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Technical note

Analyzing honey producton in Aguascalientes, Mexico, using the Cobb-Douglas Function

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Abstract:

In beekeeping, honey yield and profits are affected by multiple variables, the influence of which can vary by region. A Cobb-Douglas function was applied to data from a direct survey of beekeepers in the state of Aguascalientes, Mexico, to estimate and analyze the economic optimum and input elasticity in honey production. The optimal economic combination for production of one kilogram of honey was 1.045 kg supplementary feed and 0.084 days labor, which generate a maximum profit of $45.38 pesos/kg honey. The production function also identified increasing economies of scale, while substitution elasticity between the inputs supplementary feed and labor was elastic. Application of a Cobb-Douglas type function effectively estimated beekeeping profitability and productivity in the study area.

Key words: Production function, Beekeeping, Economic optimum.

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Beekeeping involves management of honey bees (*Apis mellifera*) with the goal of producing honey, and is important in the natural, human, material, social and above all economic spheres(1). It is done throughout Mexico, though primarily in the southeast, and there are about 43,000 beekeepers nationwide. Honey production is also a major agricultural product, with 29,449 tons (worth US 90.9 million dollars) exported from 2016-2020(2). In 2021, Mexico was the ninth largest honey producer worldwide, and thirteenth largest exporter (US 69.7 million dollars)(2). In response to honey's importance, the Ministry of Agriculture and Rural Development (Secretaria de Agricultura y Desarrollo Rural - SADER) in Mexico developed the National Strategy for the Conservation and Sustainable Use of Pollinators (Estrategia Nacional para la Conservación y Uso Sustentable de Polinizadores - ENCUSP) to focus policy and the productive and environmental sectors on sustainable development and food security at a national level(2).

However, beekeepers are abandoning the activity for various reasons(3,4), including climate change, low wholesale honey prices, lack of training, low productivity, higher market standards, and high input costs(5-9). Low production efficiency per beekeeping unit and total production costs are particularly problematic(4,10). In Mexico, abandonment of honey production and high production costs have been reported in small and medium-sized producers in the states of Guerrero, Jalisco, Yucatan and Aguascalientes(3,4,5,11).

The Cobb-Douglas function is widely applied to analyze the influence of production factors or inputs on production. In beekeeping, the production function technique has been used to study the variations that affect honey yield per productive unit(12). It allows measurement of profitability and productivity in beekeeping(13), as well as the elasticities and behavior of variables. The Cobb-Douglas can be used to make recommendations on relevant changes in the honey production process(14,15).

The present study objective was to estimate the production function that maximizes productivity in beekeeping, and to analyze production input elasticities. The state of Aguascalientes was chosen as a study area due to the need to increase the state's honey production and its competitiveness at the national level through better understanding of its beekeeping sector.

Aguascalientes (21°38'03", 22°27'06" N; 101°53'09", 103°00'51" W) has eleven municipalities. The state's climate is semiarid BS(16), and more than half the state is dominated by xerophilic vegetation(17). Given the climate and vegetation, there are two major annual natural nectar flows: one in the spring (mainly from mesquite *Prosopis laevigata*), and another in the fall (based on weed plants such as black-jack *Bidens odorata*(7), tree marigold *Tithonia tubaeformis* and bush sunflower *Simsia amplexicaulis*.

Beekeeping data were collected via a semi-structured questionnaire addressing technical management, inputs and production costs. It was applied during December 2019 and January 2020. The sampling universe constituted the 130 member beekeepers in the New

Apiculture Committee (Nuevo Comité Apícola) of the state of Aguascalientes. Sample size (n= 24) was calculated with the formula proposed by Wayne(18), using a 95% confidence level and 8% accuracy.

$$n = \frac{N * Z_{\propto}^{2} * p * q}{d^{2}(N-1) + Z_{\propto}^{2} * p * q}$$

Variable selection was done based on previous studies(19): honey production, supplementary feeding, labor, queen replacement (Table 1).

Table 1: Beekeeping variables included in production function

Variable	Acronym	Units
Honey yield	Y	Kilogram
Supplementary feed	SF	Kilogram
Labor	LA	Day
Queen replacement	QR	Percentage

The data collected with the questionnaire refer to the 2019 production cycle, and input prices are expressed in Mexican pesos, at current prices. Supplementary feed (SF) was sugar syrup or high fructose corn syrup supplied to hives at least 45 days prior to flowering periods and during the dry season. The production system is labor intensive during harvest, in March and April.

Queen replacement rate (QR) was calculated considering the number of colonies in which a queen was replaced during 2019 versus the total number of colonies in the same year. Most (90 %) beekeepers replace queens annually in an average of 40 % of their colonies; that is, for every 10 hives, 4 will experience queen replacement.

Using the database of variables generated from the surveys, statistical analysis was done of variable effects on honey production. The indirect method was used to formulate the production function, the variable data transformed to logarithms(20), and a linear regression implemented (0.05 confidence level). This was done to identify the relationship between production yield and the inputs used in the process(21). The Cobb-Douglas type function was applied to estimate maximum production when using all available inputs or the production gap(22), which is the distance between actual and potential production(23). One of the key features of a Cobb-Douglas production function is that it can derive the corresponding dual cost function by making use of first-order optimization(24,25).

Model statistical evaluation was done considering the adjusted R^2, an *F*-test was used to evaluate model statistical significance and a Students' t-test to evaluate sample regression coefficients(26). The stochastic form of the Cobb-Douglas function model is therefore(27):

$$Y_i = \beta_0 SF_i^{\beta 1} LA_{2i}^{\beta 2} QR_{3i} U_i$$

The relationship between production and inputs is not linear, and therefore, for the estimation, the model was transformed into a logarithmic function(27):

$$\ln(Y) = \ln(\beta o) + \beta 1 * \ln(SF) + \beta 2 * \ln(LA) + \beta 3 * \ln(QR) + \ln(U)$$

Where: Y = honey yield; β_0,β_1,β_2,β_3 = regression coefficients. Consequently, β_1 is the elasticity (partial) of production versus feeding, all other variables remaining constant; β_2 is the elasticity of production versus the number of work days per hive, all other variables remaining constant; and β_3 is the elasticity of production versus the queen replacement rate.

If the sum of $\beta_0 + \beta_1 + \beta_2 + \beta_3$ is 1, there are constant yields at scale. If it is less than 1, yields decrease at scale, in other words, if inputs are doubled yield grows at a rate less than double. When the sum is greater than 1 yields grow at scale(23,28). This growth is multiplicative rather than additive, meaning that a doubling in inputs more than doubles yield(25).

A Lagrange method was used to solve the model(29,30), because once it has been built a restricted mathematical function is added. In terms of maximization:

$$L = f(SF, LA, QR) - \gamma(PSF + PLA + PQR + M)$$

The first step is to partially derive L in relation to the corresponding inputs and to γ. The function is then maximized by equaling the function of the quotient of the partial derivatives to the price relationship(29,30), which generates the economic optimums(31,32) according to the function built.

For the general model test, different tests or suppositions were applied to the variables (Table 2). Multicollinearity was evaluated with the variance inflation factor (VIF)(33), which produced a value less than 0.10 for all variables. The supplementary feeding, labor and queen replacement rate variables were significant ($P<0.05$) (Table 3).

Table 2: Variables used in model

Variables	Unit	Mínimum	Máximum	Mean	SD	CV
SF	kg	1,050.0	8,700.0	4,550.0	2,135.3	46.9
QR	%	10.0	80.0	39.4	17.5	44.6
LA	Days	48.0	157.0	101.0	36.1	35.7

SF= Supplementary feeding; QR= Queen replacement rate; LA= labor; SD= Standard deviation; CV= coefficient of variation.

In the regression equation results (Table 3), the model adjustment indicates that the independent variables explain 94% of the variations in honey production; that is, the three regression coefficients have a direct relationship to honey production. The SF and LA inputs were of equal importance and represented more than four times that of the QR input.

Table 3: Regression and model adjustment results

	Minimum	1Q	Mean	3Q	Maximum	
	-0.23736	0.08644	0.01199	0.05379	0.26626	

Coefficients:

Variables	Standard estimation	Error	t Value	Pr(>|t|) (associated p)
(Intersect)	0.72204	0.44336	1.629	0.118312
SF	0.57877	0.12173	4.755	0.000107 ***
LA	0.55016	0.16544	3.325	0.003213 **
QR	0.13728	0.05987	2.293	0.032283 *

Residual standard error: 0.133 with 21 degrees of freedom (DF).
Multiple R^2: 0.9484; Adjusted R^2: 0.9411.
F statistic: 128.8 in 3 and 21 DF; *P* value: 1.113e-13.
'***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

After applying antilogarithms, the Cobb-Douglas empirical production function took this form:

$$Y = e^{0.72204} SF^{0.57877} LA^{0.55016} QR^{0.13728}$$

In economic terms, the honey production function shows that a 1 % increase in SF will increase honey production by 0.57 %, while a 1 % increase in LA will increase it by 0.55 %, all other inputs remaining constant. Since the sum of the coefficients is greater than 1, the production function exhibits increasing returns at scale.

In technical terms, increasing SF in the days prior to the beginning of the nectar season helps to increase hive population before flowering season, which improves honey yield. A greater amount of LA also implies additional costs. The sugar input marginal product shows that the addition of 1 kg sugar increases honey production by 0.57 kg, although this can vary in response to environmental conditions.

The economic optimum was established based on input prices of $17/kg for SF and $200 for LA. Queen replacement rate (QR) was kept constant, using the average for this variable (QR= 39.40). The function appears as follows:

$Y = 3.4088 SF^{0.57877} LA^{0.55016}$ (1); Subject to: $17SF + 200LA = 80$ (2)

Thus, the objective restriction was imposed on the estimated function in the form of input prices and honey sale price ($80) (Lagrange multiplier).

The estimated values are: SF= 2.4140 and LA= 0.1948.

Substituting these values in the production functions generates the optimum amount of honey given the inputs used.

$$y = 3.4088(2.4140)^{0.57877}(0.1948)^{0.55016}$$
$$y = 2.3082$$

Production and profit are functions of multiple variables; however, the present study is an abstraction in that it estimates optimal combinations using only statistically significant variables. Based on model results, 2.4140 kg sugar and 0.1948 d LA would result in 2.3082 kg honey yield. Conversely, production of 1 kg honey would require 1.0458 kg SF and 0.08439 d LA. From these data it can be inferred that maximum profit from production of one kilogram of honey would result from an optimal investment of $17.78 pesos in SF and $16.84 pesos in LA. Expressed in another way, production of one kilogram of honey assuming a SF cost of 17 pesos and a LA cost of 200 pesos per unit would generate profit of approximately $45.38 pesos. Before the present analysis was done, a pilot study was carried out using variables such as colony size, vaccination, transportation costs, and equipment and tool depreciation; only the variables analyzed in this model were statistically significant. Studies done in other countries have also analyzed competitiveness in beekeeping with the Cobb-Douglas production function using variables such as supplementary feeding, colony size, labor, medicine use, and capital(13).

The function also described the input elasticities(34) of honey production in the study area. For instance, a 10 % increase in SF, QR or LA would raise production by 5.7 %, 5.5 % and 1.3 %, respectively. These increases apply only for the present study case because proportional input costs can vary widely between different regions. On a national level, sugar (supplementary feed) represents 12 % of total production costs and labor 31.2 %(10). In the state of Aguascalientes, supplementary feed accounts for a much higher 47 % of costs while labor accounts for only 14 %(4); unfortunately, supplementation contributes to higher survival rates and thus favors production, making it a vital input. The reverse occurs in states such as Yucatan, where labor constitutes a higher proportion of production costs than supplementary feed(35,36). No matter the region in Mexico, both supplementary feed and labor are highly determinant inputs in honey production.

The estimated average cost of producing one kilogram of honey in the present study was 35 pesos, which is almost double that of the costs in the state of Yucatan: 19.7 pesos for small producers, 16.6 pesos for medium, and 14.4 pesos for large(37). Production costs can differ widely between regions in response to the sale price of honey, required inputs and their costs. Factors such as temperature, precipitation, genetics, and labor, among others, can also generate variations in production costs(12). This is reflected in the estimated profit of 45 pesos in the present study, compared to 23 pesos in previous studies in other regions(37). Fundamental factors that may have influenced these discrepancies between studies are year and geographical space in which the they were done.

In the state of Aguascalientes in 2019 the inputs of supplementary feed (sugar) and labor (wages) best explained honey production in the surveyed producers. The estimated elasticities suggest that increases in these inputs raise honey production, all other inputs remaining constant. However, when taken separately, both supplementary feed and labor exhibit diminishing returns, highlighting the need to monitor the effects of inputs on production and profits to ensure they do not start trending negative and generating losses.

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