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Article

Spatiotemporal dynamics of the use of agricultural technologies in DDR 043 Durango

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Abstract

The study analyzed the evolution of agricultural technology use in the Rural Development District 043, Durango, from 1991 to 2019 and its impact on productivity and agricultural area. Based on spatiotemporal analyses using GISs and descriptive statistics, there was a more than 50% increase in the technified area with irrigation between 1991 and 2007, which remains stable until 2021, and a greater use of chemical fertilizers and herbicides. These results show rural modernization processes and sustainability challenges.

Keywords:

agricultural landscape, agricultural technification, rural development district.

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Introduction

Agricultural landscapes, the result of the interaction of ecological and social factors, offer essential ecosystem services (raw materials and scenic beauty) (Kizos and Spilanis, 2004; Popa, 2014; Jones *et al*., 2016; Gaitán-Cremaschi *et al*., 2017; Yang *et al*., 2022). However, as dynamic systems influenced by policies, technological advances, and economic interests, they are exposed to environmental impacts that are difficult to foresee and to processes of social unsustainability (Gutiérrez-Yurrita, 2007; Molinero, 2013).

In Mexico, agricultural modernization has been promoted through public policy instruments, such as the creation of rural development districts (DDR, by its Spanish initialism) in 1988 and the Sustainable Rural Development Law (2001), to optimize resources and promote comprehensive rural development (DOF, 1987; DOF, 1988; DOF, 2021). Nevertheless, agricultural development has been uneven, as the north and center have more infrastructure and technology, while the south practices family farming with less access to resources and technical support (Hernández, 2014; Vázquez and Cruz, 2014; FAO, 2018).

This inequality is reflected in the Durango countryside, whose agriculture is represented by 60% of smallholding units (INEGI, 2016). On the other hand, national and regional agriculture faces challenges such as growing demand for food, land use change, climate change, and natural resource degradation, making it necessary for producers to balance productivity and sustainability through the use of innovative and affordable technologies (Aguilar and Ortiz, 2000; FAO, 2015).

Therefore, this work aimed to analyze the use of agricultural technologies over time and its impact on the productivity and agricultural area of DDR 043.

Materials and methods

The study was conducted in the rural development district (DDR) 043, located in the south of the state of Durango, covering the municipalities of Canatlán, Durango, Mezquital, Nombre de Dios, Nuevo Ideal, Poanas, Súchil and Vicente Guerrero, which represents 22.01% of the state territory (≈27 134 km^2).

A mixed exploratory-descriptive design was followed to analyze the changes in land use and vegetation during the 1997-2009 and 2009-2021 periods, through map algebra and Boolean aspects, with the ArcGIS and Idrisi Selva software and series I, IV, and VII of INEGI (scale 1:250 000), a reclassification of maps was carried out based on the proposal by Palacio-Prieto *et al*. (2004) to homogenize the information and subsequently perform a cross-tabulation between series.

Likewise, descriptive statistics from the Agricultural and Ejido Censuses (1991, 2007, 2022) were used to evaluate the evolution of the agricultural frontier relative to other land uses, technification, and regional production.

Results and discussion

Land use change

The land-use analysis shows that forests predominate in DDR 043; from 1997 to 2021, rainfed agriculture declined, and human settlements increased. Although most of the area remains conserved, irrigated agricultural land increased between 1997 and 2009 due to productive activities and changes in use. In that period, irrigated agriculture increased by 51 420.31 ha, whereas scrublands decreased by 119 976.56 ha and rainfed agriculture decreased by 9 368.75 ha (Table 1).

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Table 1. Balance of land use cover in DDR 043 from 1997 to 2009.

Categories	Increases in areas to other covers (ha)	Loss of original areas (ha)	Balance (ha)
Irrigated agriculture	61 496.88	10 076.56	51 420.31
Rainfed agriculture	60 439.06	69 807.81	-9 368.75
Forest plantation	28.13	50	-21.88
Natural vegetation	338 670.32	406 646.89	-67 976.56
Human settlements	12 009.38	3.13	12 006.25
Bodies of water	15 032.81	1 092.19	13 940.63

Prepared using information from series I and IV of land use and vegetation data from INEGI.

Between 1997 and 2009, the scrubland area was converted to areas for irrigated (0.21%) and rainfed agriculture (0.28%), and the grassland area was also converted to the same modalities (0.48% and 1.35%). Rainfed agriculture went to grassland (0.51%) and both types of agriculture to human settlements (0.15% and 0.17%). Also noteworthy were conversions from scrubland and grassland to forest (3.67% and 1.55%), from forest to jungle and grassland (1.43% and 2.76%), and from rainfed to irrigated agriculture (1.54%) (Table 2).

Table 2. Land-use change matrix in DDR 043 from 1997 to 2009 (%).

Categories	Irrigated agriculture	Rainfed agriculture	Forest plantation	Forest	Rainforest	Scrubland	Grassland	Other types of vegetation	Human settlements	Bodies of water
Irrigated agriculture	2.16	0.12	0	0.01	0.01	0.02	0.04	0.01	0.17	0
Rainfed agriculture	1.54*	6.5*	0	0.17	0.02	0.15	0.51	0	0.15	0.03
Other areas	0.51	0.65	0	0.55	0.81	0.48	0.93	0.25	0.11	0.84

*= higher rates. Prepared using information from series I and IV of land use and vegetation data from INEGI.

Regarding the 2009-2021 period, forests recorded the largest increase in area, with 32 523.4 ha, whereas grassland was the cover that decreased the most, losing 21 271 ha. Irrigated agriculture showed a notable growth of 4 493.75 ha, while rainfed agriculture fell by 12 692.19 ha (Table 3).

Table 3. Balance of land use cover in DDR 043 from 2009 to 2021.

Categories	Increases in areas to other covers (ha)	Loss of original areas (ha)	Balance (ha)
Irrigated agriculture	9 378.13	4 884.38	4 493.75
Rainfed agriculture	11 771.88	24 464.06	-12 692.19
Forest plantation	217.19	1.56	215.63
Natural vegetation	93 951.56	94 676.57	-725
Human settlements	5 621.88	56.25	5 565.63
Bodies of water	5 089.06	1 962.5	3 126.56

Prepared using information from series IV and VII of land use and vegetation data from INEGI.

The largest trends of change observed were from grassland to forest (1.22%), from rainfed agriculture to grassland (0.44%), and from rainforest to forest (0.48%). On the other hand, the transformation from both irrigated and rainfed agriculture to human settlements was low, registering 0.08% and 0.05%, respectively. In addition, rainfed agriculture showed a trend of becoming irrigated agriculture of 0.16%. On the other hand, grassland presented probabilities of change to irrigated and rainfed agriculture, with values of 0.10% and 0.26%, respectively. Nonetheless, rainfed agriculture showed a greater propensity (0.44%) to be converted to grassland (Table 4).

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Table 4. Land-use change matrix from 2009-2021, in DDR 043 (%).

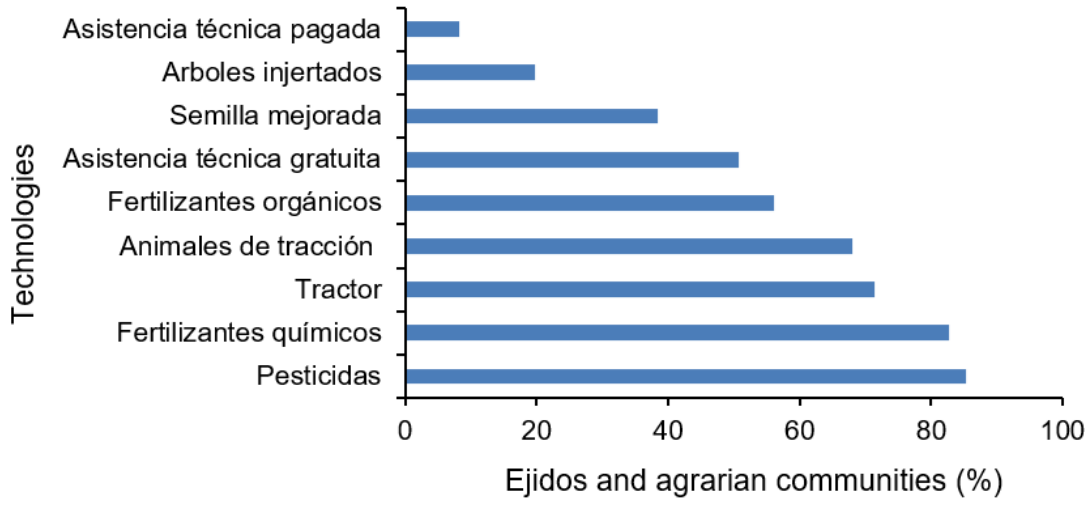
Categories	Irrigated agriculture	Rainfed agriculture	Forest plantation	Forest	Rainforest	Scrubland	Grassland	Other types of vegetation	Human settlements	Bodies of water
Irrigated agriculture	4.24	0.04	0	0.01	0	0	0.03	0.01	0.08	0.01
Rainfed agriculture	0.16	7.82	0	0.12	0.04	0.07	0.44*	0	0.05	0.02
Other areas	0.18	0.13	0.01	55.46	6.05	5.32	15.36	0.32	0.56	0.97

Prepared using information from series I and IV of land use and vegetation data from INEGI.

Use of technologies

In 1991, INEGI collected information on 97% of the ejidos and agrarian communities in DDR 043 (n= 244). The most used technologies were pesticides (82%) and chemical fertilizers (82.7%), whereas paid technical assistance was used the least (8.2%) (Figure 1).

Figure 1. Percentage of technology use in DDR 043, 1991. Prepared based on the INEGI Ejido Census, 1991.



According to the 2007 Agricultural Census of INEGI, DDR 043 registered 269 723.3 hectares of agricultural land, of which 35.2% used fertilizers and 25.5% used chemical herbicides; in contrast, the use of organic insecticides (0.23%) and hand tools (0.86%) was limited (Figure 2).

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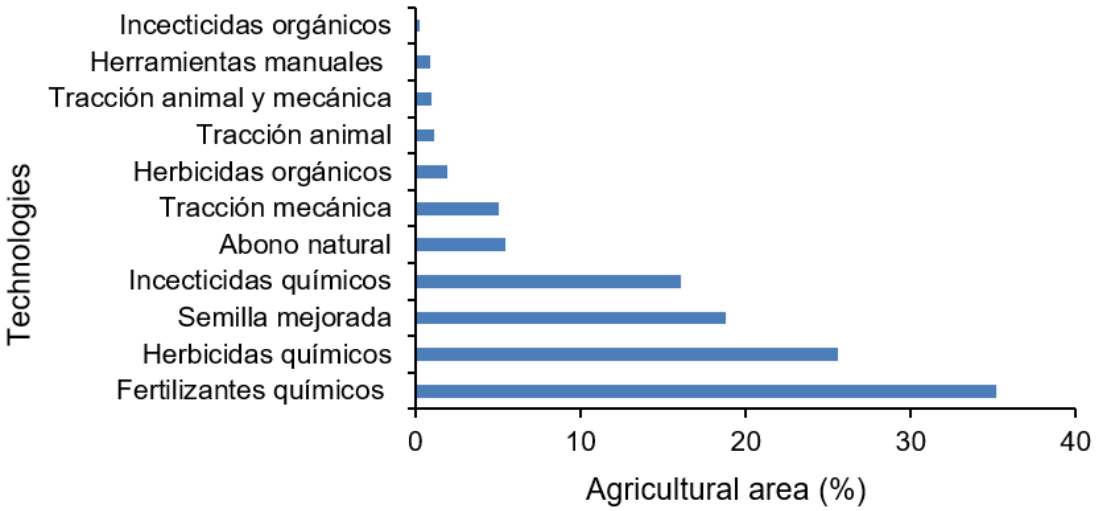
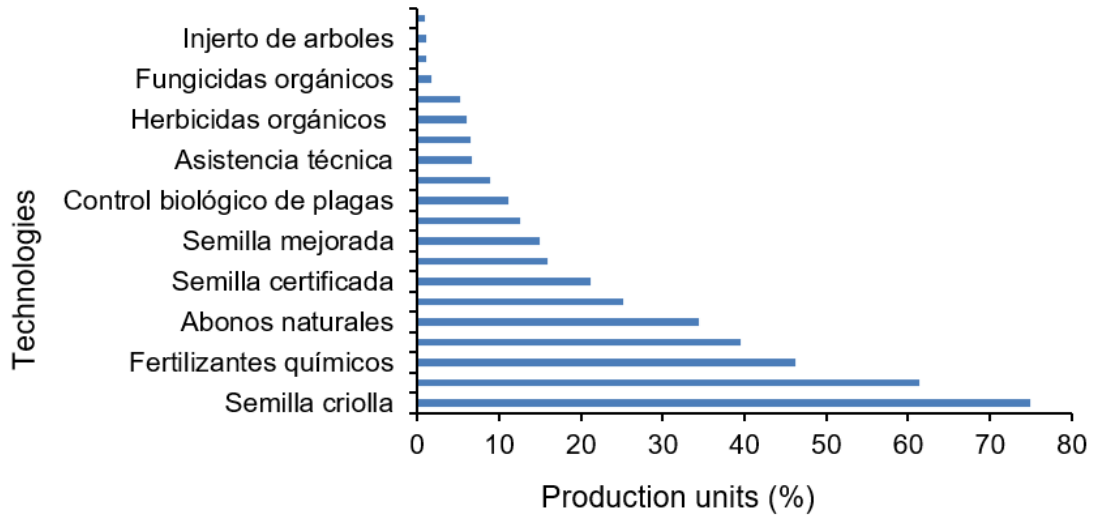
Figure 2. Percentage of use of technologies in DDR 043, 2007. Prepared using information from series I and IV of land use and vegetation data from INEGI.



In 2021, INEGI reported 15 352 agricultural production units in DDR 043, mainly in Durango, Mezquital and Nuevo Ideal. Seventy-four-point nine percent used improved seed and 61.3% used herbicides. Transgenic seed and mulch were the least adopted technologies, present only in 0.88% and 1.06% of PUs, respectively. The 2021 census included other technologies such as biological control, fungicides, certified and transgenic seeds and crop rotation, among others (Figure 3).

Figure 3. Percentage of use of technologies in DDR 043, 2021. Prepared based on the 2021 Agricultural Census by INEGI.



Because the 1991, 2007 and 2021 censuses used different measures, it was not possible to directly compare the use of agricultural technologies in DDR 043. In 1991, ejidos and communities were counted, whereas subsequent censuses recorded the planted area and production unit. The data show how the irrigated area has changed: although rainfed agriculture predominated and grew between 1991 and 2021, the area under irrigation increased by more than 50% between 1991 and 2007 and then remained stable until 2021 (Figure 4).

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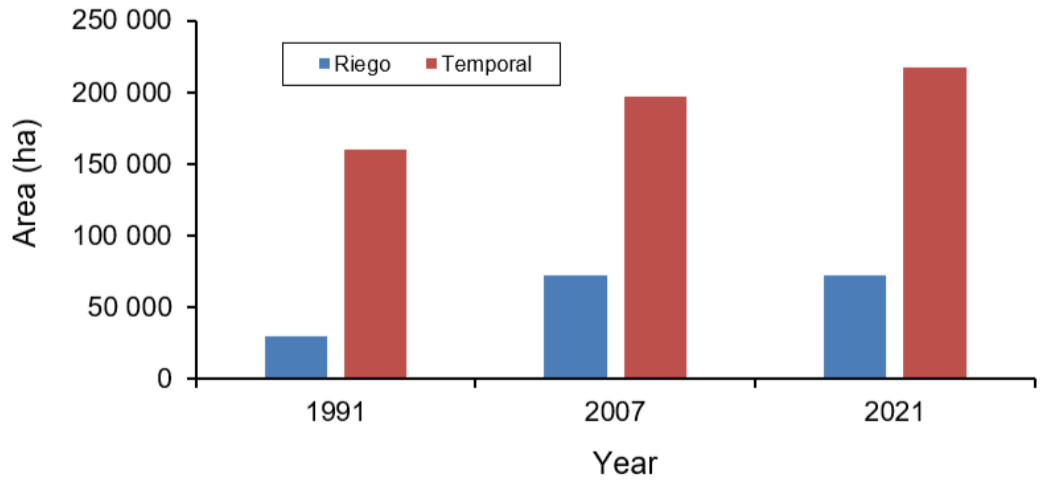
Figure 4. Agricultural area by water modality in DDR 043, 1991, 2007 and 2021. Prepared based on the 1991 Ejido Census and the 2007 and 2021 Agricultural Censuses of INEGI.



Production function

According to INEGI, DDR 043 had six main crops in 1991 and 2007, and 16 in 2021. The constant crops were forage oats, barley, beans, corn (forage, yellow, white) and sorghum (forage and grain). The cultivated area increased from 155 801 ha in 1991 to 214 481 ha in 2021. Corn and beans were the most planted, but the highest yields corresponded to sorghum and forage oats (Table 5).

Table 5. Production of DDR043, spring-summer cycle in 1991, 2007 and 2021.

Crop	1991		2007		2021	
	Planted area (ha)	Yield (t ha^{-1})	Planted area (ha)	Yield (t ha^{-1})	Planted area (ha)	Yield (t ha^{-1})
Forage oats	20 435.9	1.6	49 702.2	12.8	38 320.4	14.8
Barley	1 837	0.8	*	*	257.8	2.4
Beans	64 644.1	0.5	55 618.5	0.7	90 124.9	0.5
Corn	68 139.5	1.1	83 829.7	3.4	82 841.7	8.6
Sorghum	745.2	2.7	2 745.6	29.8	2 937.1	10.6
Total	155 801.7		191 896.1		214 481.9	

*= data not recorded in the census. Prepared based on the 1991 Ejido Census and the 2007 and 2021 Agricultural Censuses of INEGI.

During the autumn-winter cycle, DDR 043 recorded six main crops in 1991 and fifteen in 2021. The planted area rose from 6 946.98 ha in 1991 to 19 454.04 ha in 2007 and fell to 1 469.13 ha in 2021. Forage oats were the main crop with the best yields in all years (Table 6).

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Table 6. Production of DDR 043, autumn-winter cycle in 1991, 2007 and 2021.

Crop	1991		2007		2021	
	Planted area (ha)	Yield (t ha^{-1})	Planted area (ha)	Yield (t ha^{-1})	Planted area (ha)	Yield (t ha^{-1})
Forage oats	2 519.73	4.68	14 539.65	13.6	797.28	23.75
Barley	836.5	1.98	*	*	184	2.58
Beans	25.17	0.6	2 078.52	0.5	61.99	0.64
Corn	39	1.14	1 938.97	3.46	313.14	15.98
Sorghum	179.75	1.96	*	*	13.25	29.71
Wheat	2 346.83	1.63	896.9	5.84	99.47	04.01
Total	5 946.98		19 454.04		1 469.13	

*= data not recorded in the census. Prepared based on the 1991 Ejido Census and the 2007 and 2021 Agricultural Censuses of INEGI.

DDR 043 had seven major perennial crops in 1991, five in 2007 and seventeen in 2021. The most constant were alfalfa, sugarcane, walnuts, grass and apples. The total area of these plantations grew by 50% between 1991 and 2007 and fell by 40% between 2007 and 2021, a trend also observed in the area under production. Apples had the largest area planted and in production in 2007 and 2021 (Table 7).

Table 7. Production of DDR 043, perennial crops in the 1991, 2007, and 2021 cycles.

Crop	1991			2007			2021		
	Total area (ha)	Plantations in production (ha)	Production obtained (t)	Total area (ha)	Plantations in production (ha)	Production obtained (t)	Total area (ha)	Plantations in production (ha)	Production obtained (t)
Alfalfa	376.64	373.1	9 540.57	4 434.7	4 284.93	306 679.35	6 508.2	6 365.6	526 709.1
Sugarcane	14.32	14.32	89.45	*	*	*	2	0.75	13.57
Walnuts	*	*	*	1 403.2	1 276.61	2 492	244.9	176.65	199.33
Grass	8 861.43	792.3	1 306	6 775.6	6 653.11	110 748.41	417.46	219.22	1 351.85
Apples	*	*	*	5 650	5 349.49	37 171.51	4 012	3 300.75	7 483.39
Total	9 252.39	1 179.72	10 936.02	18 264	17 564.15	457 091.27	11 184.7	10 062.97	535 757.24

*= data not recorded in the census. Prepared based on the 1991 Ejido Census and the 2007 and 2021 Agricultural Censuses of INEGI.

As observed by Trucíos-Caciano *et al*. (2012), although part of the territory retains its original use, there is a gradual conversion of natural vegetation areas (forests and scrublands) to agricultural uses. In addition, Trucíos-Caciano *et al*. (2022) indicate that landscape fragmentation and reduced vegetation cover are due to unsustainable production practices, such as limited adoption of sustainable technologies and constant pressure on natural resources.

Technological adoption in DDR 043 was low and uneven, favoring profitable crops and increasing the social and territorial gap. Differences in the censuses make it difficult to compare technologies between large and small farms; nevertheless, chemical fertilizers and herbicides are the most widely used, with a 7% increase nationally between 2012 and 2018 (CEDRSSA, 2020).

There are about 140 unauthorized pesticides in the country, including 19 dangerous herbicides; although they favor agricultural production, their improper use can harm the environment and health, which is why the Secretariat of Science, Humanities, Technology, and Innovation (SECIHTI, by its Spanish acronym) (formerly CONACYT) recommends bioherbicides as a sustainable alternative. The legislation recognizes irrigation as a key technology, and the INEGI censuses allow the evaluation of agricultural evolution and the efficiency of these systems.

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In DDR 043, crops such as apples, corn, beans, and forage oats have increased their yields in the period studied (Urrutia-Cardenas *et al*., 2023). According to Hernández *et al*. (2021), DDR 043 has lower productivity than the Laguna Region due to its lower irrigation water availability (24% *vs* 60%), since its dams are small.

On the other hand, national development plans show low agricultural technification (Solleiro *et al*., 2015; Rendón *et al*., 2015). In the case of the state of Durango, CONACYT and SAGARPA (2018); Robles (2016) proposed strengthening extension services in the face of climate change and limited technological adoption.

Conclusions

The agricultural modernization of DDR 043 between 1991 and 2019 was limited and uneven, since although land use was maintained, irrigation agriculture increased and rainfed agriculture decreased due to urban and forest expansion. Technological change could not be analyzed due to a lack of census data; however, the use of fertilizers and herbicides increased, which generates environmental and health risks, so it is recommended to seek safe and sustainable alternatives.

Rural laws consider irrigation vital for agricultural progress, but insufficient water infrastructure reduces DDR 043's productivity compared to other districts and primarily benefits those who make greater investments.

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