TECHNOLOGICAL CHARACTERISTICS OF THE IRRIGATED AGRICULTURE IN THE VILLA JUÁREZ AQUIFER, DURANGO. NORTH OF MEXICO

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SUMMARY

The present study constitutes an important part of a broader project that seeks to predict the risk of contamination by nitrates of an aquifer considered as the reserve of drinkable water of the Comarca Lagunera, which is formed by several municipalities of Durango and Coahuila states in the North of Mexico. The objective was to characterize the agricultural cropping systems of the Villa Juárez aquifer and estimate the economic efficiency of the water used by each crop. We use statistical and documentary information generated by federal, state, and local public institutions present in the region, as well as to design and apply a survey to rural farmers in the 26 % of the total agricultural surface. Results indicate that fodder production represents more than the 90% of the regional agriculture in which more than the 80 % of the farmers employ fertilizers and other chemical products. The study showed that farmers decide the quantity and type of fertilizers to apply without using soil analysis or expected nutrient demand by crops. This could be causing a reduction to crops profitability but also a negative impact to the environment if the fertilizers are not been well used with the consequent risk of aquifer contamination. Regarding the economic efficiency of water, it was found that the profit value of water used in fodder production is much less than that for pecan tree or horticultural crops, concluding that in spite of the agriculture is an important activity in the zone, it is necessary to improve the practices for the use of agrochemical products, if this zone will continue be considered as a reserve of drinkable water for a population over a million of inhabitants that live in this region.

KEYWORDS: *Comarca Lagunera, fodders, economic efficiency, contamination*.

INTRODUCTION

The present study is product of documentary investigation and field work carried out in the Comarca Lagunera region, located within the Villa Juárez aquifer, in the state of Durango, Mexico, in the middle-low part of the Hydrological Region 36, Nazas river watershed. The study was part of a broader project "Calibration of water and nitrogen flow simulation models to predict the risk of underground water contamination by nitrates".

The Comarca Lagunera region is considered as a drinking water reserve for of a population of nearly one million inhabitants. It was necessary to perform a general characterization of the agricultural cropping systems. We describe with some detail the crop yields, amount and type of fertilizers, and water depths that are being applied to the crops in this region. Finally, we show the economic efficiency of the water applied by crop.

METHODOLOGY

Firstly, a survey was applied to farmers to obtain information about management practices and products been used. The questionnaire caught information of a 3 889.5 ha which represented 27% of the planted area in 2003 in the Municipality of Lerdo, Durango, site where the Villa Juárez aquifer is located. Twenty six surveys were applied, corresponding 21 to private properties and the rest to ejidos (communal properties). The survey was carried out at the end of 2004 and once the information was available, it was processed in Excel, in preparation for the analysis.

The data collected by the survey was validated against the information reported in statistics published in the region by SAGARPA. The correct identification of the agrochemicals used for the control of insects and pests was carried out with the aim of a dictionary of agrochemical specialties published in 2003.

The calculation of the economic efficiency of the water was made from the value of the production reported by SAGARPA in 2001, divided by the volume of water required by each crop per hectare. This data was supplied by farmers.

The context of the study was developed with secondary sources of information such as the Secretary for Agriculture, Livestock, Rural Development, Fishing and Food production; the National Commission of Water and the Censuses of Population for the State of Durango.

RESULTS AND DISCUSSION

Characteristics of the area of study

The Comarca Lagunera region belongs to the Hydrological Region 36, endorheic basin with a surface of 92 000 km^2 distributed partly in the states of Coahuila, Durango and Zacatecas. The region is very important in agriculture and industry depending both upon surface and underground waters. The first came from the upper part of the watershed (Sierra Madre Occidental) and the second, extracted from the aquifer in the lowest part of basin (Orona, 1993).

The situation of the water in this region is as it follows: the number of wells in operation is 3 823, which extract a volume of 1 251.89 Mm^3 per year. The estimated recharge is 760.57 Mm^3 with a net over extraction of 491.32 Mm^3. Of this water, 87% is used for agriculture, 11% for public use and only 2% for industry (CNA, 1999).

Table 1. Situation and uses of underground water in the Comarca Lagunera Region.

Activity	Number of wells	Extraction Mm^3/year
Agriculture	2 707	1 031.40
Domestic rural	573	57.06
Public	459	136.60
Industry	84	26.83
Total	3 823	1 251.89
Recharge		760.57
Deficit		491.32

According to the underground water department of the National Commission of Water (CNA, 1999), the static level of well water in the Comarca Lagunera, during period 1975-1998 has descended in average 41.7 m.

Table 2. Phreatic levels of water for several municipalities of the Comarca Lagunera in 1998.

Municipalities of the State of Durango	Depth of the phreatic level (m)	Municipalities of the State of Coahuila	Depth of the phreatic level (m)
Gómez Palacio	129.82	Torreón	136.18
Lerdo	11.20	San Pedro de Colonias	89.94
Tlahualilo	107.16	Francisco I. Madero	116.80

Mapimí	107.70	Matamoros	143.02
Nazas	26.22	Viesca	135.12
Simón Bolívar	75.12		
San Luis del Cordero	30.20		
Rodeo	25.80		
San Pedro del Gallo	36.66		
San Juan de Guadalupe	Not determined		

The Villa Juárez aquifer.

This is a free type aquifer constituted by granular material, covering an approximated area of 214 km^2; there are 254 water wells in operation with an estimated annual extraction of 57.12 Mm^3. The recharge has been estimated in 100.34 Mm^3, and for this reason it is considered to be in an underexploited condition. Its main source of recharge is the water that year by year flows throughout the Nazas river. This water is stored in the Lazaro Cardenas dam and used to irrigate different crops located in the Irrigation District No. 17. An average of 1200 Mm^3 are used with this purpose every year. On the other hand, according to CNA (1999) the static level depth of underground water was 11.2 m. In other study, Martinez (2001) found phreatic levels in the range between 3 and 43 m.

In this aquifer there are 55 wells used to measure twice a year the phreatic level depths. One of the measurements is taken when the water if flowing throughout the nazas river (March to October) and the other during the dry period (November to February). This zone is located in the municipality of Lerdo in the State of Durango and a great part of this valley is considered as the drinking water reserve for the whole Comarca Lagunera region: This was published in the Federal Government Official Newspaper on August 13, 1991. Also, since April 1958 and 1965, the Federal Government prohibited the perforation of new wells in this zone. The uses of water extracted from this aquifer are shown in Figure 1.

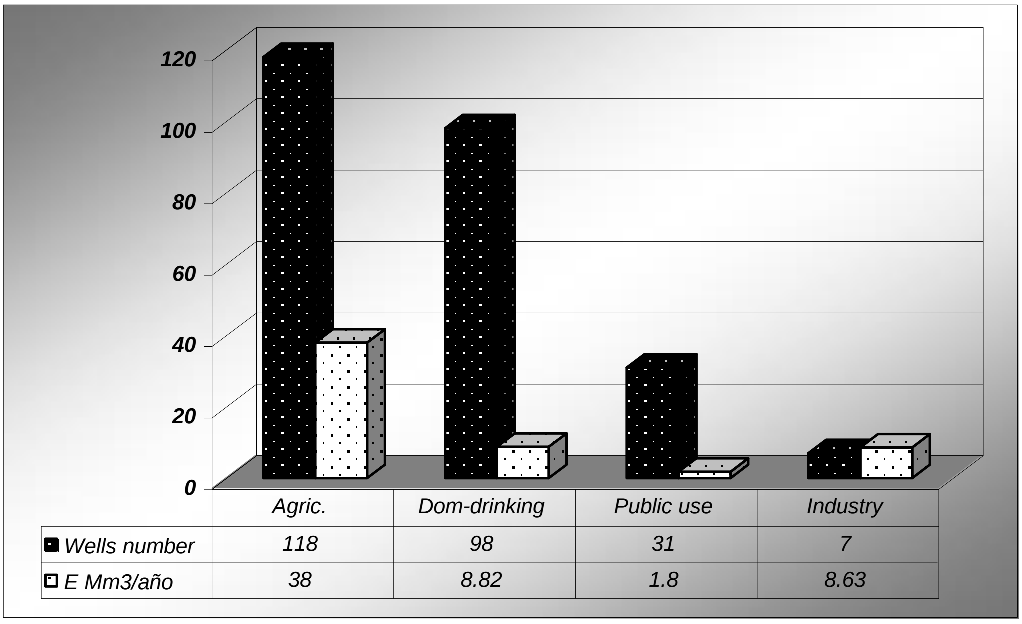

Figure 1. Uses of water extracted form the Villa Juárez aquifer, Municipality of Lerdo, Durango, Mexico.

In this aquifer, underground water is used as follows: 66.4% agriculture, 15.4% for drinking and domestic services, 3.1% public use, and 15% for industrial production.

The initial hypothesis that the nitrate concentration in underground waters came only from fertilizers and other agrochemical products used to produce forages for dairy cattle feeding has been challenged by other studies and a final conclusion has not been reached yet. Castellanos (1982) mentioned that in addition to the fertilizers applied it was very common the application of dairy cattle in amounts above 100 t ha^{-1}, by-product that has been characterized in diverse studies, in which has being determined to contain significant amounts of nitrogen, phosphorus, potassium, calcium, magnesium, micronutrients but also of soluble salts.

The agricultural surface reported by official institutions for the Municipality of Lerdo Durango, indicates that 14594 ha were planted in 2001 (SAGARPA, 2001); 51% for the spring-summer growing season; 38.6% was established with perennial crops and 10% with winter crops (Figure 2).

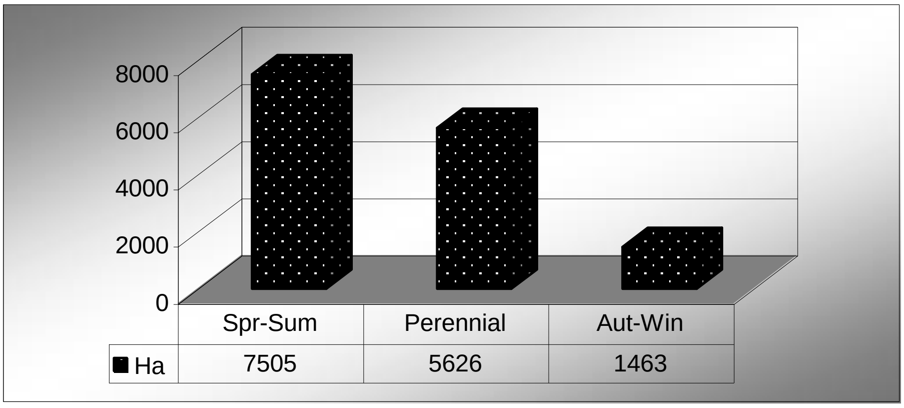

Figure 2. Agricultural surface in the Municipality of Lerdo, Durango, located in water-bearing Villa Juárez. 2001

It is important to mention that about 90% of the cultivated surface in this municipality was planted with forage crops to supply the increasing demand of the also growing dairy cattle population. In 2001, the dairy cattle inventory according to SAGARPA was 87783 dairy cattle heads and 49140 goats with a milk production of 336 582 589 L equivalent to 1 242 million mexican pesos.

Agricultural crops in Villa Juárez, Durango.

The most important crops in this zone are: alfalfa, forage maize, vegetables and flowers, forage triticale, pecans, forage oats and forage sorghum. Of these, the most common production system includes alfalfa, followed by forage maize, oats, triticale, and sorghum, present in 73, 80, 42, and 16% of the productive units of the study. Figure 3 shows the surface occupied by crop.

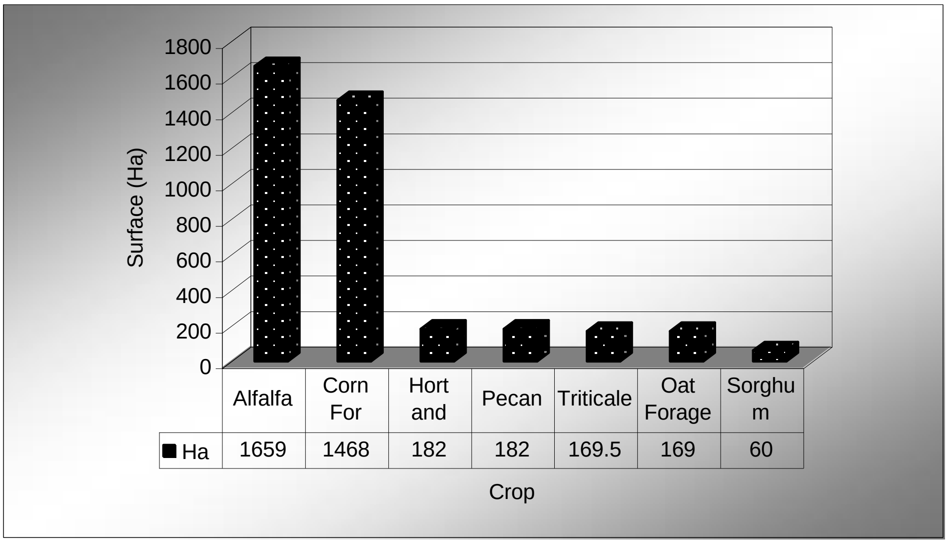

Figure 3. Surface by crop in Villa Juárez, Durango, 2004.

Of the 19 agricultural production systems identified in the zone, 31% combines three crops; 21% combines four, and those that combine five, two and cultures represent each one 15.8%, (Figure 4). Next, a general analysis of the crops is presented.

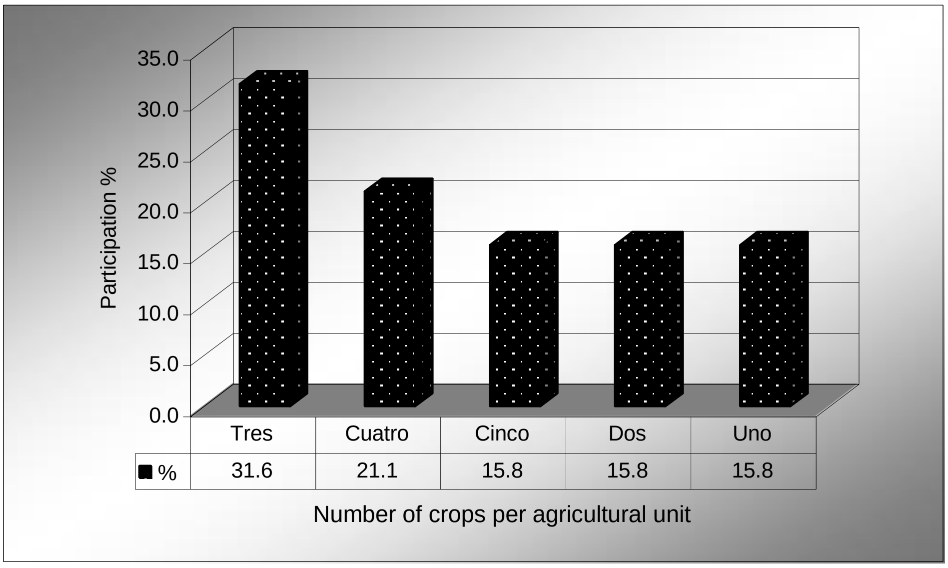

Figure 4. Number of crops in agricultural production systems from the Villa Juárez aquifer, Durango, 2004.

Alfalfa (*Medicago sativa*)

This crop is present in seven of each ten production units. Fresh dry matter yield fluctuated between 90 and 100 t ha^{-1} generally obtained in ten harvests per year. The production was concentrated from spring to autumn. During the cold months (January-February) the crop develops very little.

The most common varieties were Cuf and El Camino, followed by Sundor and Jupiter. Farmers use in average 35.8 kg of seed per hectare; the method of application of water was flood irrigation (62.5% of the producers); flood with multigates pipes (18.75%); flood combined with central pivot (12.5%), or sprinkler irrigation (6.25% of the producers).

The number of irrigations per year under the flood irrigation system was 12; those using sprinkler (including central pivot) irrigated every 21 days, although this may change according to the administrator of the production unit; however, according to Rivera *et al*., (2004), the highest yield of alfalfa may be obtained applying an irrigation depth equivalent to 80% of the potential evapotranspiration. In the Comarca Lagunera, this value corresponds to 180-190 cm of water depth per year.

Farmers said that they used to apply 15 cm per irrigation under flood irrigation. If we multiply this value by the number of irrigations per year (12) an irrigation depth of 180 cm is calculated which agree with the recommended amount suggested by Rivera *et al*., (2004).

Several fertilizers are applied directly to the soil and foliage of alfalfa. However, the type, amount, and frequency of product applied are defined based on soil analysis or crop demands only by the 15.7% of the farmers included in the survey. This may represent two things: not reaching the potential yield because the lack of nutrients or be applying them in excess. The second option could reduce the crop profit but also could damage the environment.

According to the field study, eight out of ten producers of alfalfa apply granulated fertilizers and four of each ten apply also foliar fertilizers. Seventy percent of the farmers surveyed applied monoammonium phosphate MAP at an average rate of 355 kg ha^{-1}; a physical granulated mixture (apparently containing N, P_2O_5, and K_2O; 0-6-10, respectively) were used by 13% of the farmers at a rate of 450 kg ha^{-1}. Finally, 6.5% of the farmers said to apply urea at a rate of 200 kg ha^{-1}. All of these products and rates are been applied every year.

The question at this point is “what is the impact that this kind of fertilizer management is having on the farmers´ economy and to the environment?

In relation to foliar fertilizers the situation is similar to granulated, the producers are applying them to the crop without using foliar analysis to determine whether or not they are necessary and in what rate.

When tasked why they are applying fertilizers 80% answered “by tradition and experience”, the answer of the rest (20%) was answered “based on technical support provided by private consultants”.

Farmers of this region (55%) apply insecticides every season against several bugs, trips, and worms (Rosenstein, 2003). The average number of applications may be as high as ten, using one litter per hectare.

Table 3. Chemical products applied to alfalfa.

Chemical product	Frecuence	%
Metamidofós 600*	7	43.75
Pívot 100**	3	18.75
Parathión metílico 500*	2	12.50
Tamarón 600*	2	12.50
Cipermetrina 200*	1	6.25
Endosulfán 50 PH*	1	6.25

* Insecticide ** herbicide

Corn Forage (*Zea mays*)

Another important crop in the zone is forage corn. This crop is planted in 80% of the surveyed farms covering 38% of the studied area. Corn is usually associated with other crops such as alfalfa and forage oats and it is seldom planted as unique crop.

Corn is usually planted in two periods February to May and May to August. Average fresh yield are 57.3 and 38.4 t ha^{-1} for the first and second period, respectively. The yield dropping has been explained in terms higher temperatures and longer photoperiod during the summer growing season. Common varieties include AS900, Berensen, Asgrow and Jaguar 95. The amount of seed used ranges between 22 and 40 kg ha^{-1}.

Most common irrigation systems are surface, multigates surface and central pivot. Surface irrigated corn receives four irrigations of 15 cm water depth each, accounting for a total of 60 cm ha^{-1} per season.

Seventy six percent of the farmers said to apply granulated fertilizers to corn. Of these, 50% apply monoammonium phosphate (MAP) and urea, another 20% said to apply a granulated mixture containing N, P_2O_5, and K_2O (12-30-12, respectively). Rates applied of MAP, urea, granulated mixture were 165.6, 197.5 and 283 kg ha^{-1}, respectively. Most of the farmers (77%) said to apply fertilizers without technical advice and that they are not sure if they are applying the correct products or rates.

Applying chemical products to control pests is a common practice among corn producers (61%); they apply products like clorpirifos 3G, folimat and lorsban, generally at a rate of one litter per hectare.

Oat Forage (*Avena sativa*)

This crop like corn is planted for forage production. It is planted in four of each ten production units usually in rotation with alfalfa or corn. This crop is planted in 169 ha which represents only 4.4% of total area dedicated to agriculture. Fresh matter yield for 2001 was 44 t ha^{-1}. Most of the planted area (90%) was under surface irrigation and farmers said to apply four irrigations 15 cm water depth each. This crop is planted during the winter season.

All farmers fertilize this crop every season, 36% of them use ammonium sulphate at a rate of 275 kg ha^{-1}, 45% use urea as nitrogen source (215 kg ha^{-1}). The sources of phosphorus that farmers are using (18%) are MAP and granulated mixtures containing N, $P_2\grave{O}_5$, K_2O (12-30-12, respectively). Rates applied ranges between 125 and 190 kg ha^{-1}. As in the cases of alfalfa and corn, farmers do not analyze their soils to decide the type or rate of fertilizers to use. This crop seldom requires the application of insecticides.

Pecan (*Carya illinoensis*)

This fruit tree is established in 182 ha which represents only 4.7 % of the cultivated area. Average yield in 2001 was 1.32 t ha^{-1}. Western and Wichita are the most common varieties and planted at a population of 70 trees per hectare. Most of the orchards use flood irrigation applying seven to eight irrigations per season with a total water depth between 140 and 160 cm $year^{-1}$.

Fertilizers applied to this crop include ammonium sulphate, MAP and potassium chloride at rates of 210, 45, and 45 kg ha^{-1} per season of N, P_2O_5, and K_2O, respectively. Generally, they applied three to five applications of foliar Zn during the growing season using products such as NZn, Nitrothed, Banathed or Goligen. Only 38% of the pecan growers said to use soil analysis to determine the type and amount of fertilizers to apply. Most of them (62%) applied fertilizers based only based on their own experience.

Water was applied every month from February to September. Pecan growers generally also grew forages in their farms, however pecan orchards of 70 ha can be grown as unique crop.

Horticultural crops

This group represents 4.7% of the agricultural area in the Villa Juárez aquifer. Figure 5 shows that chile was the most important; followed by tomato and ornamental crops.

These crops were usually established in the margins of the Nazas river, within the Monterrey sector and the ejidos León Guzmán and Juan Eugenio García. In order to show use and management of pesticides and fertilizers, it is exemplified with chile, tomato and the flower crops.

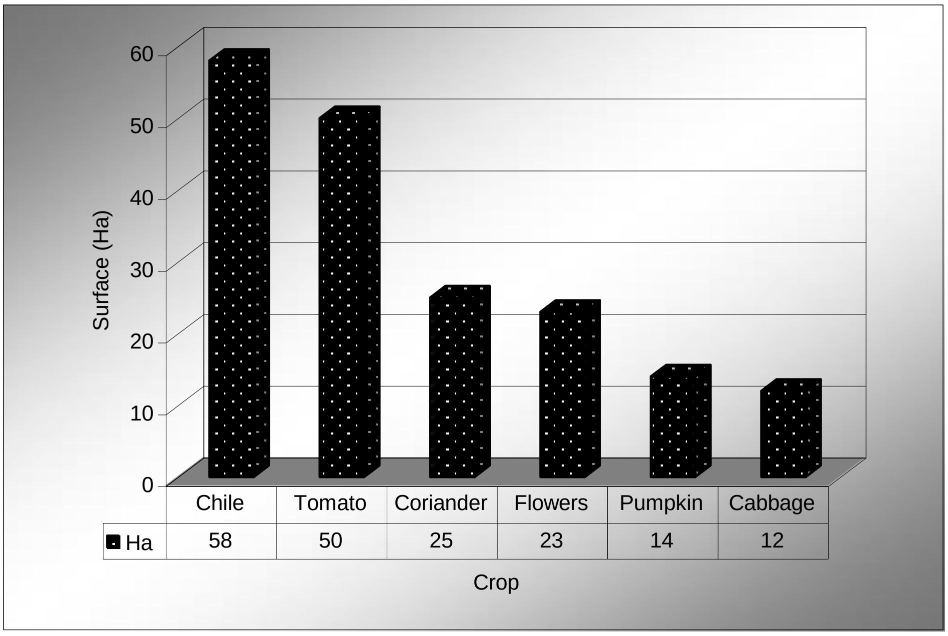

Figure 5. Area cropped with vegetable and ornamental crops in the Villa Juárez aquifer area, Durango, Comarca Lagunera, 2004.

Chile (Capsicum annumm)

Cultivar Tula was generally grown with a plant population ranging between 30 and 40 thousands of plants per hectare under flood and drip irrigation systems. The number of irrigations was eight, with an average of 15 cm of water depth per irrigation, which resulted in a total per season of 120 cm.

The harvest period was from the end of February to the beginning of July, involving the use of fertilizer to improve the yield. Although each farmer applies different amount and type of fertilizer, some of them apply 320 kg ha^{-1} of granulated ammonium sulphate and 14 kg ha^{-1} of nutri K as a foliar spray, advised basically by commercial houses in the region, without any soil or plant analysis. It was hard to obtain the yield of the chile crop; nevertheless, the agricultural statistics for the zone of study reported an average yield of 13 t ha^{-1}.

Pest and disease control involved the use of a variety of products such as confidor 350 SC, thiodán 35 EC, lucathion 1000, agromil V, benomyl 50, cipermetrina 200, among others. The number of applications was a function of the incidence of the pest or disease.

Tomato (*Licopersicum esculentum*)

The 90 ha planted with this crop involved the cultivars Rio Grande and Yaqui, at a density of 40 thousand plants per ha, under flood irrigation. The cropping season was from March to July, applying an average of eight irrigations of 12 cm; for a total of 96 cm per growing season. Fertilizer use was very important for this crop, in which 500 kg ha^{-1} of urea was split in two and applied without any criteria based on soil analysis or crop nutrient demand. The yield reported by SAGARPA in 2001 was 12.3t ha^{-1}.

Pest control included two applications of metamidofos 600 and furadán 300 at a rate of 2 L ha^{-1} each one.

Other horticultural crops found were cabbage, zucchini and coriander. Coriander is cropped year around in a surface of 25 ha. Zucchini and cabbage were cropped in 14 and 12 ha, respectively. For these crops, an average of 150 kg of urea and 50 kg of ammonium sulphate was used, and two pesticide applications were necessary to control several pests.

Ornamental crops

This activity was located in the margins of the Nazas River within the area of Villa Juárez aquifer, in the sector of Monterrey, ejido Leon Guzmán. The activity is seasonal since the flower is produced mainly for the local market. The harvested area was 23 ha, in which a variety of flowers are cropped, such as mano de león; cempasúchil and margarita. The period of these crops goes from August to the end of November. Depending on the type of flower, plant density oscillates in 23 thousand per ha, which are irrigated by flooding.

Crops were irrigated with groundwater extracted from a depth of 2 to 10 m, located in the margins of the Nazas River, where it is pumped with portable pumps.

These crop received four to five irrigations with a depth of water of 10 cm for a total of 40 to 50 cm of water per season.

Fertilizers application was minimum with an average of 80 kg ha^{-1} of urea. According to the farmers, the fertilizer applied to the previous crop was enough to meet the flowers' requirement. Obviously, soil and plant analysis were not made to determine the amount and type of fertilizer ti apply. Also, they applied pesticides to control several pests at a rate of 1 L ha^{-1}.

Economic efficiency of the water

The profitability of the water used in agriculture was based on the amount applied water to each crop and the value of the production obtained in 2001 according to SAGARPA (2001.

Table 4 shows that even though alfalfa was the most important crop in terms of cultivated area with a high value of the production, the profit obtained per cubic meter was hardly 0.80 pesos m^{-3} followed with higher profit by maize and forage sorghum (0.84 and 1.28 pesos m^{-3}, respectively). However, these crops are inputs for the milk industry, where they can have an added value.

The crops where the water produces higher yields per cubic meter used were the vegetables, headed by chile, watermelon and melon; however, these crops have a high risk due to the incidence of pests and diseases, as well as the fluctuation of their prices in the regional and national markets.

Table 4. Economic efficiency of water for several crops grown in the Villa Juárez aquifer, Durango. 2001.

Crop	Ha	Value (Thousands of pesos)	$/m³ of water	Order
Alfalfa	5 159	74 606.0	0.80	11
Corn forage	4 061	38 432.2	1.58	7
Sorgghum forage	1 651	15 221.6	1.28	9
Corn grain	949	4 755.2	0.84	10
Oat forage	668	5 295.6	1.32	8
Chile	363	20 088.6	4.61	1
Peca	292	9 010.0	2.06	6
Tomato	212	5 498.7	2.70	4
Horticultural crops	37	841.8	2.37	5
Cantaloupe	30	975.0	3.39	3
Watermelon	30	1 080.0	3.75	2

CONCLUSIONS

The forage production in Villa Juárez, Durango, main drinking water reserve for the Comarca Lagunera region occupy more of 90% of the agricultural surface. These forages are consumed mainly by a population of 87740 of dairy cattle.

Eighty percent of the producers used chemical fertilizers. However, only 16% of them do it based on technical recommendations. The rest of them use fertilizers by tradition or based on their "own experience". This situation could represent two things: obtaining low yields due to lack of nutrients or applying them in excess. The second option may reduce the producer profitability but also may be causing contamination of underground waters.

Economic efficiency of water ranged from 0.8 and 1.28 pesos per m^{-3} for forage crops, much lower of that obtained for horticultural and ornamental crops. However, forage crops will continue be planted because they are necessary for the milk industry.

Although agriculture is an important activity in the zone, there is a real threat associated with the indiscriminated use of chemical fertilizers and manures ignoring the crops nutrient demands and soil testing. The risk of contamination with nitrates of underground waters of this aquifer must be evaluated.

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