Modeling the Productivity of a Breeding Sheep Flock for Different Production Systems

A. Kamalzadeh*
Islamic Azad. University, Karaj, Islamic Republic of Iran

ABSTRACT : Individual production traits, such as reproduction and mortality rates, are partial measures, but may be used to evaluate the performance of different systems by comparing the rate of flock growth and potential offtake. The productivity of two existing sheep production systems, one extensive, one intensive, was compared with an alternative semi-intensive system. The future flock sizes, offtakes and structures were predicted based on the age structure of the flock and age-specific reproduction, mortality and growth rates. The measurements were illustrated with reference to growth of a sheep flock of different age and sex categories. The flock was in a so-called dynamic situation. During the dry period, the digestible organic matter intake of the animals in the intensive system and both extensive and semi-extensive systems was 36 and 20.1 g $kg^{-0.75}d^{-1}$, respectively. During the cold period, the digestible organic matter intake of the animals in extensive, intensive and semi-extensive systems was 34, 34.5 and 41 g $kg^{-0.75}d^{-1}$, respectively. During the dry period, the animals in the both extensive and semi-intensive systems lost in body weight at a rate of 19 g per day, but the rate of gain in body weight of the animals in intensive system was 57 g per day. During the cold period, the animals in extensive, intensive and semi-intensive systems gained in body weight at rates of 56, 67 and 97 g per day, respectively. The higher gain of animals during the cold period in the semi-intensive system was related to a sustained higher intake of low-quality roughage and more efficient use of the available feed. Compared to the intensive system, the annual concentrate input of the semi-intensive system was about 48% lower for each livestock unit. The productivity of the semi-intensive system was higher than that of the extensive system. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 5 : 606-612)***

Key Words : Sheep, Model, System, Productivity, Growth, Seasonality

INTRODUCTION

Livestock production forms 41% of agricultural output in Iran. Flocks of small ruminants are mainly managed under two different systems, namely, village and migratory. In the village system, the flocks are allowed on the natural communal grazing pastures, irrigated lands, or even mountain ranges in summer. In the tribal migratory system, the flocks migrate annually from the lowland winter ranges to the higher mountain grazing area in the summer. Both systems are extensive and the animals are mostly kept on natural vegetation of the range and farmlands with a little supplementary feeding. Intensive systems of sheep production are employed in only a few cases. In these systems, the animals are mostly kept in barns, fed commercially prepared pellets, and concentrate mixtures.

Stocking rate on the natural ranges is not controlled and depends on the seasonal rainfall and conditions of the pastures. Overgrazing and as a consequence land degradation is high and the overall performance of animals is low. For most parts of the year, the grazing animals subsist at a low plane of nutrition.

The effect of low-quality forages on animal production is accentuated by seasonal variation, which varies with the climatic conditions. At the beginning of the growing season, the grasses contain on average 9-11% crude protein (CP), while the digestibility is about 60-65%. These values decrease during the dry season. During much of the year, the protein content is only 4-5% and the digestibility between 40 and 50% (Figure 1).

The present system of nutritional management, which largely depends on natural vegetation, is unsatisfactory. However, the intensive production system may give higher output, but it needs a large amount of high quality concentrate mixtures. An alternative strategy is that both extensive and intensive systems of production gradually change to a semi-intensive system. In this respect, using a strategy of compensatory growth could be of special importance and a suitable way to increase the efficiency of the available feed (Ledin, 1983; Kabbali et al., 1992). In this strategy only a part of the livestock feed requirements need to be produced to supplement the insufficient low-quality feed obtained from the ranges and farmlands. The delay in growth during the dry time is compensated by supplying supplementary feed at a proper period, resulting in a more efficient use of the available feed. Compared to the extensive system, the grazing pressure on the vegetation could be reduced, allowing regeneration of the range species. The objective of research reported here is to simulate and evaluate the productivity of three different systems in Iran, using a flock growth model.

* Corresponding Author: Azizollah Kamalzadeh. Deputy Ministry for Livestock Affairs, Ministry of Jihad-e-Agriculture, Taleghani Ave. Building no. 2, Tehran, Islamic Republic of Iran. Tel: +98-21-6461223, 6460041, Fax: +98-21-6463730, E-mail: akamal57@yahoo.com
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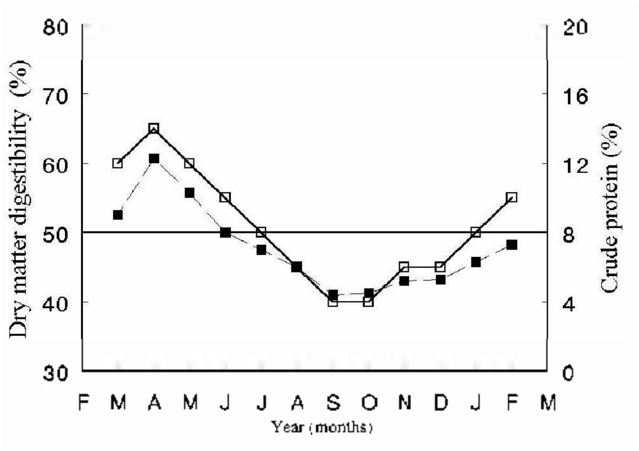

Figure 1. Seasonal variation in crude protein (CP) content (--■--) and digestibility (—□—) of pasture forages in Iran.

METHODS

Based on the model suggested by Upton (1993), a method was developed for building a 'flock growth model' from the knowledge of birth, mortality and production parameters. The growth model proposed by Upton (1993), for assessing livestock productivity was base on a "steady-state (stationary)" situation. The model used by Upton (1993), was not affected by constraints imposed on animals such as nutrient restriction during dry period. The livestock production in many parts of the word is usually dynamic and is affected by constraints. The model developed in this study is for the productivity of small ruminants' flocks or cattle herds in a "dynamic" situation.

Systems

The productivity of a sheep flock was compared in the following production systems :

i) System I extensive (migratory) : the flocks migrate annually from the lowland winter ranges to the higher mountain grazing areas in the summer. From October till March they stay on lowland ranges with minimal amounts of supplement between November and February. From March till June natural pastures between lowlands and highlands are the main source of feed. From June till September/October, the flocks are allowed on higher mountain grazing ranges or cereal stubble and straw (about 50 g CP and 16 KJ of GE per kg DM).

ii) System II intensive : animals are mainly kept in the barns, and the diet consists of roughage, supplemented with large amounts of concentrates (about 160 g CP and 16.5 KJ of gross energy (GE) per kg DM). The animals may feed from pastures during the spring period and cereal stubble during early summer.

iii) System III semi-intensive : in this system, the natural pastures are the main sources of feed in spring. In the summer, the feed largely consists of cereal stubble and straw. In autumn and winter, animals are taken off the ranges, and cereal straw supplemented with concentrates.

Model description

The measurements were illustrated with reference to growth of a sheep flock of different age and sex categories in which replacements are only from the same flock. The flock is in a so-called 'dynamic situation'. The young lambs which were produced may either be slaughtered for consumption, sold or retained as additions to the breeding stock, in other words for capital investment. Due to variations in age and size across categories, the measurements were expressed in terms of livestock units (LSU). One LSU is equal to a sheep of 50 kg live weight. The average live weight of ewes in most Iranian breeds is about 50 kg. The conversion factors were based on the relative feed requirements per head, and were calculated based on the metabolic weight ($LW^{0.75}$). It implies a non-linear relationship between LW and LSU (Table 1).

Season

Based on the seasonal conditions, the year has been divided into three periods:

- Period 1: 3 to 4 months (March till June/July). Lambs are mainly born in March and weaned in May; plant growing period.
- Period 2: 3 to 4 months (July/August till September/October); dry and warm period.
- Period 3: 5 to 6 months (October/November till March); wet and cold period.

Performance

The 'production traits', which represent the performance, are reproduction, mortality and yield. Of these, the first two determine the size of the flock and possible offtake, while the latter relates to the quantities of meat, milk and other outputs (*i.e.* hides, wool) produced by the animals.

Table 1. Live weight (LW) per age class and converted livestock unit (LSU) for each sheep production system

System	I		II		III	
Sex and age category	LW	LSU	LW	LSU	LW	LSU
Females and males aged up to 12 months	27	0.54	30	0.59	27	0.54
Immature females (aged 12 to 24 months)	45	0.90	50	0.87	48	0.96
Immature males (aged 12 to 24 months)	50	1.00	56	1.12	53	1.06
Females aged 2 years and above	55	1.10	60	1.20	58	1.16
Males aged 2 years and above	67	1.34	80	1.60	75	1.50

Table 2. The production traits[1] for different systems

	Age class						
	0	1	2	3	4	5	6
System I							
Lambing rate (%)			80	84	87	86	82
Mortality rate (%)	28	8	4	4	6	8	10
Milk yield per lactation (kg)			80	80	80	80	80
Milk offtake per lactation (kg)			0	0	0	0	0
Ratio of adult males to females (%)			10	10	10	10	10
System II							
Lambing rate (%)			90	95	103	97	93
Mortality rate (%)	15	3	2	3	4	6	10
Milk yield per lactation (kg)			100	100	100	100	100
Milk offtake per lactation (kg)			20	20	20	20	20
Ratio of adult males to females (%)			5	5	5	5	5
System III							
Lambing rate (%)			85	90	95	91	87
Mortality rate (%)	22	5	4	4	5	7	10
Milk yield per lactation (kg)			90	90	90	90	90
Milk offtake per lactation (kg)			15	15	15	15	15
Ratio of adult males to females (%)			5	5	5	5	5

[1] For explanation of production traits and sources see text.

The production traits were estimated on an age and sex specific basis (Table 2). Reproductive performance of ewes increases to a maximum at an age of five to six years old. Assuming that the total replacement rate of adult ewes is 20% per year, the average reproductive life of a ewe is approximately five years. Reproductive rate was presented by lambing rate. A range of 80 to 105 percent for lambing rate has been observed for sheep under extensive and intensive production systems in Iran, respectively. White et al. (1993) in Australia have reported a range of 97 to 118 percent for ewes. In this study, a value of 84 percent has been set for system I, a value of 95 percent for system II and a value of 90 percent for system III (Table 2). For milk production, a range of 0.3 kg to 1 kg per day (Akinsoyinu et al., 1977; Monem, 1984) has been proposed. Part of the milk (10-20 kg/ewe) is considered as offtake.

Different mortality rates have been chosen for the systems. In general, the mortality rates for system I were set at higher rate than the other systems due to the annual moving from one place to the other place and lack of adequate nutrition during much of the year. A range of 3 to 20 percent for mortality rate has been derived from the data reported by Monem (1984) and White et al. (1983) during pre-weaning period in pastures of high to low plane of nutrition.

The flock growth model

General model : Based on the model suggested by Upton (1993) and a growth model for an age structured population (Crow, 1986), a flock growth model was constructed. The model is expressed in numbers of females per age class in time. The scale for age classes and time is years. The numbers are counted at time of birth and it is assumed that all births are at one fixed time in a year, within a short period (say one week). The growth of a population is determined by *birth rate* and *survival rate* of the female part of the population. It is assumed that females in age class 2 starts to reproduce, and all females of 7 years are culled.

Birth rate (b_x) is defined as the number of females born from females of age x. Survival rate (p_x) is the probability for a female to survive from age x to age x+1.

The schematic flow in time for females of different ages for this model is:

	age class (x)							
time	0	1	2	3	4	5	6	7
t	$n_{t,0}$	$n_{t,1}$	$n_{t,2}$	$n_{t,3}$	$n_{t,4}$	$n_{t,5}$	$n_{t,6}$	0
t+1	$n_{t-1,0}$	$p_0n_{t,0}$	$p_1n_{t,1}$	$p_2n_{t,2}$	$p_3n_{t,3}$	$p_4n_{t,4}$	$p_5n_{t,5}$	0

The number of newborn females at time t+1 is calculated as:

$$n_{t-1,0} = b_2p_1n_{t,1}+b_3p_2n_{t,2}+b_4p_3n_{t,3}+b_5p_4n_{t,4}+b_6p_5n_{t,5}$$

Stable flock size : For a fair comparison between systems, the flocks should be about the same in size and stable in time. For a stable population the condition is: $n_{t,x}/n_{t-1,x}=1$, for all x. In such a situation, the numbers for each class are stable over time and for further calculation time can be ignored, and the population structure in terms of n_0, p_x and b_x can be derived by developing the above scheme in time. The result is:

Age class	Number	Expression
0	n_0	$n_0=b_2n_2+b_3n_3+b_4n_4+b_5n_5+b_6n_6$

$b_5n_5+b_6n_6$

1	n_1	p_0n_0
2	n_2	$p_0p_1n_0$
3	n_3	$p_0p_1p_2n_0$
4	n_4	$p_0p_1p_2p_3n_0$
5	n_5	$p_0p_1p_2p_3p_4n_0$
6	n_5	$p_0p_1p_2p_3p_4p_5n_0$
7	n_7	0 (p_6 is 0)

Birth and survival rates : Survival rate (p_x) contains two factors, mortality rate (m_x) and culling rate (c_x), and therefore: $p_x = (1-m_x)(1-c_x)$. It is assumed that mortality occurs throughout the year and culling is always at the end of the year. Mortality is a factor determined by the system. Culling however is a factor, which can be used to manipulate the survival rates to reach a stable flock size in time. For each of the systems a culling strategy will be determined in a way that the flock is stable in time. To find culling rates for the different age classes some additional assumptions are necessary:

1. The number of females in the mature classes of age 2 and higher (N_m), is constant.
2. Within the mature classes the same fraction (c_m) of the females will be culled each year, and: $c_2=c_3=c_4=c_5=c_6= c_m$.
3. Culling rates for all immature females are assumed equal: $c_0= c_1 = c$.

Calculation of c and n_0 for a stable flock : From the formula for the number of newborns a value for p_0p_1 can be derived:

$$p_0p_1 = 1/[b_2+b_3p_2+b_4p_2p_3+b_5p_2p_3p_4+b_6p_2p_3p_4p_5] \quad [1]$$

Having values for p_0p_1 and for N_m, a value for n_0 can be computed:

$$n_0 = N_m/\{p_0p_1 [1+p_2+p_2p_3+p_2p_3p_4+p_2p_3p_4p_5]\} \quad [2]$$

Equation [1] offers the opportunity to calculate c from p_0p_1, because $p_0p_1 = (1-m_0)(1-c)(1-m_1)(1-c)$, and c can be solved:

$$c = 1-\sqrt{\{p_0p_1/[(1-m_0)(1-m_1)]\}} \quad [3]$$

Table 3. Average live weight (LW) for sheep and average milk offtake per ewe

	System		
	I	II	III
Live weight (kg)			
Females:			
1 year old	27	30	27
2 years and older	53	60	58
Males:			
1 year old	40	50	45
2 years and older	67	80	75
Milk (kg per ewe)	10	20	15

Offtakes

In Table 3, the average live weight (LW) of sheep at the end of year and average milk offtakes per ewe are given. These data are used to evaluate the total annual offtake. No account of flock appreciation or depreciation was taken, and it is likely that the product outputs vary from year to year. Upton (1993) recommended that output should be measured as the total product offtake from a flock, which is assumed to be maintained at a constant size and structure, so that the flock depreciation or appreciation is zero. Because of differences in types of feed, animals in various systems had different live weights.

Table 4. Population parameters of the female part for different systems (derived values are in bold italics)

Parameter	System		
	I	II	III
b_2 [1]	0.400	0.450	0.425
b_3	0.420	0.475	0.450
b_4	0.435	0.515	0.475
b_5	0.430	0.485	0.455
b_6	0.410	0.465	0.435
p_0 [2] (m_0, c) [3]	***0.693*** (0.278, ***0.040***)	***0.673*** (0.154, ***0.204***)	***0.685*** (0.219, ***0.123***)
p_1 (m_1, c)	***0.883*** (0.080, ***0.040***)	***0.772*** (0.030, ***0.204***)	***0.833*** (0.050, ***0.123***)
p_2 (m_2, c_m)	0.883 (0.040, 0.080)	0.702 (0.020, 0.080)	0.883 (0.040, 0.080)
p_3 (m_3, c_m)	0.883 (0.040, 0.080)	0.892 (0.030, 0.080)	0.883 (0.040, 0.080)
p_4 (m_4, c_m)	0.865 (0.060, 0.080)	0.883 (0.040, 0.080)	0.874 (0.050, 0.080)
p_5 (m_5, c_m)	0.846 (0.080, 0.080)	0.865 (0.060, 0.080)	0.856 (0.070, 0.080)
p_6 (m_6, c_m)	0.000 (0.100, 1.00)	0.000 (0.100, 1.00)	0.000(0.100, 1.00)
n_0 [4]	***84***	***95***	***90***

[1] Birth rates (b_x) are 1/2 of the lambing rates in Table 2, assuming a sex ratio of 1:1.
[2] Survival rates (p_x) are derived from m_x and c_x.
[3] Mortality rates (m_x) are from Table 2, culling rate (c_m) is assumed to be 8% and c is derived by Equation 3.
[4] The number of newborns (n_0) is a result of Equation 2, assuming a constant mature female number (N_m) of 200 in the flock.

Table 5. Numbers of breeding females and males with the numbers that died and culled in a stable flock for different systems

System	I		II		III	
Sex	♀	♂	♀	♂	♀	♂
Age class						
0	84	84	95	95	90	90
Mortality	23	23	15	15	20	20
Culled	3	58	16	77	9	67
1	58	3	64	3	61	3
Mortality	5	0	2	0	3	0
Culled	2	0	12	0	7	0
2	51	3	50	3	51	3
Mortality	2	0	1	0	2	2
Culled	4	0	4	0	4	0
3	45	3	45	3	45	3
Mortality	2	1	1	1	2	1
Culled	3	0	4	0	3	0
4	40	2	40	2	40	2
Mortality	2	0	1	0	2	0
Culled	3	1	4	1	3	1
5	35	1	35	1	35	1
Mortality	2	0	1	0	2	0
Culled	3	0	4	0	3	0
6	29	1	30	1	30	1
Mortality	3	0	3	0	3	0
Culled	26	1	27	1	27	1
7	0	0	0	0	0	0

RESULTS

Assuming a culling rate (c_m) of 8%, and a constant number (N_m) of 200 for the mature females in the flock for all systems. the population is determined by the parameters as presented in Table 4. For the males the same survival rates (p_x) are taken as for the females, except c_0, which is assumed to be 95% for system I. 96.5% for system II and 95% for system III. so that always 10 mature males are available in the flock. In Table 5, the numbers per age class are presented. with the number of animals that died and the number of animals culled.

To be able to compare the productivity of various systems. it was assumed that the average live weight of the flock, which is composed of all different age and sex categories, is 50 kg at the onset of the dry period in all systems. It was also assumed that during spring. animals in all systems are kept on natural pastures. The feed intake data (Table 6) were derived from the observed values in Iranian sheep. During period 1 (plant growing period). the animals in systems I. II and III lost in body weight at a rate of 84, 147 and 139 g per day. During period 3 (wet and cold period). the animals in system I. II and III. gained in body weight at a rate of 56, 67 and 97 g per day. During the dry period. animals in system II gained in body weight at a rate of 57 g per day. The rate of loss in body weight of the animals in systems I and III were set at 19 g per day. For low-quality feed during the dry period. a value of 20.1 g $kg^{-0.75}$ d^{-1} digestible organic matter intake (DOMI) was estimated for animals in systems I and III. Considering 26 g $kg^{-0.75}$ d^{-1} DOMI (ARC, 1980) for zero weight gain

Table 6. Initial and final live weight, live weight gain, feed intake (roughage and supplement) and intake of digestible organic matter (DOMI) from roughage[1] and supplement[2] during different periods in all systems

	Period 2 (dry, 105 days)			Period 3 (cold, 165 days)			Period 1 (95 days)		
	I	II	III	I	II	III	I	II	III
Initial live weight (kg)	50	50	50	48	56	48	56	67	64
Final live weight (kg)	48	56	48	56	67	64	48	53	51
Live weight gain (g/day)	-19	57	-19	49	67	97	-84*	-147*	-139*
Intake (DOMI, g/day)									
Roughage	378	289	378	385	290	403	561	453	600
Supplement	0	418	0	256	468	434	0	220	0
Intake (DOMI, $g/kg^{-0.75}$ d^{-1})									
Roughage	20.1	14.7	20.1	19.9	13.2	19.7	29	21	29
Supplement	0	21.3	0	13.2	21.3	21.2	0	12.2	0
Total intake (DOMI, kg/LSU)									
Roughage	39.7	29.1	39.7	63.5	47.9	66.5	53.3	43	57
Supplement	0	43.9	0	42.2	77.2	71.6	0	11.6	0
Intake (g/day)									
Roughage	990	791	990	1,030	819	911	1,250	1,050	1,305
Supplement	0	598	0	407	769	716	0	350	0
Intake ($g/kg^{-0.75}$ d^{-1})									
Roughage	53.4	40.3	53.4	53.2	37.3	44.5	72.1	58	73.4
Supplement	0	30	0	21	35	35	0	20	0
Total intake (kg/LSU)									
Roughage	104	83.1	104	170	135	150	119	100	124
Supplement	0	62.8	0	67.2	127	118	0	33.2	0

[1] Roughage contains about 50 g/kg dry DM protein during periods 2 and 3 and about 60 g/kg DM crude protein during period 1. *ad libitum*.

[2] Supplement contains about 160 g/kg DM crude protein, offered at rates of 30, 35 and 20 g $kg^{-0.75}$ d^{-1} for the animals in system II during periods 2. 3 and 1, respectively. The amount of supplement offered to the animals of systems I and III, during period 3, was about 20 g $kg^{-0.75}$ d^{-1}.

* Most of the weight loss is because of giving birth (considering about 9 kg for fetus, placenta and amniotic fluid).

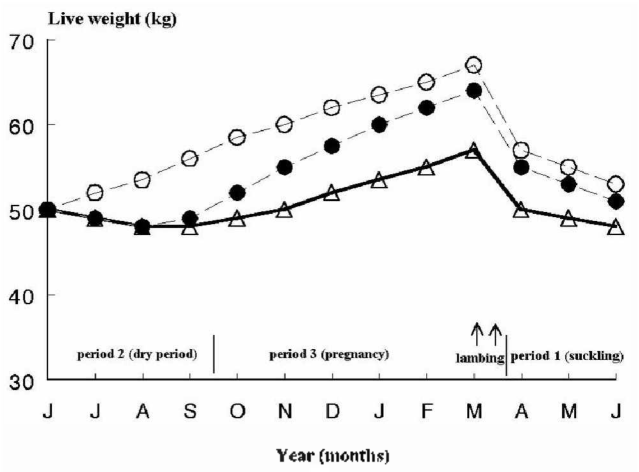

Figure 2. The annual growth patterns for different sheep production systems; (Δ) extensive, (O) intensive, (●) semi-intensive.

(maintenance requirement), the 20.1 DOMI resulted in approximately 19 g per day weight loss in animals of systems I and III, at the end of dry period. During the dry period, the digestible organic matter intake of the animals in system II was about 36 g $kg^{-0.75}$ d^{-1}. During the cold period, the digestible organic matter intake of the animals in systems I, II and III was 34, 34.5 and 41 g $kg^{-0.75}$ d^{-1}, respectively. At the end of cold period (March), the estimated average live weight for animals in systems I, II, III was 56, 67 and 64 kg, respectively (Figure 2).

DISCUSSION

Various livestock models have been proposed to evaluate the productivity of production systems under subtropical and semi-arid climates. The models (Knipscheer et al., 1984; Bosman, 1995) assess the productivity of small ruminants in terms of production per individual animal or per flock. While, the model suggested by Peacock (1987) was used to evaluate the productivity of animals in terms of net production per flock.

Animal production in many parts of the world, particularly in the subtropics and semi-arid areas is usually dynamic. The detailed and complex models that consider a large numbers of assumptions are not suitable and may not necessarily lead to better results. Many available models are affected by constraints imposed on animals such as nutrient restriction. The input data in the model should be easily obtainable. Those that consider important traits and offer an easier way for estimation of the parameters are more feasible. The herd growth model proposed by Upton (1993) for assessing livestock productivity is modified to a stable model, and offers a quick way to achieve reasonable estimates. The model used in Upton's study was not affected by feed quality restriction imposed on the animals during the dry period.

Most of the weight loss of the animals in all systems during period 1, was because of giving birth (considering between 7 to 12 kg for fetus, placenta and amniotic fluid for different systems). The negative growth of the animals in systems I and III during period 2 was related to the consumption of the available low-quality roughage. Roughage contains about 50 g per kg dry matter crude protein during both periods 2 and 3 and about 60 g per kg dry matter crude protein during period 1. The weight gain of the animals in system II during dry period was related to a sustained consumption of the supplement.

Part of the higher gain of animals during the cold period in system III compared to animals in system II was related to a sustained higher intake of low-quality roughage and more efficient use of the available feed. The higher intake of low-quality roughage in realimented sheep, compared to controls, increases with increasing live weight (Rayan, 1990; Kamalzadeh et al., 1997). The natural feed quality restriction imposed during the dry period, resulted in a lower maintenance requirements of the animals (Graham and Searle, 1979; Gingins et al., 1980). This lower maintenance requirement persisted during the initial part (first month) of the recovery period (Hogg, 1992; Kamalzadeh et al., 1997) and therefore more net energy was available for growth when sufficient nutrients were made available for the animals in system III. Applying sufficient nutrients for animals in system III during the cold period had a remarkable effect on the rate of gain. The results of this study show that integration of the extensive and intensive systems can increase the productivity of the animals and reduce the damage on the environment. Miao et al. (2004) also found that with successful management and integrating the outdoor pigs into cropping pasture system can reduce the negative impacts on the environment and have similar production to indoor pig production system.

IMPLICATIONS

The flock growth model used in this study provides estimates of flock size and structure, together with offtakes of animals and milk. These are derived by applying the average production traits and given offtake rates. The flock structure and offtake rates are determined by the need to maintain constant animal numbers in each age/sex class and the given production traits. This model is readily adapted for assessing the growth or productivity of small ruminant flock or cattle herds. Implementation of a semi-intensive system relative to intensive system, enable a reduction of the concentrate input of 48% per livestock unit in year. This indicates that animals on a discontinuous growth path require a lower input of feed than animals on a continuous growth path to achieve the same live weight and productivity. The productivity of the semi-intensive system was higher than the extensive system. A change from the currently widespread extensive system to a semi-intensive system would mean a serious reduction of the land requirements per kg sheep product.

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