Land-cover changes in South Africa 1911–1993

R. Biggs[a,b*] **and R.J. Scholes**[a]

THE AREA UNDER CULTIVATION IN SOUTH Africa more than tripled during the twentieth century, while plantation area increased more than tenfold. These land covers now constitute 12% and 1.5%, respectively, of the country's surface area. This paper describes the changes that have occurred in relation to the production and yields per hectare of major crops (maize, wheat, sorghum and sugar cane) and discusses the factors that contributed to the changes. Both domestic and global population growth partly underlie the increased demand for crop products over the past century. Increased production was initially achieved mainly by expanding the area under cultivation, and, from the 1960s onwards, principally through enhanced yields per hectare. In the latter period, nationally averaged productivity in a given year was related to fertilizer use, irrigation and the proportion of the country experiencing dry conditions. The crops grown and the yields per hectare differed significantly between the predominantly commercial, former white-owned areas and the mainly subsistence, former homeland areas. Independent estimates of historical cultivated area at the national level were derived from estimates of production and productivity per hectare, presenting a method that could be used to obtain improved historical land-cover estimates in data-poor countries.

Introduction

The land cover of the earth has changed dramatically during the last millennium, and particularly in the past two centuries, as a result of human activities.[1,2] Land-cover change impacts directly on biogeochemical cycles, climate and hydrology,[3] as well as contributing to species loss through habitat fragmentation and destruction.[4,5] These effects are felt at local and regional levels, as well as having important influences on processes on a global scale.[6] Moreover, they have consequences for employment and ways of life, sustainable development and human responses to global change. Previous studies suggest that, at the time scale of a few decades, economic conditions, mediated by factors such as political policies and social conditions, are the main factors influencing an individual's decision on how to use land.[7] Over longer periods and on larger spatial scales, changes in population and per capita consumption are strongly related to modified land cover.[8–10]

Lack of knowledge about historical changes in land cover are currently the main source of uncertainty in global carbon budgeting.[11,12] Transformation of natural ecosystems and changes in land-use practices over the past 150 years account for approximately one third of the total anthropogenic carbon dioxide emissions in this period[11]. Several studies have attempted to reconstruct spatially explicit historical changes in global land cover by redistributing national statistics on land cover.[13–15] In Africa particularly, there are few records of historical changes in land cover, limiting the accuracy of these reconstructions[14]. Improved national estimates can therefore contribute significantly to enhancing the accuracy of spatially explicit models of historical land cover for a region.

An objective of this study was, first, to describe the land-cover changes that have occurred in South Africa during the past century and outline the principal factors that have contributed to these changes. A second aim was to determine whether historical cultivated area at the national level could be estimated from more readily available statistics (such as population numbers and crop exports), and hence to present a method for obtaining improved historical land-cover estimates for data-poor countries.

The historical land-cover data set

The primary source of historical land-cover data is the South African National Census of Agriculture.[§] The census has been conducted annually since 1918, and reports data by magisterial district. Before 1994, the census focused on agricultural activities in the former white areas; few data are available for the former homeland areas. Long-term census data may show inconsistencies in the definition of variables and in the units of reporting as a result of altered census methods and changes in provincial and local boundaries[16] The transformations applied to the census data in this study are adjustments for inconsistent definitions, corrections for changes in magisterial district boundaries and estimation of missing data. A full description of the data set is available on the Internet,[†] while the raw data and details of the transformations may be requested from the authors.

The definitions of the area under cultivation and afforestation have changed over time. In this study, the Food and Agriculture Organization's (FAO)[17] definition of arable lands and permanent crops was used to define cultivated land consistently as: land under annual and perennial crops (including orchards and vineyards) and temporarily fallow land (resting for less than five years), including land used for market and kitchen gardens but excluding land under timber plantations. Planted pasture was also classified as cultivated land. Afforested land was defined as the area under timber plantations.[‡]

Changes in magisterial districts over time were corrected for by reallocating data to the magisterial districts as defined in 1994. The 1994 map included the former homeland districts as separate units. All data were reallocated in proportion to the fraction of cultivated land (that is, the sum of the cultivated and improved grassland classes) in each district, as derived from the 1995 national land-cover map.[18] Plantation data were reallocated in proportion to the distribution of forest plantations on the 1995 land-cover map.

Three instances of missing data were estimated by interpolation (sugar production in 1965) or disaggregation of a national estimate (afforested area in 1976 and 1988). Cultivated area in the former homelands was estimated by linear interpolation from data available for 1918, 1965 and 1995. Separate interpolations were performed for 1918–1959 (based on the 1918 and 1965 data) and 1960–1993 (based on the 1965 and 1995 data).

The consistency between the 1993 census and the 1995 land-cover map was investigated at the magisterial district level by linear regression. The two districts for which the largest cultivated areas were recorded in 1993 (Vryburg and Lichtenburg) were excluded from the analysis owing to the high leverage of these values. For the former white areas,

[a]CSIR Environmentek, P.O. Box 395, Pretoria 0001, South Africa.
[b]Faculty of Science and Agriculture, University of Natal, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa.
*Author for correspondence. Present address: CSIR Environmentek. E-mail: rbiggs@csir.co.za

[§]Conducted by Statistics South Africa (http://www.statssa.gov.za)

[†]Http://www.nsif.org.za/linux/sddf_index.htm (Historical Agricultural and Forestry Land-cover Dataset).

[‡]Between 1911 and 1960 government and municipal plantations were excluded from the census. From 1960 onwards all plantations in the former white areas were included in the census.

the 1993 census reported 89% of the cultivated land given on the 1995 land-cover map, therefore underestimating the cultivated area on the land-cover map by a factor of 1.07 ($r^2 = 0.91$, $P < 0.001$, $n = 276$ magisterial districts). The census reported that 10.2% of the former white area was under cultivation, whereas the 1995 land-cover map gives a corresponding value of 11.3%. This amounts to an absolute difference of approximately one million hectares in the area calculated to be under cultivation. The difference is probably due to the recording of recently abandoned land on the 1995 land-cover map, under-reporting in the census and because the agricultural activities of farm labourers on commercial farms are not included in the agricultural censuses.

Patterns of agricultural change

Privately owned farms*, as covered by the agricultural census, currently occupy 68% of South Africa's land area; the rest consists of communally owned land (14%), national parks (6%) and other, mainly state, land (12%). This study focuses on agricultural change in the former white areas, owing to the lack of data for the former homeland areas. The former white areas made up 86% of South Africa and accounted for 79% of the total cultivated land in 1995.

The total area of privately owned farms has remained relatively stable over the past century. The total number of farm units has decreased, however, since the 1950s; consequently, the average farm size is now the largest in recorded history. More than 80% of privately owned farmland remains under natural rangeland. In 1993, 13% of the area of privately owned farms was under cultivation, compared with only 4% in 1911. As cultivated land has expanded, changes have taken place in the relative areas planted to different crops (Fig. 1). Forest plantations have expanded rapidly since the 1960s, and covered 1.5% of the privately owned farm area in 1993 and, together with the plantations in the former homeland areas, 1.5% of South Africa in 1995. The 1995 land-cover map indicates that 11% of the former white area was mapped as cultivated, compared to 18% in the former homelands; 1.5% of the former white area was mapped as afforested, compared to 1.2% in the former homelands.

In the former white areas, production of staple cereal crops (maize, wheat and sorghum) has increased significantly over the past century (Fig. 2). Production of sugar cane, a major export crop, similarly increased. By contrast, agricultural production in the former homeland areas showed little apparent change over the period it was recorded (Fig. 3). Although the area under sorghum cultivation is relatively small, sorghum was included in our analysis because of its importance in subsistence farming. The lower productivity (yield per hectare) in the former homelands implies that production of a ton of maize or sorghum required almost triple the land necessary in the former white areas.

Estimating cultivated area

Cultivated area until the mid-1900s can be estimated from population numbers using simple linear regression (Fig. 4). Until 1960, the average cultivated area per person in South Africa was consistently about 0.55 ha. Thereafter, the cultivated area per person dropped sharply to less than 0.3 ha by 1993.

The area under cultivation for a specific crop can be derived mathematically by dividing actual or estimated crop production by the calculated crop productivity per unit area (Fig. 5). Crop production statistics are sometimes available in cases where the area under cultivation has not been recorded (for example, for the former homelands of South Africa), or can be estimated from consumption and export data. Consumption may be direct (as a crop or a derived crop commodity such as maize meal or bread) or indirect (for example, as meat that has been produced by feeding crop products to livestock). Productivity per unit area is primarily related to nutrient and water availability.[19]

The reported total production of maize, wheat and sugar cane was estimated as the sum of the independently recorded domestic consumption and net exports (exports minus imports) (Fig. 5a). Direct consumption of maize has decreased since 1960 ($r^2 = 0.87$, $P < 0.001$, $n = 39$ years),

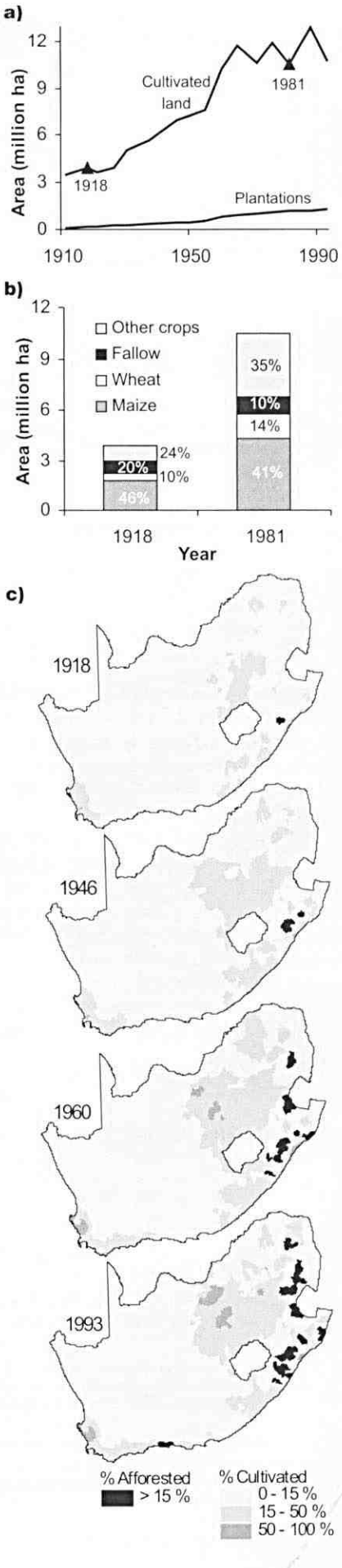

Fig. 1. (**a**) Between 1911 and 1993 total cultivated land in South Africa more than tripled while forest plantation area increased more than tenfold in the former white areas. After plateauing in the 1960s, the area under cultivation shows increased variability, possibly due to the sporadic cultivation of marginal land. (**b**) Maize and wheat account for almost half the total area under cultivation. In terms of area planted, other important crops are oats, sunflower seed and sugar cane. The relative area planted to non-staple food crops has increased, mostly at the expense of fallow land. (**c**) During the past century, agricultural expansion occurred mainly in the highveld region. Despite the large increase in afforestation since the Second World War, plantations still covered only 1.5% of the country's surface area in 1995.

*Defined in the agricultural census as any land on which livestock are kept, crops, fruit or flowers are grown or afforestation is practised.

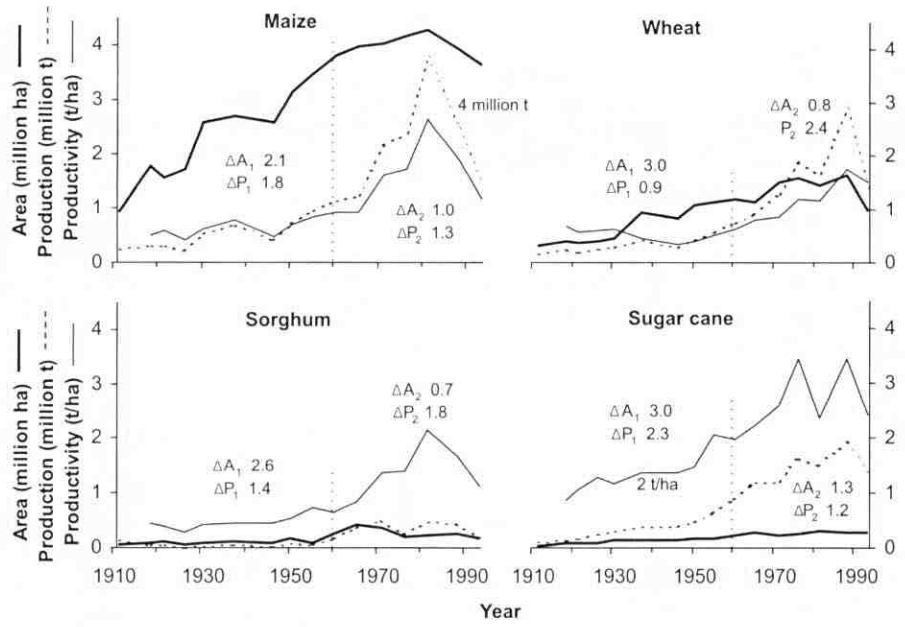

Fig. 2. Crop production has increased significantly over the past century. These increases were initially brought about mainly by expanding the area under cultivation. From the 1960s onwards, higher production was achieved largely through significant increases in crop yield per hectare. Declines in crop production during the early 1990s can be attributed to drought and the withdrawal of agricultural subsidies. Dry-weight sugar production was estimated by multiplying the recorded unprocessed sugar production by a factor of 0.115. ΔA is the relative change in cropped area; $\Delta A_1 = \text{Area}_{1960}/\text{Area}_{1918}$; $\Delta A_2 = \text{Area}_{1993}/\text{Area}_{1960}$. Similarly, ΔP is the relative change in productivity.

while indirect consumption has increased ($r^2 = 0.36$, $P < 0.001$, $n = 39$). For wheat, 95% is consumed directly and the consumption per person is increasing ($r^2 = 0.21$, $P = 0.004$, $n = 39$). On average, 40% of sugar produced has been exported annually since 1960. Net exports of all three crops show significant inter-annual variation since 1960, but no overall trend. The productivity of maize, wheat and sugar cane farming in South Africa was modelled (using multiple linear regression) as a function of total nitrogen fertilizer use, total area under irrigation and the percentage of the country experiencing dry conditions in a particular year (Fig. 5b).

The estimated area under cultivation (derived by dividing the modelled crop production by the modelled crop productivity) shows greater inter-annual variation in cultivated area than is reported in the census, particularly in the case of maize (Fig. 5c). This is partly due to the coarseness of the crop productivity model, resulting from the lack of crop-specific data on the drivers of productivity, especially data on rainfall. It is also partly because the crop production model does not account for the delayed consumption or export of crops.

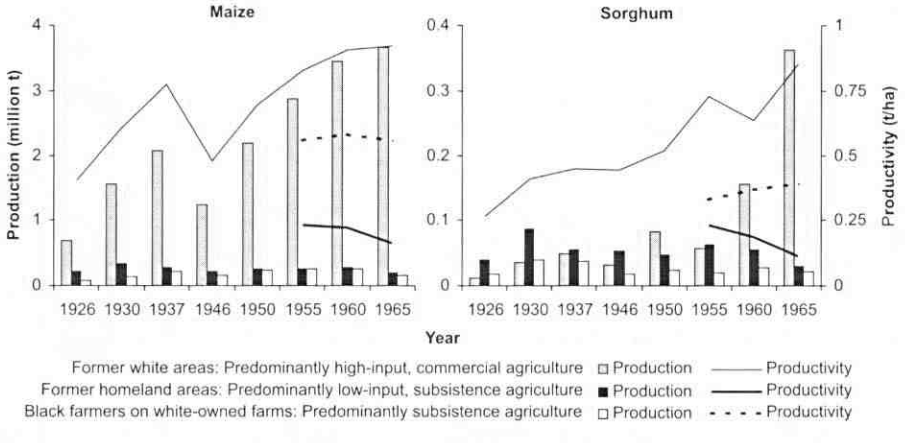

Fig. 3. Subsistence production of maize and sorghum remained at roughly the same level during the 40 years in which it was recorded. Commercial production rose sharply over the same period. Sorghum was a relatively more important crop in the former homeland areas. Over the ten-year period for which comparative productivity data are available, yield per hectare of commercial farmers in the former white areas was almost triple that of subsistence farmers in the former homeland areas. Yield per hectare of black farmers on white-owned farms was almost double that in the homeland areas.

Discussion

The patterns of agricultural change in South Africa are partly related to population growth, as well as being influenced by cultural, political and economic conditions.[20] Population growth and rising affluence have been important factors contributing to increased local and export demand for food products. Enhanced demand has been met in two main ways — initially, mainly through expansion of the area under cultivation (Fig. 4), and later, principally through technological changes that increased yields per hectare.

Most of the agricultural expansion took place before the 1960s, and was largely restricted to the wetter eastern and extreme southern parts of the country (Fig. 1). The environmental impacts of land transformation (such as habitat loss) are therefore borne disproportionately by the biomes in these areas, particularly by the highveld grassland and fynbos biomes.[21] The main expansion in forestry occurred after the Second World War, driven by the demand for mine support timber, domestic need for construction timber and the international pulp market. Forestry impacts mainly on the grassland biome along the eastern escarpment.

The large increases in crop yields per hectare during the 1960s and 1970s (Fig. 2) resulted from the introduction of higher yield cultivars and pesticides together with enhanced use of inorganic fertilizers and irrigation (Fig. 5b), the legacy of the Green Revolution.[22] The decline in sugar yield per hectare since 1960 is mainly due to a reduction in the mean crop age (the older the crop, the greater the yield per hectare), resulting from the expansion of the sugar industry and harvesting at younger ages to limit damage by *Eldana saccharina*, a stalk boring pest. Moreover, small-scale growers, who obtain lower average yields, are producing an increasing proportion of the sugar crop (R. Bailey, pers. comm., South African Sugar Association).

The lower yields per hectare in the former homelands compared to the former white areas (Fig. 3) are mainly a result of the lower use of fertilizer, irrigation and pesticides. The higher yield per hectare achieved by black farmers on white-owned farms than by black farmers in the homeland areas can be explained by the greater access that the farmers on white-owned farms have to inputs and to technical knowledge about how to apply them. Other analyses have shown that, on average, climatic and soil conditions for agriculture are comparable in the former homeland and former white

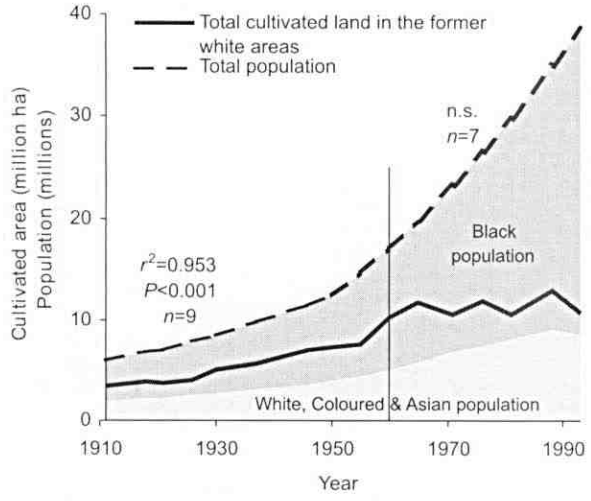

Fig. 4. Until 1960, the expansion of cultivated land in the former white areas was highly correlated with total population growth. This implies that rising food demands were largely met by increasing the area under cultivation. After 1960, the relation between population and cultivated area disappears. During this period, rising demand for production was met mainly by increasing the yields per hectare (net imports show no trend). Population data were obtained from the FAOSTAT database (*FAO Production Yearbook*, Food and Agriculture Organization of the UN; http://apps.fao.org) and Statistics South Africa (http://www.statssa.gov.za).

areas.[23] The observed differences in yields per hectare should therefore be attributed to social and economic conditions rather than to biophysical constraints.

The importance of sorghum in the former homeland areas (Fig. 3) is a consequence of the lower input and rainfall requirements of sorghum relative to maize, and reflects the traditional demand for sorghum products in rural areas. Rising per capita income creates a change in the composition of demand, with traditional grains giving way to livestock products and processed foods such as bread.[24] The rise in affluence of the population over the twentieth century is the likely reason for the shift from direct to indirect consumption of maize.[10] Along with export demand, growing affluence may also partly explain the increased proportion of cultivated land devoted to speciality crops grown by horticulture (Fig. 1).

The threat of international economic sanctions during the Apartheid era resulted in the government of the time pursuing a policy of national food security. The introduction of policy instruments[25] such as agricultural subsidies and minimum selling prices stimulated domestic production by artificially lowering production costs. The increased variability in the area under cultivation in the former white areas after 1960 (Fig. 1) was probably due to the cultivation of marginal land resulting from the introduction of agricultural subsidies. Marginal areas are more prone to crop failures brought on by climatic fluctuation and are therefore cultivated only during years of good rainfall.

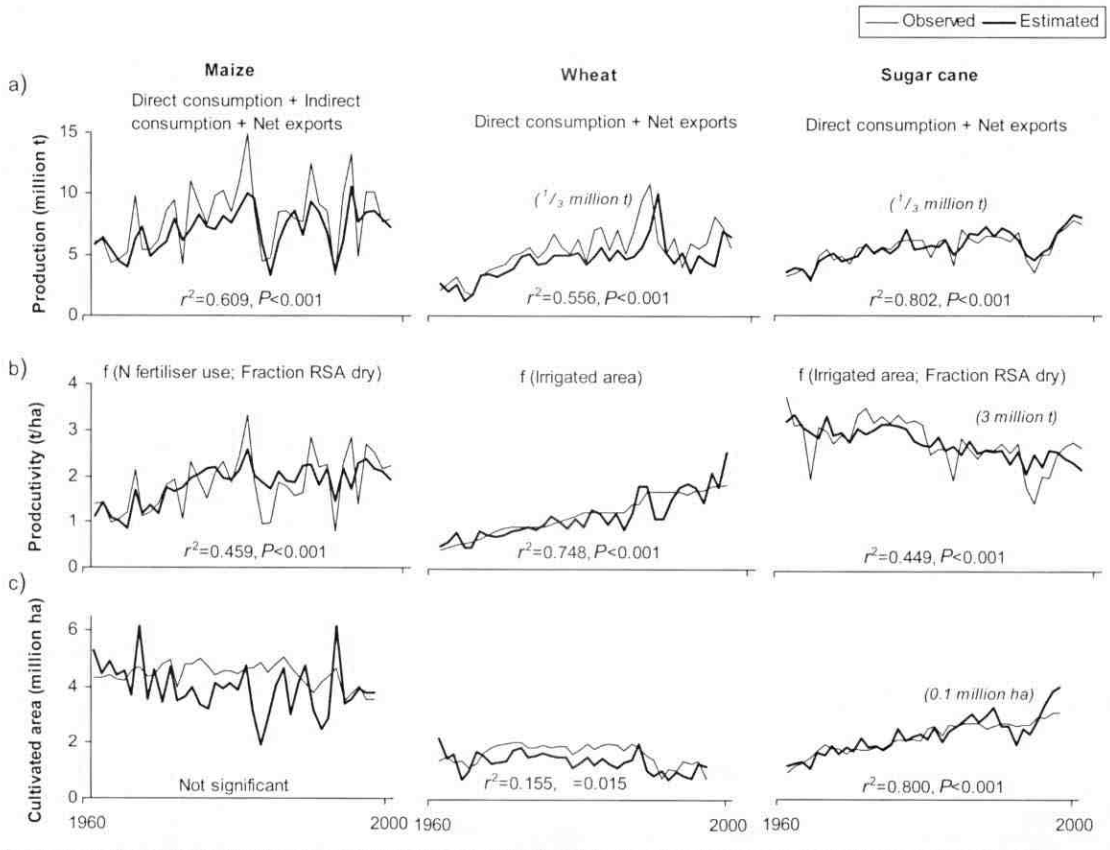

Fig. 5. (**a**) Fitted crop production models for maize, wheat and sugar cane. The full models are given above each graph. The lag in the estimated crop production can be explained by carry-over of production from one season to the next. (**b**) Fitted crop productivity models. The factors used in the final regression model are given above each graph (non-significant factors were ignored). Note that the factor data are based on national, and not crop-specific, data. (**c**) Area under cultivation was estimated by dividing the estimated crop production by the estimated crop productivity. Data sources: FAOSTAT database (*FAO Production Yearbook*, Food and Agriculture Organization of the UN; http://apps.fao.org), except for consumption data (Abstract of Agricultural Statistics, National Department of Agriculture (http://www.nda.agric.za), dry-weight sugar production (South African Sugar Association, Mount Edgecombe; http://www.sasa.org.za) and the fraction of South Africa experiencing dry conditions (University of Natal, Scottsville, Pietermaritzburg[28]; http://www.nu.ac.za).

Conclusion

Cultivated and afforested land expanded significantly in South Africa during the twentieth century, and now jointly make up almost 14% of the country's land surface. This expansion has implications for the management of biodiversity, freshwater and soil resources and also impacts on global biogeochemical cycles. While population growth and rising affluence have been important factors contributing to agricultural change over the long term, the data also point to the important effects of economic and political factors highlighted by other studies.[20,26,27]

Prior to the Green Revolution, the expansion of cultivated land in South Africa was closely related to domestic population growth. As population statistics or estimates are more readily available than agricultural data, this suggests a simple means for obtaining estimates of cultivated land at national level before the introduction of Green Revolution technologies in regions or during periods for which no agricultural data are available. Estimates of the area planted to specific crops can be derived by dividing actual or estimated crop production by the estimated crop productivity per unit area. As only one or two crops generally account for most of the cultivation in a region, this provides a possible alternative method for estimating cultivated area.

The data presented in this study were obtained from a variety of institutions that put time and effort into making them available. We would especially like to thank the following: Dorothy Mathebula and Moses Mnyaka (Statistics South Africa), Phindiwe Tsebe (National Research Foundation), Roger Godsmark (Forest Owners Association), Hilmar Venter (Fertilizer Society of South Africa), Steven Lynch (University of Natal, Pietermaritzburg), Denzil Whitfield and Roger Bailey (South African Sugar Association), Rona Beukes and Mbini Kutta (National Department of Agriculture), and Timm Hoffman (University of Cape Town). Special thanks to Helen de Beer for her great help in collecting the census data. We also thank the Environmentek GIS group for their help with GIS-related queries.

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The table shows the latest citation records issued by the Institute for Scientific Information [in the form of average citations per paper (C/P) that summarize journal 'performance' over several years] in its list of multidisciplinary science periodicals in the *Science Citation Index*. Of the 19 titles included in this category, 7 are published in the United States, 6 in the European Union, 3 in the former U.S.S.R., 1 in China and 1 in India. The only journal published in Africa or in the southern hemisphere to make the list is the *South African Journal of Science*.

The three groupings in terms of C/P ratio is arbitrary — but clearly, the top three journals are way ahead of the others, and *New Scientist*, at the bottom, does not publish citable, original research papers. Other lists of so-called impact factors, also issued by the ISI, give different comparative values according to the period of assessment and the disciplinary field.

Journal	C/P
Proc. Natl. Acad. Sci. USA	16.1
Science	15.5
Nature	14.6
Naturwissenschaften	2.72
American Scientist	2.09
The Scientist	1.83
Ann. N. Y. Acad. Sci.	1.70
S. Afr. J. Sci.	**1.53**
C. R. Acad. Sci. (Paris)	1.32
Dokl. Akad. Nauk SSR	1.02
Synthèse	0.92
Current Science	0.92
Scientific American	0.86
Dokl. Akad. Nauk	0.67
Interdisciplin. Sci. Rev.	0.46
J. Sci. Ind. Res. (India)	0.39
Dokl. Akad. Nauk Belarus	0.37
Chin. Sci. Bull.	0.31
New Scientist	0.08