Anatolian Merino lambs in their responses to a low-cost feeding system based on fodder crops or a high-cost feeding system based on a concentrated feed source. The LWG (129–163 g/head/day) achieved under the low-cost forage-feeding system were within the range for forage legumes [vetch (*Vicia sativa*), grass pea (*Lathyrus sativus*)] and cereals (barley, oat (*Avena sativa*), triticale) grazed by Awassi and South African Mutton Merino lambs reported previously in the literature (Bahhady *et al*. 1997; Larbi *et al*. 2008; Van Niekerk *et al*. 2008). The decline in the nutritive quality of the fodders was reflected in the responses of the lambs with LWG being 33 g/head/day lower in the late than early spring periods. On average, both lamb genotypes had higher feed intake but poorer FCRs in the late than the early spring periods. However, lambs that were fed Hungarian vetch in the late spring period maintained high LWG with superior FCRs due to its high nutritive quality compared to triticale or the T + HV mixture. A number of previous studies report that a high legume content in sheep diets leads to increased LWG compared with cereals forages or grasses (Hyslop *et al*. 2000; Litherland & Lambert 2007; Ates *et al*. 2008), primarily due to the higher rate of rumen fermentation, physical breakdown and passage rates through the rumen, as well as higher DM intake (Waghorn & Clark 2004; Dewhurst 2013). The current results are also consistent with the findings of Ates (2009) who reported that LWG of weaned lambs

Table 5. *Plasma PUN concentrates (mg/dl) and daily CP intake (g/head/day) of Akkaraman and Merino lambs that were fed either Hungarian vetch, triticale, a mixture of two (HV+T) or concentrated feed*

		PUN (mg/dl)			CPI (g/head/day)		
Genotype	Diet	27 April	24 May	10 June	0–28 days	28–56 days	Mean
Akkaraman	Vetch	25	21	21	249	188	219
	Triticale	23	21	20	188	113	150
	HV+T	27	20	22	236	167	202
	Concentrate	21	14	15	140	201	171
A. Merino	Vetch	23	14	16	261	197	229
	Triticale	22	18	16	185	111	148
	HV+T	21	17	17	248	176	212
	Concentrate	24	18	16	152	208	180
P_{Diet}			0·001			0·001	
$P_{Genotype}$			0·486			0·050	
P_{Period}			0·002			0·001	
$P_{Diet \times Genotype}$			0·079			0·562	
$P_{Diet \times Period}$			0·001			0·001	
$P_{Genotype \times Period}$			0·008			0·704	
$P_{Diet \times Genotype \times Period}$			0·859			0·992	
S.E.$_{Diet \times Genotype \times Period}$			1·3			7·0	

Table 6. *Plasma calcium (Ca), phosphorous (P) and magnesium (Mg) metabolites concentrates of Akkaraman and Anatolian Merino lambs that were fed either Hungarian vetch, triticale, a mixture of two (HV+T) or concentrated feed (mg/dl)*

		Mg			P			Ca		
Genotype	Diet	27 April	24 May	10 June	27 April	24 May	10 June	27 April	24 May	10 June
Akkaraman	Hungarian vetch	2·6	2·0	1·7	6·5	5·2	5·3	7·9	8·4	8·7
	Triticale	2·2	2·0	1·6	5·2	5·4	5·1	10·4	8·5	8·3
	HV+T	1·9	1·7	1·7	4·9	5·0	5·0	9·7	8·5	8·2
	Concentrate	2·6	2·5	2·3	5·2	5·5	6·1	9·2	8·3	8·9
A. Merino	Hungarian vetch	1·9	1·8	1·7	5·1	5·7	6·5	9·4	8·2	9·1
	Triticale	2·0	1·6	1·6	6·0	6·2	6·3	10·0	8·5	8·3
	HV+T	1·6	1·7	1·7	5·7	5·7	6·4	9·4	8·4	8·5
	Concentrate	2·4	2·5	2·2	5·4	5·7	5·8	10·0	8·0	8·5
P_{Diet}			0·001			0·834			0·452	
$P_{Genotype}$			0·020			0·021			0·701	
P_{Period}			0·001			0·172			0·092	
$P_{Diet \times Genotype}$			0·667			0·255			0·334	
$P_{Diet \times Period}$			0·017			0·734			0·296	
$P_{Genotype \times Period}$			0·020			0·111			0·780	
$P_{Diet \times Genotype \times Period}$			0·206			0·294			0·709	
S.E.$_{Diet \times Genotype \times Period}$			0·13			0·42			0·68	

followed a similar trend to the changes in ME content of pastures over a 2-year grazing period.

An important feature of the results was that Akkaraman lambs had better feed conversion efficiencies compared to Anatolian Merino lambs in the late spring period, when the nutritive quality of forages was declining. The poorer feed conversion efficiency of Anatolian Merinos was most evident in lambs that were fed triticale, and the difference between the lamb genotypes was accentuated towards the end of the feeding trial as the plant maturity advanced. There are ample research results in sheep and cattle reporting

Table 7. *Cost-benefit ratio analyses*

	Akkaraman				Anatolian Merino			
	Hungarian vetch	Triticale	HV + T	Concentrate	Hungarian vetch	Triticale	HV + T	Concentrate
DM intake								
Average DMI (kg/head/day)	0·856	0·879	0·94	1·081	0·891	0·903	0·968	1·142
Feeding costs*								
Daily feeding cost per lamb (US$/day)	0·17	0·07	0·12	0·54	0·17	0·076	0·13	0·57
Total feeding cost per lamb (US$)	7·95	3·59	6·52	32·7	8·53	3·82	6·94	36·5
Liveweight gained								
Average LWG (kg/head/day)	0·163	0·143	0·151	0·286	0·159	0·129	0·138	0·294
Total meat production per lamb (kg/head)	9·15	8·02	8·45	16·04	8·88	7·22	7·72	16·45
Liveweight gained value								
The value of meat production per lamb (US$)†	91·5	80·2	84·5	160·4	88·9	72·2	77·2	164·5
Cost–benefit ratio	8·68	4·47	7·71	20·37	9·59	5·28	8·98	22·19

* Feeding costs: production cost of Hungarian vetch = 0·19 cents/kg, triticale = 0·08 cents/kg; and triticale-Hungarian vetch = 0·13 cents/kg and the cost of concentrated based diet in the market = 50 cents/kg.
† Value of lamb meat = 10US$/kg.

significant genotypic differences in feed conversion efficiency, diet selection and ruminal degradation rate (Greeff *et al*. 1995; Lechner-Doll *et al*. 1995; Osoro *et al*. 1999). The higher plasma calcium and phosphorous concentrations in Akkaraman lambs compared to Anatolian Merino lambs and higher PUN concentration of Anatolian Merino than Akkaraman lambs in the first sampling date may also indicate possible differences in the digestion efficiency of both genotypes, which is similar to the findings of Silva *et al*. (2004) who reported genotypic differences in the net requirements for protein and energy of lambs for maintenance and production. This highlights the importance of matching the best available feed resources with the most suitable class and breed of livestock to optimize production.

The results of the composition of the uneaten feed revealed that Akkaraman and Anatolian Merino lambs also differ in their feed preferences. It appears that Anatolian Merino lambs were more selective in their diet compared to Akkaraman lambs, both in the early and the late spring periods. Several studies have reported an effect of animal genotype on feed selection, mainly in grazed pasture systems (Lechner-Doll *et al*. 1995; Osoro *et al*. 1999; Steinheim *et al*. 2005). Previous studies also report higher intake of forage or pasture legumes by livestock compared to grasses or cereal forages (Parsons *et al*. 1994; Waghorn & Clark 2004; Dewhurst 2013), but this was not observed in the present study. The preference of both Akkaraman and Anatolian Merino lambs for triticale over Hungarian vetch in early spring, despite the high nutritive quality of the Hungarian vetch which supported rapid lamb growth rates, was in complete contrast to the late spring period, probably due to increasing cell wall content of triticale as it became more mature. The low preference of weaned lambs for Hungarian vetch appears to conflict with the commonly reported preference pattern of sheep for a mix of legumes plus grasses (Broom & Arnold 1986) and the higher DMI of common vetch compared to cereal forages (Assefa & Ledin 2001). However, the current results are in line with the findings of Thomas (2005), who reported that common vetch was among the group of legumes that were strongly avoided by Merino hoggets at the vegetative stage. This was probably due to phenolic secondary metabolites compounds that some legumes accumulate as a defence mechanism to *Orobanche* infections (Goldwasser *et al*. 1999). Thomas (2005) also found that common vetch was the most preferred forage at the senescence phase for maximum growth, probably due to its high proportion of grain and nutritive value.

A feature of the results was that triticale and Hungarian vetch had almost an inverse temporal growth pattern during the spring–early summer period. Triticale had faster growth rates of over 200 kg/ha/day until mid-May compared to pure Hungarian vetch

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stand or the mixture of Hungarian vetch triticale, which had a growth rate of 80–160 kg/ha/day until the third week of May before exceeding 250 kg/ha/day at the pod-forming stage in early June. Unlike this result, Lithourgidis *et al*. (2006) did not detect any growing season × forage interaction for the growth rates of common vetch, triticale and oat when they were grown alone or in mixtures in Northern Greece. The forage × period interaction that occurred in the present study was probably due to the higher than average rainfall in late May–June, which may have provided Hungarian vetch the opportunity for an extended production period at the pod-forming stage. However, the results on growth pattern of triticale and Hungarian vetch, meat production potentials (kg/ha/day) and sheep preference may suggest that they can complement each other and extend the season for lamb feeding in the spring–early summer period. The high preference of lambs for triticale in early spring and for Hungarian vetch in the late spring periods may also support the value of sequential grazing of these forages in spring. In practice, triticale can be fed to lambs in early spring before its high nutritive quality and palatability diminish and its rapid growth decelerates towards summer. On the other hand, Hungarian vetch or a T + HV mixture will be more beneficial than pure triticale in late spring, providing sustained high nutritive quality for fattening of lambs in the dry areas. This sequential feeding system with the annual cereal and legume forages may help maximize sheep production in low-input crop livestock farming systems. Also, this system may enable farmers to manage triticale crop for dual purposes (grazing and grain production) with grain and straw production in summer in addition to spring grazing before turning lambs onto Hungarian vetch or paddocks containing vetch and triticale mixtures depending on the cropping system. It was of note that the mixture of Hungarian vetch and triticale also had high early spring growth rate because of the triticale component of the mixture. It is also well documented that intercropping has the potential to increase the protein content of forage-based diets (Assefa & Ledin 2001; Lithourgidis *et al*. 2006), as well as having agronomic benefits (Christiansen *et al*. 2000; Iptas 2002).

It is noteworthy that Anatolian Merino lambs did not demonstrate any advantage over Akkaraman lambs, neither with concentrate (high input) nor with forage-based (low input) diets, although they consumed more daily DM and CP (g/head/day) than Akkaraman lambs. In contrast, one factor contributing to the greater lamb LWG of Akkaraman lambs compared to Anatolian Merino lambs in the second half of the fattening trial was due to their more efficient feed utilization, in particular when the nutritive value of the forage crops decreased with advancing maturity. These trends were also reflected in the total revenue that was obtained from the cost–benefit analyses. These results are in line with the findings of Fletcher *et al*. (1985), who compared the lamb production from indigenous and exotic × indigenous ewes in Indonesia and reported that crossbred ewes required more feed to produce fewer, although heavier, lambs without any real increase in total productivity. Similarly, in another study in the USA, Wildeus *et al*. (2005) reported that lambs of Katahdin sheep were not able to express their improved growth potential on a high-forage diet as compared to Barbados Blackbelly or St. Croix Hair sheep lambs.

The high-cost fattening system with the concentrated diet in the present study resulted in higher DMI and faster lamb growth rates compared to low-input forage diets. The intake of forages was lower than the concentrate-based diets in both the early and the late spring periods, presumably due to their higher bulk and intake limitations at the vegetative stages in the early spring and the high cell wall content in the late spring (Waghorn & Clark 2004). The average LWG of lambs from the concentrated-feed-based system was similar in early (287 g/head/day) and the late spring periods (293 g/head/day). However, the lambs had poorer FCRs and decreased fattening performance due to increased feed intake in the late spring period and declining nutritive value of the forages (Nicol 1989).

Another significant observation in the present study was the lower plasma Ca and P concentrations of lambs that were fed the forage-based diets compared to those on concentrated feed diet, particularly at second and third sampling dates. Of note was the lower Mg and P concentrations in lambs that were fed the forage-based diet, despite the vitamin–mineral supplementation, suggesting that the supplements did not offset the reduction in ash content of forages from 131 g/kg on 18 April to 79 g/kg on 13 June. However, the plasma Ca, P and Mg levels measured in the present study were within the normal range (Ca: 8–12, P 6–9 and Mg 1·8–3·5 mg/dl; NRC 2007). In a review of many studies, Dove (2006) reported a wide range of LWG (140–360 g/day) in young sheep grazing dual purpose cereal crops, and the LWG were generally attributed to the low mineral contents of green cereal crops. Therefore, forage-based feeding may require supplementation with concentrated feeds and vitamin–mineral premixes depending on the quality of the forages, animal requirements and economic considerations (Rihawi *et al*. 2010).

Considerable fluctuation occurred in the PUN levels of the lambs in the present study, although values were within the normal range [10–26 mg/dl; Kahn & Line (2005); Carro *et al*. (2006)] in both the low-cost forage and high-cost concentrated diets. Lambs fed Hungarian vetch or the concentrated feed had higher PUN concentrates than the lambs fed with triticale, particularly on 24 May and 10 June when the CPI of lambs on triticale diet was 113 g/head/day and crude protein contents of triticale were lower than 100 g/kg. Similarly, the lower CP content of the concentrated feed (158 g/kg) compared to forage-based diet (over 200 g/kg) on 27 April led to 30–92 g/head/day lower CPI and subsequently lower PUN in both lamb breeds. Overall, higher PUN levels is probably due to either the rapid protein degradation or non-protein N content of Hungarian vetch, or the concentrated diet exceeding the capacity of the ruminal microbes to utilize released amino acid or ammonia–N. It is noteworthy to mention that the high CP content (197–233 g/kg) of forages, particularly in the early spring with Hungarian vetch diet, may have led to the excess N intake relative to requirements of lambs, reducing the efficiency of utilization of dietary N which typically occurs with forages or pastures when CP content exceeds 210 g/kg of digestible organic matter (Poppi & McLennan 1995). This excess N may have caused extra energetic cost for metabolism related with disposal of the excess N for particularly the lambs that were fed Hungarian vetch in early spring as similarly reported by Pacheco & Waghorn (2008).

CONCLUSIONS

The present study shows that fat-tailed Akkaraman lambs demonstrated better utilization of the forages with low nutritive value compared to Anatolian Merino lambs. Thus, it may be possible that fat-tailed Akkaraman lambs can be grown more efficiently in the arid and semiarid areas, where crop and livestock production are highly integrated. Considering the feeding of sheep is heavily dependent on poor quality cereal straw and barley grain, the importance of hardy sheep is central for efficient sheep production. The forage crops provided satisfactory meat productions but fattening performances of lambs could be increased with the concentrated feed supplementation to a certain extent depending on the economic conditions. Despite the fact that the sale of animals in open market is hardly based on the weight of lambs in Central Anatolia and there is a high customer preference for the meat from indigenous sheep with fat tail further research is needed to investigate the impacts of feeding system and genotype on meat quality and contribution to methane emissions, etc.

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