

TECHNIFICATION OF MAIZE CULTIVATION AS A STRATEGY FOR THE REGIONAL DEVELOPMENT OF VERACRUZ

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ABSTRACT

Development requires strategies at the microeconomic level because competitive advantages are dynamic in nature and based on the introduction of technological innovations that will improve productivity, quality and diversification of goods and services. Clearly, the introduction of innovations to the productive base of a territory enables advancement of economic development. By agricultural innovation, we refer to new technologies that complement the tasks in the field and generate data and information that can be used by the producer to improve decision making. This study was designed to generate a diagnosis for technical innovation for maize cultivation in the municipality of San Juan Evangelista, Veracruz, employing precision agriculture (PA), to optimize the use of soils and by this means, boost regional development. The methodology employed was quantitative and qualitative, through the collection of documentary information and the structured interview method, aimed at maize producers in the region. Results indicated that technological application tools increase the yield of the harvest, in economic terms and grain volume. However, group participation of farmers in the municipality must occur, in order to work together with the agricultural management of the municipal government. This will ensure machinery is introduced to the fields in a less expensive and more organized way.

Keywords: agricultural technology, economic development, sustainable agriculture, territorial growth, technology and production.

INTRODUCTION

Maize is one of the most important cereals in the world; it provides nutritional elements for humans and animals and is a basic raw material for industry. Specifically, in Mexico, it represents the crop with the greatest economic, social and cultural relevance. In 2016, it contributed 14.5% of the agricultural Gross Domestic Product (GDP), likewise, in social terms it represents one of the population's food staples "with an average per capita consumption per year of 196.4 kg. of white corn, especially in the form of tortillas, representing 20.9% of the total expenditure on food, beverages and tobacco, made by Mexican families" (Ministry for Agriculture, Livestock, Rural Development, Fisheries and Food: Secretaría de Agricultura, Ganadería, Rural Desarrollo, Pesca y Alimentación [SAGARPA], 2017, p. 2).

Usually, maize production consists of both white and yellow. In Mexico, the first is mainly destined for human consumption and represents 86.9% of production; while yellow maize is destined for industry or the manufacture of balanced food for livestock production (SAGARPA, 2017). According to the government of Mexico (2020), small producers

Citation: Garizurieta-Bernabe J, García-Sánchez E. 2024. Technification of maize cultivation as a strategy for the regional development of Veracruz. *Agricultura, Sociedad y Desarrollo*. <https://doi.org/10.22231/asyd.v21i3.1609>

ASyD 21(3): 348-368

Editor in Chief:

Dr. Benito Ramírez Valverde

Received: May 18, 2023.

Approved: July 11, 2023.

Estimated publication date:

June 18, 2024.

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contribute around 60% of national maize production; and the State of Sinaloa stands out, with a production of more than 6 million tons.

Although in 2019, more than 7 million tons per hectare of maize were harvested (National Institute of Statistics and Geography [Instituto Nacional de Estadística y Geografía, INEGI], 2019b), this production has been insufficient to cover demand in the interior of the country, which has led to increased imports, now signifying third place in the world, in terms of maize imports (Statista Research Department, 2022).

Apparently only 15.5% of farmers use pruning tools and harvesters; while 25.3% still use draft animals or teams in their cultivation process (INEGI, 2019b); it is therefore evident that one of the factors affecting insufficient production is that farmers do not have the necessary infrastructure, as most farmers do not have access to technology.

This has led to a deficit in production; last year alone, production decreased by 1.8% compared to 2020, and a lower value was obtained in real terms (Agri-Food and Fisheries Information Service [Servicio de Información Agroalimentaria y Pesquera, SIAP], 2022). For this reason, despite being in seventh place in terms of production worldwide (Government of Mexico, 2020), maize is one of the most imported cereals (Statista Research Department, 2022). Regarding labor force in maize cultivation, by 2021, this comprised 2 million people, with an average salary of \$948 for 37.5 hours a week (DataMéxico, 2021).

According to the Veracruz Institute of Municipal Development (Instituto Veracruzano de Desarrollo Municipal, INVEDEM, 2019) and the Statistical and Geographic Information System (Sistema de Información Estadística y Geografía) of the State of Veracruz by Ignacio de la Llave (SIEGVER, 2021), the State of Veracruz is one of the entities with the highest percentage of population employed in the countryside (21.7%). In 2019 alone, the total number of producers contributed “610.2 thousand tons of maize, with a yield of 2.2 tons per hectare and self-consumption of 53.7% of production”, Study Center for Sustainable Rural Development and Food Sovereignty Center for Studies for Development [Centro de Estudios para el Desarrollo Rural Sustentable y la Soberanía Alimentaria CEDRSSA], 2019, p. 10).

Although in the State of Veracruz, the main agricultural products are sugar cane, lime, orange and banana (National Institute of Statistics and Geography [INEGI], 2019a), in the municipality of San Juan Evangelista, Veracruz, 50.5% of the total surface used for agriculture is used for growing maize. This means that it is the main economic activity of a population characterized by its high rate of poverty and marginalization (Municipal Development Plan, 2018; SIEGVER, 2021).

This municipality is considered to be mostly dedicated to agricultural and livestock farming, although fishing also takes place; there is no research to describe or corroborate these activities. Even so, economic growth has not been achieved from the principal productive activity, because the hectares used for planting are mainly located in marginalized regions with medium or low productive potential. For this reason, production is mainly destined to self-consumption.

In order to boost productivity indices in the region, as well as socioeconomic development, this study sought to identify the feasibility of modernizing maize cultivation in the region of San Juan Evangelista, Veracruz, by implementing precision agriculture, using a diagnosis that takes a systemic approach. To this end, initially the theoretical data that corroborate the research are presented in a conceptual framework, with reference to precision agriculture. Subsequently, the methodological process is described and the method explained, along with data collection work, in order to develop a proposal for improvement by applying a SOWT analysis.

THEORETICAL FRAMEWORK

Traditional agriculture is not based on the use of modern technology. Rather, it is a rudimentary activity, where the way of working the land is based on ancestral and empirical knowledge, or practices that are communicated from generation to generation. For the most part, production depends on the physical capabilities of the farmer and his workers, as tools used consist of the sickle, hoe or shovel, and in some cases, the tractor, but not at maximum capacity. This means that both performance and the optimization of resources to produce better products are limited.

In the search to improve agricultural conditions, during the seventies, the incorporation of new approaches in agriculture initiated, in the form of support from technological advances and mechanization with agricultural equipment (Purón and Tejeda, 2021). Subsequently, at the end of the eighties and beginning of the nineties, with civil access to the Global Positioning System (GPS), this technology began to be incorporated into the management of agricultural tasks based on location; with this set of capabilities and tools, termed Precision Agriculture (PA) (Purón and Tejeda, 2021). From then on, up to the present, more than 269 research articles have been published on the topic, with Asian countries representing those which have made most contributions, in contrast to Latin America, in some countries such as Colombia, Ecuador and Mexico, only the intention for its application is apparent, (Díaz et al., 2021).

Mantovani et al. (2014) defined precision agriculture as the application of technologies and principles for the management of spatial and temporal variability, associated with all aspects of agricultural production. These authors, whose intention was to improve crop productivity and environmental quality, concluded that the application of technologies must comply with soil characteristics (chemical, physical, topographic, etc.), in order to make the most of soil resources and improve product quality. Therefore, the use of this type of agriculture must conform to soil type.

Concurring with these ideas, we have Rambauth's definition (2022); here precision agriculture refers to the use of Information and Communication Technologies (ICT), with the aim of obtaining detailed information on the characteristics of the soil, irrigation systems, amount of water and other variables related to the crops in a specific area or plot. This information can be used, both to describe the current state of these elements and to predict their future behavior, which allows the planning of strategies

to more effectively control and manage the variables involved in agricultural production. Therefore, precision agriculture includes a set of crop management strategies, applied with technological knowhow and according to the characteristics of the field and the production system, allowing producers to improve the use of resources and the quality of their harvests (Berger, 2019; De Carvalho et al., 2007, Ramírez et al., 2021), which, in the end, represents greater demand and consequently, greater economic returns.

The application of precision agriculture to produce traditional crops provides a variety of benefits to farmers, as it speaks, not only of procedures, but of great and better results in production, as indicated by Rambauth (2022), who mentions that It is about being able to produce the greatest amount of crops in the shortest possible time and at the lowest cost, while as far as possible respecting the environment. When talking about cost reduction, benefit is attributed to the use of suitable and improved agricultural machinery, as precision agriculture aims to reduce farmers' expenses, minimizing the need for fertilizers, pesticides and herbicides, as this technology uses components sparingly and only when necessary, for example alternatives to water jet spraying, has resulted in massive savings and allows farmers to budget better and keep costs to a minimum.

Likewise, by applying more effective practices, it is possible to produce higher quality products. This is achieved by various means, such as actively monitoring nutrient levels in the soil, carrying out cleaning and watering of plants precisely and only when necessary, thanks to information generated by precision agriculture systems. This, in turn leads to reduced waste, as with more efficient growing practices and healthier plants, crops are more likely to thrive, making growing seasons more sustainable. Furthermore, improvements in storage technology significantly reduce crop losses, during this phase.

As for management benefits, these refer to the processes necessary in crops for production. De Carvalho et al. (2007) reduced these types of benefits to four processes:

1. Sowing. Identification of problems or opportunities in the field for sowing the seed. Likewise, these help evaluate planting systems to enable ideal growth and development of the plant.
2. Fertilization and application. Assessment of crop quality and irrigation needs, knowledge of the quantities of each of the substances that the plant needs to develop and produce in greater quantity and quality and determination of effects on yield (insects, patches, weeds, etc.).
3. Harvest. Support in decision making, about the destination of the harvest; considering the need for drying and available storage capacity.
4. Planning. Improvement in the organization of field operations (greater efficiency).

Application of precision agriculture in maize crops

Generally, technologies adopted in precision agriculture are usually divided into three stages: data collection, processing and interpretation of information, and application of inputs (Flores, 2019; Moreira, 2022). However, for Hernández (2021); Mantovani and

Magdalena (2014); and De Carvalho et al. (2007), the application of precision agriculture is possible thanks to the evolution of five technologies:

1. Global Positioning System (GPS). Establishes the location and supports decision-making in real terms, to reduce errors in data collection.
2. Geographic Information System (GIS). Software composed of several modules dedicated to the storage and processing of data with known geographical location (geoprocessing), which enables the analysis of patterns, integration and spatial models, monitoring, simulation of precisions and presentation of a large amount of information in the form of maps, graphs, figures and multimedia systems; these contribute to decision-making for future intervention, in areas of low productivity.
3. Analysis of geo-referenced data (performance monitors and mapping). Spatial representation of data about yield, recorded during the harvest of a crop. The amount of information obtained at each point on the performance map depends on the monitor used; this may include: plant height, harvest yield, distance traveled, speed of advance, grain flow, grain humidity, crop losses, among others.
4. Remote sensing. Set of techniques that allow data about a certain object, area or phenomenon, to be collected and recorded through sensors; without direct physical contact.
5. Variable dose technologies (sensors, controllers and others). These allow for the mapping of variations; for example showing fertility within cultivated areas, and defining localized (or site-specific) management interventions, which seek to optimize the use of correctives and fertilizers by applications at varying doses, depending on requirements, according to the location of the crop.

Among the previous technologies mentioned for maize crops, those that stand out include, the use and application during the entire maize production phase, of platforms for data analysis to aid in decision making and remote perception, using drones and technologies with two-variables to optimize the fumigation process (Contreras, 2020; Ramírez et al., 2022).

Likewise, their positive impact on maize crops is apparent, as they generate increases of up to 10% in production, enable savings in the cost of inputs, reduce the environmental impact of maize crops and ensure greater performance, as they improve efficiency in the use of resources (Flores, 2019; González, 2022; Moreira, 2022; Ramírez et al., 2022).

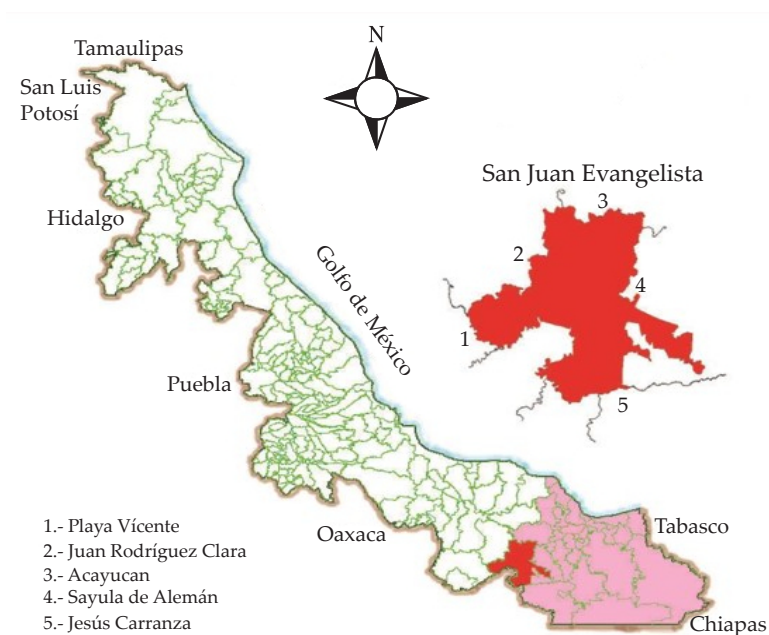
Among the limitations that should be considered when applying these tools are: lack of knowledge concerning systems and their use, farmers not wanting to substitute traditional procedures and lack of resources or the fear that this will not be profitable. In Mexico alone, one of the main factors that limits the use and application of precision agriculture is limited access to production factors, as traditional practices are more familiar, the low income of people who work the land, causing increased emigration and the scarce technical advice offered to land owners (López et al., 2019).

METHODOLOGY AND CHARACTERISTICS OF THE STUDY AREA

With a view to contributing to a reduction of marginalization and favoring an increase in economic development by the application of precision agriculture, a study was carried out in the municipality of San Juan Evangelista in the State of Veracruz, whose location is shown in Figure 1, where the agricultural production of maize predominates, as this is one of the most solicited crops in the country.

The first phase, consisted of a diagnosis taking a systemic approach, from which it was possible to identify the types of systems, tools, technologies and production techniques applied to maize crops, as well as their economic performance; simultaneously, the current state of maize cultivation in the municipality was described, and opportunities for growth were identified, by applying AP. Subsequently, the feasibility of modernizing the maize cultivation field using precision agriculture, as well as the implementation strategies of precision agriculture, were determined by applying an analysis known as SOWT, considering Strengths, Opportunities, Weaknesses, and Threats. Strategies were formulated (Cross references of variables) were undertaken using a SOWT Matrix. This technique was significantly adjusted to develop four categories of strategies: those comprising strengths and opportunities, those comprising weaknesses and opportunities, those comprising strengths and threats, and those comprising weaknesses and threats.

SO strategies use the internal environment's strengths to take advantage of positive aspects of the external environment (opportunities). The general rule concerning strategies is



Source: SIEGVER (2021).

Figure 1. Location of San Juan Evangelista, Veracruz.

formulated in the following way: WO, ST or WT to position oneself in the environment and thus implement SO tactics. WO strategies seek to overcome the weaknesses of the internal environment and benefit from external opportunities. Contrarily, in the case of ST strategies, strengths prevail by depriving or reducing the consequences of threats emanating from the external environment. Finally, WT strategies are defense strategies that seek to reduce internal weaknesses and curtail threats from the environment (Tobar, 2007). Finally, after having prepared cross-references of internal and external factors, the results were analyzed and similar strategies were combined, in order to generate a plan of action and a viable proposal for applying precision agriculture tools.

Sample selection

According to the Development Plan (2018), in the municipality of San Juan Evangelista, there is a total population of 1,080 maize producers, distributed throughout the 72 communities in the municipality. In order to carry out the study and with the objective of creating a state of knowledge about the current environment of maize cultivation in the region of San Juan Evangelista, Veracruz, a proportional sample was created consisting of 144 producers from the total, contemplating a sampling error of 10 %, a reliability margin of 2.57 and a probability of success and failure of .50 (Equation 1).

$$n = \frac{Z_{\alpha/2}^2 PQN}{\varepsilon^2 (N-1) + Z^2 PQ}$$

where n : necessary sample size; Z : reliability margin; P : probability that the event will occur; Q : probability that the event will not occur; E : estimation error; N : population size.

Subsequently, with the objective of distributing the entire sample throughout all the communities that make up the municipality and thus improving this study, by taking into account the diversity of experiences and practices of maize cultivation, in each of the different towns, a stratified sample was considered, with equal allocation of 2 producers per community (Equation 2).

$$\eta_h = \frac{\eta}{\mathcal{L}} = \frac{144 \text{ producers}}{72 \text{ communities}} = 2 \text{ producers by community}$$

Method for data collection

For the purposes of this research, a structured or directed survey method was used, as it ensures accurate information to be amassed.

This method consists of 23 aspects assigned to five categories of analysis, which refer to the farmer's personal information and his level of access to technology, the season and way in which he carries out the cultivation process, tools used during the planting process and the financial gain they obtain from planting.

Each of the statements was prepared intending to respond to the categories of analysis designed for this research, according to the context of the study area, permitting us to identify the type of maize grown, the type of soil present in the municipality, problems that arise during the cultivation process, the knowledge that farmers have about precision agriculture and the investment in technology that they are prepared to make.

It should be noted that to ensure the reliability of the method, Cronbach's Alpha coefficient was calculated, which is a measure used to evaluate the reliability and internal consistency of a scale or method. The value was calculated based on the results of the pilot test, applied to 5 maize producers in the municipality of San Juan Evangelista, contemplating the 23 aspects, resulting in a Cronbach's alpha value of 0.72, which represents an acceptable value for a method.

RESULTS

In the municipality of San Juan Evangelista, 54.8% of the population work in the agricultural sector; agriculture is the main economic activity (Veracruzano Institute of Municipal Development [INVEDEM], 2019). Likewise, 6.7% of the land is used for agriculture and of this total, 9,004 hectares are dedicated to the cultivation of maize, equivalent to 86.5% of the total hectares used for agriculture, with a yield of 3.4 tons per hectare (SEIGVER, 2021). An average of 1,080 producers are involved in cultivation; the majority sow 0.5 to 3 hectares and are located mainly in marginalized regions with medium or low productive potential; with production basically destined to self-consumption.

Traits of farmers

Farmers are almost entirely from the municipality (83%) and have families consisting of 4 to 5 people. Almost all farmers own the land they work (97%), and their income depends entirely on the use they give to the land. The work day they undertake consists of 8 hours working their land, permitting them to generate \$200 per day, plus drinks and food; and if this period is extended by one or two hours, this increases to \$300 or \$350 for the day worked.

Characteristics of maize cultivation

Of the total surface area, 85.4 km² are used for agriculture and on average, one hectare of maize is grown per farmer. Those who have land areas exceeding one hectare dedicate the extra space to livestock, and very few dedicate 2 hectares or more to planting. 83% produce white corn and 17% yellow corn, and depending on the season of the year and where they live, they are planted at high altitudes, or on plains or lowlands, consisting of areas that are sandy, gravelly, flagstone or black soil. It was observed that sandy (41%) and black soil (34%) predominate.

Regarding the preparation of crop lands, this process is carried out almost entirely, in an "artisanal" manner; 79% of farmers do this by hand, mowing or tilling 10 days prior to sowing, and subsequently, herbicides are applied to lengthen the time that the land

remains clear or they simply fumigate and then 3 or 4 days later, planting is undertaken. Prior to sowing, they keep their seed in barrels, bags or sacks and use chemicals such as “semebin”, either to either cure their seed or combat pests and maize diseases. During sowing, everyone uses picks or planting sticks and sowing is carried out in furrows, one meter apart with 50 cm between each hole, in which they deposit 3 to 5 seeds, resulting in a total of 200 plants per hectare. There are very few people who use a tractor to plant and they harrow and prepare the land ready for planting day (Figure 2). Based on the above, it is possible to affirm that the production instruments most used in maize cultivation are pointed digging sticks and spikes, which are tubes or sticks with a metal tip in the shape of a 10 to 15cm length shovel. (Figure 3). To a lesser extent, people use tractors, disc plows (made up of concave discs to open deep furrows), sub-soil excavators to remove deep soil, harrows and mowers. And throughout the area, chemicals are used to combat maize pests and diseases; this being the greatest expense made. Cultivation is usually based on *a priori* knowledge, looking for or waiting for signs of rain indicated by the color or state of the land; two recognized plantings are undertaken: seasonal, which occurs between the months of May-June, and “tapachol”, between the months of September-December. This suggests that farmers have not attempted to carry out analysis of soil characteristics.

Financial gain

In order to determine whether there is any relationship between the investment made by farmers and the yield they obtain, the Pearson coefficient was calculated, resulting in $r = 0.97$.

If this result is interpreted, it means that if a value less than 1, but close to +1, that is, $0 < r < 1$, the correlation between investment and performance is positive. In this instance, the more they invest, the greater the returns.



Source: own photography, in San Juan Evangelista, Veracruz.
Figure 2. Soil preparation for planting.



Source: own photography in San Juan Evangelista, Veracruz.

Figure 3. Farmer with spade.

Moreover, comparing national yield and that of the interviewed farmers, applying a simple t test, it was found that there is no statistical difference ($t=1.469$; $p=0.928$) between the national yield (3.2 ton/ha) and that of the farmers interviewed (3.5 tons/ha), so we can affirm that the yield is acceptable, compared to the national yield and considering level of investment.

Access to and use of technology

Although almost all communities have wireless network service in their community, 76% of farmers do not have access to any network on their plots; 20% have access to the telephone network and only 4% have access to WIFI network on their plot. As mentioned previously, all farmers use traditional tools; evidently, irrigation systems are lacking, and there is scarce use of tractor, plow, harrow or harvester (20%).

Finally, the existence of unattended problems becomes evident, for example climate change and the planting methods used, which affects the harvest and therefore the quality of the product and yields obtained. However, the farmers themselves recognize that they must improve planting techniques, as well as the tools used, and 65% of them would even be willing to incorporate technologies such as sensors or machinery in their production process.

More specifically, considering the total number of producers interested in using technology to grow crops, 53% are interested in implementing an automated irrigation system, and

42% are more interested in the use of remote sensors in their production process, while the rest would prefer to apply an automated fertilization system, due to the presence of pests. As for the investment they would be willing to make, this fluctuates between \$2,000 and \$4,000 pesos.

SOWT analysis

In the case of this study, the internal analysis focused on the strengths and weaknesses that exist in the municipality of San Juan Evangelista Veracruz. Then, in the external analysis, national and international factors were considered and simultaneously, the opportunities and threats found in the agricultural sector, specifically concerning the cultivation of maize.

Among the strengths of the San Juan Evangelista Veracruz municipality, stand out extensive highland soils, which continue to be productive because use of chemicals or large quantities of fertilizers is limited. Likewise, the division into “ejidos” has ensured that almost all of the residents have a plot of 20 hectares, so they have the opportunity to plant appropriate quantities and choose the area to be cultivated, depending on the season. Besides this, residents help each other to carry out the work, repaying a day’s labor with another day’s labor.

Considering weaknesses, limited access to communications networks and wireless technologies stands out, as well as the poor use of resources, as all farmers depend on traditional work methods and what they have learned from their parents and grandparents, leading to apathy regards changing the way they work by some, due to fear and uncertainty about whether the harvest will be abundant if they do something different. This has resulted in low profits from crops, few resources to implement new technologies and machinery, failure to adequately exploit land and crop losses.

Among opportunities we find, the use of specialized machinery and biotechnology, with which cultivation techniques could be improved, to maximize planting and take advantage of new markets abroad, to export surplus maize.

Another opportunity is the application of bioenergy, which consists of a type of renewable energy produced from the use of organic and industrial matter produced from certain biological or mechanical processes or where appropriate, making use of biofuels, which are obtained from renewable plant or animal biomass, enabling us to substitute fossil fuels obtained from petroleum. This could increase profits for all farmers and generate jobs.

Regarding threats, two general ones are evident: climate change and the introduction of genetically modified species. The first factor generates heavy rainfall, droughts, hurricanes and floods of higher intensity; and the second factor causes the extinction of many or all native species, due to preference for a more profitable product. These factors, in addition to increasing health risks and environmental damage, foster indecision when planting.

Then, a third is evident; the growing emigration of labor. As already mentioned, cultivation is essential for food production, however, a large part of the people who dedicate themselves to this work emigrate due to lack of money; this represents a threat,

because without sufficient labor, internal demand cannot be covered, leading to exports and increased expenses, due to the adoption of trade tariffs or barriers by some countries towards one or more countries.

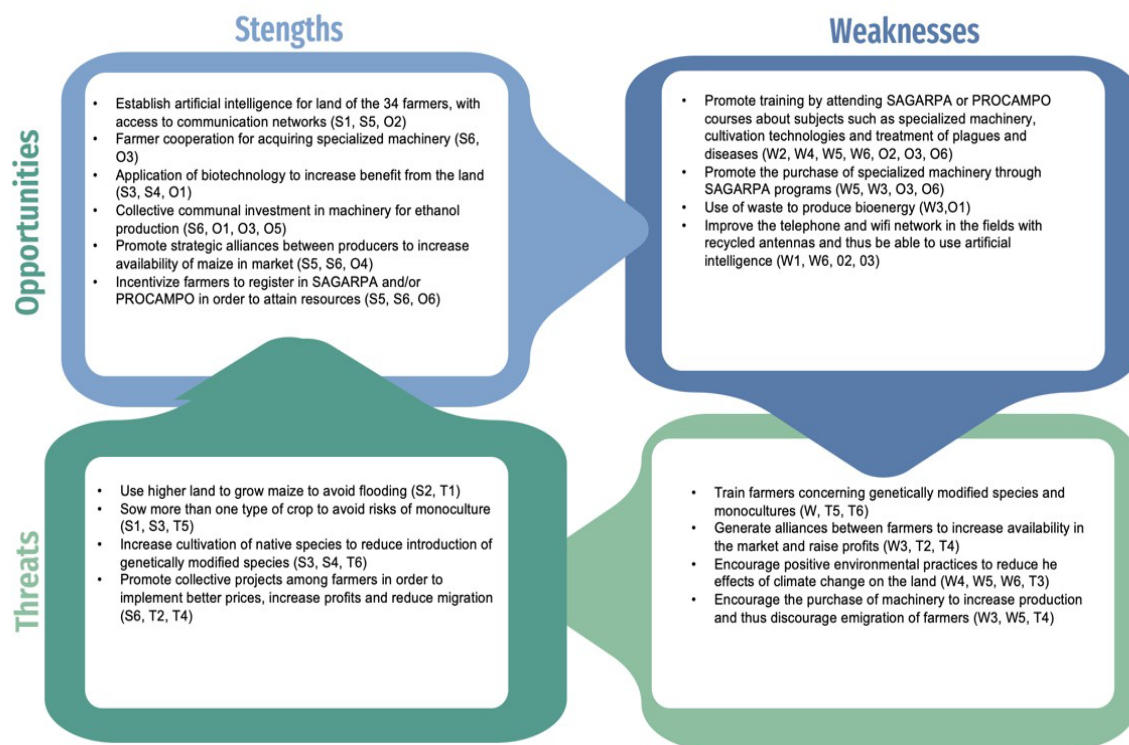
Finally, each of the factors that make up the SOWT analysis is presented according to its type, whether internal or external (Figure 4).

Based on the particular characteristics of the previous Strengths, Opportunities, Weaknesses, and Threats, cross-references were made between the relevant internal and external factors, from which it was possible to establish strategies for procedure and, with this generate the SOWT matrix with the four types of corresponding strategies (Figure 5). After having elaborated the SOWT matrix, the results obtained from the cross references were analyzed and similar strategies were combined, in order to elaborate a plan of action and a viable proposal for methods to apply precision agriculture. The plan of action (Figure 6) is made up of five strategic proposals:

1. Use of technology to implement precision agriculture.
2. Acquire specialized machinery to increase maize production and generate bioenergy (bioethanol).



Source: self-elaborated based on data from the interview and research carried out.
Figure 4. SOWT analysis.



Source: self-elaborated based on data from Figure 4.
Figure 5. SOWT matrix.

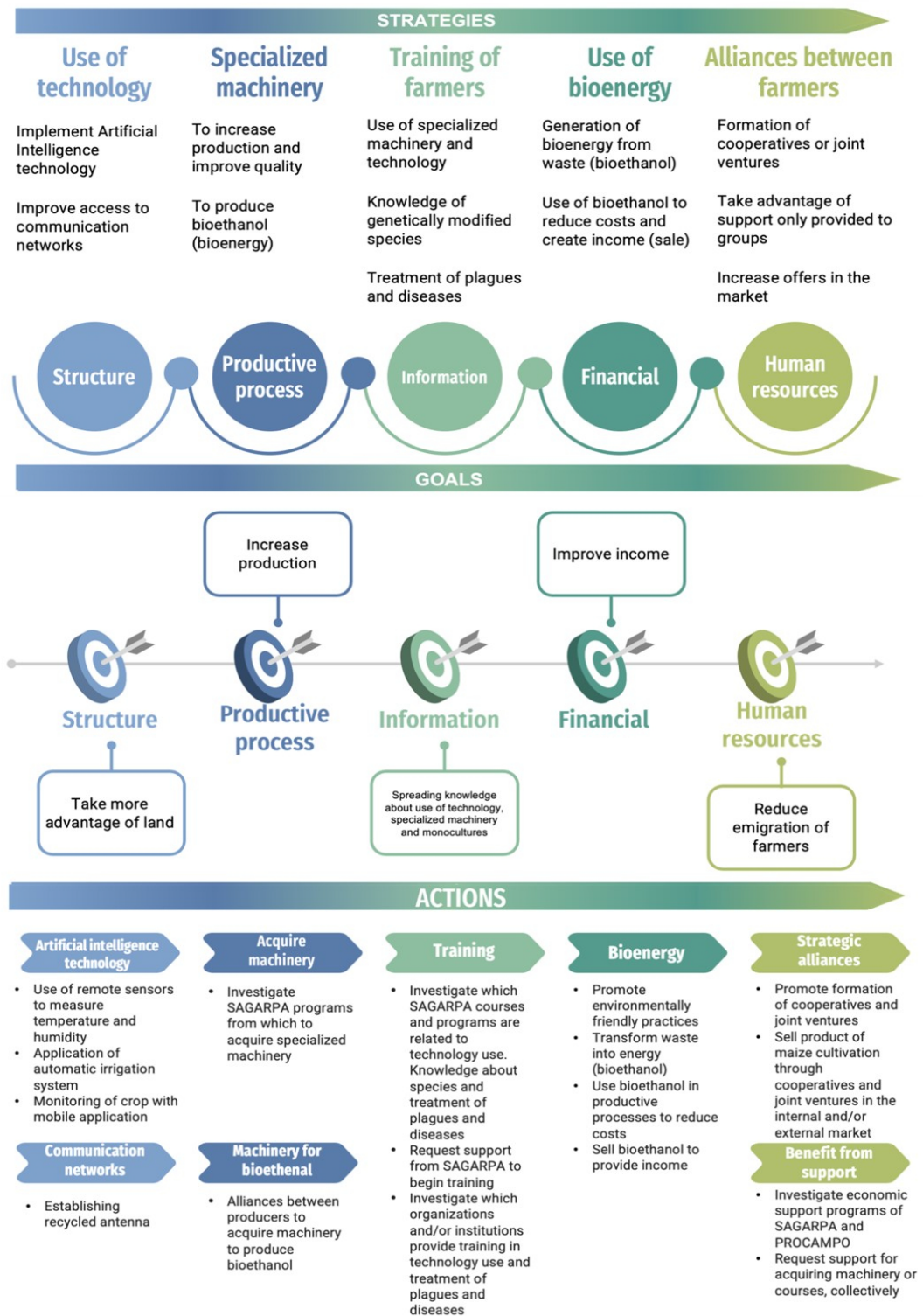
3. Train farmers in the use of specialized machinery and technology, about genetically modified species and in the treatment of pests and diseases.
4. Use of bioenergy to reduce costs and generate profits (bioethanol sale).
5. Promote the formation of strategic alliances between farmers, in order to increase opportunities for growth and development within the sector.

In turn, each of these strategic procedures has a particular objective, these include: improving land use, increasing maize crop production, providing information about the benefits of the use of technology, specialized machinery and monocultures, in order to generate greater income for producers and reduce migration of farmers

Technological proposals for precision agriculture

Based on diagnosis through technification of the maize field in the region of San Juan Evangelista Veracruz, with the application of precision agriculture and considering that only 34 farmers have access to a communication network, two main proposals are considered and a third overall of great impact.

The first proposal focuses on farmers with network access, as the use of variable dose technologies is proposed, with support from the Internet of Things (IoT), such as: sensors,



Source: elaborated by the authors, with data derived from collected and observed information.
Figure 6. Plan of action.

automated irrigation system and mobile app. Remote sensors are devices that convert physical magnitudes into electronic signals, which aid in the management and provision of information (Hernández, 2021) collected directly from the field, which aid decision making. These help improve the quality of crops, anticipate problems and improve the harvest. There are various types, going from those that allow the PH of the soil to be identified, to those that calculate the maturity of the crop; each of these adjusts to the needs of the producer and, they also represent economical tools, that are easy to use and apply.

Specifically, we propose measurement of temperature and humidity for this municipality, together with the use of an automated irrigation system. Automated irrigation systems are systems that with the help of sensors, measure humidity in the soil, thus enabling decisions to be made about when to hydrate and thereby save water consumption (Castro et al. , 2008).

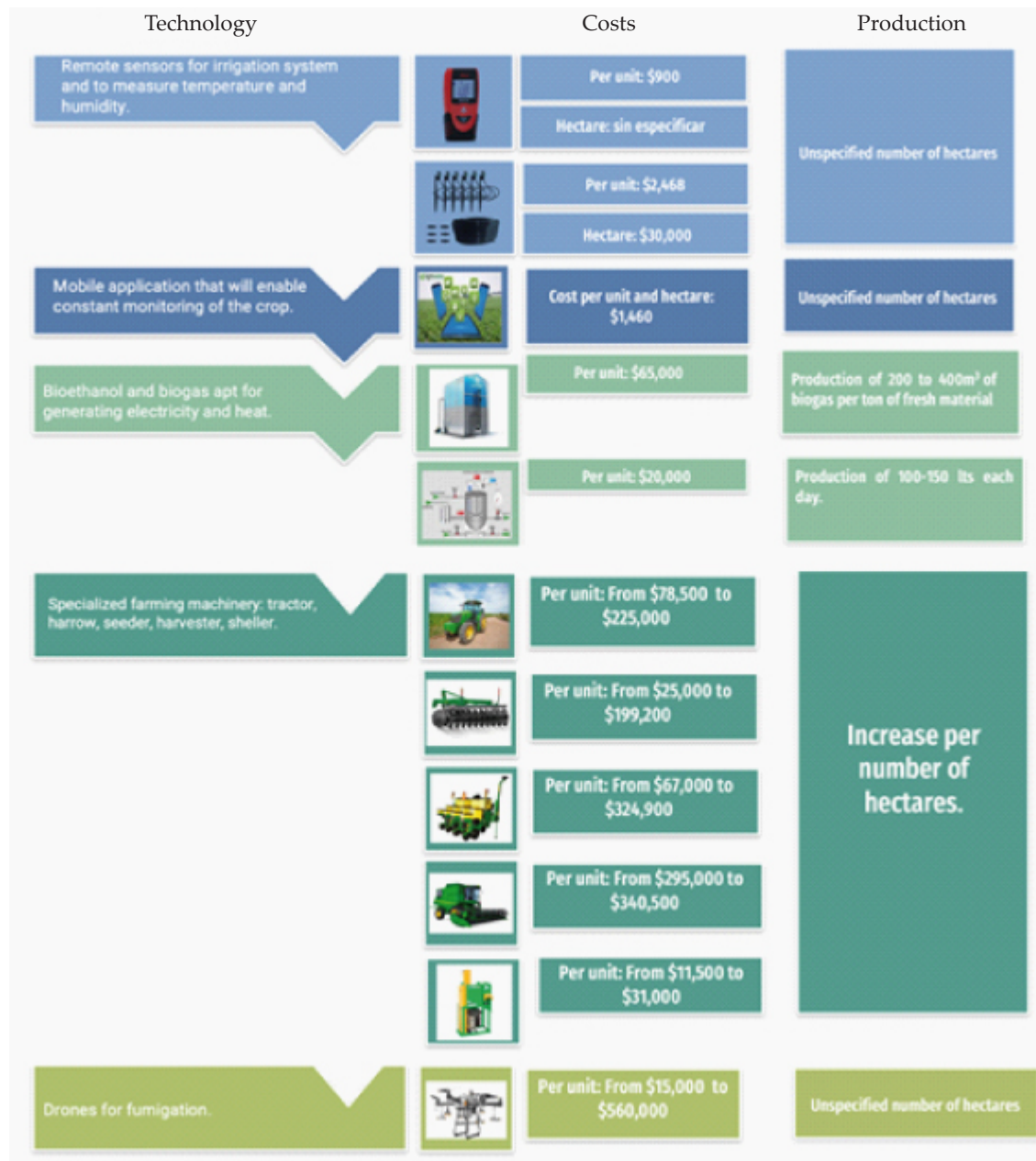
All this favors optimum plant growth and development, by establishing automatic irrigation. For their part, mobile applications represent technologies that permit remote monitoring. Although Rodríguez et al. (2022) only mention them in relation to monitoring climatic conditions, a variety of mobile applications exist that serve for planning, administration and control of the cycle from start to finish, and likewise, control of costs, finances and profitability, such as “Agroware”, which facilitates comprehensive management of the crop in an easy and practical way, using a mobile device. Therefore, its application will allow farmers in the municipality to constantly monitor their crops; and in conjunction with the use of specialized machinery in cultivation, an optimal environment can be generated to improve maize cultivation. Considering all this, it is important to highlight that these precision agriculture implements remain within the margin that those interviewed are willing to invest, which ranges from \$2,000 to \$4,000.

The second proposal consists of implementing the use of specialized machinery maize cultivation, to achieve optimal use of the soil and thus increase productivity. This will be achieved by each farmer working together with his other colleagues; machinery costs will be shared, whether by purchase or rental, and the option offered by municipal officials to provide machinery for cultivation will also be accepted, although payments for fuel will continue. The machines will be used for specific periods during established seasons; the number of farmers and work time required per hectare will be taken into account.

Finally, when considering the large amounts of waste that each farmer generates and the possibility of using it, the inclusion of bioenergy is proposed as a viable alternative, with the long-term goal of both providing income and benefiting the environment. Bioenergy refers to renewable energy produced from organic matter derived from specific crops or refuse from other industrial processes. In this way, agriculture offers a new option for producing energy, as an alternative to fossil fuels; from agricultural raw material waste, it is possible to produce biogas and bioethanol.

Evidently, if these proposals for precision agriculture technologies are incorporated, economic and harvest performance would increase significantly, even taking into account

the costs per hectare associated with the implementation of each of these technologies and introduction of specialized machinery (Figure 7).



Source: self-elaborated with images and data taken from websites (Gobierno de México (Mexican Government), 2022; Mercado libre, 2022a; Mercado libre, 2022b; Mercado libre, 2022c; Mercado libre, 2022d; Tractores y Maquinas (Tractors and Machinery), 2021).

Figure 7. Technological proposals for improvement.

DISCUSSION

Now that the current situation of maize crops in the region of San Juan Evangelista, Veracruz, and the problems faced by producers have been identified, we consider it important to work on the application of precision agriculture in the municipality, in order to contribute to the improvement of procedures, grain quality, yield and profits (Flores, 2019; Garelli, 2022); because, as mentioned in the results, only 20% of the producers in the municipality use tractors and combines and none use precision agriculture technologies in their production process, a case similar to that of other producers throughout the country, as described in the analysis carried out by García (2021), who states that there is a tendency in Mexico to undertake cultivation in a traditional way, using limited technology.

Rambauth (2022) mentions that thanks to ICT, a wide variety of resources have become available to agriculture, permitting more informed and precise decisions to be made for the cultivation of land; just as has occurred for maize producers in Ecuador, who apply disease and pest control systems, and drones to optimize the fumigation process (Ramírez et al., 2022); and in Argentina, where GPS is applied for monitoring maize yield and planting (Kemerer et al., 2020); resulting in greater efficiency in the use of resources and higher yields (Kemerer, et al., 2020; Ramírez et al., 2022).

However, we must not forget that it is important to devise a procedure for the application of technologies that are feasible to apply and that are within the investment possibilities of the municipality's producers, in order to truly respond to their needs. For Moreira (2022) and Ramírez et al. (2022), the use of drones represents the best method for monitoring and controlling maize cultivation; however, according to situation in the municipality analyzed and considering the aforementioned, only: remote sensors, automated irrigation systems, mobile applications, specialized farming and bioenergy machinery are applicable in this municipality. Of these five technologies, for Contreras (2020) and Kemerer et al. (2020), the development of sensors and devices, enable more effective management of the maize crop, by allowing corrections at precise moments (Argumedo, 2022; Contreras, 2020; Kemerer et al. 2020).

This concurs with González's idea (2022), about the importance of following a plan of action for the implementation of precision agriculture, as this allows more efficient management of its application, in terms of time and space, while guaranteeing improvement of various aspects with reference to monitoring.

Of the proposed technologies, those supported by IoT are the most recommended (Rambauth, 2022), as they permit cost reduction and minimize input losses within agriculture, while simultaneously improving productivity for the benefit producers and farmers (Ramírez et al., 2022). These contrast with specialized cultivation machinery, which seeks to optimize time in each of the harvesting processes, by replacing traditional methods with machinery such as the tractor, harrow, seeder, harvester, fumigator and sheller.

However, it should be noted that, although the IoT technological approach provides farmers with greater control and more effective and sustainable production, it involves a considerable initial investment and requires trained labor (Rodríguez et al., 2022); this leads us to conclude that the application of this type of technology is a remote possibility for small and medium-sized producers in the municipality, due not only to the absence of communication networks on their plots, but also to the investment required to acquire this type of technology (García, 2021; Rambauth, 2022), as well as the training for its use by producers (García, 2021; Kemerer et al., 2020).

In contrast, waste management is considered one of the most viable proposals, because it differs from that proposed by Rodríguez et al. (2022), where waste is used only as direct animal feed; the idea here is that, in the micro plantations, all crop residues are used, with the consequent generation of biogas and bioethanol, as products of the bioenergy process. These fuels may be used for own consumption or for sale. In this way, everything produced will be used and expenses can also be reduced with this extra profitable income, for general improvement of life quality.

CONCLUSIONS

Growing demand for food, soil degradation and various problems related to the environment require us to rethink means of production and analyze technological advances that allow the application of productive strategies, as part of a sustainable development approach. Precision agriculture presents viable alternatives through the use of information and communications technology, to support decision-making associated with crop production, in such a way that it allows demands to be met, without neglecting the environmental aspect.

In Mexico, maize represents the main staple and source of economic income for farmers, who sell certain percentages of their harvest.

After analyzing the situation of the municipality of San Juan Evangelista, Veracruz and its "ejidos", regarding the perspective of applying precision agriculture, while investigating context and future scenarios, it is evident that, despite the ready availability of land for cultivation and the potential to produce generous harvests, use of soil is inadequate, due to ignorance, tendency to maintain traditional work procedures and the low level of investment in improvements, on the part of farmers.

Evidently, changing from traditional crops to crops grown with improved techniques, as well as taking courses for improved use of chemicals or industrial products, and increasing knowledge for better use of the soil and implementations of technologies that help predict changes in climatic conditions, would allow the agricultural sector of the municipality to adequately integrate its productive processes and increase its production. Likewise, outlining and applying a strategic plan, in order to gradually incorporate precision agriculture techniques, would generate better opportunities in the future and also for regional development.

It is important to emphasize that there must be group participation by farmers in the municipality, to participate in the agricultural management of the municipal government, to introduce machinery to the fields, at less expense and with greater organization. Finally, it is essential to remember that any of the three proposals included in this document to begin implementing precision agriculture in the municipality may be useful, as the aim is to increase the productivity of crops, through a more efficient use of resources, ensure sustainability and minimize environmental risks.

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