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SUSTAINABILITY AND HISTORICAL LAND-USE CHANGE IN THE GREAT PLAINS: THE CASE OF EASTERN COLORADO

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ABSTRACT—The Great Plains is one focus of the debate in the United States over appropriate land use and sustainability. Within the Plains region, eastern Colorado represents a case study that permits researchers and policymakers to focus on important relationships between agricultural land use, population change, and the sustainability of agriculture, environment, and communities. Colorado Front Range urban areas experienced large increases in population from 1950 to 2000 that resulted in a 35% reduction in total farmland. In the urban fringe region, farmland declined rapidly since 1978 and harvested irrigated cropland declined by 16% since 1990. Rural population in eastern Colorado decreased from 1950 to 1970 and then stabilized. Rural areas experienced decreased total farmland, harvested dryland, and rangeland, as well as intensification of agriculture because of a 76% increase in harvested irrigated land (1950 to 1997). Inflation-adjusted agricultural product income remained stable because of large increases in crop yield

from irrigated crops and animal production. The surprising result of this analysis is that agriculture and population are not declining throughout the Great Plains.

KEY WORDS: cropland, Great Plains, land-use change, population, rangeland

Introduction

In the United States, one debate in the large set of discussions about appropriate land use and sustainability focuses on the Great Plains, a 1.3 million km^2 area of semiarid grasslands in the middle of North America. The successes and failures of Great Plains agriculture have been analyzed in many places by many authors (Webb 1931; Borchert 1971; Bowden 1975; Worster 1979; Popper and Popper 1987; Riebsame et al. 1994). The story, in short, starts with over-optimistic development and poor crop practices in the late 1800s and early 1900s. In the 1930s a mixture of economic depression and drought led to widespread crop failure, soil erosion, farm loss, and net rural out-migration. Mechanization, irrigation, continued economic stress, and broader social movements sustained the Great Plains experience of farm consolidation and rural population decline into the 21st century. In human ecological terms (Albrecht and Murdock 1990), the system has adapted to an environment less amenable to agriculture than was originally perceived, and to social-structural changes such as government policy, technological and management innovation, and corporate consolidation of grain and meat markets. In other opinions, this pattern has been a sign of regional "failure" and continued maladaptation (Popper and Popper 1987). In all too many cases, authors writing about the Great Plains see it as a monolithic region with a very narrow range of experiences, despite its enormous size.

The historical pattern of actual Great Plains land use, however, is less well known and hardly monolithic. Some analysts assume that population loss always leads to loss of land in agriculture (Popper and Popper 1987, 1989, 1994; De Bres and Guizlo 1992; Callenbach 1995), but regional statistics do not support this. Despite claims of "deserts on the march" and widespread desertification (Sears 1936; Heathcote 1980), Great Plains agricultural lands increased into the 1960s and burgeoned again in the 1970s (Gutmann et al. 1999), even for drought-sensitive crops like dryland wheat (Riebsame 1990). Temporary reductions in the amount of cropland accompanied the droughts (as in the 1930s and 1950s) and government conserva-

tion programs (Bedenbaugh 1988; Skold 1989; Reeder et al. 1998), but much land returned to cropping. More important than anything else, there is considerable diversity of experience in the Great Plains, even within a single state. Rural agricultural life is everywhere beset with difficulties, but the scale and nature of the difficulties and their impact on population, agricultural productivity, and the environment differ from subregion to subregion.

The loss of farmland is an important element in many discussions of rural change in the United States. Farmland loss occurs in two modes, one we call "farm abandonment" and the other "urban sprawl" (Gutmann et al. 1999). Farm abandonment occurs when economic, environmental, or policy pressures reduce agricultural viability. This process is so widely held to epitomize Great Plains trends that it could be referred to as the Great Plains "signature" in American agricultural history (Murdock et al. 1986; Baltensperger 1993; Jim 1997; Rathge and Highman 1998).

The other main "signature" of farmland loss in the United States is caused by urban sprawl. Several studies have revealed why and how farmland is converted to nonagricultural use at the urban fringe in the United States (e.g., Vesterby and Krupa 1993; American Farmland Trust 1997). Simply stated, in the growing industrial and postindustrial American economy, urban and suburban demand for land wins out over agricultural use. Alig and Healy (1987) used farmland price as a variable in a national land-use-change assessment, assuming that high-value crops in at least a few of their sample areas would restrict urban growth, but they found no significant impact of farmland prices on urban land conversion.

Great Plains agricultural land loss mostly follows the farm abandonment model because of the rural nature of the region, but as Gutmann et al. (1999) suggest, the Colorado Front Range urban corridor is one part of the Plains where the urban sprawl process vies with the classic farm-abandonment signature. Gutmann et al. (1999) found surprising results at both the urban and rural ends of the land-use gradient, suggesting complexities of both the farm abandonment and the urban sprawl models.

In this paper we concentrate as much on the modest successes of Great Plains agriculture and rural life as we do on their well-known and distinct problems. We present an analysis of production and productivity in agriculture, and of two basic elements of rural society: overall population size and agricultural employment. In order to keep the problem manageable, we focus our analysis on eastern Colorado, an excellent choice because it brings together a diversity of experiences. We divide eastern Colorado into four regions and use their distinctive patterns to demonstrate that eastern

Colorado has a combination of more and less sustainable agricultural and social communities.

Methods

We collected data on agricultural land, population, value of agricultural production, and employment for the 27 Colorado counties on the Great Plains. Annual agricultural land-use data are from the Colorado Agriculture Statistical Service and the Great Plains US Census database at the Inter-university Consortium for Political and Social Research (http://www.icpsr.umich.edu/plains). Employment data are from the Bureau of Economic Analysis, US Department of Commerce. As in most studies of agricultureal land-use change, we used county-level data that are not spatially explicit. The county unit can hide development differences within counties; some counties in our area span urban to rural land uses, but most can be resonably well classified as urban, urban fringe, or rural.

We combined two data sources to improve the accuracy of our assessment of land-use change. We started with Census of Agriculture data and examined patterns in changes in "farmland," "cropland," and "rangeland" as calculated at roughly five-year inervals (Tables 1 and 2). These data are often cited to show patterns of "farmland loss" across the United States, though some studies have suggested that they overstate land loss (Colorado Department of Agriculture 2000). We also used state annual crop data collected as a joint effort of the Colorado Department of Agriculture and the USDA aimed at estimating production. These include data on "harvested" and "planted" cropland. Comparison of the Colorado agricultural statistical data with the federal Census of Agriculture showed agreement between the two databases. For example, county-level harvested wheat and corn area for the two databases had an r^2 of 0.99 and 0.92, respectively. The annual Colorado data did not enumerate rangeland, total cropland, or total farmland.

We assumed that land removed from the cropland and grazingland categories was converted to nonagricultural land uses (residential, commercial, industrial, or infrastructural). This assumption is supported by the fact that tax laws give preferentially low rates to agricultural land, so that some land planned for development, but currently only in the most superficial agricultural use, remains classified as agricultural. In our study area, land dropping out of crop- or rangeland categories along the Front Range urban corridor went to commercial or residential development, or was purchased

TABLE 1
CHANGES IN RANGELAND, CROPLAND, AND TOTAL FARMLAND IN EASTERN COLORADO COUNTIES

		Census of Agriculture data*		
		Rangeland (ha X 10^6)	Cropland (ha X 10^6)	Farmland (ha X 10^6)
Urban	1950	1.43	0.42	1.85
	1997	0.98	0.23	1.21
	Absolute Change	-0.45	-0.19	-0.64
	% Change	-32	-44	-35
Urban fringe	1950	0.90	0.68	1.58
	1997	0.83	0.64	1.48
	Absolute Change	-0.07	-0.03	-0.10
	% Change	-7	-5	-6
Southeast mixed	1950	2.73	1.05	3.78
	1997	2.41	0.94	3.35
	Absolute Change	-0.32	-0.11	-0.43
	% Change	-12	-10	-11
Northeast mixed	1950	1.83	1.50	3.33
	1997	1.64	1.74	3.38
	Absolute Change	-0.20	0.24	0.04
	% Change	-11	16	1
Total	1950	6.90	3.65	10.54
	1997	5.86	3.56	9.42
	Absolute Change	-1.04	-0.09	-1.13
	% Change	-15	-2	-11

Note: The changes reflect 1997 values minus 1950 values and the percentage change is based on the 1950 area.

* Census data: Great Plains Population and Environment Database (Gutmann et al. 1999)

as nonagricultural open space. The fate of "disappearing" farmland in the rural regions of eastern Colorado is not clear (Heimlich 1985; Hart 1992; Lowe et al. 1993; Tegene et al. 1999). It may have been converted to housing or other uses, or literally abandoned.

TABLE 2
HARVESTED DRYLAND, HARVESTED IRRIGATED, AND TOTAL HARVESTED LAND IN EASTERN COLORADO COUNTIES

		Annual crop data*		
		Harvested dryland (ha X 10^6)	Harvested irrigated (ha X 10^6)	Total harvested area (ha X 10^6)
Urban	1950	0.12	0.07	0.19
	1997	0.06	0.05	0.12
	Absolute Change	-0.06	-0.02	-0.08
	%Change	-48	-26	-40
Urban fringe	1950	0.25	0.12	0.37
	1997	0.17	0.13	0.30
	Absolute Change	-0.08	0.01	-0.07
	% Change	-32	8	-19
Southeast mixed	1950	0.30	0.13	0.43
	1997	0.36	0.17	0.52
	Absolute Change	0.05	0.04	0.09
	% Change	17	30	21
Northeast mixed	1950	0.78	0.08	0.86
	1997	0.67	0.35	1.02
	Absolute Change	-0.11	0.27	0.15
	% Change	-15	318	18
TOTAL	1950	1.45	0.41	1.86
	1997	1.25	0.71	1.96
	Absolute Change	-0.20	0.30	0.10
	% Change	-14	73	5

Note: The changes reflect 1997 values minus 1950 values and the percentage change is based on the 1950 area.
* Colorado State Annual Agricultural Data.

Land-Use Regimes

The Colorado Great Plains display a gradient of land uses from central business districts to low-density rural landscapes dominated by grazing lands and dryland cropping. Eastern Colorado also contains significant areas of irrigated land along the South Platte and Arkansas Rivers and over

the Ogallala Aquifer (Kromm and White 1992). We classified the 27 counties into four categories: urban, urban fringe, and rural landscapes further subdivided into northeast mixed and southeast mixed (Table 3, Fig. 1).

We define the urban counties as those that have had large urban populations, that became densely urban and suburban, and that experienced massive population growth since 1950 (>400%). These counties are located along the Colorado Front Range where the Great Plains meet the Rocky Mountains; the cities are tied together by the north-south Interstate Highway 25. We define the urban fringe counties as including large towns but also encompassing large areas that are rural and agricultural in character. Urban fringe counties also experienced population growth (Fig. 2, Table 3) since 1950 (Botham 1980). All remaining counties we defined as rural.

All rural regions had stable or decreasing population from 1950 to 2000. The northeast mixed and southeast mixed regions had substantial amounts of irrigated cropland (35% and 33%, respectively, of total harvested land). The two rural regions had different dominant cropping systems, with a wheat/corn/hay system for the northeast mixed region and a wheat/sorghum/hay system for the southeast mixed region. The land-use and population patterns described below suggest that the classification is sound and consistent for the counties included within each region.

Results

Colorado Great Plains

For all of eastern Colorado (Table 1), rangeland decreased by 15%, cropland by 2%, and land in farms by 11% between 1950 and 1997. Rangeland decreased substantially in all four regions, with 43% of the total decrease in rangeland area in the urban region. The urban counties lost most of the rangeland in absolute and percentage (-32%) terms, while the urban fringe (7%) and rural regions (11% in the northeast mixed and 12% in the southeast mixed) all showed similar, more modest losses. Total cropland area decreased in all the regions except the northeast mixed, where cropland area increased by 13%. As expected, the largest losses of cropland occurred in the urban region (44%), while the southeast mixed decreased by 10% and the urban fringe by 5%.

Eastern Colorado lost only 2% of its cropland since 1952, while total harvested area actually increased 5%. There was a general pattern of decreasing area of harvested dryland, with the largest losses in the urban area (48%) and smaller losses for the urban fringe (32%) and northeast mixed

TABLE 3
COUNTIES INCLUDED IN LAND-USE CATEGORIES, EASTERN COLORADO

Urban	Urban fringe	Rural northeast mixed	Rural southeast mixed
Larimer	Weld	Morgan	Herfano
Boulder	Adams	Washington	Las Animas
Jefferson	Elbert	Lincoln	Baca
Douglas		Logan	Kiowa
El Paso		Sedgwick	Cheyenne
Pueblo		Phillips	Crowley
Arapahoe		Yuma	Otero
		Kit Carson	Bent
			Prowers

(15%) regions. Beginning in 1950, harvested irrigated area increased in all the regions except the urban, with the largest increases in the northeast mixed region (318%). Total harvested area in eastern Colorado increased, because harvested irrigated land increased more than the harvested dryland area decreased. Total harvested irrigated cropland in eastern Colorado increased by 73% between 1950 and 1997. In irrigated areas there was a closer correlation between cropland and harvested land because irrigated land experienced little crop failure due to water shortage.

Another interesting pattern was the dramatic increase in dryland winter wheat area from 1970 to 1985, followed by a reduction in harvested winter wheat acreage in 1987 to 1988 due to enrollment of land in the Conservation Reserve Program, a government program that paid farmers to take land out of production (Dicks 1990; Heimlich and Kula 1990; Harrington and Dubman 1998; Leathers and Harrington 2000). The data suggest that the increase in harvested winter wheat area from 1970 to 1985 was subsequently removed from production by the Conservation Reserve Program (Table 4). It is possible that some of this land went back to winter wheat production after the end of the 10-year commitment required for program participation, but the available agricultural census data (Table 4) do not show this trend by 1997.

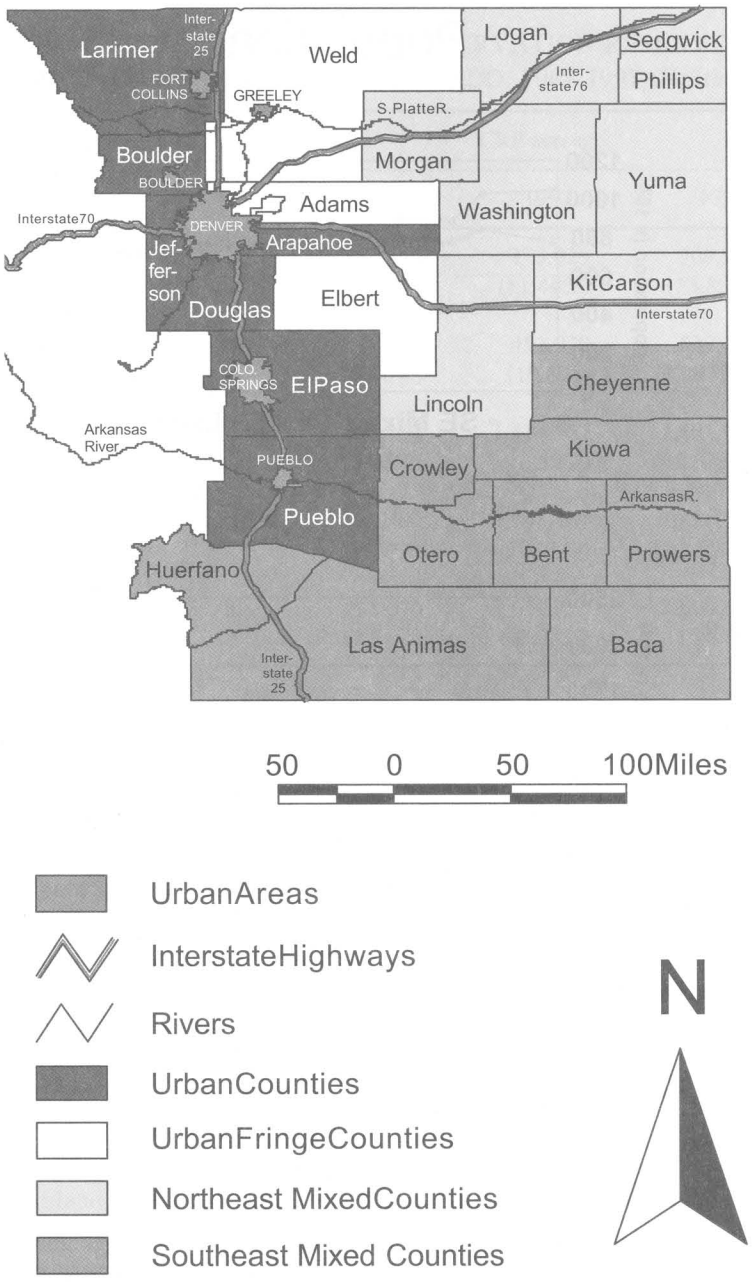

Figure 1. Eastern Colorado, showing major urban areas, interstate highways, rivers, and four categories of counties.

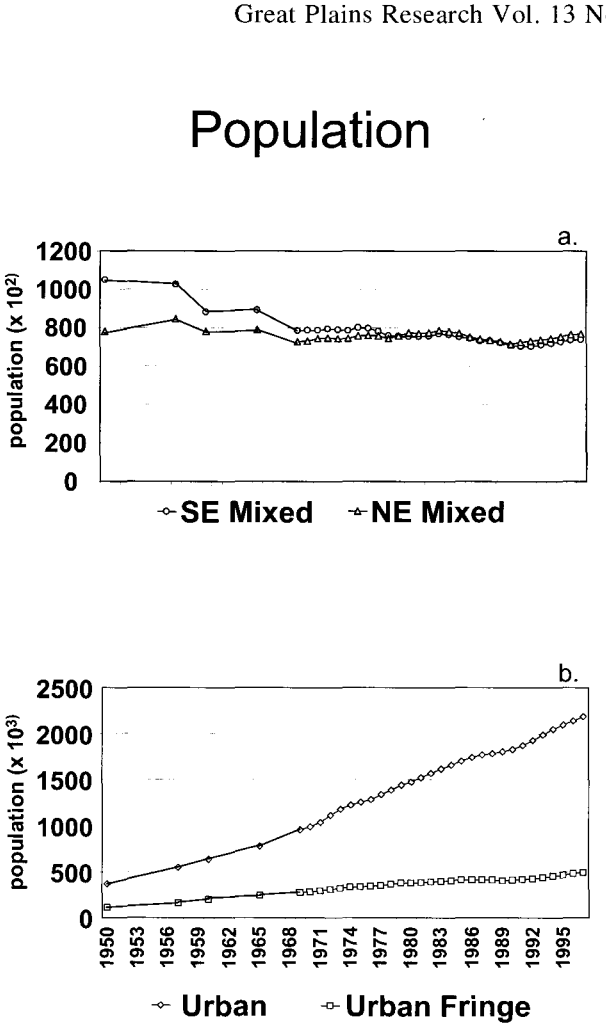

Figure 2. Population trends since 1950 for (A) southeast mixed and northeast mixed rural regions and (B) urban and urban fringe regions.

Urban Areas

The urban region had 77% of its total farmland in rangeland and the remainder in cropland (Fig. 3A). The major agricultural crop in the urban region (Fig. 4A) is harvested hay (mainly alfalfa hay) followed by winter wheat, corn, and barley (50% irrigated). The data (Fig. 4) show a gradual

TABLE 4
LAND CONTRACTED TO THE CONSERVATION RESERVE PROGRAM (CRP) IN EASTERN COLORADO, 1987-1997 (Hectares)

	Cropland acreage	CRP acreage		
	1987	1987	1992	1997
Urban	1,512,082	138,559 (9.16%)	173,029 (11.44%)	209,911 (13.88%)
Urban fringe	4,169,432	225,155 (5.40%)	453,970 (10.895)	539,773 (12.955%)
Northeast mixed	10,807,751	406,954 (3.77%)	1,144,567 (10.59%)	1,402,065 (12.975%)
Southeast mixed	6,069,740	1,024,402 (16.88%)	1,248,147 (20.56%)	1,426,916 (23.515%)
Total	22,559,004	1,795,070 (7.96%)	3,019,713 (13.39%)	3,578,665 (15.86%)

Note: Percentages appear in parentheses.

decline in hay area (20% decline over 47 years), a steep decline in harvested barley area (85%), and a more moderate decline in harvested corn (29%) and winter wheat (30%).

Cropland declined by 44% in urban counties over the half-century. Of the agricultural land lost in the urbanized counties, 70% was rangeland and 30% was cropland. Nonetheless, the dominance of rangeland over cropland in the region means that cropland declined by 44%, while rangeland declined by only 32%. Harvested dryland dropped more than any other category (48%), while harvested irrigated land declined by only 26%, perhaps reflecting the higher agricultural value of irrigated land.

Total farmland area showed little change prior to 1960, a rapid drop in total farmland area from 1960 to 1980, and a slowing rate of decrease in farmland from 1980 to 1997. Urban population (Fig. 2B) has increased steadily during the last 50 years (an average of over 38,000 people per year), with the initial decline in farmland acreage starting when the urban population reached 0.5 to 0.6 million. The pace of farmland decline slowed after

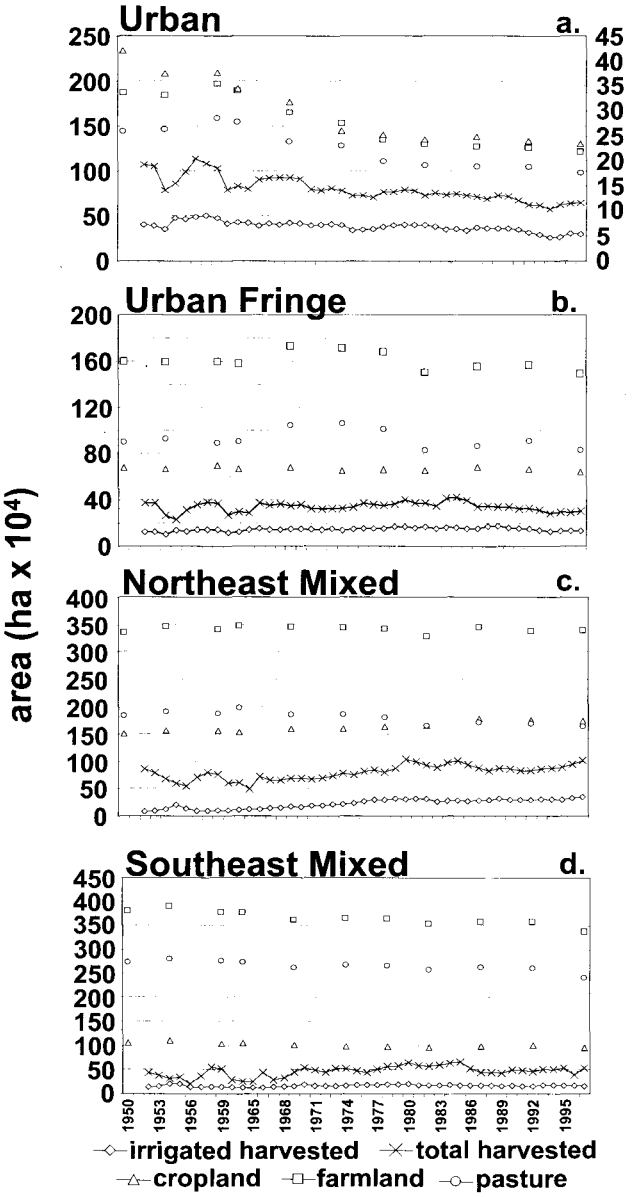

Figure 3. Changes in irrigated harvested area, total harvested area, cropland, pasture, and total farmland since 1950 for regions of eastern Colorado: (A) urban, (B) urban fringe, (C) northeast mixed, and (D) southeast mixed. In (A), irrigated harvested, total harvested, and cropland are all on the secondary axis.

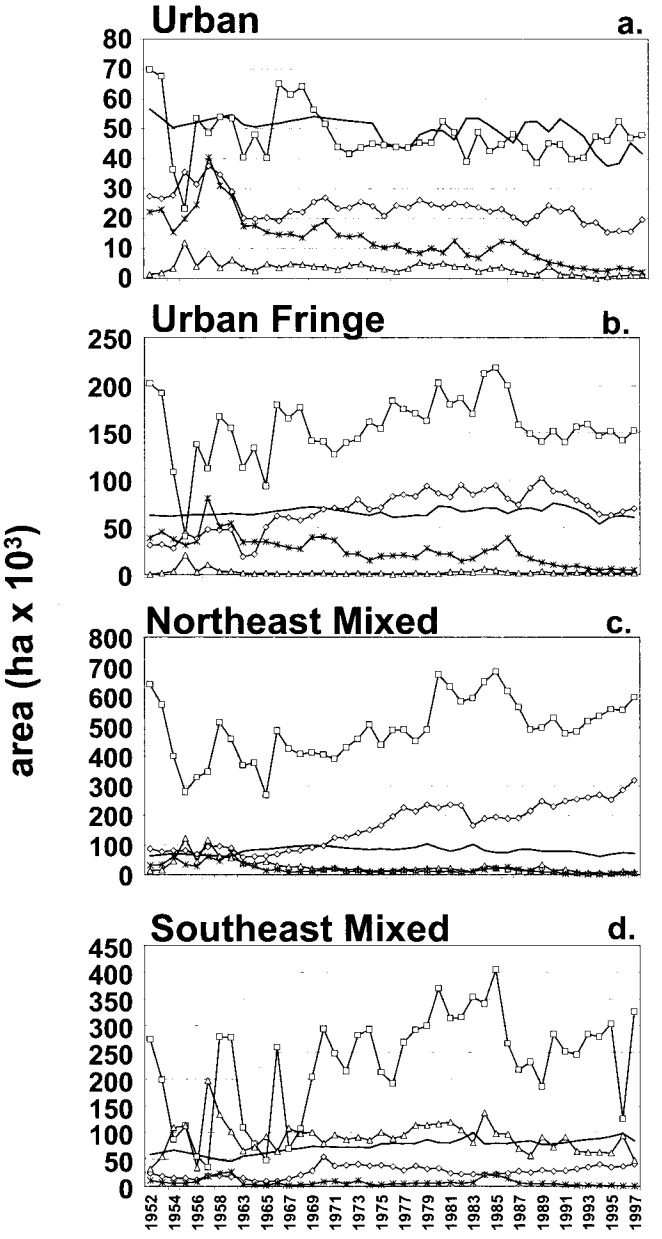

Figure 4. Changes in harvested area, from 1950 to 1997, for corn, winter wheat, sorghum, barley and hay in regions of eastern Colorado: (A) urban, (B) urban fringe, (C) northeast mixed rural, and (D) southeast mixed rural.

the population reached 1.4 to 1.6 million. During the period of rapid farmland decline (1959-1978), an average decrease of 0.78 ha occurred for each person added to the population, while after 1977 the loss of farmland declined to 0.17 ha for each person added to the population.

This reduction in the rate of farmland decline is probably a result of significant open-space programs in many Front Range urban counties. For example, Boulder County governments have purchased over 12,000 ha of open space in the last three decades, more than half of which is still in agricultural use. Another surprising result of this study is the relatively high level of irrigated hay production in the urban corridor (Fig. 4). This is probably influenced by increased demand for high-quality hay in the recreational-horse market, and is associated with an exurban pattern of "horse properties," typically 2 to 3 ha home sites.

Urban Fringe

The urban fringe area includes counties with substantial increases in population during the last 50 years, but which retain large amounts of agricultural land. Fifty-six percent of the total farmland is currently in rangeland and the remainder is in cropland, with 57% of the harvested area in dryland crops and 43% in irrigated crops. The urban fringe region has experienced less loss of farmland than the urban region, with the most significant decline starting in 1980. Most of the farmland loss in this area came from rangeland, which accounts for 70% of the total farmland loss. The total cropland and harvested area has remained fairly constant since 1950; the drop in harvested land in 1987 was probably due to enrollment of dryland winter wheat acreage in the Conservation Reserve Program. Harvested irrigated land has decreased by 16% since 1990.

Winter wheat is the dominant harvested crop in the urban fringe, followed by corn, hay, barley, and sugar beets. Harvested winter wheat area varied considerably in the 1950s and 1960s due to severe droughts, increased from the early 1970s until 1985, and then decreased after 1986 due to enrollment of winter wheat land in the Conservation Reserve Program. Harvested hay area has remained constant over the long term, while corn area increased from 1950 until 1989 and decreased since.

Population data for both the urban and urban fringe regions (Fig. 2B) show that population increased after 1950, with the urban population increasing four times as fast as the urban fringe population (38,684 people per year in the urban area compared to 8,016 per year in the urban fringe). Comparison of the agricultural land-use data (Figs. 3A, 3B) with the popu-

lation data (Fig. 2B) suggests that the decrease in farmland in urban areas started in 1960, when the population reached 0.5 to 0.6 million people, but began in the urban fringe region in about 1978, when the population reached 0.36 million people. The loss of farmland in the urban fringe region after 1978 is equal to 1.5 ha per person added to the population. By comparison, the urban region lost an average of 0.78 ha per person from 1960 to 1977, and 0.17 ha per person from 1978 to 1997. The large loss of farmland relative to population growth in the urban fringe is probably a result of conversion of rangelands into housing developments, but harvested irrigated land also decreased rapidly (by 16%) after 1990.

Southeast Mixed

A large area of southeastern Colorado is dominated by dryland cropping in the southern counties and irrigated crops along the Arkansas Valley. This group of counties exhibited a 10% decrease in total cropland area, while harvested dryland crop area increased by 17% and harvested irrigated area increased by 30% (Figs. 3D, 4D; Table 2). Total farmland decreased by 11% since 1950, with most of the decrease (74% of the total loss) coming from a decrease in rangeland (10% since 1950). The dominant crop in the region is dryland winter wheat, followed by grain sorghum and hay. The area in harvested winter wheat was erratic during the 1950s and 1960s due to drought. It increased from the 1960s to a peak in the mid-1980s, decreased in 1987 due to enrollment of land in the Conservation Reserve Program, and recently has increased. The southeast mixed region had significantly more land contracted to the Conservation Reserve Program than the other regions (Table 4), probably because the extent of land in dryland cropping made the Conservation Reserve Program more attractive in the southeast mixed region than elsewhere.

Northeast Mixed

The rural counties of northeastern Colorado (Fig. 1) had 67% of their harvested land in dryland and an even balance between pasture and cropland. This region exhibited a continuous increase in total cropland (16% since 1950) and harvested cropland (18% since 1950), in contrast to the classic Great Plains pattern of decreased crop area. This pattern of increased total and harvested cropland was primarily a result of the dramatic increase in harvested irrigated land (>300% increase since 1950), while the harvested dryland crops generally remained steady or decreased. Irrigated

cropland has increased for a variety of reasons (Kromm and White 1992). Among the most important reasons are improvements in irrigation technology and in the technology for pumping water, as well as changes in the regulatory environment for irrigation, and several time periods when high prices for grain products encouraged the speculative construction of irrigation systems (Green 1992; Musick and Stewart 1992; Roberts 1992; Templer 1992). The availability of irrigation has accompanied the rise in demand for grain to be used for feeding livestock in feedlots. The net effect of the decrease in rangeland was that total farmland remained constant between 1950 and 1997. This is the only region in eastern Colorado where total and harvested cropland increased.

The increase in total harvested land is primarily a result of the phenomenal rise of harvested irrigated corn acreage and a recent trend toward increasing harvested dryland corn. The dominant harvested crop in the region is winter wheat, which increased from 1970 to a peak in the mid-1980s, then decreased rapidly during 1987 to 1988 due to enrollment in the Conservation Reserve Program, and has increased during the last five years. The third most important crop is harvested hay, which has remained steady since 1950.

Corn is in demand for the increasing number of animal confinement facilities in eastern Colorado, especially hog operations. Indeed, it is easier to explain the increase in irrigated area here than to understand the persistence of dryland cropping (Norwood 1995; Dhuyvetter et al. 1996; Krall and Schuman 1996). Irrigation water has continued to be available for agriculture despite competition from urban uses. Both surface water and groundwater is in demand for development of the Front Range urban corridor and for mitigation of urban impacts on flows of the Platte River system. Either efficiency gains are so great that farmers can sell water and continue to crop similar areas, or they have extra water in their portfolio. We also know that some cities lease water back to farmers. In any case, a potential for significant irrigation decline still looms as cities actually use more water.

Findings: Population, Value of Products, Crop Yields and Agricultural Employment

Population Data. Much attention is given to population in Great Plains studies (Albrecht 1993; Rathge and Highman 1998; Beale 1999). Almost every Great Plains analyst cites population decline as the key measure of

regional "health," and Popper and Popper (1987, 1994) carry this to its extreme, predicting the depopulation of much of the Plains. Recent trends in population for the rural regions of eastern Colorado (Fig. 2A) run counter to the standard Great Plains pattern. Population declined in the southeast mixed region from 1950 to 1970 but stabilized thereafter. The decrease in population from 1950 to 1970 was most rapid in the dryland cropping counties as compared to the counties along the Arkansas Valley (Fig. 1) that had substantially more irrigated cropland. Population remained stable in the northeast mixed region where towns anchored on I-70 and I-76 grew slowly, due to a combination of service-economy growth and the boom in irrigated corn production (Miller 1979; Moon 1987, 1988). Dryland cropping counties within the northeast mixed region experienced population patterns similar to the southeast mixed region, with population decreasing from 1950 to 1970. In contrast to popular perceptions about the Great Plains, and counter to the expectations of many researchers, we find that the rural population is now relatively stable throughout the Colorado Plains (Fig. 2A).

Agricultural Employment. Reliable and consistent county-level annual employment data are available back to 1970, while decadal census data for employment in agriculture are available from 1950 (Fig. 5). The census data included total employment in the agricultural sector, while the annual employment data differentiate between the number of jobs in the farm and ranch sector and in the agricultural service sector. The Census of Agriculture employment data for rural eastern Colorado counties show a pattern of large decreases (more than 50%) in total agricultural employment from 1950 to 1970, with slow decreases in employment beginning in 1970. This pattern is similar to population trends in many counties in eastern Colorado (Fig. 2). The annual agricultural employment data show that farm and ranch employment decreased from 1970 to 1997 for all the rural eastern Colorado counties and that employment in the agricultural service sector (difference between total agricultural employment and farm and ranch employment) increased for all the rural regions. The net result is a decrease in total agricultural employment in rural eastern Colorado counties. The general pattern was a rapid decline in agricultural employment from 1950 to 1970, followed by low to moderate decreases since 1970. Thinking about these results in terms of the percentage of the labor force (combining Figs. 2 and 5) leads to contradictory results. Where population grew, as it did in the urban and urban fringe areas, the decline in agricultural employment is even

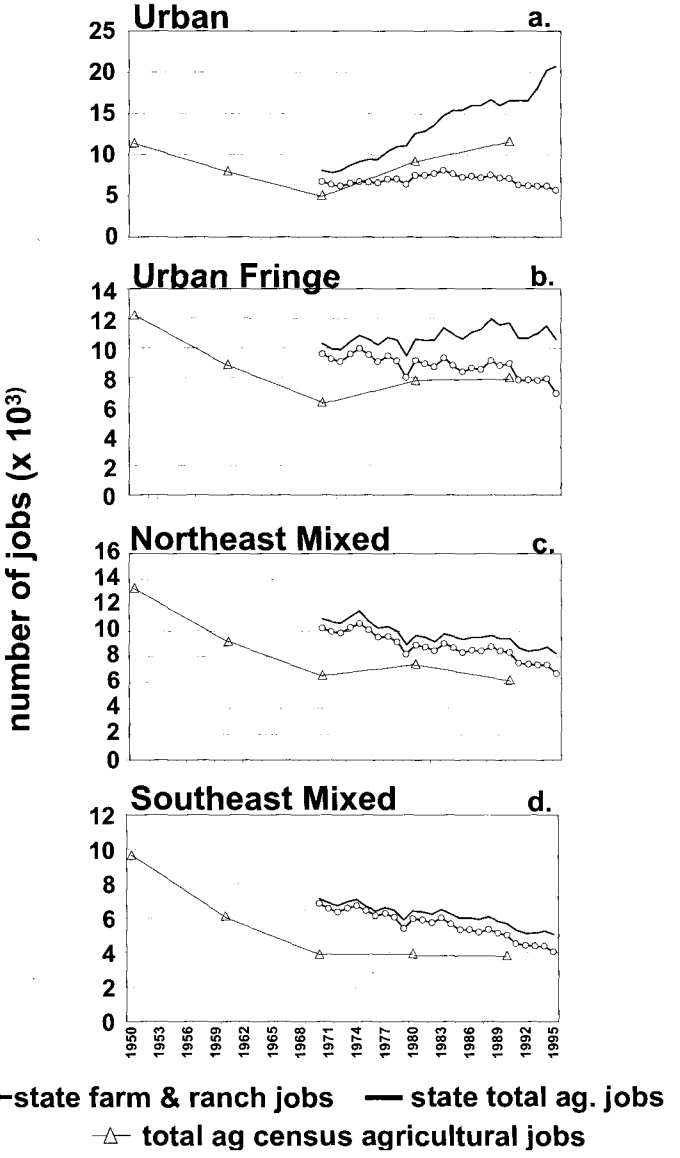

Figure 5. Colorado state data for employment in the farm and ranch category and for total agricultural employment, and federal census data for total agricultural employment, from 1950 to 1997, for the eastern Colorado regions: (A) urban, (B) urban fringe, (C) northeast mixed rural, (D) southeast mixed rural. The agricultural service employment is equal to the difference between the total Colorado state agricultural employment and the employment in the farm and ranch sector.

starker in percentage terms, heightening the impression of agricultural employment decline. Where the population was stable or shrinking, as it was in rural areas, the decline in agricultural employment is striking but not so dramatic.

The two agricultural employment data sets show the same general patterns in employment for both the urban and urban fringe regions. Total agricultural employment decreased by 50% from 1950 to 1970 and then increased from 1970 to 1997 (50% for the urban fringe and 100% for the urban regions). The labor force in agriculture is declining in percentage terms, nonetheless. The annual employment data suggest that an increase in agricultural service jobs was responsible for the increase in total agricultural employment. Farm and ranch employment decreased from 1970 to 1997 in the urban fringe region; however, farm and ranch employment remained surprisingly stable in the urban area despite a 50% loss of total cropland and harvested acreage (Fig. 5). Agricultural service employment increased in urbanizing counties as more dispersed services (e.g., retail and financial) moved out of small towns and concentrated nearer cities. Most surprisingly, we find that farm and ranch employment declined the least in the urban region. Urbanization might have reversed the decline in farm and ranch employment and increased total agricultural employment by increasing the number of service jobs.

Agricultural Market Value. The market value of all agricultural products and crops was derived from the federal Census of Agriculture data for the four regions in eastern Colorado and was adjusted for inflation using the consumer price index (converted to 1981 dollar values). Harvested crop values comprised approximately 20% to 40% of the total value of agricultural products, with over 50% of the total value of agricultural products from the sale of cattle and calves. The peak value of all agricultural products and crops occurred during the 1970s for all regions (Fig. 6). Values of agricultural products increased during the 1970s, mainly an effect of a few large export sales in the early 1970s (notably to the Soviet Union). Other than this run-up in value of production during the 1970s, the value of crops and all agriculture products was fairly stable from 1950 to 1997.

The major exception to this pattern of long-term stability was the increase in the value of crops and all agricultural products in the northeast mixed region. This reflects increased harvested irrigated land and production of animals in the region; it also contributed to the region's pattern of stable-to-increasing total population. The southeast mixed region experienced population decreases from 1950 to 2000 but relatively stable market

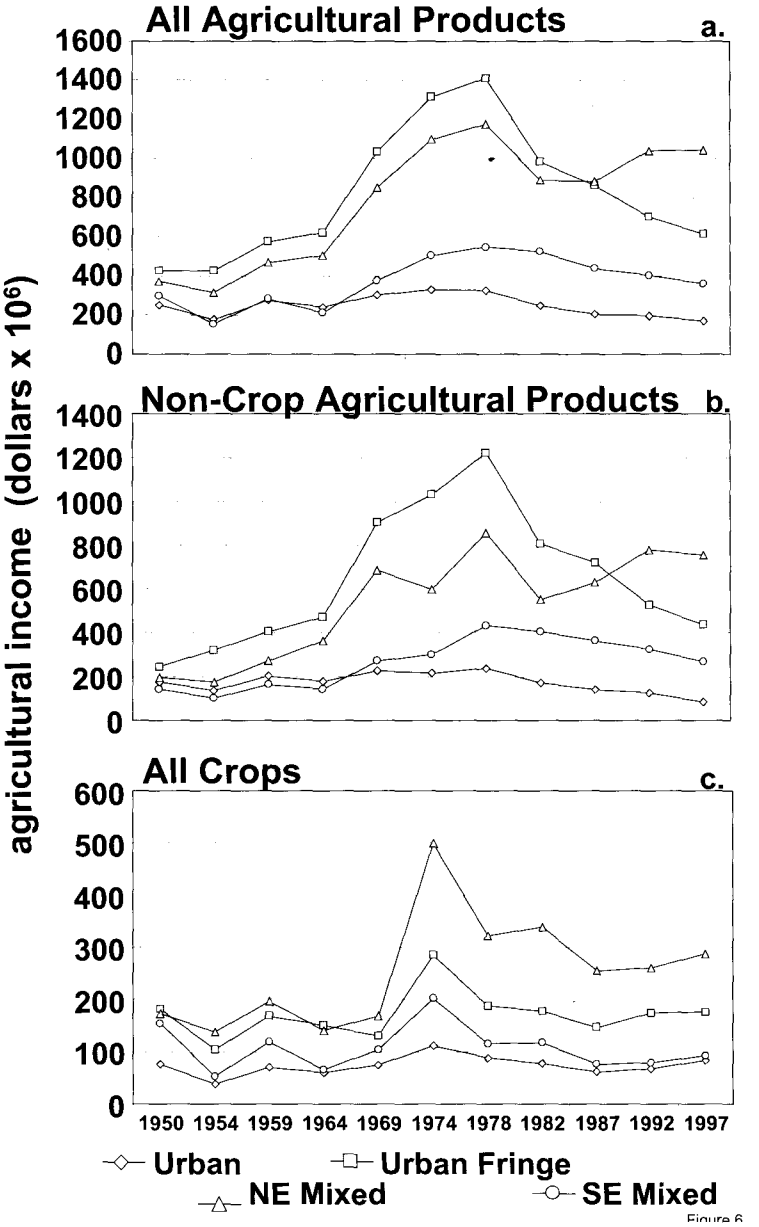

Figure 6. Changes in market value of (A) all agricultural products, (B) noncrop agricultural products, and (C) all crops in the urban, urban fringe, northeast mixed rural, and southeast mixed rural regions of eastern Colorado. The market values are adjusted for inflation using the consumer price index.

values for their agricultural products. In the urban fringe all agricultural products gained value, while crop value was steady. This is probably the result of a large increase in cattle feedlots and other animal production in this region between 1950 and 1997 (Heimlich 1989; Vesterby and Heimlich 1991; Vesterby and Krupa 1993).

Data for the urban region show that the value of crop production remained steady since 1950 despite a 40% to 45% decrease in cropland and harvested area. This pattern mostly resulted from a 100% increase in the value of hay during the last 20 years, hay being the dominant harvested crop (>60% of the total harvested area) in the urban region. The value of noncrop agricultural products in the urban region declined during the last 15 years (reaching its lowest value for the entire period in 1997), suggesting that urbanization is reducing the amount of animal production.

Crop Yields. Total grain yield and yields per hectare have changed for the major crops (hay, corn, barley, and wheat) in eastern Colorado during the last 47 years (Fig. 7). Total grain production in eastern Colorado increased dramatically since 1950 for corn and wheat (~1000% and ~200%, respectively), and decreased for barley (80%), while hay production increased by 100%. The data also show that over 70% of the total hay and corn production comes from irrigated cropland. These results demonstrate the dramatic rise in corn production since 1950.

Yields per hectare increased substantially since 1950 for all crops and for both irrigated and dryland crops (Fig. 7). Improvements in crop yields are a result of improved plant varieties, increased fertilizer use, improved tillage techniques, and increased herbicide and pesticide use. Dryland hay production showed the lowest increases in production since 1950 (+30%). The data show that crop yield increased dramatically as a result of irrigation, which increased production from 200% to 400% depending on the crop and the year. Analysis of the data for annual yield per hectare shows that corn and wheat yields have stabilized since the 1980s for both irrigated and harvested land, while irrigated barley and hay yields continued to increase during the last 10 years.

Increased total hay and wheat production in eastern Colorado since 1950 was a result of the dramatic increases in yields per hectare for these crops, while harvested area remained steady (Figs. 3 and 7). The large increases in corn production were produced by increases in both yields and irrigated area, particularly in the northeast mixed region. Overall, the increase in yield of the major crops produced the relatively stable value of crop production (Fig. 6) in the urban fringe, northeast mixed, and southeast

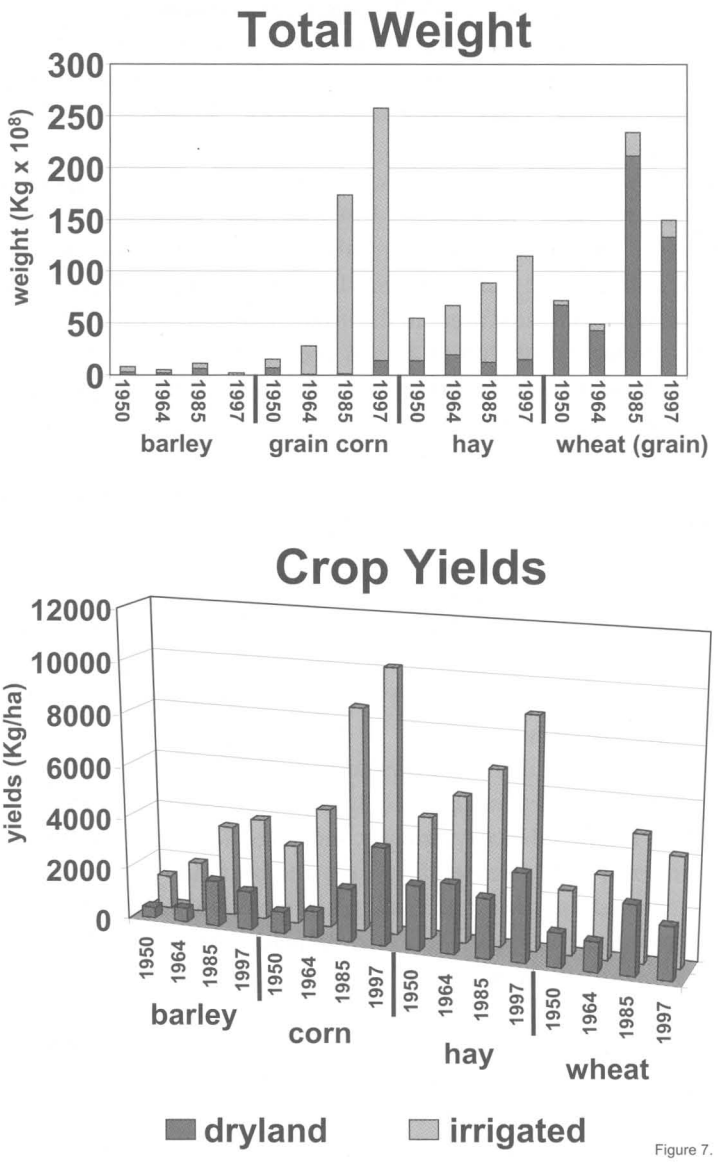

Figure 7.

Figure 7. Changes since 1950 in total harvested weight (top) and yields per hectare (bottom) for irrigated and nonirrigated barley, corn, hay, and wheat in eastern Colorado. The weight of the grain is represented for barley, corn, and wheat, while the total weight of harvested hay is included in the figure. Corn, wheat, hay, and barley are the dominant crops in eastern Colorado (>90% of the harvested acreage).

mixed regions. The lack of change in value of harvested crops in the urban region was a result of the higher yields and value of hay, balanced against the steady decrease in area of all harvested crops since 1950. The large increases in total value of crops in the northeast mixed region were a result of increases in irrigated corn and the yields of the major crops. The unit value of barley, corn, and wheat have not kept up with inflation, while hay prices have increased more rapidly than inflation (USDA-NASS 1994; Picanso and Fretwell 2002).

Crop technology factors that contributed to the increased crop yield include increased irrigation (yields are two to four times greater for irrigated crops; Fig. 7), improvements in tillage practices (Smika and Wicks 1968) and crop varieties (Olmstead and Rhode 2002), increased herbicide and insecticide use, and increased use of summer fallow for wheat systems. The increases in wheat yield during the 1950s were associated with increased use of summer fallow (ARS-USDA 1974), improved water storage in summer fallow via stubble mulching techniques (Smika and Wicks 1968), increased applicaton of nitrogen fertilizer, and improved wheat varieties (Quisenberry and Reitz 1974; Olmstead and Rhode. 2002). Increased wheat yields during the 1970s were most correlated with an increase in nitrogen fertilizer applicaton (from 20 $kgNha^{-1}$ in 1964 to more than 40 $kgNha^{-1}$ in 1982). Corn yield increased because of increased use of irrigation, improved varieties, and increased application of nitrogen fertilizer (from 60 $kgNha^{-1}$ in 1964 to more than 10 $kgNha^{-1}$ in 1980).

Discussion

Agricultural Land Use, Population, and Sustainability

Large increases in population in the urban area since 1950 led to decreases in rangeland, harvested cropland, and total cropland. A substantial fraction (57%) of the loss of total land in farmland in eastern Colorado is in the urban region, with most of the loss consisting of rangeland (70%). The decrease in farmland started in 1959 for the urban region and in 1978 for the urban fringe region. Loss of farmland in proportion to increase in population was the highest for the urban fringe (1.5 ha per person since 1978 vs. 0.78 ha per person from 1957 to 1978 and 0.17 per person from 1978 to 1997 for the urban region). The urban fringe region has also had a large loss of irrigated harvested land (16%) since 1990, suggesting that urbanization has begun to have a substantial impact on active farms in the urban fringe region.

Total cropland area decreased in all regions in eastern Colorado except the northeast mixed, where it increased. Total farmland declined almost everywhere, with most of the land loss consisting of rangeland, while the amount of cropland harvested increased in many areas. This appears to be related to the ratio of irrigated cropland to total cropland. Irrigated cropland increased dramatically in many parts of eastern Colorado since 1950 (except the urban area), which led to higher proportions of total cropland being planted every year and reduced likelihood of crop failure. More irrigation also substantially increased crop yields, and greater yields sustained farm incomes (measured in constant dollars) through most of the period from 1950 to 1997. The increase in yield per hectare occurred for both irrigated and nonirrigated cropland.

The southeast Colorado rural region shows some of the typical Great Plains patterns of decreases in cropland and grazingland and decreases in agriculture employment and population since 1950. This contrasts with the recent (1970-1997) pattern of stabilization of population, harvested land, and agricultural employment, and substantial increases in crop yields. Over the entire half-century, total land involved in agriculture decreased at the same time that production from the remaining agricultural land intensified.

The northeast Colorado rural region shows few of the typical Great Plains patterns of decreasing agricultural activity. Total land in agriculture remained stable; total cropland and harvested land increased; population remained steady; and crop yields and gross farm income (crop and other income) increased from 1950 to 1997. The only negative pattern was a general decrease in agricultural employment. Clearly, the northeast Colorado region experienced growth in the agricultural sector, a pattern atypical of most of the Great Plains.

One surprise in our results is the persistence of agriculture despite declining farmland and total cropland associated with larger urban populations and generally smaller rural populations. The key to the persistence of agriculture and of some rural populations in eastern Colorado has been the growth of irrigation, plus the economically sustaining roles played by the nearby urban areas and the transportation infrastructure that extends through the rural areas. These geographical features appear capable of supporting a small, stable rural population in the face of declining farm and ranch employment.

The central question about the future of the Great Plains involves the sustainability of the factors that have preserved yields, incomes, and generally stable populations. Exurban development and transportation infrastructure are important geographical features throughout the American West,

and it can be argued that the wealth and cultural preferences associated with urban and exurban development appear to have stabilized the agriculture sector through the demand for hay production and through increased job growth in the service sector. Urban growth at the edge of the Colorado Great Plains may be stabilizing population and suppressing agricultural use. The role of irrigation in sustaining Great Plains agriculture is more uncertain, however, and its prognosis depends on the balance between water availability, water demand for urban populations, and agriculture's ability to adapt its water use to availability while maintaining yields, overall production, and employment.

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References

Albrecht, D.E., and S.H. Murdock. 1990. *The Sociology of US Agriculture: An Ecological Perspective.* Ann Arbor, MI: Books on Demand.

Albrecht, D.E. 1993. The renewal of population loss in the nonmetropolitan Great Plains. *Rural Sociology* 58:233-46.

Alig, R.J., and R.G. Healy. 1987. Urban and built-up land area changes in the United States: An empirical investigation of determinants. *Land Economics* 63:215-26.

American Farmland Trust. 1997. Farming on the edge. Washington, DC: American Farmland Trust.

ARS-USDA (Agricultural Research Service–US Department of Agriculture). 1974. *Summer Fallow in the Western United States.* Conservation Research Report No. 17. Washington, DC: US Government Printing Office.

Baltensperger, B.H. 1993. Larger and fewer farms: Patterns and causes of farm enlargement on the central Great Plains, 1930-1978. *Journal of Historical Geography* 19:299-313.

Beale, C. 1999. Nonmetro population rebound: Still real but diminishing. *Rural Conditions and Trends* 9:20-27.

Bedenbaugh, E.J. 1988. History of cropland set aside programs in the Great Plains. In *General Technical Report RM 158: Rocky Mountain Forest and Range Experiment Station*, 14-17. Washington, DC: US Department of Agriculture/Forest Service.

Borchert, J.R. 1971. The Dust Bowl in the 1970s. *Annals of the Association of American Geographers* 61:1-22.

Botham, R.W. 1980. The regional development effects of road investment. *Transportation Planning and Technology* 6:97-108.

Bowden, M.J. 1975. The Great American Desert in the American mind: The historiography of a geographical notion. In *Geographies of the Mind: Essays in Historical Geosophy in Honor of John Kirtland Wright*, ed. D. Lowenthal and M.J. Bowden, 119-47. New York: Oxford University Press.

Callenbach, E. 1995. *Bring Back the Buffalo!: A Sustainable Future for America's Great Plains.* Washington, DC: Island Press.

Colorado Department of Agriculture. 2000. *Tracking Agricultural Land Conversion in Colorado.* Denver: Colorado Department of Agriculture.

De Bres, K., and M. Guizlo. 1992. A daring proposal for dealing with an inevitable disaster? A review of the Buffalo Commons proposal. *Great Plains Research* 2:165-78.

Dhuyvetter, K.C., C.R. Thompson, C.A Norwood, and A.D. Halvorson. 1996. Economics of dryland cropping systems in the Great Plains: A review. *Journal of Production Agriculture* 9:216-22.

Dicks, M.R. 1990. Southern Great Plains CRP lands: Future use and impacts. *Current Farm Economics* 63:43-54.

Green, D.E. 1992. A history of irrigation technology used to exploit the Ogallala Aquifer. In *Groundwater Exploitation in the High Plains*, ed. D.E. Kromm and S.E. White, 28-43. Lawrence: University Press of Kansas.

Gutmann, M.P., A. Peri, D. Sysma, I.C. Burke, W.J. Parton, and G.D. Deane. 1999. The transformation of land from agricultural to non-agricultural uses in the US Great Plains, 1964-1999. Unpublished paper presented at the annual meeting of the Social Science History Association, 12 November 1999, Fort Worth, TX.

Harrington, D.H., and R. Dubman. 1998. Agriculture and new agricultural policies in the Great Plains. *Rural Development Perspectives* 13:7-18.

Hart, J.F. 1992. Nonfarm farms. *Geographical Review* 82:166-79.

Heathcote, R.L. 1980. Perception of desertification on the southern Great Plains: A preliminary enquiry. In *Perception of Desertification*, ed. R.L. Heathcote, 34-59. Tokyo: United Nations University.

Heimlich, R. 1985. *Characteristics of Landowners Converting Land in the Western Great Plains, 1975-77.* ERS Staff Report, AGES850409. Washington, DC: US Department of Agriculture/Economic Research Service.

Heimlich, R.E. 1989. Metropolitan agriculture: Farming in the city's shadow. *Journal of the American Planning Association* 55:457-66.

Heimlich, R.E., and O.E. Kula. 1990. Grasslands: The future of CRP land after contracts expire. *Journal of Production Agriculture* 3:7-12.

Jim, C.Y. 1997. Land use problems associated with farmland abandonment. *Geography* 82:277-80.

Krall, J.M., and G.E. Schuman. 1996. Integrated dryland crop and livestock production systems on the Great Plains: Extent and outlook. *Journal of Production Agriculture* 9:187-91.

Kromm, D.E., and White, S.E., eds. 1992. *Groundwater Exploitation in the High Plains*. Lawrence: University Press of Kansas.

Leathers, N., and Harrington, L.M.B. 2000. Effectiveness of Conservation Reserve Programs and land "slippage" in southwestern Kansas. *Professional Geographer* 52:83-93.

Lowe, P.J., J. Murdoch, T. Marsden, R. Munton, and A. Flynn. 1993. Regulating the new rural spaces: The uneven development of land. *Journal of Rural Studies* 9:205-22.

Miller, J.P. 1979. Interstate highways and job growth in nonmetropolitan areas: A reassessment. *Transportation Journal* 19:78-81.

Moon, H.E. Jr. 1987. Interstate highway interchanges reshape rural communities. *Rural Development Perspectives* 4:35-38.

Moon, H.E. Jr. 1988. Interstate highway interchanges as instigators of nonmetropolitan development. In *Relationships of Transportation and Land Use, Economic Development, and Intercity Bus Issues*, Transportation Research Record 1125, 8-14. Washington, DC: Transportation Research Board/National Research Council.

Murdock, S.H., D.E. Albrecht, R.R. Hamm, F.L. Leistritz, and A.G. Leholm. 1986. The farm crisis in the greater plains: Implications for theory and policy development. *Rural Sociology* 51:406-35.

Musick, J.T., and B.A. Stewart. 1992. Irrigation technologies. In *Groundwater Exploitation in the High Plains*, ed. D.E. Kromm and S.E. White, 110-44. Lawrence: University Press of Kansas.

Norwood, C.A. 1995. Comparison of limited irrigated vs. dryland cropping systems in the US Great Plains. *Agronomy Journal* 87:737-43.

Olmstead, A.L., and P.W. Rhode. 2002. The red queen and the hard reds: Productivity growth in American wheat, 1800-1940. National Bureau of Economic Research Working Paper 8863, Cambridge, MA.

Picanso, R.R., and Fretwell, L.A. 2002. *Colorado Agricultural Statistics 2001 Preliminary—2000 Revised.* Denver: Colorado Sunflower Administrative Committee. Retrieved 20 January 2003, http://www.nass.usda.gov/co.

Popper, D.E., and F.J. Popper Jr. 1987. The Great Plains: From dust to dust; A daring proposal for dealing with an inevitable disaster. *Planning* 53:12-18.

Popper, D.E., and F.J. Popper Jr. 1989. The Fate of the Plains. In *Reopening the Western Frontier*, ed. E. Marston, 98-113. Washington, DC: Island Press.

Popper, D.E., and F.J. Popper Jr. 1994. Great Plains: Checkered past, hopeful future. *Forum for Applied Research and Public Policy* 9:89-100.

Quisenberry, K.S., and L.P. Reitz. 1974. Turkey wheat: The cornerstone of an empire. *Agricultural History* 48:98-99.

Rathge, R., and P. Highman. 1998. Population change in the Great Plains: A history of prolonged decline. *Rural Development Perspectives* 13:19-26.

Reeder, R., F. Bagi, and S. Calhoun. 1998. Which federal programs are most important for the Great Plains? *Rural Development Perspectives* 13:52-58.

Riebsame, W.E. 1990. The United States Great Plains. In *The Earth as Transformed by Human Action*, ed. B.L. Turner, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Myers, 561-75. Cambridge, UK: Cambridge University Press.

Riebsame, W.E., W.J. Parton, K.A. Galvin, I.C. Burke, L. Bohren, R. Young, and E. Knop. 1994. Integrated modeling of land use and cover change: A conceptual scheme for applying an integrated strategy to agricultural land use on the US Great Plains. *BioScience* 44:350-56.

Roberts, R.S. 1992. Irrigation technologies. In *Groundwater Exploitation in the High Plains*, ed. D.E. Kromm and S.E. White, 88-109. Lawrence: University Press of Kansas.

Sears, P.B. 1936. *Deserts on the March*. Norman: University of Oklahoma Press.

Skold, M.D. 1989. Cropland retirement policies and their effects on land use in the Great Plains. *Journal of Production Agriculture* 2:197-201.

Smika, D.E., and G.A. Wicks. 1968. Soil water storage during fallow in the central Great Plains as influenced by tillage and herbicide treatments. *Proceedings of the Soil Science Society of America*. 32:591-95.

Tegene, A., K. Weibe, and B. Kuhn. 1999. Irreversible investment under uncertainty: Conservation easement and the option to develop agricultural land. *Journal of Agricultural Economics* 50:203-19.

Templer, O.W. 1992. The legal context for groundwater use. In *Groundwater Exploitation in the High Plains*, ed. D.E. Kromm and S.E. White, 64-87. Lawrence: University Press of Kansas.

USDA-NASS (US Department of Agriculture–National Agricultural Statistics Service). 1994. Prices received by commodity, historic data series, and indexes. Herndon, VA: ERS-NASS. Retrieved 20 January 2003, http://jan.mannlib.cornell.edu/data-sets/crops/92152/.

Vesterby, M., and R.E. Heimlich. 1991. Land use and demographic change: Results from fast-growth counties. *Land Economics* 67:279-91.

Vesterby, M., and K.S. Krupa. 1993. Effects of urban land conversion on agriculture. In *Urbanization and Development Effects on the Use of Natural Resources*, ed. E.M. Thunberg and J.E. Reynolds, 85-114. Southern Rural Development Center (SRDC) Series 169. Starkville: Mississippi State University/SRDC.

Webb, W.P. 1931. *The Great Plains*. Dallas: Ginn and Company. Reprint, Lincoln: University of Nebraska Press, 1981.

Worster, D.E. 1979. *Dust Bowl: The Southern Plains in the 1930s*. New York: Oxford University Press.