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Technological proposal for a greater irrigated corn (*Zea mays* L.) production

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ABSTRACT
Objective: To validate the experimental results of corn (*Zea mays* L.) production under irrigation during the 2019-2022 autumn-winter cycles.
Design/Methodology/Approach: Six validation plots were established, three in the Cuxtepeques irrigation district and three in irrigation systems in Chiapas, Mexico.
Results: Corn grain production is 64% higher with the INIFAP technology than the traditional methods; however, the average yield obtained in the validation phase (11.5 t ha^{-1}) was lower than the yield of the experimental phase (15.9 t ha^{-1}).
Study Limitations/Implications: None.
Findings/Conclusions: Production requires machinery for sowing and precision fertilization, efficient irrigation infrastructure, access to credit, and permanent technical assistance to achieve yields similar to those obtained in the experiment.

Keywords: Corn; Irrigation; Frailesca, Chiapas.

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INTRODUCTION

Although corn (*Zea mays* L.) is native to Mexico, the country is unable to meet the needs of its population. Several production systems have potential in Mexico, including rainfed agriculture and irrigation on flat soils or hillsides (slopes). The highest productivity should be recorded in the latter system, decreasing the dependence on imports. Irrigated areas in Mexico are crucial to increase corn production, since they are not impacted by uncontrollable agricultural factors (*e.g.*, shortage or excess of rain, winds, etc.), during the spring-summer (SS) cycle. For their part, rainfed agriculture areas face greater risks.

Corn contributes 31.5% of the agricultural production value in Chiapas, occupying 690,653 hectares (SIAP, 2021), out of which 58,129 are distributed in four irrigation districts. The Cuxtepeques irrigation district is located in the region of La Frailesca, Chiapas, considered the main corn-producing area. This district is being under used for corn production; since only 40% of the 12,500-hectare land is irrigated, and the water is usually used to irrigate pastures (forages). Additionally, 10,000 hectares from irrigation systems (IS) are classified as fluvisols and are located on river banks. These IS use water in different forms and from different sources, such as direct intakes from rivers by gravity, pumping, water diverter structures, and artesian wells. Only 50% of the area is used to produce corn.

Although Chiapas has vast soil and water resources and a favorable climate for production, the average yield of irrigated corn is 4.0 t ha^{-1}, which is lower than the 8.0 t ha^{-1} national average.

Producers grow little irrigated corn as a consequence of low profitability. Therefore, based on a diagnosis of the irrigated areas, our results detect the lack of technology and technical assistance focused on driving greater productivity as the main causes, along with poor infrastructure conditions resulting from the lack of maintenance (Camas, 2017; Camas, 2020).

Therefore, during the 2017-2018 and 2018-2019 autumn-winter (AW) cycles the corn production model was evaluated under irrigation conditions with the purpose of helping to increase the productivity of the crop in La Frailesca, Chiapas, Mexico.

MATERIALS AND METHODS

A sub-split plot design with two replicates was established. The large plots (LP) were assigned to four treatments resulting from the combination of two sowing dates and two irrigation contributions (with and without limitation). The split plots (SP) were assigned to 26 treatments of a double hypercube design (central composite rotatable), divided into one third of a plot, in three incomplete lots, and two repetitions of the center (Cochran and Cox, 1957; Martínez and Martínez, 1996; Volke *et al.*, 2005). Hyperspace was explored using five equally spaced levels with four factors; $(80<N<240 \text{ kg ha}^{-1})\times(0<P_2O_5<160 \text{ kg ha}^{-1})\times(0<K_2O<160 \text{ kg ha}^{-1})\times(50 \text{ thousand } <D<90{,}000 \text{ plants ha}^{-1})$. The split plots (SP) were assigned to six hybrids. Each experiment had 1,248 sub-split plots where information on the best sowing date was generated and the optimal management of fertilizers, population density and hybrids were calculated.

The following agronomic recommendations were the result of the two-year experimentation in the Cuxtepeques irrigation district and the IS of Villaflores and Villa Corzo municipalities: sowing date from December 15th to January 15th; 90,000 seeds at sowing; 190N-160P-160K and 240N-160P-60K fertilization for the Cuxtepeques irrigation district and the irrigation systems, respectively. Taking into account that the regional diagnoses showed that all the soils have B deficiencies and that eight out of ten soils have Zn deficiencies, 2 kg ha^{-1} of B and 20 kg ha^{-1} of Zn were mixed with the first N-P-K fertilization (Camas *et al.* 2019). In this study, the validation was performed with cooperating producers as final users of technology. The main results are presented below.

Three plots were established in the Benito Juarez ejido, located on La Concordia municipality, Cuxtepeques District. Each plot belonged to each of the AW cycles (2019-2020, 2020-2021, and 2021-2022). In the IS of Villa Corzo, three plots were established in the 2019-2020 AW cycle. Loam soils and moderate organic matter stand out in the plots, except at El Limón. The 1.2 gr $cm^{3\ -1}$ apparent density corresponds to fine-textured soils. These physical characteristics favor soil tillage and the development of the corn crop.

El Cedral is a highly important locality where the pH is strongly acidic, exchangeable aluminum is found at a toxic level, and the percentage of aluminum saturation is close to 20%, which is considered the critical level for corn (Tasistro *et al.*, 2022). The rest of the localities do not record significant pH and exchangeable aluminum problems. Limiting B values and low to moderately low Ca values were detected (DOF, 2002). This result is of great importance to solve these limiting levels using amendments (Table 1).

Treatment distribution

Plots of 1.5 to 2.0 hectares were subdivided into 3,000-4,000 m^2 strips (one per hybrid). The INIFAP technology was established in two thirds of each strip, while the control or the producer's traditional management method was established in the remaining third.

Assessed treatments

Traditional management of the producer	INIFAP Technology
Medium to low yield genetic materials. Sowing: December 1 to 15 Planting density 70,000 seeds ha^{-1} Fertilization: Nitrogen with 180 to 240 units	INIFAP hybrids and transnational commercials with yield potential and adaptation to the region. Sowing: December 1 to January 25 Planting density 90,000 seeds ha^{-1}. Fertilization: with 190-160-160 for La Concordia and 240-160-60 in the Villa Corzo irrigation units for nitrogen, phosphorus, and potassium, respectively. Correction of micronutrients with militant levels in the soil.

Table 1. Soil chemical characteristics of the study locations.

Region	Location	pH water 1:2	MO %	P Bray	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	B	S	$N\text{-}NO_3$	Al	CIC	Sat Al
				Mg kg^{-1}												meq/100 g		%
La Concordia	La Vega	5.9	2.2	27	77	10.3	203	27	68	2	25	1.1	0.1	2	4	0.02	7.2	0.3
Villa Corzo	San Lorenzo	5.0	1.7	102	132	934	160	17	108	3	30	0.7	0.1	47	31	0.40	6.9	6.0
	El Limón	5.5	1.3	61	88	810	208	21	119	4	14	0.8	0.1	20	10	0.24	6.3	3.8
	El Cedral	4.8	1.6	34	74	756	147	34	83	1	22	0.6	0.1	44	21	1.43	7.5	19.1

Loc=locality; pH 1:2 in water; OM (MO)=organic matter; P=phosphorus; K=potassium; Ca=calcium; Mg=magnesium; Na=sodium; Fe=iron; Zn=zinc; Mg=manganese; Cu=copper; B=boron; S=sulfur; $N\text{-}NO_3$=nitrates; Al=aluminum; CEC (CIC)=Cation Exchange Capacity; and Al Sat (Sat Al)=aluminum saturation.

Assessed variables

Yield was estimated with three sub-samplings per strip (hybrid) for the two management treatments. The following items were quantified: number of plants at harvest, earless plants, total and diseased corncobs, poor pollination, shelling factor, 1,000-grain weight, harvest index, and economic indicators.

RESULTS AND DISCUSSION

In the experimental plots where the validated technology was generated, an average yield of 14.8 t ha^{-1} and 17 t ha^{-1} were recorded, for the localities of the Cuxtepeques irrigation district, municipality of La Concordia, and the IS San Pedro Buenavista, municipality of Villa Corzo, respectively.

These results exceed the 12 t ha^{-1} recorded by Turrent *et al.* (2004), in the Granos del Sur project during the 1997-1998 and 1998-1999 AW cycles, at the IS of Villaflores. The 70,000 seeds ha^{-1} density and base dose of 200N-100P-60K kg ha^{-1} fertilization of that study is lower than the 90,000 seeds density and the 240N-160P-60K kg ha^{-1} fertilization determined in the experimental phase of the 2017-2018 and 2018- 2019 AW cycles of this study. In addition, micronutrient limitation problems were not solved; therefore, the experimental results of the aforementioned cycles suggest an important technological difference. In the 2019-2020 AW cycle, the experimentally generated technology was validated in plots managed by the cooperating producer. In the four localities, all the hybrids had higher grain yield with the INIFAP technology, but with lower readings than those obtained in the experimental phase.

Traditional management (control) was exceeded by 52% with the use of the INIFAP technology and, at the local level, the increase was 57% in Benito Juárez, municipality of La Concordia (Table 2). The average yield obtained using INIFAP technology was 10.4 t ha^{-1}. This figure was higher than the 7.1 t ha^{-1} obtained during the technology validation of the Granos del Sur project during the 1997-1998 and 1998-1999 WA cycles.

The highest yield (12.3 t ha^{-1}) was obtained in the San Lorenzo locality using INIFAP technology. This result was related to the use of drip irrigation, which improved the efficiency of water use, unlike gravity irrigation, which has a $<$50% application efficiency at the plot level (Chávez *et al.*, 2010). The water used was obtained from an artesian well whose water table recorded a decrease in April. The producer chose to make his well deeper; nevertheless, irrigation provided with the appropriate irrigation lamina was limited when the temperature in the area reached 40 °C.

The greatest photosynthetic capacity in corn occurs in the flowering season; therefore, the assimilable matter available in this period is a critical factor that determines the yield of the grain and the lower carbon and nitrogen flow towards the developing grains, which is important since these determine their size (Lafitte, 2001). Cheikh and Jones (1994) mention that a temperature higher than 35 °C and a low relative humidity cause desiccation of the stigmas in corn, and that temperatures higher than 38 °C reduce the viability of pollen. Some estimates suggest that, for each degree centigrade (°C) above the optimum environmental temperature (25 °C) grain yield is reduced between 3 and 4% (Rincón *et al.*, 2006).

Table 2. Corn grain yield of commercial hybrids in four localities in La Frailesca, Chiapas, Mexico, 2019-2020 AW cycle.

Hybrid	Irrigation units of the municipality Villacorzo						Irrigation district Cuxtepeques municipality of la Concordia		Average	
	Villacorzo		San Pedro Buenavista				Benito Juárez			
	San Lorenzo		El Cedral		El Limón		La Vega			
	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness
Impact	11143 d	5312 f	6911 d	4506 fg	10662 cb	6559 d	11450 b	4384 e	10042	5190
P4279W	13833 a	6565 e	8245 b	5423 e	11949 a	5628 de	12433 a	5222 d	11615	5710
H-386	11715 c	6675 e	6994 d	4158 h	11474 ab	5403 e	10809 c	4903 d	10248	5285
H-568	12757 b	6522 e	7762 c	4221 hg	11683 ab	5549 de	11452 b	4930 d	10914	5306
H-377	11866 c	5256 f	8017 bc	4761 f	10256 c	5941 de	10873 c	4889 d	10253	5212
B3993			9256 a	5642 e					9256	5642
Average	12263	6066	7864	4785	11205	5816	11403	4866	10388	5391
% Increase	51		39		48		57		52	
DMS	475		343		1072		439			
CV	5		6		7		6			

The lowest yield in El Cedral (7.8 t ha^{-1}) was attributed to a high level of exchangeable aluminum with 19% aluminum saturation. Although this result did not exceed the critical level for corn (20%), it can influence the availability of other elements, such as phosphorus, potassium, and magnesium (Tasistro *et al.*, 2022). This suggests that, to obtain the maximum benefits of the nutritional recommendation of the proposed technology, it would be advisable to apply moderate amounts of dolomitic lime that help reduce aluminum and provide calcium and magnesium. Additionally, a higher harvest index (HI) was obtained in El Limón (Villa Corzo) using the proposed technology, which suggests a more efficient accumulation of dry matter in the grain (Escalante *et al.*, 2015). The shelling factor and the 100-grain weight had desirable values for all the assessed hybrids (Table 3).

Table 3. Harvest index (HI/IC), shelling factor (SF/FD), and 1,000-grain weight in five hybrids under irrigation. Locality of El Limón, San Pedro Buenavista ejido, municipality of Villa Corzo, Chiapas, Mexico, 2021 AW cycle.

Hybrid	IC		FD (%)		weight 1000 grains (g)	
	Technology		Technology		Technology	
	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness
Syngenta	0.45	0.40	85	82	312	288
H-386A	0.43	0.39	85	79	366	315
H-568	0.46	0.41	84	81	312	298
H-377	0.43	0.40	85	83	302	285
P-4072W	0.44	0.41	85	81	356	328
Average	0.44	0.40	85	81	330	303

In the 2020-2021 and 2021-2022 AW cycles, one of the cooperating producers oversaw two plots. This producer had been trained during previous cycles, when he participated in the validation plots using the proposed technology. The increase regarding control was greater than the yield for the 2019 and 2020 cycles, whose average readings of 9.4 and 11.5 t ha^{-1} represented an increase of 57% and 64%, respectively (Table 4). This result suggests that, with adequate training for the correct application of the components of the proposed technology, an increase in yield is feasible compared with the traditional management used by the producer.

Financial analysis in commercial validation plots

Excluding the yields of El Cedral —due to the aluminum problem that could not be solved in a timely manner—, the financial analysis (August 2022) indicates that the INIFAP technology obtained higher net benefit and benefit-cost than the traditional management in the Cuxtepeques irrigation district and in the irrigation systems. The net benefit and benefit-cost were higher when using INIFAP seeds, which are approximately 50% less expensive than commercial seeds, possibly because they are the result of a research carried out with public resources (Table 5).

Table 4. Hybrid corn grain yield in two localities of the municipality of La Concordia, Chiapas, 2020-2021 and 2021-2022 AW cycles.

Hybrid	Technology	Locality and cycle	
		El Alto OI 2020-2021	El Alto OI 2021-2022
		Yield[1] (t ha^{-1})	
SKW-505	INIFAP*	7.8[1]	
	Producer	4.5	
P4279W	INIFAP	9.3	10.1
	Producer	4.9	4.1
P4028W	INIFAP	10.3	
	Producer	6.1	
P3966W	INIFAP		11.5
	Producer		4.2
NB-830	INIFAP	10.1	
	Producer	6.2	
B3937	INIFAP		13.6
	Producer		4.2
B3916	INIFAP		10.7
	Producer		4.3
H-377	INIFAP		11.6
	Producer		3.9
Average Yield	INIFAP	9.4	11.5
	Producer	5.4	4.1
Increase in yield		57%	64%

[1] Real yield; *INIFAP technology applied by a cooperating producer.

Table 5. Financial analysis of corn production using INIFAP and traditional technology in the Cuxtepeques irrigation district and the Villaflores and Villa Corzo irrigation systems, La Frailesca, Chiapas, Mexico.

	Locality							
	Irrigation district Cuxtepeques, La Concordia				**Irrigation units of Villa Corzo and Villaflores**			
	Technology INIFAP		**Technology Testigo**		**Technology INIFAP**		**Technology Witness**	
	Seed		**Seed**		**Seed**		**Seed**	
	INIFAP	**Company**	**INIFAP**	**Company**	**INIFAP**	**Company**	**INIFAP**	**Company**
Total cost ($)	44985	47080	26463	28591	45324	47879	28405	29945
Yield (t ha^{-1})	11322	11184	4403	4807	11625	11897	5891	6016
Gross profit ($)	72891	72002	28346	30947	74680	76593	37926	38731
Net profit ($)	27906	24923	1883	2357	29357	28714	9522	8786
B/C	1.6	1.5	1.1	1.1	1.7	1.6	1.3	1.3

*Average yield of validation in the 2019-2020, 2020-2021, and 2021-2022 AW cycles.

These results suggest that —in the event of the reactivation of the 12,500 hectares of the Cuxtepeques irrigation district and the approximately 10,000 hectares in the irrigation systems— 259,000 tons of white and yellow corn could be produced in the AW cycle, using the INIFAP technology, which would represent a net profit of 62 million pesos (García *et al.*, 2000).

CONCLUSIONS

The technology proposed by INIFAP increases the production and profitability of irrigated corn by more than 50% with respect to the traditional management of producers in La Frailesca, Chiapas. Once the irrigation infrastructure, equipment, and input problems are solved, larger increases could be obtained.

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