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Article

Dynamics of grazing in the association of crops and sheep of temperate climate agroecosystems in Mexico

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Abstract:

The study analyzed the dynamics of grazing in sheep production associated with agricultural crops based on the social, productive, market, income, and environmental dimensions in the temperate region of Puebla and Tlaxcala, Mexico. The use of grazing, topography, climate, crops and type of vegetation in the production systems and data on the family, means of production, market and income were recorded with interviews applied to 256 sheep producers. Data were analyzed with descriptive statistics and response surface linear regression models and multilevel models, with the SAS statistical package. Five crop and sheep associations were defined as results. The response surface linear regression models, fitted for grazing percentage, had differences in the slopes estimated ($P<0.05$) for producer experience, schooling, days of work spent on sheep, value of facilities and flock size. The multilevel analysis showed that 19 % of the variance in grazing time (hours) was explained by the variables of crop and sheep associations (level 2) and the rest by production units (level 1). Multilevel models associated grazing time with income ($P<0.01$), percentage of lamb sales ($P<0.01$), schooling ($P<0.05$), days of work spent on sheep ($P<0.05$), flock size $P<0.05$) and grazing percentage ($P<0.001$). The study allowed the classification of agroecosystems and the identification of the most appropriate profile of producer for sheep production in the socioecological and economic context in the temperate region of Puebla and Tlaxcala, Mexico.

Keywords: Regression analysis, Sheep income, Multilevel models, Grazing time, Grazing lands.

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Introduction

Sheep farming in temperate climate agroecosystems is a socioeconomic tradition in central Mexico[1,2], due to environmental and orographic conditions, availability of grasslands and market[3,4]. Lambs and adult sheep for *barbacoa* are the main products for sale[1,5,6]. Production units are classified, by their level of technology use, as traditional or extensive grazing, semi-intensive or mixed and intensive[4,6,7]. In the first two, sheep feed freely from grazing[3-6]. The production of sheep-cereals[8,9], sheep with use of multiple resources[8], extensive mountain grazing[9], use of rangelands plus stover and grazing of rangelands plus meadows[10], and use of grasslands and conservation areas[11] have been characterized by the resources used for grazing. This indicates that producers adapt feeding practices to locally available forages[12,13,14], using grasses, native weeds, and agricultural crop residues[13,15,16].

It is common for producers to be interested in adopting new technologies and require technical advice for grazing and feeding management[17], especially to adjust the stocking rate to the availability of forages and to the biology of sheep in different environments[18].

This study addressed grazing as a complex socioecological process with changes in time and space[19] and explained it with the approach of the dynamic behavior of the management of ecological systems[20,21,22], to place it in decisions for social, economic and environmental sustainability[22]. From this perspective, it is pointed out that the availability of forage is not in balance with production, which can have adverse consequences for producers and their animals[23], in this case sheep. Especially because subsistence producers carry out their activity with a reduced asset base, with limited access to land and subject to stressors[24]. Where the most common adaptation practices of livestock production are animal mobility, forage storage and exchange with the market[19]. Also, when there are risks of forage scarcity, it is common for livestock to be housed[25] and forages from agricultural crops to be a resource for food[26]. Due to the scarcity of forages, it is urgent to identify vulnerability and adaptation strategies to mitigate these risks[7,27]; where the relationship between humans and their environment is complex and difficult to predict. For this purpose, the study aimed to analyze the dynamics of grazing in sheep production associated with agricultural crops based on the social, productive, market and income and environmental dimensions in the temperate region of Puebla and Tlaxcala, Mexico. The states of Puebla and Tlaxcala represent a region of interest due to the presence of protected natural areas and the climatic, socioeconomic, and cultural diversity in sheep production in temperate climate agroecosystems.

Materials and methods

Study area

The study was conducted in the ecological province of Lagos y Volcanes de Anáhuac, east of the Trans-Mexican Volcanic Belt[28], in 12 municipalities in the state of Puebla: Aquixtla, Atzitzintla, Atempan, Chignahuapan, Chignautla, Cuautempan, Guadalupe Victoria, Oriental, Libres, Ixtacamaxtitlan, Tetela de Ocampo and Tlatlauquitepec, and two municipalities of Tlaxcala: Calpulalpan and Nanacamilpa. The study area is located at coordinates 18°54' and 19°56' NL and 97°17' and 98°37' WL and altitude of 1,621 to 3,164 m asl. The climate is temperate humid in the high mountains and temperate subhumid in the plains, with rainfall of 600 to 1,600 mm and temperature of 12 to 20 °C. The dominant vegetation is *Pinus* forest, *Quercus* forest, grassland and scrubland[29].

The economic activities in the study area are rainfed agriculture, livestock farming and fruit-vegetable crops[8,10,30]. Livestock farming is small scale, with multiple use of cattle, sheep, goats and horses. The growth of native forages is concentrated for six months (June to November) and common land and agricultural plots in rest are used. In the dry season of the year, sheep graze the stover of agricultural crops and are supplemented with byproducts of agricultural crops[30].

Information record

The type of zone of crop and sheep association was identified with field trips and the typologies of the production systems previously defined in the study region[9,11,30]. For each zone, the following were recorded: average annual temperature (°C) and rainfall (mm) of the last 26 yr[31], altitude in meters above sea level[29], physiographic information from Google Earth® 2021 databases, flocks with grazing use (%), producers with their own land (%), who buy forage (%) and with access to irrigation water (%).

For the production unit, the demographic variables, means of production, income and market[19,21,25] were recorded through a semi-structured survey with a sample of 256 producers selected by simple random sampling[32], with a maximum variance of 0.25 and an error level of 6 %. In the demographic variables, the age of the head of the family (years), experience in sheep (years), schooling (years), family members (number) and days of work spent on sheep (number) were recorded. In the means of production, the following were included: the value of the facilities at prices of 2019 ($) and at scale (1= less than $1,000, 2=$1,000-$4,999, 3=$5,000-$10,000, 4= more than $10,000), total land (ha), flock size (number of sheep), cost of technical services ($) and participation in an organization (1 if they participate, 0 if they do not participate). In grazing, the use of rangelands (1 yes, 0 no), forests (1 yes, 0 no), roadsides (1 yes, 0 no), induced meadows (1 yes, 0 no), stover fields (1 yes, 0 no) and use of resting land (1 yes, 0 no) were recorded. For pen feeding, the use of corn grain (kg), stover (kg) and commercial feed (kg) was recorded. In the part of markets and income, the total annual income ($) and at scale (1= less than $10,000, 2= $10-50 thousand, 3=more than $50,000), sale of sheep (number and % of flock) and type of market (1 they do not sell, 2 they deliver to intermediaries and 3 sale to the consumer) were included.

Data analysis

With the SAS statistical package, the following data analyses were performed: a) descriptive statistics for the study variables, b) least squares regression analysis for response surface of grazing time (hours) and study variables and c) multilevel analysis to explain the nature and extent of the relationship between grazing time and the two levels of study: production units (level 1) and zones of crop and sheep association or production systems (level 2).

Least squares response surface regression analysis for data with collinearity problems was used to explore grazing time dispersion with the variables of production unit and grazing percentage in each zone, with the ORTHOREG procedure, EFFECTPLOT statement, and Jitter option[33].

To explain the grazing time, six multilevel models were used, with two levels of analysis: variables of the production unit (level 1) and variables of the zones of crop and sheep association or production systems (level 2), under the following functional form[34]:

$$y_{ij} = \beta_{0j} + \beta_1 x_{ij} + u_j + e_{ij}$$

Where:

$\boldsymbol{y_{ij}}$ is the grazing time (hours) measured in the *i^th^* production units (level 1) of the *j^th^* production systems (level 2);

$\boldsymbol{\beta_{0j}}$ intercept/overall mean of level 1, which varies between the units or groups of level 2;

$\boldsymbol{\beta_1}$ is the slope of the random coefficient of the production units or the context of level 2;

$\boldsymbol{x_{ij}}$ are the explanatory variables of level 1 (demographic, means of production, market and income) and level 2 (context);

$\boldsymbol{u_j}$ is the error term of the crop and sheep systems (level 2);

$\boldsymbol{e_{ij \sim n(0,\, \sigma^2)}}$ is the random error term of the production unit (level 1).

For the construction of the multilevel models, the procedure of Wang *et al*[35] and Bell *et al*[36] was followed. Model 1, used as a reference, was of random intercept without explanatory variables, which resulted in obtaining the variance of grazing time (hours) separated into two parts, which correspond to the production unit and to the production system. Models 2, 3 and 4 incorporated the demographic variables, means of production and income and market of the production unit, respectively. In model 5 (general), it included all the variables of models 2, 3 and 4. Model 6 included the variables of model 5 plus the variables of the production system with a significant effect on grazing time (percentage of grazing use and percentage of producers who buy forage). For the multilevel analysis, the following were used: the MIXED procedure of SAS, the estimation of parameters with the restricted maximum likelihood (REML) method and the fit with the Akaike criterion (AIC) and the Schwarz Bayesian information criterion (BIC)[35]. Due to the difference in the units of measurement, the variables were standardized with the STANDARD procedure[37], except for the days of work spent on sheep and flock size, which, since as they are a counting measure, the transformation $\sqrt{x+1}$ was used.

Results

Grazing and explanatory variables between and within crop and sheep associations

The five crop and sheep associations in the study region are (Table 1): a) high mountain (corn, grassland and scrubland), b) corn-forest (corn and *Pinus* forest), c) sheep-cereals (sheep and small grain cereals), d) sierras (corn, *Quercus* and *Pinus* forest) and e) valley-diversified crops (corn, vegetables and cutting forage). The sheep-cereals association, located in the state of Tlaxcala, was characterized by being the second with the lowest average annual rainfall, grazing use, greatest use of land owned by the producer and highest percentage of producers who buy supplementary forage. The corn-forest association, located in the municipalities of Chignautla, Guadalupe Victoria and Tlatlauquitepec, ranks second in grazing use and has the highest average annual rainfall in the study area. The high mountain, located in the municipalities of Atzitzintla and Guadalupe Victoria, has the highest average altitude, ranks second in grazing use and has the lowest proportion in forage purchase. For that of valley-diversified crops, located in the municipalities of Libres, Oriental and Cuyoaco, a change towards sheep housing is occurring, due to lower average annual rainfall, less access to land owned by the producer, with greater access to forage from agricultural crops and use of irrigation meadows (Table 1). The northern sierra, located in the municipalities of Tetela de Ocampo, Atempan and Aquixtla, has the lowest average altitude, the production units have greater access to irrigation water and because of the use of hair sheep crosses for lamb fattening, less grazing and more housing are used.

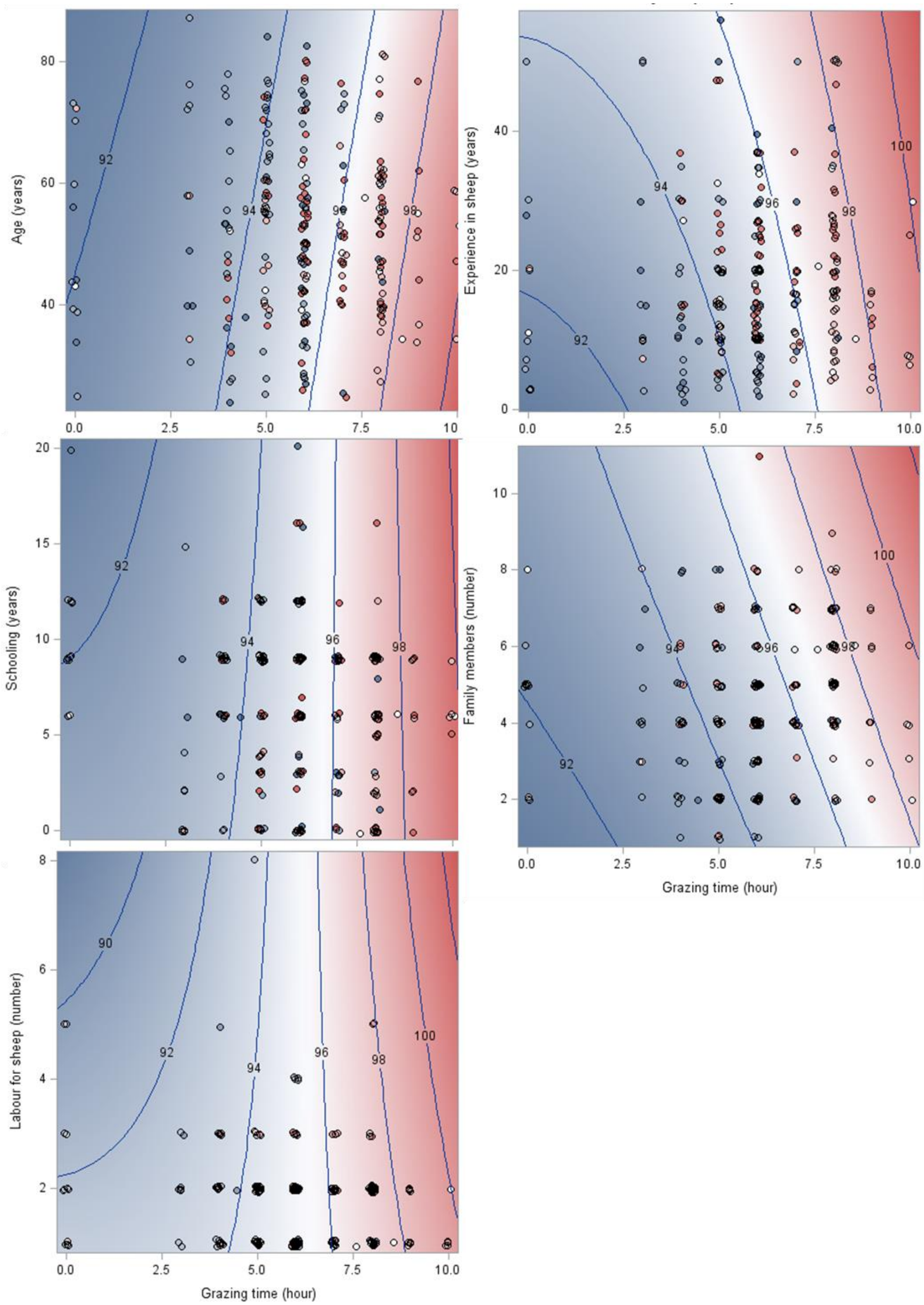
Table 1: Characteristics of the zones of crop and sheep associations in temperate climate agroecosystems

Variable	**High mountain (n=22)**	**Corn-forest (n=44)**	**Sheep-cereals (n=73)**	**Sierra (n=41)**	**V-DC (n=76)**
Grazing, %	95.5	97.7	100	90.2	92.1
Producer’s own land, %	95	93	97	100	84
Who buy forage, %	4.5	13.6	13.7	7.3	11.8
AAT, °C	12	12.2	13.4	14.3	14
AAR, mm	756.3	860.0	773.5	817.9	602.6
Irrigation water, %	9.1	11.4	17.8	31.7	15.8
AA, masl	2931	2456	2509	2088	2303

SE=standard error; V-DC= valleys-diversified crops; AAT= average annual temperature; AAR= average annual rainfall; AA= average altitude.

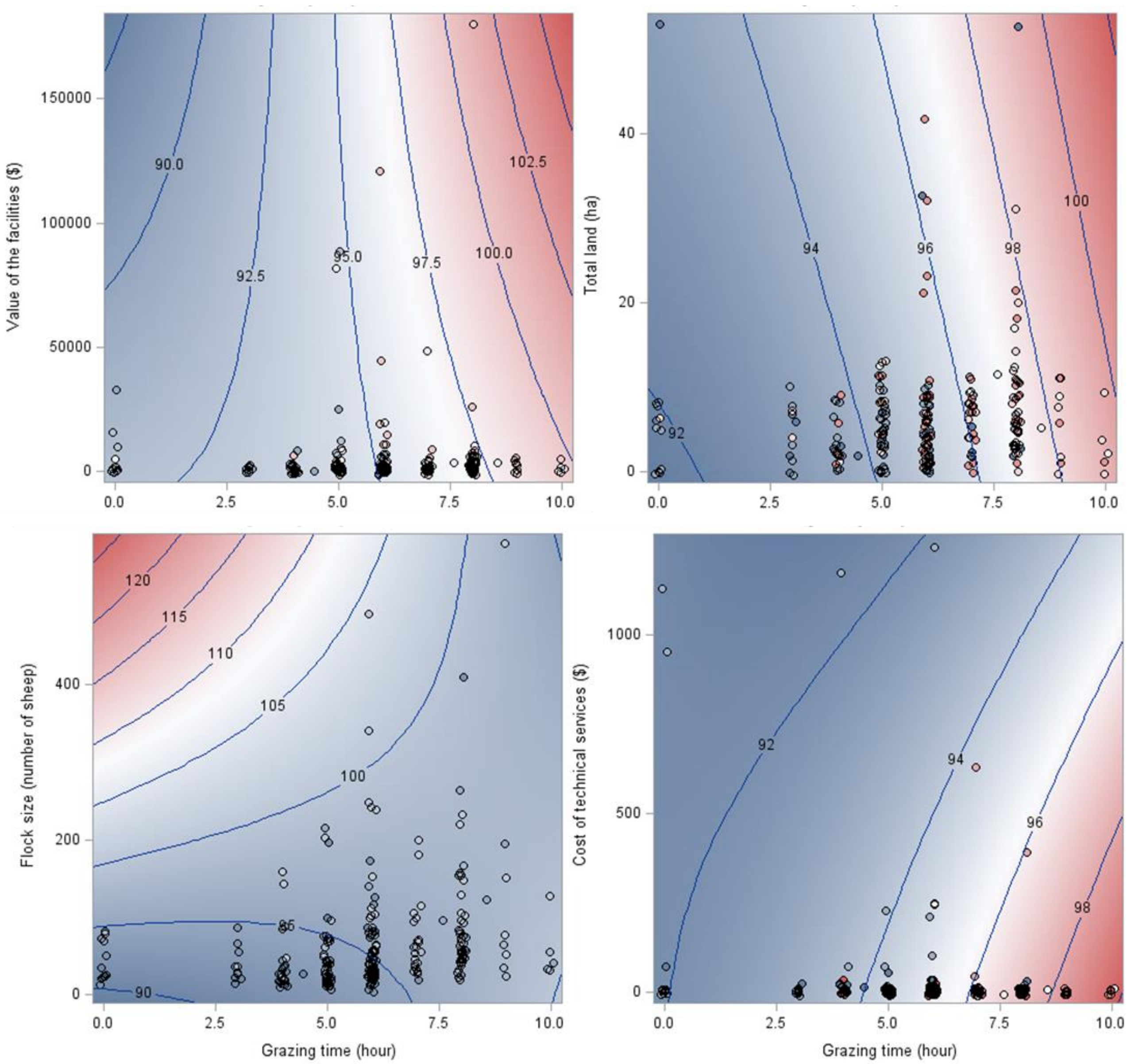
The results of the response surface regression models are presented in Figure 1. In the age of the head and members of the family, it is observed that the surfaces of the slopes estimated for grazing percentage are parallel, which indicates the absence of a significant relationship with grazing time. Meanwhile, in the experience, schooling and days of work spent on sheep, the surfaces of the estimated curves do not have a single optimum, which indicates that they have slopes with a significant difference in the fit for grazing percentage (P<0.05).

Figure 1: Contour fit for grazing percentage with changes in observations of demographic variables



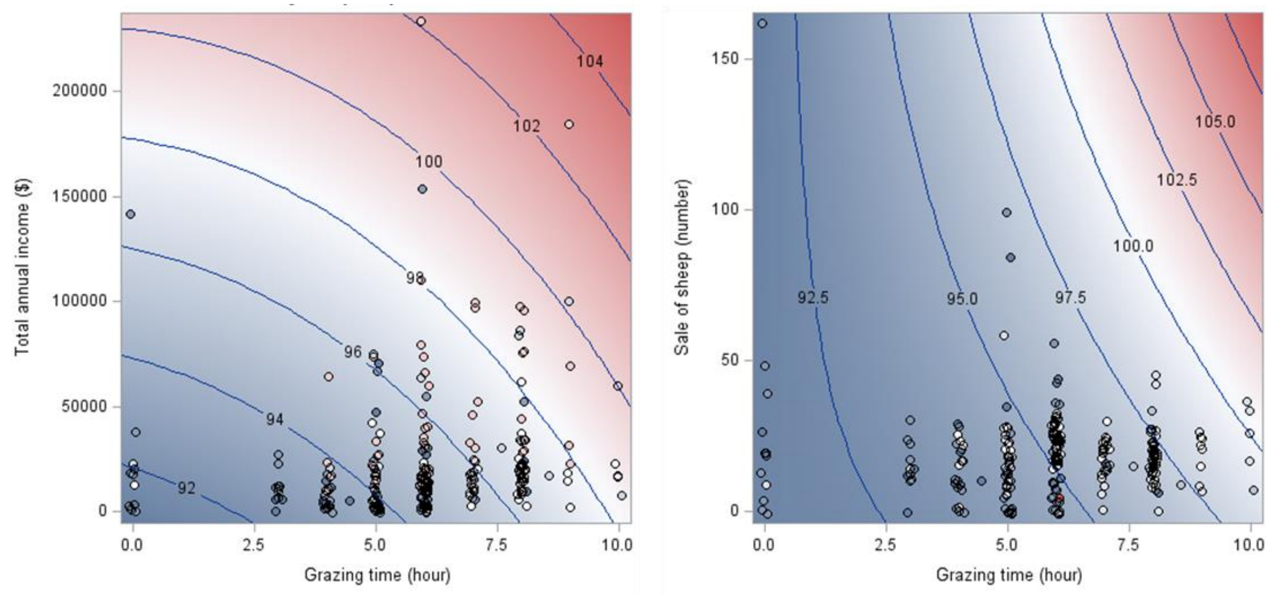
For the variables of means of production, grazing time showed a significant difference for the value of facilities, flock size and cost for technical assistance (Figure 2). The opposite was observed for land area, where the regression curves estimated for grazing percentage were parallel in grazing time.

Figure 2: Contour fit for percentage of sheep grazing with changes in observations of the variables of means of production



In the income from sales ($) and the sale of sheep (number), the slopes estimated for grazing percentage had a significant difference with the grazing time (Figure 3).

Figure 3: Contour fit for percentage of sheep grazing with changes in observations of income and sales



Proportion of variance explained with multilevel models between and within the crop and sheep association

In the results of the multilevel analysis, the empty model (model 1) was used to estimate the variance between production systems and within production units using the intraclass correlation coefficient (ICC), based on the ICC ($\frac{\hat{\sigma}^2_{SP}}{\hat{\sigma}^2_{SP}+\hat{\sigma}^2_e}$), which had a value of 0.19; result of dividing the proportion of the variance of the production systems (0.7678) by the total variance (0.7678+3.2741). This result determines that 19 % of the variance of grazing hours is explained by production systems (*P*= 0.07), therefore, multilevel analysis can be used to explain the difference between them in the study region with 7 % reliability. Meanwhile, 81 % of this variance is determined by the internal factors of the production unit (Table 2).

Table 2: Estimates of the covariance parameter for crop and sheep associations

Parameters	Estimator	Standard error	Z-value	Pr > Z
Crop and sheep associations	0.7678	0.5286	1.45	0.0732
Residual	3.2741	0.2922	11.20	<0.0001

Of the variables of the context of production systems (Table 3), only the percentage of forage purchase and the percentage of grazing use had a significant effect (*P*<0.01) on grazing hours.

Table 3: Fixed effects of the variables that explain the variance between crop and sheep production systems

Effect	Estimator	Standard error	Degrees of freedom	T-value	Pr > |t|
Intercept	-12.25	2.99	256	-4.09	<0.0001
Forage purchase, %	-0.053	0.019	256	-2.71	0.0072
Grazing, %	0.19	0.03	256	6.38	<0.0001

Table 4 shows the multilevel models fitted by the demographic, productive, market and income variables and the variables of the context of production systems. The model with the variables of the production units and the production system (model 6) had the best fit (BIC=1037.3), in which the days of work spent on sheep (*P*<0.05) and the percentage of grazing (*P*<0.001) had a significant effect.

Model 4 (income and market) was the second in importance (BIC=1041), in which the level of income (*P*<0.01) and percentage of lamb sales (*P*<0.01) had an influence on the explanation of the variance of grazing time.

The rest of the models had the lowest fits; however, it is important to note that in the model of demographic variables (Model 2), schooling and days of work spent on sheep (*P*<0.05) were significant. Meanwhile, in the case of the variables of means of production (Model 3), flock size had a significant effect on grazing hours (*P*<0.05).

Table 4: Marginal estimation of fixed-effect models of sheep grazing

Effect	Model 1 Null	Model 2 Demographic variables	Model 3 Means of production	Model 4 Markets and income	Model 5 General	Model 6 General and contextual
Intercept	6.0*** (0.41)[1]	7.9*** (0.9)	6.1*** (0.44)	4.69*** (0.62)	6.8*** (1.1)	-7.8* (3.5)
Age of the head of the family		-0.02 (0.14)			0.04 (0.14)	0.07 (0.14)
Experience in sheep		0.04 (0.13)			0.01 (0.13)	-0.01 (0.13)
Schooling		-0.24* (0.12)			-0.2 (0.13)	-0.2 (0.13)

Family members		0.21			0.19	0.2
		(0.13)			(0.13)	(0.12)
Days of work spent on sheep		-1.16*			-1.2*	-1.2*
		(0.51)			(0.51)	(0.5)
Value of facilities			-0.04		0.04	0.08
			(0.13)		(0.14)	(0.14)
Total land			0.003		-0.08	-0.09
			(0.12)		(0.12)	(0.12)
Flock size			0.30*		0.15	0.15
			(0.13)		(0.17)	(0.16)
Technical services			-0.76		-0.58	-0.62
			(0.77)		(0.81)	(0.8)
Producers organized			-0.07		-0.14	-0.41
			(0.43)		(0.43)	(0.4)
Income level				0.57**	0.39	0.29
				(0.24)	(0.32)	(0.31)
Sale of lambs				-0.02**	-0.01	-0.01
				(0.01)	(0.01)	(0.01)
Type of market				0.37	0.36	0.32
				(0.27)	(0.29)	(0.26)
Percentage of grazing						0.16***
						(0.04)
Percentage of forage purchase						-0.03
						(0.02)
Random effects						
Level 1: Production unit	3.27***	3.17***	3.21***	3.16***	3.1***	3.03***
	(0.29)	(0.28)	(0.29)	(0.28)	(0.27)	(0.27)
Level 2: Production system	0.76	0.54	0.63	0.45	0.33	0
	(0.52)	(0.39)	(0.45)	(0.34)	(0.27)	
Model fit						
AIC	1048.6	1048.7	1052.6	1043.4	1053.8	1044.0
BIC	1047.4	1045.6	1049.5	1041	1047.6	1037.3

[1] Standard error in parentheses; * significance level 0.05,** significance level 0.01, *** significance level 0.001; AIC= Akaike criterion; BIC= Schwarz Bayesian criterion.

Discussion

Grazing is the basis of sheep feeding in temperate climate agroecosystems in the study area and is widely valued in other studies for its importance in sustainable agriculture(38), local economy(39) and ecosystem services to maintain or improve the condition of the land(40). In sheep farming associated with agricultural crops, the use of grazing is similar to other studies in the temperate region of the central area of the country[8,11,30], but different from the conditions of sheep production in the state of Oaxaca[41]. As has been pointed out in other studies, the integration of sheep farming into agriculture ensures the survival of both production processes[42] and with minimal capital investment in supplementary feed, health, and infrastructure[3,4]. Also, in this study it was found that the use of grazing is being reduced in the systems of sierra and valley-diversified crops; which coincides with the research works where the land is used only for agriculture[5], as is the case of valley-diversified crops, and the housing of sheep[6,11] and the change towards other land uses[43], as found in the sierra system.

The complexity of grazing ecosystems involves variables of the context and the unit of production. In the prediction of variance between crop and sheep associations, with multilevel models, the percentage of grazing and percentage of producers who buy forage had a difference in grazing time (P<0.05), this coincides with Hernández-Valenzuela[44], where grazing was the factor that explained the variance in sheep farming in the Valley of Toluca, State of Mexico. The sheep-cereals, corn-forest and high mountain associations stand out for their dependence on grazing, use of land owned by the producer and availability of grazing areas, and they can be considered as the most appropriate systems for sheep production. In these systems, it is agreed that, with grazing land, sheep graze freely and the cost of supplementation is lower[5,11].

The strategy for the use of grazing areas in this study was the daily movement of flocks, as indicated for the state of Tlaxcala[8]; this was also observed in sedentary livestock systems in Africa, where livestock movement is part of adaptation strategies to climate variability[25]. Meanwhile, 14 % of producers in the corn-forest and sheep-cereal systems buy supplementary feed for sheep, which is a widespread practice in the State of Mexico[11] and is included within what is called focus feeding[18], especially for the fattening of lambs[4,7]. They also represent strategies to adapt to grassland degradation, fluctuations in livestock prices, and changes in institutional policies and resources[25,40].

The variables of the production system that did not have a significant effect with grazing time are average annual temperature, rainfall, and altitude; this may be an indicator of the adaptation of sheep farming to the environmental conditions of the region, because it has been found that they are variables that influence grazing and related resources[45,46].

In production units, demographic variables, means of production, markets and income had an effect on grazing time, as has been pointed out in other studies[19,25]. In demographic variables, grazing time decreases with a higher level of schooling of the head, members of the family and days of work spent on sheep; this is related to changes in production systems, especially with pen feeding, which may imply a reconversion of the system to semi-housing and with this, the modification in the intensity of use of grasslands(47). In this study, the use of labor had a negative effect on grazing hours, which is explained by the fact that sheep production is a secondary activity and when the number of days of work spent on sheep increases, grazing time decreases, because the family engages in agriculture and has forage from agricultural crops for pen feeding and therefore, grazing time decreases. This contrasts with what was reported in China(48), where at a greater use of labor, there were more sheep and more grazing use in the production unit. On the other hand, in the sheep-cereals association, the greater experience in sheep farming was related to a higher percentage of grazing as an adaptation strategy in the production process.

In the means of production, there was a reduction in grazing time when producers have greater investment in infrastructure, access to land and organization. Flock size had a significant effect on grazing hours (P<0.05), a lower number of sheep in flocks was related to the use of pen feeding; with the change in flock size, producers have the advantage of developing resilience mechanisms for the management of stocking rate and vegetation use(49). In this sense, in other studies, it was recorded that access to land with potential for grazing allows promoting sheep farming(50), as was the case of the high mountain, where scrublands and grasslands are used, which are generally common grazing areas(12) and are the most preferred by shepherds(51).

Other important variables to consider in sheep grazing are producer organization and technical assistance. In this study, the organization of producers was greater when the sheep system-product was part of the policies of state governments, as is the case of the state of Tlaxcala. In multilevel models, producer organization had no significant effect in explaining grazing time in the production unit, however, as has been pointed out, cooperativism, mutual trust relationships and political strategies increase the level of efficiency of a livestock cluster(52), promote changes in land use(27) or collective management of resources(53) and decisions on the type of grazing(27).

The lower income and sale of lambs in producers is changing the use of grazing for pen feeding; which is explained by the smaller flock size, which does not justify the use of grazing; according to Herrera-Haro *et al*(11), sheep production is important when it contributes up to 50 % of the income of the production unit. In the case of markets and exchanges, it is agreed that these constitute a mechanism for adaptation to environmental risks and for regulating local livestock densities, which could reduce the ecological vulnerability of agropastoralism(54,55). Regarding market access, the sheep-cereals system of the study is the most favored, due to its proximity to the Valley of Mexico, which is the main center of *barbacoa* consumption in the country(56), and because it is oriented towards the production of lambs for sale, as has been indicated for other regions(55); which was classified as a typical form of production in temperate areas with low rainfall, similar to sheep production systems in Spain(57). On the other hand, the non-commercial functions of sheep are still difficult to assess, but they can contribute to a better understanding of mixed systems and producer management decisions[12]; which are important when adapting the use of grazing to community regulations and the prohibition of land use in protected natural areas.

Finally, grazing as a means of production for sheep farming has been subject to several regulatory or elimination pressures in the study area. Among these actions are the public policies and norms of the communities that seek to regulate or end grazing[39,40,58,59]. The first, with the decrees creating protected natural areas in temperate zones and with the sowing life program in recent years; with the advantage that sheep have always been part of the landscape and the inhabitants accept them as the least destructive species in the community regulations for grazing[27]. It has also been mentioned that community regulations for livestock grazing are an opportunity for the governance of forests and lands of common use[60]. While in order to avoid the disappearance of activities related to the use of grazing, the following have been suggested: the control of stocking rate and the delimitation of community areas of special interest for conservation as a way to maintain landscape use, cultural values and biodiversity in an ecosystem[39]; reassessing *in situ* fertilization of grazing land[59,61] and creating or promoting quality marks or protected geographical indications that offer consumers guarantees on the origin of sheep, the production system or traditional dishes[2].

Conclusions and implications

At the level of production system, there are two conditions that determine the use of grazing: a) the high mountain and corn-forest agroecosystems have the optimal environmental conditions and availability of land for the use of grazing in sheep production, and b) the sheep-cereals association is the typical agroecosystem of sheep production in regions with low rainfall, greater use of grazing and purchase of supplementary forage, land owned by the producer, organized producers and better market conditions. At the level of the production unit, it is established that, at a higher educational level, with small flocks and use of hair sheep crosses, there is a change to pen feeding; this strategy is appropriate in case of land scarcity, regulation of forest use by communities or due to the presence of protected natural areas; while older producers, with access to land and more experience presented roots for sheep farming dependent on the land. The explanation of the variance of grazing time indicates that demographic, means of production, market and income and context variables participate in sheep farming dependent on the land, which, when analyzed with mixed linear models, allow predicting the trend of grazing use based on the information of the production units and the production system.

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