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Estimation of the usable residual biomass through a digital map in barley cultivation in the State of Hidalgo, México

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Abstract

This study shows the estimation of residual biomass production from the agricultural sector of barley for its use as a solid biofuel. The methodology developed to fulfill the objective is based on the tools provided by the Digital Map of the National Institute of Statistics, Geography and Informatics (INEGI, Mexico) and the data of agricultural production from the Integral Farming System (SIAP, Mexico). Based on the scarce information, in the state and nationwide, about the use of agriculture waste, this study focuses on the estimation of waste and the calculation of the calorific value of barley cultivation in the state of Hidalgo Mexico. It includes maps which facilitate the access to the subject knowledge and its effective analysis.

Keywords: Residual, biomass, Crops, agricultural.

Introduction

Biomass is the organic matter of vegetable or animal origin that can be transformed into fuels to generate electric, mechanical and thermal energy through physical, chemical and biological processes. Biomass heat properties are related to the specific composition of the species[1-3] potentially influenced by the cultivation conditions such as sunlight, geographic location, climate, soil type, water availability, soil pH and nutrients[3,4]. Biomass is a source of clean, renewable energy with a wide range of developed technologies for the majority of its applications. The energy systems based on biomass, differ from other energy systems on the primary resource used[5]; internationally, bioenergy or energy obtained from biomass represents the 10% of the total energy consumption and the 77% of renewable energy. In Mexico, there is a great energy potential of biomass resource which can sustainably produce 3,569 PJ[6]. The biomass energy contribution to the national energy balance is 2.5%, and it has traditionally been supplied by firewood and sugar cane bagasse. However, there are other important sources of energy yet untapped such as the agricultural residues from barley crop;in Hidalgo 21% of its surface issown, and it is the second producer of barley nationwide contributing with 18.2% to the national production. The spatial knowledge of biomass production is useful for generating policies which encourage its use, the technological analysis based on the System of Geographic Information (SIG in Spanish) is a useful tool which integrates different users, hardware, software and processes that allow the knowledgeof energy production from biomass from a geographical context[7]. SIG is useful to perform a simultaneous analysis of the two components of the geographical data: spatial and thematic, providing solutions to complex spatial problems. The advantage of using SIG is to show a quantified and geo-referenced framework of the territorial differences and the factors that can influence biomass availability and the forthcoming of social and environmental problems[5]. Due to the issues above described, this study consists of: i. Estimating the energy potential of the agriculture residual generated from barley cultivation; ii. geographically representing the total residual biomass of agricultural nature derived from the cultivation of barley in the Valle del Mezquital in the state of Hidalgo, Mexico, through the use of a Digital Map.

Material and Methods

Area in study: The state of Hidalgo has an area of 20,846 square kilometers which represents 1.1% of the national land surface. The planted area is equivalent to 2.7% of the total national sown[7]. The region studiedis Valle del Mezquital which is located within the south western boundary in the state of Hidalgo (north longitude 20°02´ and west longitude 99°15´).It is positioned on the top of the Mexican plateau, 60 km from Mexico City, at an altitude between 1,640 m and 2,400m above the sea level. It consists of 27 of 84 municipalities that form the state of Hidalgo (figure-1). The main climate of the region is warm with rain in the summers (BS), and its variants BS1 and BSo. The annual average temperature is 18.3°C and the thermal oscillation is -9°C to 38°C. In regards to the precipitation, the site is one of the driest. Annual precipitation average range between 350 to 425 mm maximum over two periods of rain: June and September. Climate conditions along with the topography, the terrain and the geological composition have led to the formation of soils of residual and mixed origin with differing levels of development, distributed in most of the region. The most common types of soil are vertisols, feozem, rendzinas, fluvisoles, regosols, litosolscastañozemsandcambisols. The most abundant vegetal community is the xeric scrub[8]. The rainy season, climatic conditions and soil type characterize Hidalgo as a temporal season crop producer. Nevertheless, the effluents from Mexico City allow for the irrigation of crops, characterizing the state as an agricultural irrigation region. The raw material was obtained from the municipality of Francisco I. Madero from crop barley residues in the fields of barley of the Polytechnic University of Francisco I. Madero.

Calorific value analysis: Agricultural barley waste (*HordeumVulgare*) from irrigation crops was used. The residuals were collected from the fields of the Polytechnic University Francisco I. Madero, located in the Valle del Mezquital in Hidalgo State. All the samples were received in 50 Kg packages, and the analyses were performed in triplicate. A proximate analysis was conducted according to the method AACC[9] for moisture (925.10), ash (923.03), fat (920.39), total dietary fiber (962.09), protein (46.10) and carbohydrates. The content thereof was obtained by the difference of percentage of all the constituents with respect to the hundred percent. The calorific value was calculated by equation-1 and 2[10] given that each gram of fat provides 9 Cal. 1 g of carbohydrate 4 Cal and 1 g of protein provides about 4 Cal. These values were multiplied by the content of each component according to the proximate chemical analysis for 100 g of residue[11]. The results were expressed in primary energy (MJ /Ha).

$$\text{Total Carbohydrates} = 100 - (\%\text{moisture} + \%\text{protein} + \%\text{fat} + \%\text{ ashes}) \quad (1)$$

$$\text{Calorific value} = \left({}^{\text{Kcal}}/_{100\text{ g}}\right) = A + B + C \quad (2)$$

Where: A= (4 Kcal)(% total carbohydrates), B= (9 Kcal)(% fat), C= (4 Kcal)(% proteins)

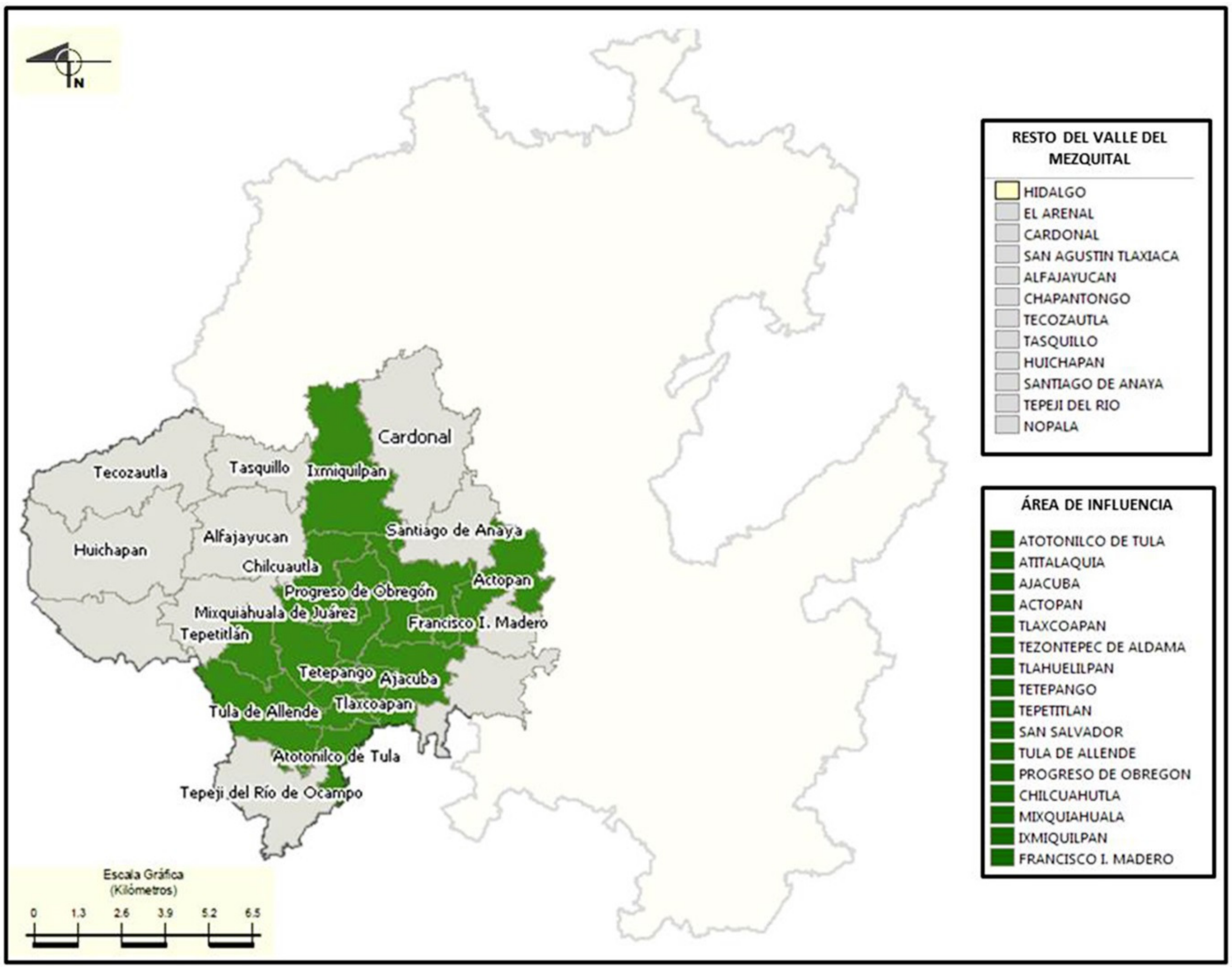

Figure-1
Municipalities in the region of Valle del Mezquital in Hidalgo State.
Source: elaborated by the authors

Spatial Analysis: In Mexico, the Federal Government offers two internet tools which are useful for obtaining statistics on population and housing services: the National Institute of Statistics and Geography (INEGI, in Spanish) and the Integrated Farming System (SIAP in Spanish) which provides crop production statistics at a national and local level. The information reported by the Integrated Farming System (SIAP) for irrigation and temporal crop of barley and grain in the agricultural year 2007 to 2012 was collected. The data obtained were used to create databases in Open Office Calc which contain fields that indicate the sown and harvested area (Ha) necessary to calculate the residual biomass. The residual biomass potential was estimated using the residual index (IR) for growing barley[10] linkingthe production of waste with the surface (kg waste/ha * year). The Open Office Calc database was connected to the Digital Map software to INEGI, obtaininga specific table with the following fields: state key (CVE_ENT), municipality key (CVE_MUN), municipality name (NOM_MUN), state name (NOM_ENT), irrigation residual biomass (RBR(Kg/Ha)) and temporal residual biomass (TBR (Kg/Ha)) with the objective of combining the numerical data with the maps.

Results and Discussion

Evaluation of the calorific power: Table-1 shows the results of the bromatologicanalysis of residual biomass of barley crops. The moisture content obtained is lower (7.37%) than that reported by Shewry[12] and Callejo[13] which range from 10 to 14%. The moisture content of the mowed straw with the suitable degree of maturity for harvesting commonly varies from 8% on a dry season to 20% on a humid one[14]. Therefore, the barley crop residue is below this range. The biomass residual moisture is an important factor for predicting its behavior during storage. A bale with moisture content below 15% is less likely to suffer mildew[14], consequently it would be less probable to deteriorate by the presence of fungi. Regarding the ash content, it is optimum to the value reported for leaves and barley stems grown in Hidalgo, which can vary from 4.5 to 17.47%[15]. Various authors have reported that mainly calcium and potassium salts predominate in the ashes of stems and leaves since these elements are the most absorbed by plants[15]. The results of the fiber content (table 1) indicate lower values than those reported for barley straw from Hidalgo State, which range from 28.9 to 58.5%[15,17]. Fiber is considered a reflection of cellulose content, hemicellulose and lignin which are the essential components of the leaves and stems of all cereals and many other plant tissues. These structural carbohydrates can be used for obtaining different commercial bioproducts such as bioethanol due to its high demand as a substitute for petrochemical-based fuels.

The protein percentage in the residual biomass is higher (13.23%) than that reported in the literature[15] which show percentages between 1.29 to 3.31%. Factors such as the degree of maturity of the plant, soil fertilization and climate conditions can contribute to the protein content of residual biomass in the cultivation of barley[18,19].

The lipid content was similar to that described which range from 0.4 to 1.8% [14] and even lower to the 1.6% reported for winter barley straw. The lipid content in the residual biomass is due to the fact that the leaves and stems contain small amounts of wax which increase the percentage of fat in these organs[15]. Regarding the total carbohydrates, the value obtained is similar to that reported in tang, leaves and stems[15]; however the results indicate that at higher carbohydrate content, there islower protein content. No reports were found which indicate that the carbohydrate content is suitable or unsuitable for the production of biofuels. The calorific value was calculated from the content of protein, lipids and carbohydrates, obtaining a residual value equivalent to 13.58 MJ/Kg, the same as other authors[11,20] who state a minimum of 12.5 MJ/Kg the reference to the total available energy in combustion. This potential can be used as primary energy in the form of pellets or briquettes (solid biofuel)[21,22]. Like any other hydrocarbon, the energy value of organic agricultural waste will depend on the chemical composition of biomass.

Incorporation of spatial analysis: Hidalgo is a state with a diverse agricultural production. The results shown by SIAP indicate that the main grain crops are corn, green alfalfa, pulque maguey and barley grain. 21% of the entity area is sown with barley grain, positioning Hidalgo from 2010 to 2012 as the second national producer of this crop contributing with 18.2% of the total national production. Table 2 shows the results of residual biomass and energy potential of the area sown with barley crop in the state of Hidalgo in a period of six years (2007-2012).

The integration of the database with the agricultural waste production factor is useful for doing the estimation of the total production of biomass obtained in the state of Hidalgo for the growing of barley (grain and forage: cultivation system, irrigation and temporal) reaching a total value of 782,415.69 Kg/Ha, equivalent to 10, 627,916.50 MJ/Ha.

The Valle del Mezquital, known as the granary of Hidalgo, produced 22,230 Kg/Ha of residual biomass, equivalent to 301,960.44 MJ/Ha. Only 11 municipalities have the highest area sown with barley crop (grain and forage, irrigation and temporal (table-3).

Figure-2 shows the incorporation of the biomass data in the Valle del Mezquital by a digital map obtained through SIG[23]. This allows the cartographic production of the residual biomass variable facilitating the location and precise delimitation of the richest areas of this resource.

Table-1
Bromatologic analysis and calorific power

Moisture	Ash	Fiber	Protein	Lípids	Total carbohydrates	$PCS_{BS(Kcal/kg)}$
%						
7.37	12.65	13.82	13.23	0.9	65.85	3244.2

Figure-2 indicates through a colored palette from yellow to brown the interval range of biomass production: lower than 95 and greater than 700 Kg/Ha. The total municipalities in Valle del Mezquitalwhich are within that interval range are shown in parenthesis.

Francisco I. Madero (irrigation) and Huichapan (temporal) were the municipalities that produced the highest waste in the agricultural cycle 2012 with 750.1 and 744.1 Kg/Ha respectively. These municipalities showed an energy potential of 16,669.62 MJ/Ha equivalent to 4.63 $MWh_{t,}$approximated energy for1000 kg of steam/hour.

Table-2
Residual Biomass and Energy Potential in the state of Hidalgo for barley crop

2007-2012			
Barley residual biomass (Kg/Ha)			
Forage		Grain	
Temporal	Irrigation	Temporal	Irrigation
21,864.63	11,542.70	743,478.43	5,529.93
Total Kg/Ha		782,415.69	
Energy (MJ/Ha)		10,627,916.5	

Table-3
Residual Biomass and energy generated in the Valle del Mezquital (2007-2012)

	Residual Biomass (Kg/Ha)		Energy (MJ/Ha)	
Municipality	Irrigation	Temporal	Irrigation	Temporal
Actopan	1,682.20	2,626.00	22,850.11	35,670.18
Ajacuba	1,293.50	2,256.80	17,570.21	30,655.16
Atotonilco de Tula	40.30	1,092.00	547.41	14,833.14
Francisco I. Madero	2,570.10	445.90	34,910.86	6,056.87
Huichapan	0.00	2,297.10	0.00	31,202.58
Mixquiahuala de Juárez	1,877.20	209.30	25,498.88	2,843.02
Progreso de Obregón	523.90	481.00	7,116.38	6,533.65
San Salvador	1,094.60	603.20	14,868.46	8,193.55
Santiago de Anaya	497.90	799.50	6,763.21	10,859.98
Tepeji del Río	0.00	1,342.90	0.00	18,241.24
Tepetitlán	189.80	306.80	2,578.14	4,167.41
Subtotal	9,769.50	12,460.50	132,703.67	169,256.77
Total Valle del Mezquital	22,230.00		301,960.44	

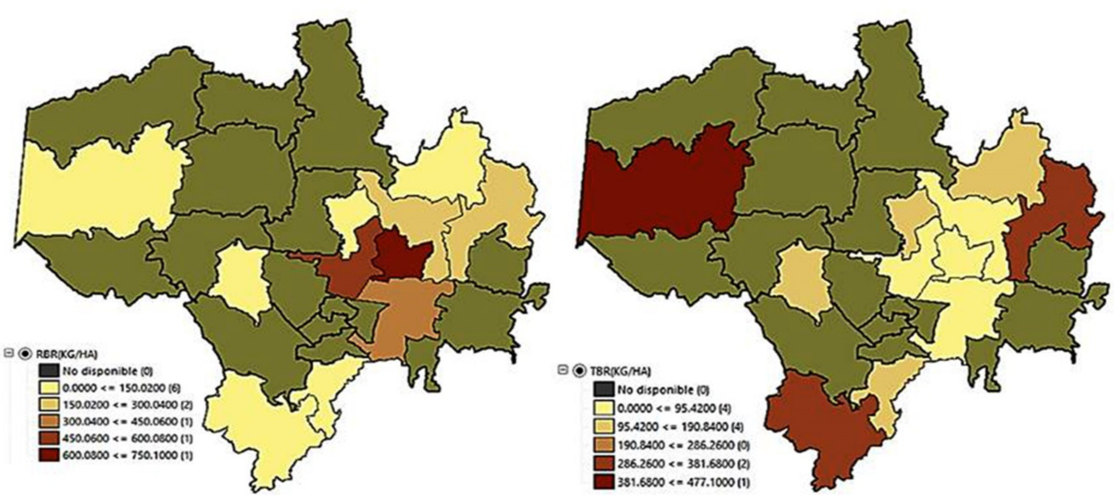

Figure-2
Map of agricultural waste for barley cultivation in the Valle del Mezquital, a) Irrigation and b) Temporal

Conclusion

The tools provided by INEGIs digital map offer a detailed geographical representation of the spatial distribution of the production potential of residual biomass of barley crop, and its energy potential in Valle del Mezquital. The total energy potential generated which has not been employed for six years in Valle del Mezquital for growing barley is 301,960.44 MJ/Ha, this represents the energy generated by liable biomass energy use.

The result 4.63 MWht in the residual biomass is the starting point to undertake subsequent studies which consider the real biomass potential, that is, the energy generated by all biomass that can be used with the available technologies, to be considered technically, economically and ecologically viable.

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