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HISTORIC DEVELOPMENT OF WINTER-WHEAT YIELDS IN FIVE IRRIGATION DISTRICTS IN THE SONORA DESERT, MEXICO

CÉSAR A. SALINAS-ZAVALA, SALVADOR E. LLUCH-COTA and IRA FOGEL

SUMMARY

The history of development of winter wheat cultivation in five irrigation districts in northwestern Mexico is analyzed. The accelerated growth of winter wheat yields in northwestern Mexico can be described by adjustment of the parameters of the logistic model. A common variation in the analyzed series exists, which is determined by the positive tendency of the series, a product of the Green Revolution. This event explains 80% of the observed variation. Nevertheless, social and economic conditions, and regional geography, suggest differential development. Four agricultural developments are defined: Borders (Mexicali-San Luis-Río Colorado), Indigenous Agriculture (Ejidales Colonias Yaquis), Private Agriculture (Valle del Yaqui and Mayo), and Pioneers (Valle de Santo Domingo in Baja California Sur). The development of each group is compared with the national efficiency curve. The purpose is to compare wheat yields in the main irrigated valleys of northwestern Mexico during the Green Revolution and the following stabilization, based on social and historic events. The possibility of increasing productivity as a function of the historic maximum reached at regional and national levels is discussed.

History

Northwestern Mexico is one of the nation's most productive and economically important regions. The development of its agriculture was intimately bound to the Green Revolution (Bazlul, 1986). The background of regional agricultural development includes participation of community organizations called *ejidos* (Gordillo, 1988), managerial agriculture (Durán, 1988), and mechanized agriculture. High yields of wheat in this region have generated interest in understanding this development (Michaels, 1981).

There are three periods in the recent agricultural development of Mexico: before the 1940s, between 1940 and 1965, and after 1965 (Hewitt, 1976). At present, Mexico is immersed in a critical issue in field production. Because of recent reforms to Article 27 of the Mexican Constitution, a new period of capital investment in Mexican agriculture will take place (Wong, 1993).

The pattern of development during the '40s was largely characterized by the concentration of investment and irrigation infrastructure in the north to favor the private local sector. The rural sector in the rest of the country continued to depend on rainfall. In the 25 following years, considered the golden era of modern Mexican agriculture (Robles, 1988), progress was made in Mexican agriculture. After World War II, the Mexican agricultural sector was oriented to export, with foreign currencies used for payment of goods and capital necessary for the industrialization promoted by the federal government. This polarized the agricultural sector, because an important characteristic of Mexican agriculture is the inequality in the level of development among regions (Luisselli, 1988).

With the land reforms made by the President Lázaro Cárdenas administration (1935-1940), cultivated areas and agricultural exports increased. This process is known as the extensive phase of Mexican agriculture, placing the agricultural sector into leadership in exports, thanks to large surpluses (Rubio, 1988).

The balance of this development was positive until the mid-70s because of the "agricultural miracle" of the Green Revolution. Technology-productivity relationships caused extensive use of machinery and equipment, of inputs (enhanced seeds, fertilizers, agrochemicals), and a strong sup-

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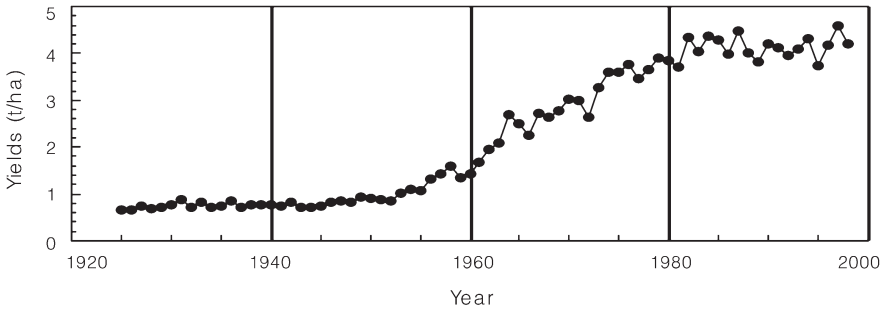

Figure 1. Mexican winter-wheat yields (FAOSTAT, 1998).

port for agricultural research that translated into significant increases in yields and the consequent increase in production. Among the crops that received greatest support were wheat, cotton, and corn. This phase is known as the intensive phase of Mexican agriculture (Rubio, 1988).

After the mid-70s, a new pattern was defined with increased cultivation of wheat and corn in northwestern Mexico because of a decline in worldwide demand for cotton and the national home market, with a 3.6% annual population increase (Appendini, 1988).

Nationally, wheat yields reached an asymptote in the '80s (Figure 1). The current agricultural crisis requires reactivation of the field economy and the strategy adopted was the opening to global markets. With the North American Free Trade Agreement (NAFTA), negative impacts for Mexico in commercial transactions were assumed because of technological inequality among the participating countries (Calva, 1994); however this is not true for northwestern Mexico, where there was a considerable infrastructure, efficient irrigation systems, good communications, and wheat yields that were superior to those of its NAFTA partners.

New strategies of agricultural development were investigated, incorporating regional limitations as a central element of modernization. Research was required on changes and technological transference to agriculture where water limitations or excessive rain existed. This offered the possibility of increasing agricultural productivity over short and long term time frames (Hayami and Ruttan, 1971).

In this paper, wheat yields in the main irrigated valleys of northwestern Mexico during the periods of the Green Revolution and stabilization are compared, based on social and historic events. The possibility of increasing productivity as a function of the historic maximum reached at regional and country levels is discussed.

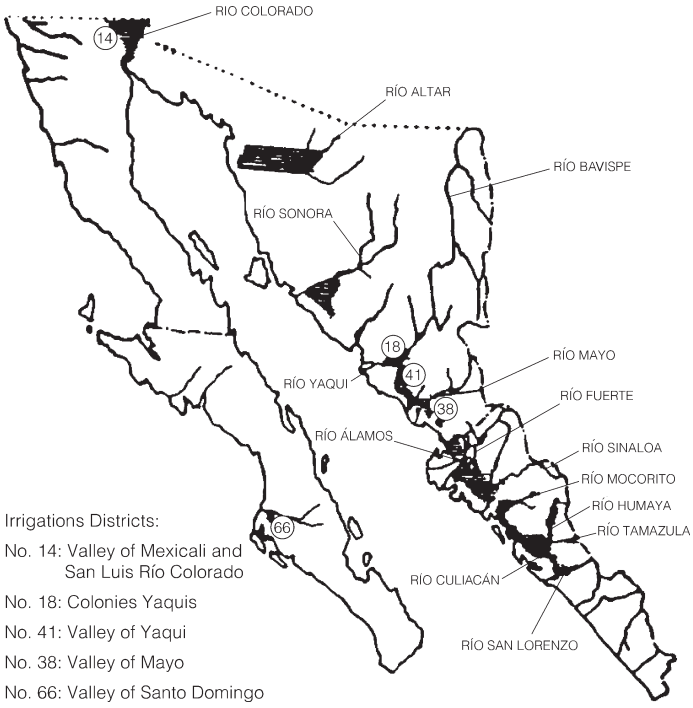

Figure 2. Irrigation districts of northwestern Mexico (modified from SARH-CNA, 1992).

Farming at the US frontier: Valle de Mexicali

Farming in the Mexicalli valley began with irrigation in the mid-19th Century. The Solfatara Canal was built (1911-1912) to bring irrigation to Mexican lands from Imperial Valley in the United States (Fuentes-Flores, 1990). The valley is located in the northernmost part of the state of Baja California, a geological extension of the Yuma and Imperial Valleys. It extends westward to the Cucapa Mountains and southward to the Colorado River delta and the northern edge of the Gulf of California. The land is rich in clay and sedimentary deposits that were carried by the river before upstream alteration of the river system.

Irrigation District Nº 14 (Figure 2) covers the Mexicali and San Luis Río Colorado Valleys; the first one with 87% of the irrigated lands and the second with the remaining area. Total area under irrigation is 207965ha, from 32º10' to 32º45' N and 115º11' to 11º31' W, at an average altitude of 15masl. The Colorado River has been decisive in regional development. At present, water comes from the José María Morelos Dam and water is pumped from 1100 deep wells. Land is distributed among 14694 users, of which 48% are *ejido* members and 52% are individual owners (SARH-CNA, 1992).

As in the rest of México, land reform was an important process in the agricultural organization of the region. In the Valle de Mexicali, land allotments were made in a uniform way, contrary to other regions of the country. Before 1937, most of the land was in concessions to US citizens who hired the resident population as manpower. This largely marked the region as "managerial agriculture", strongly influenced by North American usage (Fuentes-Flores, 1990).

The regional economy of Mexicali is an example of agricultural growth driven by export. Big transnational companies promoted the cultivation of cotton, making this one of the more important mono-producing regions of cotton of the country, with foreign economic dependence, especially the North American market.

The '50s represent a period of great dynamism in agricultural activity. In 1964, the general economy of the state depended 70% on agricultural production (Pérez, 1986). The uncertainty of the cotton market demanded agricultural diversification to decrease dependence on a single crop. In the '60s, cultivation of wheat, alfalfa, and safflower increased. At the beginning of the '60s, rye grass was widely grown and from the

‘80s, production of vegetables increased, characterized by small cultivated areas and high production value. In the absence of crops like beans and given the little importance of corn in the Valle de Mexicali, wheat represented the most important crop in the agricultural change of the region. This change in cultivation had a direct effect on the reorganization of agricultural production from 1965 to 1985.

The Valle de Mexicali is one of the more mechanized agricultural regions in México. On average, there is one tractor for every 22ha, so that most of the valley can be prepared for sowing at the same time (INEGI, 1991). The tax-free imports in this region facilitated the acquisition of low-cost used machinery.

Agriculture in this valley is characterized by the use of the technological elements of the Green Revolution. Agrochemicals played an important role in increasing production. Only 1% of the cultivated area is not fertilized. The total cultivated land is seeded with improved seed, an important element of the technical package. Yield from wheat varieties in this region are among the highest of the world (Fuentes-Flores, 1990).

The Valle de Mexicali and the Yuma-Imperial Valley form a geographic and economic unit divided by the international border, but the two areas kept a constant and intense relationship and interaction. As a geographic unit, they share the waters of the Colorado River. As an economic unit, they share agricultural technology, seeds, quality fertilizers, and a significant commercial and population exchange because the active labor force on both sides of the border comes mostly from the interior of Mexico. Regional development is based on the agro-industry and commercial and financial companies. These ties created new forms of exchange between the valleys, mainly for the use of transnational capital in Mexicali. The exchange continues, even though the economic and demographic conditions have changed (Anguiano-Téllez, 1985).

Wheat represents an attractive option for the borderland producers and has the endorsement of the Mexican government, with liberal credit policies and agricultural research. This has allowed the region to become one of the most important production areas of Mexico.

Sonora. Private ownership and ejidos

Agricultural development in Sonora began in 1890, when President Porfirio Díaz authorized a program of colonization financed by American banks to divide the Valle del Yaqui into parcels and build a net of irrigation canals to distribute water in the area (Dabdoub, 1980). Irrigation and development of agro-technology in the Valles del Yaqui-Mayo at the end of the 19th Century laid the foundations of a modern and productive agriculture (Aguilar-Camín, 1977).

The most decisive factor for agricultural development of the region was foreign-owned investment, which started at the beginning of the 20th Century with the arrival of the Richardson Construction Co. The selection of the Yaqui-Mayo region as one of the centers of the Mexican Green Revolution was based on conditions created before 1940. The agriculture of southern Sonora was behind the times, a characteristic that made it susceptible for capital development (Hewitt, 1976). This was the beginning of development of one of the largest agricultural areas in Mexico. It took more than four decades for these valleys to become the bastion of the golden era of agriculture in Mexico.

Valle del Yaqui. This valley is in the lower part of the Río Yaqui, the largest in Sonora. The Sierra Madre Occidental flanks its eastern side and the Gulf of California provides its western limit. It is located at 27º10' to 27º50' N and 109º55' to 110º36' W, at an average elevation of 35masl. The valley covers ~450000ha.

Irrigation Districts Nº 18 and Nº 41 (Figure 2) administer this valley. The former covers the Colonias Yaqui, indigenous peasants of the Yaqui tribe that inhabit eight towns. This irrigation district is the oldest in northwestern Mexico, beginning operation in 1937. It has 2807 distinct users, all organized into *ejidos*, with 23000ha under irrigation. The water sources are the Gral. Álvaro Obregón Dam (Oviachic) and La Angostura Dam, with water distributed by gravity. There is no official information on mechanization within the area.

Irrigation District No. 41 was established in 1951, beginning operation in July 1952. It includes the largest area in the Valle del Yaqui, 232999ha, with 56% of the land organized as *ejido* land and 44% as private property. The number of users is 19687, of which 73% are in *ejido* land and the rest are private owners. Water comes from three dams: La Angostura, Gral. Plutarco Elías Calles and Gral. Álvaro Obregón (Oviachic), which irrigate 83% of the land. The remaining area is supplied from 400 deep wells and 42 superficial water bodies. Mechanization is extensive, with an average of one tractor for every 74ha. Commercial fertilization (99%) and improved seeds (100%) are used (SARH-CNA, 1992).

A pioneer of agricultural development in the Valle del Yaqui was Carlos Conant, who obtained a concession for water from the Yaqui, Mayo, and Fuerte Rivers from the Mexican government. In 1891, he built the Canal Bajo with the help of the Sonora and Sinaloa Irrigation Co. This canal was connected with another built by the Scientific Commission of Sonora, which provided irrigation to lands surrounding two Yaqui towns, Cocorit and Bacum (Dabdoub, 1980).

In 1904 the Richardson Construction Co. obtained the rights to purchase the Sonora and Sinaloa Irrigation Co. In 1909 it acquired the concession for the Valle del Yaqui. When this company began preparations in 1910 for construction of La Angostura Dam, the project was suspended with the beginning of the Mexican Revolution.

Another important event in the agricultural history of southern Sonora was the Land Reforms of 1937. The *ejidos* possessed 17000ha for agriculture and 24000ha for summer pasture. The next year, private farmers helped the *ejidos* sow their lands because the members of the *ejidos* could not afford machinery. Several years later, the Gral. Álvaro Obregón Dam was built, along with a new canal, the Canal Alto, to irrigate an area not covered by the existing canal. Work was completed in 1954, converting the Valle del Yaqui into the most extensive and best irrigated agricultural area in Mexico.

Valle del Mayo. The Río Mayo provides water to irrigate this valley, 80km south of the Valle del Yaqui. Its development was similar. The region has a sown area of 97000ha, 52% controlled by *ejidos* and 48% under private ownership. Of the 11582 users, 68% are *ejidos* and the rest private owners. Irrigation District Nº 38 (Figure 2) administers water use from the Lic. Adolfo Ruíz Cortínez (Mocuzari) Dam and 129 deep wells. Agricultural mechanization is complete, all farm land is fertilized and farming is completely automated (SARH-CNA, 1992).

These two broad valleys contain two different societies, one is private management and the other is peasant *ejido*, both able to develop mechanized and technical agriculture.

The managerial society: Private owners

At the end of his presidential term, Alvaro Obregón returned to the Valle del Mayo to renew his agricultural activities. At his request, the Mexican government bought the Yaqui Land & Water Co., all of the stock of John Hays Hammond and Harry Payne Whitney, the main partners of the company, 66% of the capital, and thus obtained control of the company for the Mexican Federal Government. The Banco Nacional de Crédito Agrícola administered the company starting in 1926, strengthening and increasing the infrastructure to open new areas for cultivation. Agricultural production increased rapidly. In 1937-1938, 52511ha were cultivated, for which there was not enough water from existing sources or delivery canals, and most of the crop was lost. The economic losses induced the Mexican government to reactivate the construction of La Angostura Dam, which was finished in 1941 (Dabdoub, 1980).

The large-scale farmers in Sonora, politically powerful families in Mexico with ties to large-scale farmers in the US, and researchers from the Office of Special Studies of Sonora began to improve the Sonora area during the second half of the '40s. During the military phase of the Mexican Revolution, 5 of the 11 governors of Sonora were closely related to national presidents, which brought many benefits to the wealthy and educated groups in the region.

The peasant society: Ejidos

In October 1937, the government under President Lázaro Cárdenas distributed 36000ha to benefit 2160 peasants in collective régimes organized into 14 social communities to work the land. Of the total, 17000ha were irrigated and the remainder subject to local rainfall. In a few years, all of the land was irrigated.

During the intensive phase, the rural *ejido* economy, as a self-sufficient economic entity, was not profitable. First, the members overused the land when farming without technology, and second, when technology was used, the members consumed their production, which prevented recovery of technological applications costs (Gordillo, 1988). The vast majority of farms in the Río Yaqui and Río Mayo valleys are operated by *ejidos*. Although the rural economy has its own social and economic dynamics, the fundamental transformation of the economy was mostly influenced by the state in development of highly-mechanized agriculture (DeVany, 1977). In these two valleys, worldwide overproduction brought a drop in cotton prices, creating a severe agricultural crisis. Between 1975 and 1976, there was a strong rural social movement in the region with the goal of farmland parceling into individual farms. This movement deepened social crisis in the region (Carnaval, 1983) and the inadequacies of collective agriculture.

Different authors believe that the agrarian reform movement represented a conflict between the federal government and the high revenue farmers. The large land owners and their ties with the presidency were factors that resolved favorably for the peasants. In November 1976, the federal government condemned 37666ha of irrigated land and 61000ha of summer pasture to benefit 8845 individual peasants (Valenzuela-Valenzuela, 1990).

When mechanization was underway, the *ejidos* faced technical problems because the plots were too small to properly use the existing technology. *Ejido* members lacked enough capital to enlarge their farms by acquiring additional land and laws restricted increase in the size of holdings. This led to the joining of individual *ejidos* into collective *ejidos*. Amalgamation of *ejidos* in the Yaqui-Mayo area began in 1977, after the government expropriations of 1976. The coalition resulted in capital intensive agriculture, with mechanization of work that led to greatly reduced need for a work force and a change in cultivation practices that reduced a major source of seasonal employment. Rapid accumulation of machinery and equipment transformed the collective *ejidos* into the most automated farm communities in the country and increased productivity. However, production was still lower than on private properties (Valenzuela-Valenzuela, 1990).

The collective *ejidos* faced problems related to differences between members and administrators of the community. The decisive factor for further change came from political opposition to the collectives from the local private managerial class (Gordillo, 1988). The campaign against the collective *ejidos* was made through support for concessions of special privileges to ejido members that opted for separation and parcelization of the collectives (Hewitt, 1976).

The pioneers of Baja California Sur

The Valle de Santo Domingo is located in the middle of the state of Baja California Sur, 24º50' to 25º30' N and 111º30' to 112º10' W, with elevation of 45m. Its covers ~2200km², with only 67200ha dedicated to agriculture. Water is pumped from 714 wells. At present, there are serious limitations to cultivating more land because of limits in water availability. According to official data (1957 to 1975), aquifers have dropped 12m (Navarro-Jiménez, 1986). Irrigation District Nº 66 has administered water use in the area since 1955. The nine towns and 75 agricultural colonies in the valley support 1346 water users, half of them *ejido* members and the rest, small land owners. The area is fertilized and its irrigation automated (SARH-CNA, 1992).

These lands were in concession to foreign companies from 1864 to 1933. The Lower California Co., which was not able to complete the agreement for colonization, was devoted to the exploitation of the "orchilla" lichen, used to dye cloth. The colonization law of 1883 allowed an influx of foreign capital to the country and granted so many concessions that, by the beginning of the '30s, the Delbert J. Haff & Co. possessed 1247000ha in the Baja California Peninsula (Mendoza-Higuera, 1992).

Based on Article 27 of the Mexican Constitution, the local governor, Juan Domínguez Cota, recovered the lands under concession in 1923. By doing this, the federal government was in the position to include those lands in the Land Reform Program. From 1932 to 1937, the first *ejido* was founded in the Valle de Santo Domingo. From the foundation of the María Auxiliadora Colony in 1942 until the end of the '50s, there was a massive colonization of the valley by the Unión Nacional Sinarquista, after permission was granted by President Manuel Ávila Camacho.

From 1950 to 1960, the federal government encouraged colonization of the Valle de Santo Domingo, based on a development plan. During this period, most of the 75 agricultural colonies were formed, thanks to land reforms. During the 1970s, 7 *ejidos* were founded after the agrarian movement promotions that culminated with delivery of land to diverse rural groups. With the *ejidos*, the agrarian structure of the valley entered the "colonization regime" (Mendoza-Higuera, 1992).

As an uninhabited area, many problems had to be overcome to develop commercial agriculture. Since there are no rivers or surface water, the first step to bring land into production was to dig wells. Another problem was the lack of efficient roads. The section of the Transpeninsular Highway connecting Valle de Santo Domingo with the state capital, La Paz, was finished in 1953.

Following the agricultural pattern in mainland Mexico, cotton and wheat were the main crops at the beginning. Sorghum became important during the '70s; since the '80s, chickpea, wheat, and cotton are the main cultivars. What

probably influenced agricultural practices in the valley was the necessity of obtaining sufficient yields to finance the high cost of irrigation and import of agricultural machinery from mainland Mexico and the US. The absence of diseases led to high cotton and wheat yields.

A number of regional characteristics helped incorporate machinery into the production process: flat topography, credit institutions and a fiscal policy of import tax exemption from the time of President Lázaro Cárdenas. However, poor land routes made import of machinery more expensive than in other regions of Mexico, such as the Valle de Mexicali.

From 1960 to 1970, cultivated land was incorporated rapidly, at an annual average of 2314ha. After 1970, the rate decreased to about 1580ha per year. This trend continued until 1980, when the total cultivated area, established as a response to water shortage, reached ~43000ha. Water reserves decreased and the aquifer has dropped (FIRA, 1982). Overuse of water caused other problems, including salinization of the well heads and the irrigated land. Currently, 39% of the land available for cultivation is severely affected by high salinity (Navarro-Jiménez, 1986). The crisis in Valle de Santo Domingo agriculture is evidenced by some productivity indicators. Since 1991, yields have declined, likely as a consequence of lower availability of water resulting from administrative constraints and salinization (Urciaga-García, 1993).

The four states of the region, Baja California, Baja California Sur, Sonora and Sinaloa had a population of ~800000 in 1930. By 2000 the population had increased about 9.5 times, to about 7.7mill, or ~135% per decade. Numbers like this hide as much as they tell, because growth is based, to a significant degree, on economic opportunities. Economically, agriculture, mining, and tourism are the major opportunities in arid climates. The development and growth in modern agriculture by stages should be reflected in population growth, and this aspect was also explored.

The Study

Methodology

Data about national wheat yields come from two agencies (INEGI, 1997; FAOSTAT, 1998). Data for each irrigation district were obtained at regional offices of the Comisión Nacional del Agua (CNA) at Mexicali, B.C. (District Nº 14), Cd. Obregón, Sonora (Districts 18 and 41), Navojoa, Sonora (District Nº 38), and Cd. Constitution, BCS (District Nº 66). Population data comes from INEGI census reports.

The most important crop in the region is winter wheat. Historic series of agricultural yields are shown in Figure 2. Logistic models were fitted to represent the behavior of time-series. This adjustment, together with the exploratory analysis of the data, allowed us to identify the difference in the third part of the curve, which is determined by the behavior around the asymptote:

$$y = a / (1 + e^{(b-c(x-x_0))}),$$

where y: wheat yield (tons/ha), a: asymptotic value of the yield, b: slope of integration that defines the position of the relative curve to the origin, c: rate of growth of the yield per unit of time, x: time, and x_0: starting time.

To identify common variations in the five analyzed series, principal components analysis (PCA) was performed under the hypothesis that the first component defines the common tendency and that it is associated with the use of the Green Revolution technological package in all of northwestern Mexico.

Historical documentation involved gathering information on agricultural development of these areas. Of particular importance was the data obtained from the state governments and government institutions, FIRA (*Fideicomisos Instituidos en Relación con la Agricultura*) and CNA (*Comisión Nacional del Agua*). Information from the Universidad Autónoma de Baja California Sur (UABCS) and the Colegio de la Frontera Norte (COLEF) was also used.

For the analysis of population growth, the central urban center of the agricultural region was chosen for each of the four states in northwestern Mexico: Mexicali for Baja California, Ciudad Constitución for Baja California Sur, Hermosillo for Sonora, and Los Mochis for Sinaloa. In the later two cases, other towns or cities could have been chosen.

Results

The wheat yield series for each area, together with the fitted logistic models, are shown in Figure 3. The fitting parameters are shown in Table I. All correlation coefficients are significant to the 95% confidence level. The parameters of maximum yield (Ymax) and rate of increase of each model were compared with the national model:

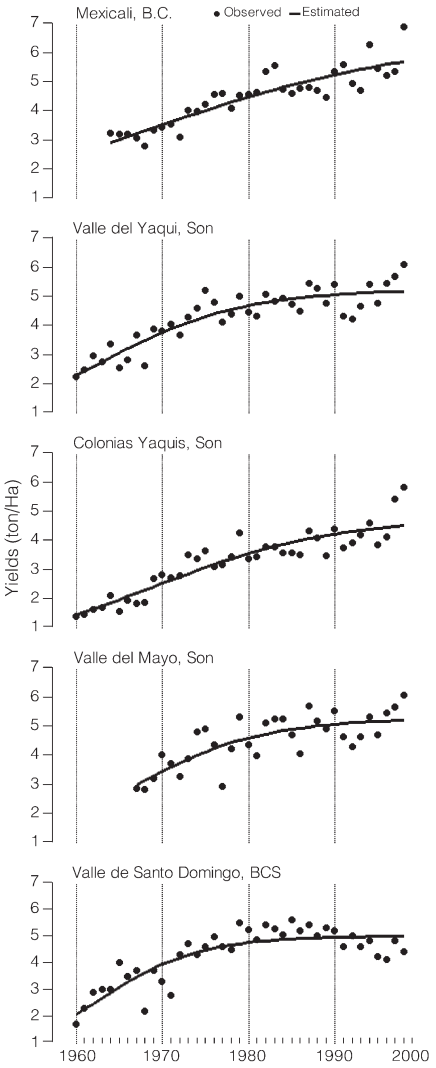

Figure 3. Observed data and model fit in the five irrigation districts of northwestern Mexico.

TABLE I
PARAMETERS OF ADJUSTMENT OF THE LOGISTIC MODEL FOR EACH SERIES

Districts	Standard Error	Correlation Coefficients	Number of observations	Ymax. (a)	Rate of increase (c)
Valle de Mexicali	0.45	0.89	35	6.59	0.06
Valle del Yaqui	0.49	0.90	39	5.25	0.12
Colonies Yaquis	0.44	0.92	39	4.82	0.09
Valle del Mayo	0.58	0.77	32	5.27	0.13
Valle de Santo Domingo	0.53	0.86	39	5.01	0.17
National	0.27	0.96	39	4.83	0.08

TABLE II
COMPARISON OF THE ASYMPTOTIC LEVELS
OF EACH LOCAL SERIES VS. THE NATIONAL ONE

Districts	Valle de Mexicali	Valle del Yaqui	Colonies Yaquis	Valle del Mayo	Valle de Santo Domingo	National
Ymax	6.6	5.3	4.8	5.3	5.0	4.3
Rate of increase (c)	0.06	0.12	0.09	0.13	0.17	0.14
90% Ymax	5.9	4.8	4.3	4.8	4.5	3.9
Year	2003	1982	1992	1983	1975	1981
95% Ymax	6.3	5.0	4.6	5.0	4.8	4.1
Year	2018	1988	2002	1988	1981	1987
90% Ynational	3.9	3.9	3.9	3.9	3.9	
Year	1974	1971	1985	1973	1970	

TABLE III
POPULATION COUNTS FOR THE 1930 TO 2000 PERIOD FOR
THE NORTHWEST MEXICAN STATES AND THEIR MAJOR
AGRICULTURE-RELATED CITIES

	Mexicali	BC	Constitución	BCS	Mochis	Sin	Hermosillo	Son
1930	14.842	48.327	47.089	10.004	395.618	19.959	316.271	
1940	18.775	78.907	51.471	12.937	492.821	18.601	364.176	
1950	64.609	226.965	60.864	21.552	635.681	43.519	510.607	
1960	174.540	520.165	1.926	81.594	38.307	838.404	95.978	783.378
1970	263.498	870.421	10.548	128.019	67.953	1.266.528	176.596	1.098.720
1980	341.559	1.177.886	23.557	215.139	122.531	1.849.879	297.175	1.513.731
1990	438.377	1.660.855	34.692	317.764	162.659	2.204.054	406.417	1.823.606
2000	549.873	2.487.367	35.589	424.041	200.906	2.536.844	545.928	2.216.969

- Valle de Mexicali (borderland): low growth rate, but high values of Ymax (clear tendency to continue to increase).

- Valles del Yaqui and Mayo (private ownership): near the national growth rate and high Ymax.

- Colonias Yaquis (*ejidos*): slow, lower growth rate than national, and low Ymax.

- Valle de Santo Domingo (pioneers): high, larger than national growth rate, but intermediate Ymax (yields show a clear decreasing tendency over the last 10 years).

We recognize three groups:

Borderland. The series for the Valle de Mexicali show a sustained tendency of yield increase. The model indicates that this region has not reached maximum yield. About 90% of maximum yield is projected until 2003 and 95% to 2018. It reached 90% in 1974 (Table II). In this region, the rate of increase toward maximum yield is the lowest of the series.

Valles del Yaqui and Mayo. Private farmers and indigenous *ejidos* had to be analyzed together (see Figure 2). The rate of increased productivity of the Yaqui colonies is lower than that for private farmers, even though they are in the same region. These findings are similar to previous reports (Hewitt, 1976); however, while recent high yields in the Yaqui Colonies (see Figure 3) are reflected in the adjusted model, the model predicts that the Yaqui Colonies can increase their yields and reach 95% Ymax by 2002. The highest yield for the private farmers occurred in 1982 and 1983 (90% Ymax) and 95% Ymax was achieved in 1988. From 90% Ymax for the national curve as the base point, the Yaqui Colonies show a 14-year delay.

Pioneers. Settlers agriculture in the Valle de Santo Domingo in Baja California Sur showed rapid development. The model predicts the highest growth rate after 1960, above national levels. This rapid advance is reflected by the 1975 condition of 90% Ymax and 95% in 1981. The curve also shows that yields are below the calculated Ymax since 1990.

Population growth

Mexicali. From 1930 to 2000 (Table III), the population expanded more than 36 times. The most dramatic increase occurred in the 1950-60 decade, a 240% change, followed by the 1960-70 decade, with a growth of 170%. Agricultural prosperity oriented to the export market accounts for most of this growth. Continued but slower growth reflects the maturity of the agricultural resource base. Over the last few decades, growth rates in Mexicali are about half of the growth rates of the Baja California state, which reflects rapid urban growth in areas surrounding Tijuana and Ensenada.

Ciudad Constitución. Of the four locations, this town of Baja California Sur is a classic, rural agricultural center, functioning exclusively as a service center to the extensive agricultural development. There was a 450% increase in the 1960-70 decade and a 125% increase in the 1970-80 decade, falling to less than 50% in 1980-90 and essentially no growth thereafter. The problems facing this area are entirely responsible for the declining growth rates.

Los Mochis. This town in the northern part of Sinaloa state serves the agricultural area based on irrigation water from the large dam, Presa Miguel Hildalgo on the Río Fuerte. Its rapid growth from the 1950s through the 1980s (67 to 80% per decade) reflects agricultural development. Growth in the last two decades (33% and 24%) is significantly lower, reflecting the maturity of the agricultural economy. However, even at this rate, it is still well above the growth rates of the state.

Hermosillo. This small city has population growth characteristics similar to Los Mochis. The most rapid growth occurred in the 1950-80 period (134, 121, 84, and 68% for each decade). Even with slower growth in the last two decades, which is comparable to Los Mochis, it is still about 50% greater than the Sonora state average, as is the relationship of Los Mochis to Sinaloa's growth.

Principal components analysis

PCA shows that one factor with eigenvalue of 3.99 can be extracted out of the five series, accounting for 80% of ther common variation. The series show a clear positive tendency and important interannual fluctuations (Figure 4). All correlations between the original series and PC 1 are significant at the 95% level (Table IV).

Discussion

The agriculture of northwestern Mexico has been characterized as capitalist in its technical development, with two stages being recognized. In the first stage, for the period up to 1940, cotton was the most important crop in irrigated areas, responding to a strong demand in the worldwide market and yielding high earnings (Durán, 1988). To a great extent, the crisis in cotton farming brought development of wheat farming along with significant increases in the use of technology.

In the second stage, the participation of the federal government was

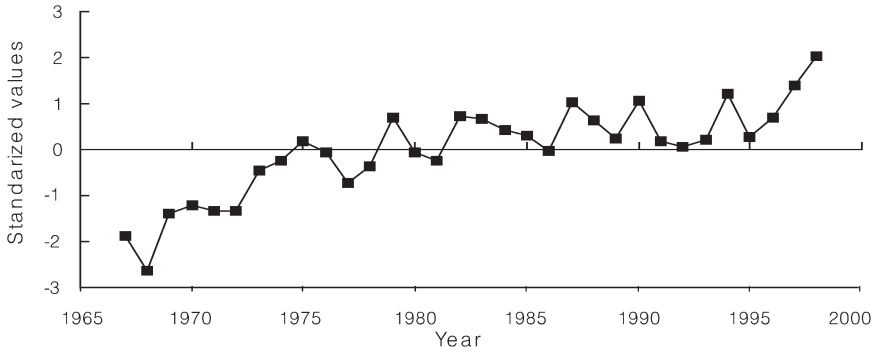

Figure 4. Summarized series that show the common variation of the winter wheat yields in northwestern Mexico.

central, stimulating agricultural modernization in valleys that could be irrigated, either from dammed rivers or tapping underground aquifers. When the Green Revolution technological package was implemented, the water tables in the aquifers dropped in the 1980s, leading to stagnating yields and an annual average rate of productivity increase of 0.8% from 1966 to 1977. This ended the period of self-sufficiency in food for Mexico and the country became an importer of basic grains. Foreign currencies obtained through agricultural exports decreased, focusing attention on industrialization of the country. Although the yields were actually increasing, production demanded more technological inputs and capital, increasing costs and reducing income.

Social and cultural conditions also cause differences in the historic wheat yield curves. The common variation represents the positive tendency of the series, a product of homogenization in agricultural development of the four states skirting the Gulf of California; that is, the application of the Green Revolution technological package.

The role of the federal government on the development of agriculture in Mexico can be questioned, but the pressure of some programs of agricultural modernization should be recognized. It takes considerable investment in the hydraulic infrastructure of a region to develop commercial agriculture. Adoption of the Green Revolution technological package does not mean that economic efficiency will be achieved automatically. To reach such a goal it is also necessary to make rational use of productive factors.

Commercial agriculture and agricultural technology are feasible in the *ejidos*, but it does not always bring economic benefits. A result of collectivization is the inefficiency at maximizing income because of capital overuse. This is not necessarily a consequence of administration policies, but rather the technological homogenization of the Valleys of the Yaqui and Mayo River (Valenzuela-Valenzuela, 1990). All the valleys were subjected to developmental pressure by the federal government during the '50s to increase agricultural production for exports. This caused excessive automation of agriculture and large consumption of industrial chemicals.

A period of rapid development was tied to the incorporation of the technological package. Since 1975, yields stopped increasing, and from 1980 to date, a slight decrease in productivity has occurred, not only for wheat, but for other crops as well (Urciaga-García, 1993). This decrease results from the irrigation and salinization problems in the Valle de Santo Domingo.

The population growth pattern reflects the relative importance of agriculture to the economy of the northwestern states. The two peninsular states have a vigorous tourist and urban economy that brings large numbers of migrants from elsewhere in Mexico to those cities. In the last decade, statewide growth has been far greater than growth in the agricultural areas. This suggests either a decline in agricultural productivity (Ciudad Constitución) or a maturity or limiting factor (Mexicali), mostly related to water quality. The northwestern mainland states of Sonora and Sinaloa reflect a proportionately greater emphasis on an agricultural base. In these states in the last decade, the central agricultural towns are still growing faster by about 50% than the overall state population, approximating the national growth rate.

Conclusions

The common features of the five agricultural regions of winter wheat culture in northwestern Mexico reflect the acceptance of the Green Revolution technological package. For the national wheat yield time series, the fitted logistic growth curve suggests regional differences in the stabilization phase caused by particular features in the various communities.

TABLE IV
CORRELATION COEFFICIENTS OF THE SERIES AND MAIN COMPONENT ($P < 0.05$)

Series	Coefficient
Valle de Mexicali	0.90
Valle del Yaqui	0.96
Colonies Yaquis	0.94
Valle del Mayo	0.93
Valle de Santo Domingo	0.72

Private farmers in the Valles de Yaqui and Mayo are the most technologically advanced. Further increase of production would require an increase of land areas under production.

Ejidos in the Yaqui colonies in the Valles de Yaqui and Mayo region, have the slowest rate of yield growth; but has the best potential for improvement. The differences between *ejidos* and private farmers suggest that yields in the Yaqui colonies can increase significantly where agricultural conditions are similar to those of private owners.

Valle de Mexicali farming in this Mexico-US border area shows a slow increase in productivity, even though present yields are among the highest in the world. The logistic model predicts that higher yields are attainable. The geographical location close to the US border is a factor promoting high yields and income.

Valle de Santo Domingo farming shows a rapid increasing rate of productivity, but with maximum yields already achieved. Recently, yields decreased because underground irrigation water has been overexploited and brackish water intrusions from well extraction has led to salinization problems, which now makes the Green Revolution technological package inefficient.

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HISTORIA DEL DESARROLLO DEL CULTIVO INVERNAL DE TRIGO EN CINCO DISTRITOS DE RIEGO EN EL DESIERTO DE SONORA, MÉXICO

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RESUMEN

Se analiza la historia del desarrollo del cultivo invernal de trigo en 5 distritos de riego en el noroeste de México. El rápido crecimiento de los rendimientos de trigo invernal en el noroeste de México se puede describir mediante el ajuste de los parámetros del modelo logístico. En las series de tiempo analizadas existe variación común, la cual está representada por la tendencia positiva de las series y la cual se considera es producto de la Revolución Verde. Esta tendencia explica el 80% de la variación observada. Sin embargo, las condiciones sociales, económicas y geográficas sugieren desarrollos diferenciales. Se definen cuatro tipos de desarrollos agrícolas diferentes: los fronterizos (Mexicali-San Luis-Río Colorado), la agricultura indígena (Colonias Ejidales Yaquis), la agricultura privada (Agricultores de los Valles Yaqui y Mayo), y los Pioneros (Agricultores del Valle de Santo Domingo en Baja California Sur). El desarrollo individual de cada grupo se compara con la curva de rendimientos a nivel nacional. Nuestro objetivo es comparar los rendimientos del trigo en los valles irrigados del noroeste de México durante los períodos de la Revolución Verde y de estabilización de los rendimientos, basados en eventos históricos y sociales. Se discute la posibilidad de incrementar la productividad como una función del máximo histórico alcanzado a nivel regional y nacional.

HISTÓRIA DO DESENVOLVIMENTO DO CULTIVO DE INVERNO DO TRIGO EM CINCO DISTRITOS DE IRRIGAÇÃO NO DESERTO DE SONORA, MÉXICO

César A. Salinas-Zavala, Salvador E. Lluch-Cota e Ira Fogel

RESUMO

Analisa-se a história do desenvolvimento do cultivo de inverno do trigo em 5 distritos de irrigação no noroeste do México. O rápido crescimento dos rendimentos do trigo de inverno no noroeste do México se pode descrever mediante o ajuste dos parâmetros do modelo logístico. Nas séries de tempo analisadas existe variação comum, a qual esta representada pela tendência positiva das séries e é considerada producto da Revolução Verde. Esta tendência explica 80% da variação observada. No entanto, as condiçðes sociais, econômicas e geográficas sugerem desenvolvimentos diferenciais. Definem-se quatro tipos de desenvolvimento agrícola diferentes: os fronteiriços (Mexicali-San Luis Río Colorado), a agricultura indígena (Colonias Ejidales Yaquis), a agricultura privada (Agricultores dos Vales Yaqui e Mayo), e os Pioneiros (Agricultores do Vale de Santo Domingo na Baixa California do Sul). O desenvolvimento individual de cada grupo se compara com a curva de rendimentos a nível nacional. Nosso objetivo é comparar os rendimentos do trigo nos vales irrigados do noroeste do México durante os períodos da Revolução Verde e de estabilização dos rendimentos, baseados em eventos históricos e sociais. Discute-se a possibilidade de incrementar a produtividade como uma função do máximo histórico alcançado a nível regional e nacional.