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GRADUATE SCHOOL OF DEVELOPMENT
Mountain Societies Research Institute

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Abstract: Farming in mountainous areas is practiced primarily by crop and livestock based small scale farmers. Prevailing agricultural production systems of these farms focus on animal husbandry, which depend on a mix of crop and pasture land around settlements and higher elevation summer pastures. The lack of sufficient production of winter feed and degradation of pastures around villages due to over-stocking, especially in early spring, results in low fattening and health of livestock, and subsequent low profitability from animal husbandry. Understanding the farm agricultural production system is crucial in order to make interventions that can contribute to improved crop and animal productivity and sustainable pasture use. This study aims to characterize prevailing farming systems in terms of their herding practices and fodder cropping, to determine annual fodder demand and supply for herds, and economic contribution of current livestock raising practices. The study derives recommendations for increasing animal productivity and ensuring sustainable pasture use. The paper is based on a survey of 72 households in the mountain villages of southern-central Tien Shan. The nutritional values of fodder type and feed requirements for animals were taken from different sources. We computed gross margins (GM) to assess the farmers' operational performance in livestock production. Linear programming (linear optimization) was applied to optimize available resources and production system and to achieve the maximum GM. Results from linear programming indicated limitations on the available fodder stocks during winter period, which lasts 7.5 months and is defined as a period during which animals should be kept indoor . On average, farmers owned 15.8 livestock units and hold 3.85 ha of arable land. More than 90% of the actual cultivated (irrigated and rainfed) land was used to grow fodder crops for winter. On average, the total amount of available fodder was 9,102 kg DM per farm. The annual feeding cycle analysis revealed that meadows and pastures near the villages were used intensively during spring and autumn due to the insufficient amount of winter feed stocks, which induced significant pasture degradation. Total gross margins from livestock raising per farm household was positive and accumulated to 139,141 KGS. However, many animals were undernourished for a significant part of the year, meaning that most farmers could only sell animals from summer to late autumn, after the summer grazing period, when market prices dropped. These and other factors made animal production highly risky and reduced the GM. Results of optimization showed a decrease in total GM by 15%, driven mainly by decrease of number of animals, as the amount of available fodder is sufficient for only 9.4 LU. Despite the fact that total GM reduced, GM per head in optimization model was higher. Overall, the results suggest that adjustments in the smallholders' production methods are required. In particular, an expansion of fodder cultivation is suggested to increase volume of fodder stock for winter period and ensure profitability of livestock production. However, provision of productive inputs and additional consultancy services would be needed to ensure success in this area

Keywords: smallholder farms, micro analysis, animal husbandry, pasture use and fodder production
JEL classification: Q12, Q15, Q16

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List of Acronyms

DLG ..... German Agricultural Society (in German)
DM ..... Dry matter
GDP ..... Gross Domestic Product
GE ..... Gross energy
GM ..... Gross margin
HH ..... Household
KGS ..... Kyrgyz som
LfL ..... Bavarian Regional Office for Agriculture (in German)
LU ..... Livestock unit
masl ..... Metres above sea level
ME ..... Metabolizable energy
MJ ..... Megajoules
NEL ..... Net energy content for lactation
NSC ..... National Statistical Committee, Kyrgyz Republic
RUSLE ..... Revised Universal Soil Loss Equation
USSR ..... Union of Soviet Socialist Republics
WOCAT ..... World Overview of Conservation Approaches and Technologies

1. Introduction

Agriculture represents one of the most important sectors of the Kyrgyz economy, comprising 14.8% of the country's GDP and engaging 34% of the labor force. Moreover, two-thirds of the population live in rural areas (MinEcon 2015). The collapse of the Soviet Union at the beginning of 1990s triggered a transformation process of the farming system. The large collective farms that were the typical agrarian unit in Soviet times were fragmented into more than 428,000 private family-managed farms (NSC 2018). Due to the specific geographical conditions of the country, most of the farms are located in mountainous regions at high altitudes. In general, the major agricultural production systems can be characterized as extensive animal husbandry combined with extensive cropland, oriented to fodder production. During this period of transformation, a number of small-scale farmers were able to improve their farm management and performance and expand their arable land and/or herd size. However, most of the family farms remain rather resource-poor and thus operate below their potential production capacities. Nevertheless, these farmers currently contribute 97% of the country's agricultural production (NSC 2018). Up to 49% of Kyrgyz territory is covered by pastures and meadows (Wilson 1997). This agroecosystem is an important natural resource for the country, as well as creating conditions that typical combine small-scale farming systems based on crops and livestock.

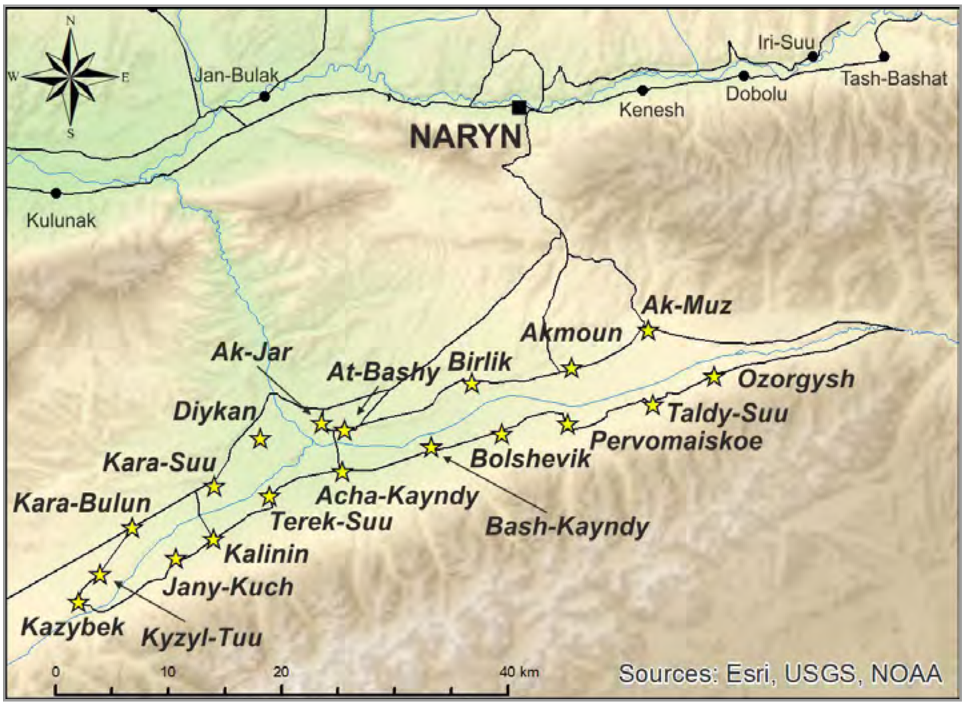
Naryn oblast is a typical example of such an agroecosystem in the country. At the same time, it is one of the most important livestock production areas in Kyrgyzstan. Highland pastures cover nearly 90% of the designated agricultural land in the oblast. However, at least 33% of the country's pastures were degraded a decade ago and the situation is getting worse (USAID, 2009). Studies have analyzed the dynamics of social and institutional aspects of pasture management during the post-Soviet period (Crewett, 2012; Farrington, 2005; Ludi, 2003; Wilson, 1997), as well as the ecological situation of the pastures (Shigaeva et al. 2007; Zhumanova et al. 2016). Most of these studies agreed that pasture use is unsustainable. Grazing pressures are particularly highly used near settlements, while remote summer pastures remain underutilized. The government has therefore introduced a number of regulations aimed at providing the required legal framework for sustainable pasture management, such as the Law on Pastures in 2006. However, despite these efforts, little progress has been made to stop the degradation of pastures to date. Among other reasons, this is due to significant knowledge gaps related to the prevailing farming systems and their socioeconomic performance (Liechti 2002).

Several studies note that smallholder rural farming systems in Kyrgyzstan have increased social and economic inequalities (de la Martinière 2012; Liechti 2002; Steimann 2011). However, most existing studies do not take into account the mutual connections between crop-livestock systems, herding practices, and profitability of livestock husbandry. Thus, this paper aims to (a) characterize the farming systems with regard to herd structure, herding practices, and fodder cropping; (b) determine the annual energy balance of fodder demand and supply for the herd and describe the feeding cycle of animals, showing feeding gaps and pressures on pastures; and (c) analyze the economic contribution of current livestock raising practices, as well as to what extent optimized feeding methods can increase animal profitability.

2. Methodology

The study was conducted in the At-Bashy District of Naryn oblast in villages located in mountainous areas at an elevation between 2200 and 2400 masl. The climate in these areas is semiarid with warm summers and long cold winters with an average annual precipitation of 300 mm (Bobojonov and Aw-Hassan 2014) Prevailing land use types are mixed cropping plots and pastures surrounding the settlements as well as remote summer pastures located at higher altitudes. There are 13,300 households distributed across 19 villages (NSC 2010). By means of single random sampling, 72 households from 16 villages were selected distributed across the region. Stratification of households was based on household statistics of livestock population and land-use size. Large 'resource rich' family farms owning more than 150 sheep or goats and households without any landholding were excluded, because such outliers could statistically distort the valuation outcome due to the presence of extreme values (Figure 1).

Figure 1. Study area and selected villages



In each sampled household we interviewed the household head and his wife in order to reflect the main decision makers' views. Data were collected in the study area between February and July 2014. Quantitative farm-level data on the organization and economic performance of smallholder farms were collected by structured questionnaire. The interviewees were asked to provide information on the agricultural production systems, the level and type of mechanization used, resource base (including human, livestock, land, and capital resources), debt status, family-household economy, off-farm activities, and the social status of the family.

The quantity of feed obtained annually from different cropping systems was calculated by multiplying the number of hectares included for each crop type by its yield. The amount of purchased feedstuff was added to the quantity obtained from farms. The feedstuff demands for the various types of animals were computed based on their content of gross energy (GE), which was converted into metabolizable energy (ME) in dry matter (DM) and used with varying efficiencies according to maintenance, growth, milk, gravidity and motion expressed in megajoules (MJ/kg DM) (for dairy cows MJ NEL; Net energy content for lactation). The average nutritional values (mid quality) of certain fodder types were taken from the Fodder of USSR book (Tommea 1964), as well as from the DLG feeding Value Tables (German Agricultural Society 1997). The feed requirements (energy and protein supply) for animals were taken from the publications of the Bavarian Regional Office for Agriculture considering feeding norms for ruminants and horses according to live weight and daily fodder intake (LfL 2010, LfL 2017).

The total livestock population of the interviewed households was converted to a livestock unit (LU). Conversion factors recommended by Government Decree No. 386 of 19 June 2009 (Government of the Kyrgyz Republic 2009) were used and adjusted, because the average weight of sheep and goats were below standards. Therefore, a conversion factor of 0.16 was used for sheep and goats; the conversion factor for horses remained as recommended at 0.8. The DM requirement of an animal was calculated based on the daily DM requirement of 300 kg dual purpose cattle (equivalent to one LU), with a maintenance requirement of 7.4 kg DM per day and animal on average. The respective requirements for sheep and goats were 1.3 kg DM per day and animal and for horses 7.6 kg DM per day and animal.

To determine the annual winter feed balance, total livestock feed produced from different feed sources, total livestock units, and their winter maintenance requirement were calculated. The winter maintenance requirement of the animals was calculated and subtracted from the total livestock feed produced or purchased per year. If the amount of feed stored per year was above the maintenance requirement of the animals, feed was in excess of the maintenance requirement, otherwise there was a deficiency of livestock feed in the farm.

We computed the gross margins (GM) to assess the farmers' operational performance in livestock production. The GM was calculated as gross income/revenue minus direct variable costs. The higher the GM, the more money will be left towards paying the fixed costs, and hence maximizing the GM is equivalent to maximizing the profit. This method helps to quantify the farmer's investment, operating costs and the output of their production (i.e., effectiveness of production techniques). Values were calculated based on actual farm gate prices. All feeding costs were included as variable costs, which also included payment for herders' services and fees for pasture use. Animal activities included their replacements, culling (price for old animals), animal mortality (loss of breeding, calves/lambs), and annual offspring. The costs for the feeding of dairy cows, mares, sheep, and goats included fodder for offspring.

Linear programming (linear optimization) with Excel Solver was applied to determine the best allocation of a farm's limited resources and production processes (e.g. different breeding practices, e.g. cows or horses) to achieve the maximum GM. Constraints in linear programming were limitations on the available fodder stocks during the winter period. The latter lasts 7.5 months in the model during at which time animals should be kept indoors to reduce pressure on pastures and maintain optimal grass coverage. We assumed in the model that farmers would not sell harvested fodder in autumn as typical because of cash shortage and avoid the purchase of fodder in spring when the prices are much higher. Furthermore, we assumed that animals could be sold at significantly higher prices from late autumn until late spring when prices for animals increase up to 35% because animals are in good condition due to improved feed ration. Assumption of increase in animal prices obtained from survey data (cf. section 3.5.). Finally, we assumed that farmers were not able to increase the number of a particular type of animal due to cultural and traditional reasons[1], so we set a minimum number of one LU for each animal species.

3. Results

3.1 Main Characteristics of Smallholder Farms

Descriptive statistics of the sample the features of agricultural production and other activities, as well as income sources of the smallholder farmers in the At-Bashy region are presented in Table 1. The average household (HH) size of the sample was 5.4 persons, of which 2.1 were children and 3.3 members were above 18 years of age. In the sample, the share of male-headed HH heads was 83%, and 13% female-headed. More than half (53%) of the HH heads had finished primary education, about 29% had a technical vocational education, and 17% of HH heads had obtained higher education.

Livestock was the most common economic activity, in particular sheep, cattle, and horse production. Results indicate that the number of animals kept by most farmers has gradually increased in recent years. On average,

1 Farmers usually sell sheep and goats if they need cash but can also sell cattle and horses if they need a larger amount of cash. Furthermore, they slaughter cattle or horses during social festivals, e.g. wedding or funeral. There is also a practice *''preparation of meat for winter''* [Kyrg. '*sogum*']; horse or cattle of a farmer in autumn slaughtered and distributed among relatives.

farmers owned 15.8 LU per household. An average herd structure in livestock production consisted of fat-tailed sheep (42.4%), goats (8.7%), local steppe cattle (21.5%), horses (20.4%) and other animals such as yaks (6.9%t) and poultry (0.05%). The animals were kept mainly for meat production: cows and horses were raised mostly for both milk and meat; sheep were more common (42.4%), followed by goats (8.7%), very likely because of fodder intake for both animals is similar. However, goat meat prices are considerably lower compared to mutton. Additionally, sheep and goats were usually kept in one enclosed space, despite goats tending to harm sheep according to farmers. The few goats were mainly kept for subsistence. Neither wool nor milk from sheep or goats was used. However, 60% of households comb out goat wool, which was then sold for 'cashmere' processing. Cattle were the second-largest livestock asset and kept mainly for personal consumption but also for sale. On average, households kept one or two dairy cows for milk. Cows were milked twice a day, and the lactation period lasts approximately seven months. Horses were kept for meat and for mare milk production. However, the share of farmers milking mares was small, as lactating mares were on remote pastures in summer. These mares were milked by herders. Farmers favored keeping horses not only because of traditional reasons, but also because they required little labor. Only 8% of farmers had yaks: usually these were given to relatives with larger yak herds to tend. Poultry did not play a significant role in the animal production systems, as families only kept a few chickens for egg consumption.

Land redistribution 20 years ago also reflected land quality, irrigation possibilities, as well as population density, which was lower in higher altitudes. On average, the farmers in At-Bashy hold 3.85 ha of arable land. The share of leased land was small. More than half of the farmland was non-irrigated reflecting the low productivity of agricultural land in higher altitudes. Only 0.10 ha of fallow land was recorded per farm-household. This land was mostly unused due to its low fertility or remote location and limited access to agricultural machinery. The quantity and the timing of irrigation was a major factor for crop productivity in each village. Farmers in a few villages complained about the need to renovate irrigation channels and the unreliable water supply from the mountains. However, it can vary from village to village.

Cultivation of livestock fodder comprises by far the largest share of the cultivated cropland; almost 91% of the actual cultivated (irrigated and non-irrigated) land was used to grow grass, fodder legumes (sainfoin) for hay making, and fodder cereals, mostly barley, very rarely oat. Potatoes, wheat, and vegetables were grown on the remaining 9% of land, mostly in kitchen gardens for domestic consumption. Most of the non-irrigated land was utilized for hay production. On the irrigated plots, legume crops were typically grown (mostly sainfoin and small amounts of alfalfa). Within cereal production, barley was the most important crop for one-third of the farms, and mainly used as livestock concentrated feed. In addition, the cultivation of barley was also important because it is used in crop rotation.

The variety of cultivated crops and the yields were low overall (see Table 2). Sainfoin was one of the main crops in almost half of the farms, and its cropping area has grown due to a proportionate reduction in areas of wheat, barley, and other crops in recent years. This was driven by the high profitability of sainfoin cultivation despite relatively low yields, low labor demand (including low soil tillage), and the availability of contractor services (e.g., combine harvesters for wheat/barley were less available than mowers). Additionally, the marketing of legume hay was easier compared to other crops including vegetables. Cereal yields were generally low and hence there was limited cultivation of wheat and oats. Wheat (grain) was not used for feeding, but for home consumption, while wheat straw was fed to animals.

Family income shows considerable variability among the sample households. The highest income is obtained from livestock. The second largest portion of household's income is obtained from off-farm revenues. Pensions and salaries from public institutions make up more than half of the total off-farm incomes. The third most important income source was crop production. Additional farm income contributed almost 31,000 KGS/year to total family income on average and included incomes obtained as professional herders, from contracting-out agricultural machinery, milk processing, or handicrafts.

Production for outside markets was generally low with subsistence production dominating. The share of market sales in total agricultural production was 35% livestock and 17% crop production. The market share of crop production was very low because most of the produce was used for livestock feeding.

Table 1. Main characteristics of the sampled household

	Unit	At-Bashy (n=72)	*(Coefficient of Variance)*
Village altitude	m a.s.l.	2,000-2,400	
Family size	persons	5.4	(0.32)
Children (0-17) Working age (men/women >18)	% %	2,1 3,3	(0.56) (0.34)
Family head			
- Male - Female	% %	87 13	
Education of household head	%		
- School education (9-11 grades) - Technicum (incl. agricultural) - Higher education (incl. agricultural)	% %	54 29 17	
Herd size	LU	15.8	(0.52)
Herd composition: - cattle - sheep - goat - horses - yak -poultry	 % % % % % %	 21.5 42.4 8.7 20.4 6.95 0.05	
Total farm land area	ha	3.85	(0,52)
-Irrigated -Non-irrigated (rainfed)	ha ha	1.78 1,97	(1,22) (1,78)
-Uncultivated area (fallow)	ha	0.10	(4,38)
Share of cultivated crops:			
- Meadow - Legume crop (alfalfa, sainfoin) - Cereals (barley, wheat) - Potatoes - Other crops (vegetables)	% % % % %	49 29 14 4 4	
Household income:	Kyrgyz som	403,574	(0.90)
- Annual income from livestock husbandry - Annual income from crop production - Additional farm income (herder, contractor) - Annual off-farm income	Kyrgyz som Kyrgyz som Kyrgyz som Kyrgyz som	135,341 91,544 30,850 126,032	(1.21) (0.91) (2.46) (0.68)
Share of market sales in total farm production:			
in livestock in crop	% %	35.0 17.1	

3.2 Feed availability

The energy demand of an animal was determined by the maintenance requirement, which is linked to live (body) weight, the energy needed for live weight gain and for output (e.g., milk production in dairy cows). Furthermore, the requirements for gravidity and motion were also considered. On average, the total monthly amount of DM needed per farm was 3,411 kg DM. However, practically the amount of feedstuff required for herd maintenance and production depends on the feed energy content, its digestibility, and content of digestible protein and other essential nutrients. The total forage resources available for livestock production came from pastures, arable land, meadows near croplands, and crop residues (grazing on cropland and meadows after harvest). Generally, natural pastures, meadows, and legume and meadow hay were the dominant feed resources in the district. The share of concentrated feed in the form of barley and oats was small; products such as grass silage were not used at all. According to most farmers, the quality of grass in pastures, as well as the produced feed was mediocre. However, the quality of legume (sainfoin) hay was indicated by farmers as good, and significantly better than the hay collected from the grass meadows.

The total quantity of feedstuff produced and purchased by farmers is shown in Table 2. Approximately 10% of farmers sold a part of their fodder, and about 50% purchased different types of fodder in addition to what they produced on their farms. These amounts were subtracted and added, respectively, to compute the total livestock feed balance. While the yield of legume crops, such as sainfoin and alfalfa, was 3.82 tons/ha of hay on average with one cut per year, the average yield of hay collected from meadows was 1.76 tons/ha with one cut per year, due to the lack of irrigation channels. Only 9% of the farmers sold fodder, and legume hay (including alfalfa hay) was the most marketable fodder crop. According to farmers, hay and other crops including cereals were sold to contractors immediately after harvesting due to financial needs. By contrast, 50% of farmers purchased additional fodder, both hay and cereals. Most of these farmers purchased additional fodder in winter or early spring, reflecting the fodder scarcity during this period. On average, the total amount of available winter livestock feed was 9,102 kg DM per farm. The predominant portion of the winter ration consists of roughage (almost 90%) in the form of hay and straw, whereby the proportion of legume hay was more than 50%. The share of concentrated feed in the form of barley and oats was slightly more than 10%.

Table 2. Total crop yield and feeding for herds in preparation for the winter

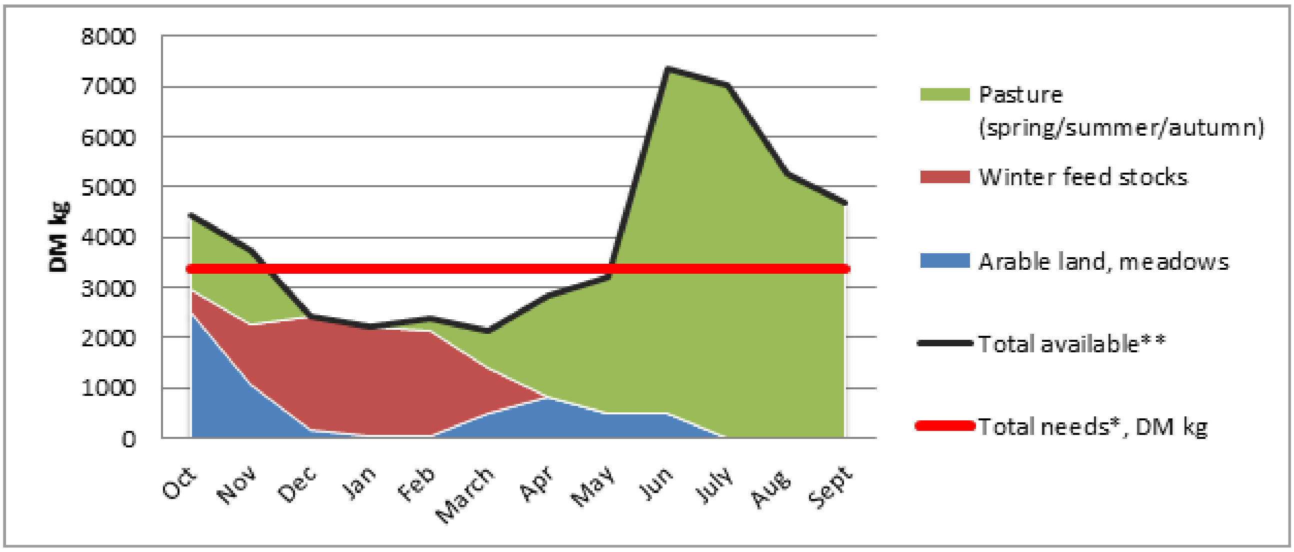
	Sainfoin hay (n=33)	**Meadow hay (n=49)**	**Barley (grain) (n=24)**	**Barley straw (n=24)**	**Wheat straw (n=2)**	**Oat (grain) (n=1)**	**Oat straw (n=2)**	**Alfalfa hay (n=3)**	**Total**
Cropping area, ha *(Coefficient of Variance)*	1.01 *(1.47)*	1.84 *(0.89)*	0.49 *(1.59)*	0.49 *(2.35)*	0.04 *(6.74)*	0.05 -	0.05 *(7.56)*	0.06 *(5.32)*	3.49 *(5.58)*
Yield, metric tons/ ha *(Coefficient of Variance)*	3.82 *(0.33)*	1.76 *(0.63)*	1.78 *(0.41)*	1.80 *(0.67)*	1.73 *(0.53)*	7.00 -	4.49 *(8.73)*	4.24 *(1.06)*	-
Total yield, tons/ year	3.85	3.24	0.88	0.89	0.07	0.34	0.22	0.27	-
Amount sold, tons/year *(Coefficient of Variance)*	0.29 *(4.15)*	0.11 *(4.59)*	0.26 *(3.74)*	0.15 *(4.87)*	0 -	0 -	0 -	0.04 *(3.48)*	0.85 *(2.49)*
Purchased amount, tons/year *(Coefficient of Variance)*	1.27 *(1.66)*	0.26 *(2.89)*	0.31 *(1.33)*	0 -	0 -	0 -	0 -	0 -	3.68 *(1.33)*
Available amount, tons/year *(Coefficient of Variance)*	4.83 *(1.22)*	3.39 *(1.02)*	0.93 *(1.58)*	0.74 *(2.19)*	0.07 *(2.94)*	0.34 -	0.22 -	0.23 *(5.74)*	10.75 *(0.65)*
Dry matter, kg	4,107	2,882	773	611	61	288	185	195	9,102

3.3 Feeding calendar of animals

The 'feeding calendar' (Figure 2) illustrates the annual feeding opportunities and gaps. The results were calculated on the basis of dry matter intake estimated by farmers. Total needs in fodder remained constant over the entire year because during warmer months animals walked longer distances and needed more energy for motion, while during cold months animals expended less energy in motion but needed more energy to maintain optimal body temperature. The major parameter determining sufficient supply of feed was the condition of the animals, e.g. the gain or loss of body weight.

Results indicate that pastures, arable lands, and meadows (near the settlements) were the main feed sources. Farmers generally attempted to keep their animals as long as possible on these lands to reduce the amount of feed required for animals housed indoor during winter.

Figure 2. Estimated monthly feed availability in DM according to main feed sources and total needs of flock



*Total needs for average heard **Total available – sum of main available feedstuff

Animals typically returned from the highland pastures to the villages in October after the crop harvest, when this was permitted by the *aiyl okmotu*[2]. Until the onset of winter, animals were left grazing on the pastures and meadows near the villages, where they remained fat due to the sufficient availability of feed throughout October. From November, after the arrival of snow cover, the winter feed stocks typically dominated as the major feed source. However, depending on weather conditions, these were supplemented by grazing pastures, meadows, and arable plots near the settlements. From December on, animals typically suffered significantly from the lack of fodder and started to lose body weight due to insufficient feeding. The lack of winter fodder prevailed until April, as farmers tried to save their feed as long as possible from late autumn until late spring. During the onset of spring, animals were left grazing shrubs and grass on arable land and meadows before the beginning of the new cropping season. However, according to most farmers, during this grazing period the fodder intake of animals was negligible, and they remained emaciated. From March to late April with the beginning of the vegetation growth period, farmers fed the remaining winter feed stocks to their animals and increasingly kept them in meadows and pastures near villages so that these became the main feed source again. However, animals typically did not gain weight during these weeks as there was not yet enough feed on these

2 Village government; the communal executive

pastures. From mid-May to June, animals, except dairy cows, that had been pastured near the villages all year round, migrated to the higher pastures (*jailoo*) again. During this time, animals had enough feed on the pastures and started to gain weight, and in July, all animals were fat and in good condition.

Summarizing the annual feeding cycle, fodder supply depended on the pasture (including arable land, meadows) near settlements as well as highland pastures. The meadows and pastures near the villages were used intensively during spring and autumn due to insufficient winter feed, which induced significant pasture degradation. We also found that the supply of fodder was enough to cover the animals' needs for approximately five months from June to November, while animals suffered from a lack of fodder during the remaining months.

3.4 Economic output of livestock activities

The gross margin (GM) and economic importance of animal production are presented in Table 3. The calculations are based on the arithmetic average of the sample population. The GM for raising animals was positive, with values ranging between 1,708 KGS for sheep and 34,010 KGS for horses. The GM also varied within specific animal types according to the age and sex of the animals. For example, fattened-up horses (not mares) more than two years old achieved the highest gross margin per animal due to high selling prices and relatively low feeding costs. Horses, including mares and foals, usually graze up to 12 months on pastures resulting in low feeding costs. Although the feeding costs of dairy cattle were twice as high compared to mares, gross margins per head were similar (13,444 KGS and 13,375 KGS, respectively) due to the sale of cow milk. Cattle (fattened-up) also had high gross margins due to a relative high market price and low feeding costs. Goat production had higher gross margins in comparison to sheep because goats deliver two kids; but this caused higher fodder demand (+16%). The structure of benefits and costs revealed that generally the major cost factors that influenced gross margins per head were winter fodder, the replacement of animals and herders' services. Other variable costs included medicine, veterinarian services and feeding of offspring, which were much less than fodder costs. In contrast to the previously mentioned animal activities, yak production did not require any supplementary feeding. Yaks were raised extensively on high altitude pastures (above 2,500 masl) throughout the year, and hardly any costs were required for medical treatment and fodder. The major cost factors were herders' services and animal losses, which could include up to 40% of animals per year in some cases. Even though yak production was highly profitable, most farmers were not able to increase their numbers because they did not have direct control over their yaks because animals were cared by yak herders (mostly relatives). They specialize in yak production and keep usually large herds on remote highland pastures all year round. Such yak herders can include into their large herds a small number of yaks from others (yaks could not be kept alone and at a low altitude). Yak herders had usually full control and could define whether the number of yaks of relatives could increase or not.

Table 3. Gross margins in livestock production, Kyrgyz som

	Dairy cow	Mare	Sheep	Goat	Yak	Cattle (fat. up)	Horse (fat. up)	Sheep (fat. up)
Output								
Milk yield	22,770	-	-	-	-	-	-	-
Wool/hair	-	-	-	242	-	-	-	-
Offspring[1]	9,444	18,309	3,664	4,477	11,800	-	-	-
Culling[2]	4,780	5890	764	429	63,00	-	-	-
Gross benefit, KGS*/head	**36,994**	**24,199**	**4,428**	**5,149**	**18,100**	**25,238**	**47,668**	**6,000**
Costs								
Replacement (heifer, ewe etc.)	3,614	4,326	778	614	-	-	-	-
Milk for offspring	8,280	-	-	-	-	-	-	-

	Dairy cow	Mare	Sheep	Goat	Yak	Cattle (fat. up)	Horse (fat. up)	Sheep (fat. up)
Fodder (hay/cereals)	9,808	4,908	1,541	1,805	-	11,508	12,067	2,649
Service of herder	1,176	1,187	364	546	6,500	1,176	1,187	364
Medicine, vet service	672	404	37	56	-	672	404	37
Variable costs	**23,550**	**10,824**	**2,720**	**3,021**	**6,500**	**13,356**	**13,658**	**3,050**
Gross margin, KGS/head of animal and year	**13,444**	**13,375**	**1,708**	**2,128**	**11,600**	**11,882**	**34,010**	**2,950**
(Coefficient of Variance)	*0.30*	*0.35*	*0.47*	*1.00*	*0.00*	*0.82*	*0.65*	*0.47*
Number of animal species (adults)	1.4	1.6	19.5	4.7	0.7	1.3	0.3	6.6
Total gross margin, KGS	**19,232**	**21,734**	**33,257**	**10,019**	**8,378**	**15,678**	**11,337**	**19,508**
LU* (Total: 15.8)	*2.1*	*1.96*	*5.75*	*1.39*	*1.1*	*1.32*	*1.26*	*0.93*

[1] loss of lambs deducted from offspring

[2] loss of cows deducted from culling

* livestock units incl. offspring

Total gross margins from livestock rising per farm household accumulated to 139,141 KGS, with sheep (including fattened-up), cattle, and horses contributing 38%, 25%, and 24%, respectively. While the gross margins of animal activities look appropriate at first glance, several observations point out significant improvement potential of the traditional livestock production system. For example, because many animals were undernourished for a significant part of the year, this resulted in poor health conditions, low productivity, and high mortality (up to 20%). Because of the poor physical state of their herds during these months, most farmers could not sell their animals during the winter months and had to sell from summer to late autumn when the market prices dropped by 25-35% because most farmers sold their animals during this time. These and other factors made animal production highly risky and reduced the GM. However, some farmers keep a small number of animals (e.g. lambs and cattle up to 17%) in good condition so that they can be sold on the market or slaughtered for own consumption if needed at any time. Farmers fed those with enough fodder so that the animals gained weight and could be sold for higher prices.

3.5 Economic output with optimized resource allocation and production processes

The optimization objective in our model is to maximize GMs and maintain animals in good condition year-round and avoid overgrazing of pastures, particularly in early spring. Therefore, we optimized or extended length of the indoor housing period up to 7.5 months in order to avoid pasture overuse and optimized the amount of winter feedstuff, which increased by 23% for this period due to its reallocation. Then optimized available winter feedstuff was converted into a standard unit (DM) for all animal species (see Methodology section). In the model, the daily DM maintenance requirement per animal was as follows: dairy cows 7.4 kg DM; sheep/goats 1.3 kg DM; and mares 7.6 kg DM; these values were then multiplied by 7.5 months (optimized indoor housing period). The main results are presented in Table 4. Gross margins ranged between 1,592 and 34,010 KGS; the GM of fattened-up horses remained highest, while the GM for sheep and mares reduced by 7% and 8%, respectively, despite higher market price because of the nearly double feed costs. In contrast, the GM for dairy cows and goats increased by 8% and 4%, respectively, due to the higher market price for animals, higher milk yields (only cows), and reduced mortality rate of animals. The structure of costs showed that overall; the major cost factors which influenced gross margins per head were winter fodder, replacement, and herders' services, similar to the '*as-is-situation*'. Total gross margins accumulated 118,979 KGS and compared to '*as-is-situation*'. This represented a decrease of 15.5% because available winter feed stocks were enough only for 9.4 LU. Interestingly, the total GM per head for dairy cows, mares, sheep and goats did not differ much, i.e. 30,654 KGS in '*as-is-situation*' *vs.* 30,620 KGS in the '*opt-situation*'.

Table 4. Gross margins in livestock production with optimized production processes

	Dairy cow	Mare	Sheep	Goat	Yak	Cattle (fat. up)	Horse (fat. up)	Sheep (fat. up)
Output								
Milk yield	27,600	-	-	-	-	-	-	-
Wool/hair	-	-	-	453	-	-	-	-
Offspring[1]	12,749	24,717	4,947	6,044	11,800	-	-	-
Culling[2]	6,453	7,952	1,031	580	6,300	-	-	-
Gross benefit, KGS/head	46,802	32,668	5,977	7,076	18,100	25,238	47,668	6,000
Costs						0	0	0
Replacement (heifer, ewe etc.)	4,518	5,407	1,011	798	-	-	-	-
Milk for offspring	8,280	-	-	-	-	-	-	-
Fodder (hay/cereals)	17,635	14,567	2,972	3,461	-	11,508	12,067	2,649
Service of herder	1176		364	546	6,500	1,176	1,187	364
Medicine, vet service	672	404	37	56	-	672	404	37
Variable costs	32,280	20,378	4,385	4,861	6,500	13,356	13,658	3,050
Gross margin, KGS/head of animal and year	14,522	12,291	1,592	2,215	11,600	11,882	34,010	2,950
Number of animal species	2.0	1.0	6.0	6.0	0.7	1.3	0.3	6.6
Total Gross margin, KGS	28,941	12,291	9,555	13,292	8,378	15,678	11,337	19,508
LU* **(Total: 9.4)**	2.0	0.80	1.00	1.00	1.1	1.32	1.26	0.93

1 loss of lambs deducted from offspring

2 loss of cows deducted from culling

* livestock units incl. offspring

In summary, our results show a decrease in total gross margin, driven mainly by a decrease in the number of animals because the available amount of fodder can only sustain 9.4 LU. As we set the DM requirement during the winter housing period and a minimum of one LU for each type of animal, the linear optimization provided two outcomes: (1) maximized the number of dairy cows and (2) minimized, as much as possible, the number of other animals (up to one LU) due to the highest GM of a dairy cow in comparison to GMs of other animals.

4. Conclusions

This study characterizes the prevailing smallholder farmers in At-Bashy District with regard to their production methods of animal husbandry and crop production. Based on a survey of 72 farms we determined the annual energy balance of fodder demand and supply for the herd and animal feeding cycle and analyzed income from the livestock husbandry. We then employed linear programming (optimization) to maximize the total gross margin where optimization problems were constrained due to winter fodder scarcity.

Our findings indicated that the resource base of prevalent farming systems in the region was poor and agricultural production was subsistence oriented. The area of farm holders cultivated land was less than four hectares. Neglected or non-available irrigation facilities reduce the productive land area even more (Steimann 2011). According to the marginal conditions in the highlands, only a limited number of crops can be cultivated, thus farming systems depend mainly on livestock production. Crop production mainly served as a source of feed for livestock. Though the fodder quality was indicated as mediocre, the amount collected and stored for winter was insufficient for the average herd size. Highland pastures, arable land, and meadows near the settlements were used as major feed sources for livestock throughout the year. Income analysis revealed that livestock husbandry was the main activity and contributed most to family income. However, despite the positive GM for raising animals, during a significant part of the year, animals could not be marketed, particularly when prices were high as animals were thin and undernourished due to lack of fodder. Optimization results revealed that despite decreasing the total GM, the margins per head differed very little.

Our results reveal several significant conclusions. First, the current production method (animal production) in the region is not only unsustainable in terms of pasture use, but also highly risky due to high mortality rates and low market prices for animals. To better benefit from market opportunities for livestock and agricultural products in a sustainable basis, farmers need to adjust and modify their farm management (production methods). This includes, for example, increasing fodder production through increasing legume fodder cultivation, higher quality seed sources, and more efficient cultivation techniques. Some new practices and technologies for sainfoin cultivation in the highlands of Kyrgyzstan have been introduced by WOCAT[3] (Asanaliev and Usubaliev 2011) within the project 'Prevention and Mitigation of Land Degradation' through demonstration studies, distributing agricultural equipment, and supporting individual smallholders via training and information. Results revealed that farmers in focal areas at elevations of 2200-2300 masl obtained higher yields of sainfoin due to introducing improved cultivation practices and high-quality seeds that required relatively small investments. This is critical as large investments can hardly be achieved by smallholder farmers. Higher sainfoin yields would increase winter feed stocks for animals. The animals kept stabled for longer periods, i.e. at least seven months, would also help prevent overgrazing of pastures in early spring. We defined a housing period of 7.5 months according to guidelines on pasture management (Isakov et al. 2015; Shikhotov et al. 1981); grazing in the pastures should start 25-35 days after complete snowmelt or 18-20 days after the beginning of grass growth. Kulikov et al. (2016) also indicate high soil loss ratio (C-factor of RUSLE) in mountain rangelands of West Tian Shan shortly after snowmelt. According to Kulikov and Schickhoff (2017) grass vegetation on most pastures of central Tien Shan (cf. Cluster 3) started developing biomass in April and optimal grazing period should start from mid-May and can last up to late October. Grazing in early spring can negatively impact grass cover and likely increase soil erosion. In addition, based on data on the onset of the grazing period for local herders, in most villages of the At-Bashy District the grazing period started from mid-May or the beginning of June. However, the grazing period in spring can start later because this depends on weather conditions. For example, in 2015 the winter was longer and the grazing period started significantly later than usual, thus a higher volume of fodder needed to be stored.

Furthermore, results of optimization showed farmers should decrease the number of animals by up to 6 LU. However, despite this, a gradual increase in the number of animals has been observed in recent years, which can be attributed to the status of livestock as saving mechanisms, representing not only subsistence but also financial security (de la Martinière 2012; Steimann 2011). As such, it is difficult to reduce the number of livestock units. Therefore, improvements in fodder production and enhancement of fodder purchases are important steps towards improving animal productivity. Optimization results showed that dairy cows and goats had higher GMs, for which production could be increased, and farmers could specialize in their animal production. In addition, goats were not milked; doing so could significantly increase GM.

Overall, these results can be interpreted as an indication that adjustments in smallholders' land use and production methods are required to increase farm income and insure sustainable pasture use. An expansion of fodder cultivation is suggested to increase the volume of fodder stock for the winter period and ensure profitability of livestock production. However, the provision of productive inputs and additional consultancy services would

3 WOCAT is the World Overview of Conservation Approaches and Technologies

be needed to ensure success in this area.

Finally, we are aware that our approach has the following shortcomings: (i) the energy content of fodder as well as fodder intake of animals were estimated on the basis of incomplete information, which we obtained from different available sources; (ii) crop production was not considered in the optimization model because livestock production was given a higher priority and crop production focused on growing fodder for the winter. Our study should spur further research to help address some of these aspects research on the energy content of different fodders and fodder intake requirements.

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