Global warming impacts on brazilian agriculture: estimates of the ricardian model*

Apurva Sanghi†
Denisard Alves‡
Robert Evenson§
Robert Mendelsohn§

RESUMO

Este artigo estima o impacto das mudanças climatológicas na agricultura brasileira usando um modelo ricardiano. O impacto líquido dessas mudanças na agricultura brasileira é negativo, embora existam diferenças entre regiões. Os efeitos da temperatura e da precipitação nos meses de março e setembro são positivos. No entanto, esses efeitos não pesam mais que os efeitos negativos mais intensos dos meses de dezembro e junho. A região centro-oeste é a mais afetada negativamente, enquanto que o sul se beneficia moderadamente do aquecimento.

Palavras-chave: aquecimento global, modelo ricardiano, agricultura.

ABSTRACT

This paper estimates the impact of climate change on agriculture in Brazil using the Ricardian approach. Our findings indicate that the net impact of climate change on Brazilian agriculture is negative, although there are varying regional consequences. March and September temperature and precipitation effects are positive, but are outweighed by the more negative December and June effects. The Center-West region is most negatively affected, whereas the South benefits mildly from warming.

Key words: global warming, ricardian model, agriculture.

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† ABD University of Chicago.

‡ FEA-USP Professor.

§ YALE Professors.

1 Introduction

Aspects of climate change involve changes in temperature, precipitation and carbon dioxide levels. Numerous studies have documented the economic impact of climate change on agriculture (Callway et al., 1982, Decker et al., 1986, Adams et al., 1988, 1990, Adams, 1989, Rind et al., 1990, Rosenzweig and Parry, 1994). The majority of the studies rely on the "production-function approach" This approach takes an underlying production function and varies the relevant environmental input variables to estimate the impact of these inputs on production. Although this controlled experimentation isolates the impact of environmental change, it fails to take into account various adaptations that farmers may make in response to varying environmental conditions. Even though some studies allow limited changes in fertilizer application, irrigation, or cultivars (Easterling et al., 1991), productionfunction models assume little adaptation by farmers to changing environmental conditions. Thus, the traditional production-function approach has an inherent bias in that it tends to overestimate the damage of climate change by failing to incorporate economic substitutions by farmers as conditions change.

By using economic county-level data on land values, Mendelsohn et al. (1994) develop a new technique that in principle corrects for the upward bias in the production-function approach. Instead of looking at the *yields* of specific crops, they examine how climate in different places affects the net *rent or value* of farmland. Doing so enables them to account for both the *direct* impacts of climate on yields of different crops as well as the *indirect* substitution of different activities, introduction of different activities, and other potential adaptations to different climates. Using U.S. county-level data, they examine the effect of climatic variables and a variety of fundamental geographical, geophysical, agricultural, economic, and demographic factors to determine the intrinsic impact of climate on farmland values. Their analysis suggests that climate has a systematic impact upon agricultural rents through temperature and precipitation, and that these effects tend to be highly non-linear and vary dramatically by season.

While there is far from complete agreement on the exact extent and timing of climate change, there is agreement that global warming over the next few decades is likely. Rainfall is also likely to increase although there is little agreement as to regional differences that might occur. Brazil's agricultural and forestry sector is particularly vulnerable to global warming since considerable production is currently undertaken under high-temperature conditions.

A number of estimates of the economic impact of climate change on agriculture have been made in recent years, but none of these relate to Brazil. In this paper we report Ricardian estimates of climate effects (temperature and rainfall) for Brazilian agriculture. We utilize data at the municipio level from the 1985, 1980, 1975, and 1970 agricultural censuses and detailed edaphic variables to control for these factors. We then simulate the effects on farm values (by region) of a 2.5°C change in temperature and 7% increase in rainfall.[1]

[1] This paper makes no attempt to assess the likelihood of climate change. The 2.5°C increase in global mean surface temperature and 7% increase in precipitation (benchmark warming) is the best guess estimate put out by the Inter-government Panel on Climate Change (IPCC) 1990b, 51, 83. Benchmark warming is associated with the doubling of carbon dioxide equivalent of all trace gases over pre-industrial levels and is expected to occur by the latter half of the next century.

Part 1 of the paper discusses methodology. Part 2 outlines the data sources and definitions. Part 3 discusses analysis and reports Ricardian climate estimates. Part 4 reports simulations of climate change. Part 5 concludes.

2 The ricardian methodology

Consider the general transformation function:

$$G(Y, X, L, I, T, C, E) = 0$$

where

Y is a vector of outputs (wheat, corn, etc.)
X is a vector of variable factors (labor, fertilizers, etc.)
L is a vector of quasi-fixed factors (land, building, trees, etc.)
I is a vector of infrastructure variables (roads, markets, etc.)
T is a vector of technological variables (research, extension, technology adoption, etc.)
C is a vector of climate variables (temperature, rainfall, solar radiation, etc.)
E is a vector of edaphic variables (soil type, slope, texture, etc.)

Using standard duality theory, the profit function associated with the above transformation function is:

$$\pi^* = \pi(P_y, P_x, L, I, T, C, E) \tag{1}$$

where

π^* is the maximized profits,
P_y is the vector of output prices, and
P_x is the vector of factor prices.

Hotelling's lemma gives the output supply and factor demand equations:

$$Y^* = Y(P_y, P_x, L, I, T, C, E) = \partial\pi^* / \partial P_y$$
$$X^* = X(P_y, P_x, L, I, T, C, E) = \partial\pi^* / \partial P_x$$

resulting in the variable profit function:

$$\pi_v = P_y Y^* - P_x X^* = \pi(P_y, P_x, L, I, T, C, E) \tag{2}$$

The Ricardian model is based on (2). In (2), the farmers have completely adapted to all of the variables L,I,T,C, and E in choosing the profit maximizing mix of outputs and inputs (Y and X). The Ricardian model implicitly presumes that variable profits π_v approximate residual rents to the land farmed. Land prices are based on discounted expected future land rents.

The issue to be analyzed is the impact of exogenous changes in environmental variables on net economic welfare. Consider an environmental change from the environmental state A to B, which leads environmental inputs to change from C^a to C^b but leaves market prices unchanged. Then the change in variable profits is given by:

$$\pi_v(P_y,P_x,C^a,E^a)-\pi_v(P_y,P_x,C^b,E^b)=P_y[Y(P_y,P_x,C^a,E^a)-Y(P_y,P_x,C^b,E^b)]$$
$$-P[X(P_y,P_x,C^a,E^a)-X(P_y,P_x,C^b,E^b)]$$

Thus, the value of the change in the environmental variable is captured exactly by the change in the value of the land rent between the different environmental conditions. Cross-section observations, where normal climate and edaphic factors vary, can hence be utilized to estimate farmer-adapted climate impacts on production and land rents.[2]

We do not observe land rents directly for Brazilian agriculture. However, land values are based on the present value of future rents, so if the interest rates are equal per hectare of land, then land value will be proportional to land rent. In the case of Brazil, we have land values, as reported by farmers, that *exclude* capital and other investments (value of buildings, machinery etc.), so that we have an *intrinsic* measure of land value that we use as our dependent variable in the land value regressions.

3 Data

Units of analysis:

Appendix A describes the land value and normal climate data sources. Our units of observations are municipios in each of the Censuses of Agriculture: 1985, 1980, 1975, and 1970. We do not pool these Censuses in our analyses. We estimate four different cross-section models corresponding to each of the censuses. In each census, farmers were asked to report separate assessments of land values, permanent crop values, and values of residences and other buildings We utilize the pure land value assessments of farmers in this analysis. To express this in per

[2] Note, however, that the validity of this procedure depends critically on controlling for edaphic (E), technology (T), and infrastructure (I) variables.

hectare terms, we divide the total number of hectares in annual crops, perennial crops, natural pastures, planted pastures, and natural forests. We treat the allocation of land to these alternative uses as an endogenous choice of farmers and do not include these land use allocations as explanatory variables in the Ricardian model.[3] Map 1 portrays land values by state for 1985.

The appropriate climate variables for this study are the "normal" climate variables that farmers have adapted to (Appendix A and Appendix B provide a complete summary of data sources and the variables used in the study).[4] We use 8 climate variables: normal temperatures (^{o}C) and rainfall (mm) for the months of September, December, March, and June (in order to capture seasonal effects). We also include the corresponding square terms of the climate variables in order to capture nonlinearities as apparent from field studies.

Estimating a climate surface:

These climate variables are available only for 310 weather stations located throughout Brazil whereas there are 3941 municipios. The assignment of climate variables to municipios presents a methodological problem. This is overcome by estimating the average climate for each municipio by the following procedure: A climate surface for each county is estimated by running a weighted regression across all weather stations within a 600 miles radius. Stations closer to a given municipio presumably contain more information about that municipio's climate, so the weight is the inverse of the square root of a station's distance from the geographical center of the municipio[5]. The dependent variables are the 4 monthly normal temperature and rainfall values for the 30 year period (1961-1990). There are 14 exogenous variables: latitude, longitude, altitude, distance from nearest shoreline, and the corresponding square and interaction terms. A separate regression for temperatures and precipitation is estimated for each municipio. This leads to. a total of 4x2x3941=31,528 regressions. The predicted temperatures and precipitation amounts for the geographic center of the municipios are the independent variables used in the land value regressions. Table 1 shows a sample prediction and the variables used for one of these municipios.

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[3] In later work, we plan to address the effect of climate on land use in a model where land use is treated as an endogenous variable.

[4] Normal climate variables are treated as the expected climate variables perceived by agents in the land market. We recognize that in any given census, current weather may depart from normal weather, but this is not expected to influence land value assessments.

[5] There are some municipios, in the Amazon for example, which have fewer than 14 weather stations within the 600-mile radius. t Temperatures and precipitation for these municipios were predicted by assigning the mean value of the climate variables from the weather stations, weighted by the distance of the stations from that municipio.

Table 1: Sample municipio climate interpolation (Paranapua)

Independent Variables	Temperature		Rainfall	
	June	September	June	September
Intercept	-49.382*	-112.28*	1337.29*	-1001.92
Altitude	-0.005	-0.176*	-0.029	-0.107
Latitude	-0.381*	2.797	32.44*	132.39*
Longitude	-3.373*	-7.978*	51.14	-110.35
Distance to sea	-0.078	-0.130*	0.514	-2.285*
Latitude x longitude	-0.133*	0.065	0.169	5.998*
Latitude x altitude	-3.70E-4	3.75E-4	-0.017*	-0.012*
Altitude x longitude	-1.87E-4*	5.29E-4*	0.009*	0.006
Altitude squared	-7.64E-8	1.43E-6*	1.67E-5	3.86E-5*
Latitude squared	0.104	-0.008	0.279	-2.919
Longitude squared	-0.004	-0.111*	0.724	-2.703*
Distance to sea squared	3.15E-7*	-4.57E-5*	6.06E-4	-8.82E-4
Distance x altitude	1.36E-5	-5.55E-6	4.68E-4*	3.45E-4*
Distance x latitude	-0.0023	1.79E-3	-0.045	0.0964
Distance x longitude	-0.3.89E-4	4.13E-3*	0.043*	-0.974
Adjusted R^2	0.90	0.92	0.88	0.81
Number of observations	114	114	114	114

Note: (*Statistically significant at the 5% level)

To assess the reliability of the above spatial statistical approach for predicting municipio-level average climate, we predicted the climate for each of the 310 weather stations by dropping the weather station and predicting its climate in the above manner, and then comparing it to the actual measurements for each station. We were able to predict temperatures between 90% to 96% of actual weather station temperatures, and precipitation between 75% to 85% of actual weather station precipitation. Thus, this method seems reasonable for the purposes of predicting climate variables.

Edaphic and control variables:

Since we had an intrinsic measure of land values, we did not have to worry about cross-sectional disparities in machinery, buildings, and other capitalizations. Land values were estimated by farmers.6 However, edaphic variables vary significantly over the municipios, and it is therefore necessary to control for these variables We had data on micro-region soil types and pre-disposition to erosion potential. A micro-region contains 10 municipios on average. We therefore assigned these micro soil variables to the municipios and created corresponding dummies for use in land value regressions. Appendix B explains how these dummies were constructed and gives a brief explanation of each soil type. Care was taken not to include soil variables that might be "hidden climate indicators" i.e. correlated to temperature and precipitation. For example, we did not include a variable for agricultural potential of soils (Index V3) or other control variables that are likely to be hidden indicators of climate such as rainfall classes (Index IV1) or thermal efficiency variables (Index IV2). Latitude is included as a proxy for day length.

4 Analysis

We regressed land values on climate and edaphic variables to estimate the best-use value function across different municipios. Table 2(i) presents the 'basic' Ricardian model for 1985 that includes the linear and quadratic temperature and precipitation terms for the four seasonal months and the relevant temperature-rainfall interactions. In Table 2(ii), we control for cross-sectional variations in soils and day length affecting agricultural activity. In both sets, each observation is weighted by the area in cropland in each municipio (acreage weights).7 As the results show, most of the quadratic and interaction climate terms are significant, capturing the underlying nonlinearities. Farm values respond as expected to soil variables. The dummy soil variables from the V1 index (soil types) included in the regression have a negative influence, as expected (the omitted class being soil most amenable to agricultural activities). Predisposition to soil erosion (V2 index) acts as expected, the omitted class being the category most predisposed to erosion. A comparison of the two sets shows that almost all the climate variables retain their significance and signs. Latitude has a diminishing effect on farm values as one moves north towards the equator. There could be two plausible explanations for this. First, in Brazil land is more valuable in the South. The Northeast and parts of the North are the poorest regions A

[6] It is likely that there are measurement errors in reporting land value estimates. However, there is no reason to expect that these errors are correlated with the independent (climate and edaphic) variables.

[7] The justification for using acreage weights is that the data are at the municipio, and not the farm level. Larger municipios have more farms resulting in lower measurement errors. Therefore larger municipios should be given a higher weight.

second explanation could be that of day length. Latitude is a proxy for day length. A bigger day length in the growing season is generally considered to be beneficial for agriculture.

Table 2: Farm value Regressions for 1985

Year	1985(i)	1985(ii)
Intercept	-166.544293	-69.633092
	(-5.697)	(-2.432)
Dec temperature	4.430675	-3.113295
	(1.336)	(-0.975)
Mar temperature	3.360756	4.512007
	(1.459)	(1.972)
Jun temperature	-6.551043	-9.091434
	(-5.341)	(-7.702)
Sep temperature	11.943992	12.374752
	(7.180)	(7.552)
Dec temperature sq.	-0.056585	0.049352
	(-0.887)	(0.806)
Mar temperature sq.	-0.085582	-0.085235
	(-1.997)	(-2.002)
Jun temperature sq.	0.100411	0.181271
	(3.442)	(6.383)
Sep temperature sq.	-0.238539	-0.241699
	(-6.594)	(-6.819)
Dec rain	0.321714	0.151381
	(6.730)	(3.232)
Mar rain	-0.078896	0.068247
	(-1.547)	(1.393)
Jun rain	-0.158407	-0.086920
	(-4.496)	(-2.516)
Sep rain	0.286387	-0.075906
	(4.187)	(-0.973)
Dec rain sq.	-0.000265	-0.000206
	(-11.356)	(-8.761)
Mar rain sq.	-0.000117	-0.000087205
	(-5.912)	(-4.564)
Jun rain sq.	-0.000038196	-0.000082308
	(-1.139)	(-2.529)
Sep rain sq.	-0.000859	-0.000339
	(-8.159)	(-3.028)
Dec temperaturexrain	-0.009948	-0.004669
	(-5.616)	(-2.743)

Year	1985(i)	1985(ii)
Mar temperaturexrain	0.005449	-0.000282
	(2.681)	(-0.145)
Jun temperaturexrain	0.007134	0.004688
	(5.080)	(3.437)
Sep temperaturexrain	-0.004615	0.005711
	(-1.797)	(2.041)
Latitude		-0.716820
		(-6.844)
DM511		-1.679406
		(-3.847)
DM512		-0.881219
		(-1.895)
DM513		-5.295138
		(-7.581)
DM514		-1.957027
		(-2.285)
DM515		-3.242703
		(-2.986)
DM516		1.891482
		(1.483)
DM517		-0.896661
		(-1.077)
DM518		-4.701620
		(-8.554)
DM521		0.289035
		(0.591)
DM522		5.939191
		(14.187)
DM523		3.390172
		(7.413)
DM524		2.918265
		(2.718)
Adjusted R-square	0.38	0.46
Number of observations	3860	3856

Note: (*t*-statistics in parenthesis)

In order to test the robustness of the model, we estimated the model again using the 1980, 1975, and 1970 agricultural censuses. The results are presented in Table 3 below. The findings are relatively similar over the years with the control variables behaving as expected.

Table 3: Farm Value Regressions for 1980, 1975, and 1970

Year	1980(i)	1980(ii)	1975(i)	1975(ii)	1970(i)	1970(ii)
Intercept	-1285.184330	-843.726085	-109.768743	-38.350183	-13.562157	-3.972976
	(-6.338)	(-4.171)	(-3.129)	(-1.065)	(-4.467)	(-1.273)
Dec temperature	-43.845400	-46.683928	2.245244	1.506347	0.382341	0.261866
	(-1.900)	(-2.057)	(0.569)	(0.377)	(1.160)	(0.791)
Mar temperature	101.415371	79.719307	6.517139	2.320955	0.397666	-0.140634
	(6.532)	(4.981)	(2.415)	(0.803)	(1.813)	(-0.601)
Jun temperature	-13.396596	-41.298070	-3.598876	-7.212890	-0.181605	-0.472033
	(-1.540)	(-4.802)	(-2.409)	(-4.758)	(-1.493)	(-3.866)
Sep temperature	63.595607	71.547355	3.868200	5.942154	0.606930	0.720576
	(5.445)	(6.111)	(1.911)	(2.883)	(3.402)	(4.019)
Dec temperature sq.	0.745595	0.623645	-0.052103	-0.056646	-0.008534	-0.008274
	(1.677)	(1.430)	(-0.682)	(-0.733)	(-1.327)	(-1.284)
Mar temperature sq.	-1.946362	-1.464292	-0.120857	-0.035799	-0.008825	0.001843
	(-6.617)	(-4.857)	(-2.421)	(-0.671)	(-2.200)	(0.431)
Jun temperature sq.	-0.011671	0.820244	0.053863	0.151187	0.001296	0.009629
	(-0.055)	(3.866)	(1.506)	(4.084)	(0.442)	(3.225)
Sep temperature sq.	-1.143831	-1.261928	-0.079450	-0.112896	-0.011475	-0.012737
	(-4.476)	(-4.960)	(-1.795)	(-2.525)	(-2.931)	(-3.255)
Dec rain	1.055126	0.263327	0.258036	0.127937	0.017663	0.004242
	(3.091)	(0.770)	(4.337)	(2.099)	(3.464)	(0.820)
Mar rain	-0.160636	0.705919	-0.096530	0.010627	-0.016241	-0.006567
	(-0.470)	(2.091)	(-1.460)	(0.161)	(-2.950)	(-1.204)
Jun rain	-1.299351	-0.745595	-0.085953	-0.013467	-0.006576	0.002686
	(-5.217)	(-3.015)	(-2.058)	(-0.312)	(-1.888)	(0.751)
Sep rain	3.074266	0.720463	0.047918	-0.272235	0.019852	-0.020659
	(6.722)	(1.379)	(0.605)	(-2.857)	(2.676)	(-2.297)
Dec rain sq.	-0.001132	-0.000765	-0.000230	-0.000154	-0.000017232	-0.000007303
	(-6.274)	(-4.153)	(-7.504)	(-4.746)	(-6.412)	(-2.581)
Mar rain sq.	-0.000783	-0.000553	-0.000092730	-0.000067325	-0.000008496	-0.000005606
	(-5.664)	(-4.094)	(-3.808)	(-2.751)	(-4.095)	(-2.693)
Jun rain sq.	-0.000116	-0.000288	0.000063065	-0.000003836	0.000001205	-0.000006279
	(-0.484)	(-1.220)	(1.542)	(-0.093)	(0.375)	(-1.946)
Sep rain sq.	-0.004126	-0.001366	-0.000343	0.000043191	-0.000043881	-5.665118E-8
	(-5.867)	(-1.835)	(-2.735)	(0.317)	(-3.752)	(-0.004)
Dec temperaturexrain	-0.032522	-0.009299	-0.008180	-0.004597	-0.000564	-0.000254
	(-2.599)	(-0.758)	(-3.729)	(-2.089)	(-2.994)	(-1.359)
Mar temperaturexrain	0.023287	-0.012395	0.005981	0.001564	0.000838	0.000435
	(1.695)	(-0.919)	(2.287)	(0.601)	(3.840)	(2.018)
Jun temperaturexrain	0.058500	0.038907	0.002900	0.000863	0.000287	-0.000003448
	(5.889)	(3.973)	(1.735)	(0.505)	(2.037)	(-0.024)

(Continue)

Year	1980(i)	1980(ii)	1975(i)	1975(ii)	1970(i)	1970(ii)
Sep temperaturexrain	-0.088444	-0.020132	0.001911	0.011386	-0.000427	0.000887
	(-5.092)	(-1.061)	(0.634)	(3.288)	(-1.508)	(2.698)
Latitude		-5.103961		-0.657080		-0.077266
		(-6.803)		(-4.934)		(-6.794)
DM511		-13.449842		-0.880446		0.057327
		(-4.474)		(-1.790)		(1.470)
DM512		-7.308929		0.176162		0.033808
		(-2.291)		(0.335)		(0.836)
DM513		-33.314570		-2.869698		-0.209619
		(-6.990)		(-3.569)		(-3.327)
DM514		-15.378046		-0.848255		-0.003337
		(-2.556)		(-0.809)		(-0.038)
DM515		-29.583345		-0.559223		-0.046480
		(-3.710)		(-0.366)		(-0.330)
DM516		4.304059		2.041322		0.135553
		(0.474)		(1.339)		(1.108)
DM517		3.809141		0.851999		0.055032
		(0.640)		(0.867)		(0.746)
DM518		-30.105216		-2.356166		-0.161855
		(-7.789)		(-3.675)		(-3.126)
DM521		-0.379777		-0.814071		-0.077291
		(-0.109)		(-1.332)		(-1.564)
DM522		32.561678		2.989756		0.287151
		(10.835)		(5.602)		(6.640)
DM523		27.619486		0.716575		0.093399
		(8.326)		(1.213)		(1.952)
DM524		64.864612		8.766780		0.760849
		(8.438)		(7.077)		(8.263)
Adjusted R-square	0.30	0.37	0.18	0.22	0.19	0.24
Number of observations	3773	3770	3736	3735	3733	3733

Note: (*t*-statistics in parenthesis)

5 Implications for benchmark warming

The standard benchmark in climate change models involves a doubling of carbon dioxide-equivalent of all trace gases over pre-industrial times. The IPCC estimates the equilibrium change in global mean surface temperature to lie between 1.5°C and 4.5°C, with a best-guess central value of 2.5°C. Mean precipitation is expected to increase by 7%. According to most models, this increase is expected to occur sometime in the latter half of the next century.

Overall impact

Impacts are measured by utilizing IPCC's best guess estimate of 2.5°C temperature increase and a 7% precipitation increase in the simulations. Table 4 shows the results of this simulation for all four census years. We measured the percentage change in farm value for each municipio and aggregated these at the state and national level (each municipio being weighted by its share in the total land value). The results are further disaggregated by partial monthly effects and partial temperature and rainfall effects in Tables 5 and 6.

Table 4: Partial monthly effects of Temperature and Precipitation
(%Change in farm value from benchmark warming)

Year	Temperature				Precipitation			
	Dec	Mar	Jun	Sep	Dec	Mar	Jun	Sep
1985	-5.31%	0.44%	0.44%	-4.03%	5.34%	-1.03%	0.46%	-0.12%
1980	-5.07%	0.90%	0.90%	-1.13%	3.42%	-0.48%	0.26%	-0.03%
1975	-16.70%	5.84%	5.84%	-5.62%	10.51%	-1.96%	0.76%	0.04%
1970	-16.49%	2.29%	2.29%	-5.12%	14.43%	-2.02%	0.66%	0.16%

Table 5: Temperature & Precipitation Effects
(%Change in farm value from benchmark warming)

Year	Temperature	Precipitation	Net Impact
1985	-3.56%	-0.87%	-4.47%
1980	-1.88%	-0.23%	-2.16%
1975	-5.97%	-1.58%	-7.40%
1970	-4.89%	-1.57%	-5.96%

Table 6: Seasonal Effects
(%Change in farm value from benchmark warming)

Year	Dec	Mar	Jun	Sep	Net Impact
1985	-6.34%	0.90%	-4.15%	5.16%	-4.47%
1980	-5.54%	1.15%	-1.16%	3.44%	-2.16%
1975	-18.66%	6.60%	-5.58%	10.09%	-7 40%
1970	-18.51%	2.95%	-4.96%	14.07%	-5.96%

In all four years, the net impact is negative, with estimates varying between -2.16% and -7.40% of mean land values. The partial and combined March and September effects are consistently positive, and negative for the other months. March is the last month of the growing season and September is the very early planting season. December is the late planting/early growing season and June is the post-harvest season. In all four years, the December effect is the most negative implying that hotter temperatures during summer will be most harmful to agricultural activity. From the above results, the climate effects are fairly seasonal and stable over time.

Regional impacts

There are strong distributional effects of climate change. In order to understand regional effects, percentage changes in land values were estimated by state for the benchmark warming scenario. Table 7 presents these results broken down by states. Maps 2, 3 , 4 and 5 displays these results for 1985, 1980, 1975, and 1970 respectively.

Table 7: Regional Net Impact

State	Regional Net Impact			
	1985	1980	1975	1970
Rondonia	-12.41%	-7.78%	-8.87%	-3.67%
Acre	-6.40%	-5.00%	-0.90%	0.02%
Amazonas	-5.63%	-4.53%	-0.99%	-1.61%
Roraima	-0.02%	-1.09%	4.28%	-0.48%
Para	-3.43%	-3.29%	-0.62%	-0.09%
Amapa	-3.71%	-2.29%	-0.07%	-1.61%
Tocantins	-12.62%	-6.21%	-13.73%	-11.66%
Maranhao	-6.82%	-4.72%	-6.03%	-6.55%
Piaui	-6.92%	-4.06%	-8.27%	-10.71%
Ceara	-2.95%	-2.42%	-3.06%	-5.69%
Rio G. Do Norte	-0.55%	-1.67%	-0.86%	-4.20%
Paraiba	-0.37%	-1.16%	-1.70%	-4.58%
Pernambuco	0.97%	-0.26%	-0.66%	-3.80%
Alagoas	1.65%	-0.78%	0.76%	-3.78%
Sergipe	1.83%	-0.65%	1.01%	-3.82%
Bahia	-2.99%	-1.81%	-5.93%	-7.57%
Minas Gerais	-8.91%	-2.97%	-16.58%	11.72%
Espirito Santo	-4.48%	-2.55%	-9.08%	-7.76%
Rio de Janeiro	-5.44%	-2.57%	-10.95%	-7.44%
São Paulo	-6.37%	-2.60%	-11.02%	-6.90%
Parana	-1.79%	-0.46%	-4.19%	-0.95%
Santa Catarina	1.24%	0.80%	0.75%	4.66%
Rio G. Do Sul	2.63%	1.44%	0.94%	4.19%
Mato G. Do Sul	-5.88%	-3.07%	10.43%	-8.41%
Mato Grosso	-10.69%	-5.41%	14.10%	-11.43%
Goias	-12.98%	-5.11%	-18.44%	-13.28%
Total Net Impact*	-4.47%	-2.16%	-7.40%	-5.96%

(*When calculating total net impact, each state is weighted by its share in total land value)

From the above table (and more so from the maps), it is readily apparent that there are distinct regional implications. Two distinct results can be gleaned from the maps. First, the Center-West states of Rondonia, Mato Grosso, and Goias are the most negatively affected in all four years (these states constitute the *Cerrados* which are hot and semi-arid plains). Second, the Southern states of Santa Catarina and Rio Grande do Sul (which are also the coolest) benefit mildly from warming. Both these results are remarkably consistent over all the four census years.

Maps 6 and 7 portray the distribution of the partial temperature and precipitation effects for 1985, and Map 8 shows the distribution of the seasonal effects for 1985.

6 Conclusions

The Ricardian estimates presented above are among the first estimates for a developing country. The model is remarkably robust across the four census years. Our findings indicate that global warming will have an overall negative impact with varying regional impacts. The Cerrado region, which is the most recently developing region, is the most vulnerable to climate. However, not all of the warming is harmful, as the above table shows. The South is expected to benefit from warming, and in general, March and September effects are positive.

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Appendix A: data definitions & sources

Climate variables:

Climate variables by month are from Normais Climatológicas (1961-1990), Ministério da Agricultura e de Reforma Agrária, Secretaria Nacional de Irrigação, Departamento Nacional de Metrologia, and the Meteorology Department of the FAO.

Variable Name	Description
Temperature (i)	Normal temperature (month i) 1961-1990
Rainfall (i)	Normal rainfall (month i) 1961-1990
Latitude	Latitude (degrees)
Longitude	Longitude (degrees)
Altitude	Altitude (m)
Distance to Sea	Distance to sea (miles)

Note: All distances are calculated using the formula below:

$\cos D = (\sin a \sin b) + (\cos a \cos b \cos p)$

where,

D = arc distance between A and B

a = latitude of A

b = latitude of B

p = degrees of longitude between A and B

Economic variables:

All economic variables are from the 1985, 1980, 1975, and 1970 Census of Agriculture. See Instituto Brasileiro de Geografia e Estatística (IBGE)

Variable Name	Description
APC	Area in perennial crops (Ha)
AAC	Area in annual crops (Ha)
ANP	Area in natural pasture (Ha)
APP	Area in planted pasture (Ha)
ANF	Area in natural forest (Ha)
APF	Area in planted forest (Ha)
AIRR	Area irrigated (Ha)
AT	APC+AAC+ANP+ANF+APF (Ha)
VL	Intrinsic Value of Land (cruzeiros)
VPC	Value of Perénnial crops (cruzeiros)
VPP	Value of planted forest crops (cruzeiros)
PPC	Production value of perennial crops (cruzeiros)
PAC	Production value of annual crops (cruzeiros)
VLHA	VL/AT (cruzeiros/Ha)

For 1985, land utilization data are from Tipo 005.

APC: VarI 7
AAC: VarI 8
ANP: VarI 10
APP: VarI 11
ANF: VarI 12
ANF: VarI 13
AIRR: VarI 17

Asset Values (Valor dos Bens) are from Tipo 024

VL: VarI 8
VPC: VarI 9
VAC: VarI 10

and production Values (Valor da Produção) are from Tipo 031

PPC: VarI 7
PAC: VarI 8

Appendix B: edaphic variables

All micro-region variables are taken from maps in Atlas Nacional do Brasil, 2ª edição, IBGE, Rio de Janeiro, 1992. Edaphic variables are from Folha V.1 (DM51(j)), Folha V.2 (DM(52(k)), and Folha V.3 (DM531-DM5310). For each map, an overlay of the 361 1985 micro-regions (Folha 1.2) was used to locate micro-regions. The dominant class or type was then recorded. Dummy variables are equal to one if the dominant class is in the dummy category. Dummy categories were defined as follows:

Index V1: Principal Soil Types

Category	Soil Types
DM511	Latossolo Amarelo
	Latossolo Bruna
	Latossolo Vermelho-Escuro
	Latossolo Roxo
	Latossolo Vermelho-Amarelo
DM512	Podzólico Amarelo
	Podzólico Vermelho-Escuro
	Podzólico Vermelho-Amarelo
DM513	Solos Litólicos
	Afloramento Rochoso
	Solos Indiscriminados de Mangue
DM514	Areias Quartzoas
	Areias Quartzoas Hidromórficas
DM515	Plintossolo
	Plintossolo Pétrico
DM516	Regessolo
DM517	Planosolos
	Planosolo Solódico
DM518	Cambissolo
	Cambissolo Bruno
	Gleissolos
	Rendzina
DM519*	Solos Aluviais
	Terra Bruna Estruturada
	Terra Roxa Estruturada
	Brunizem
	Brunizem Avermelhado
	Bruno Não Cálcio

(*omitted category in land value regressions)

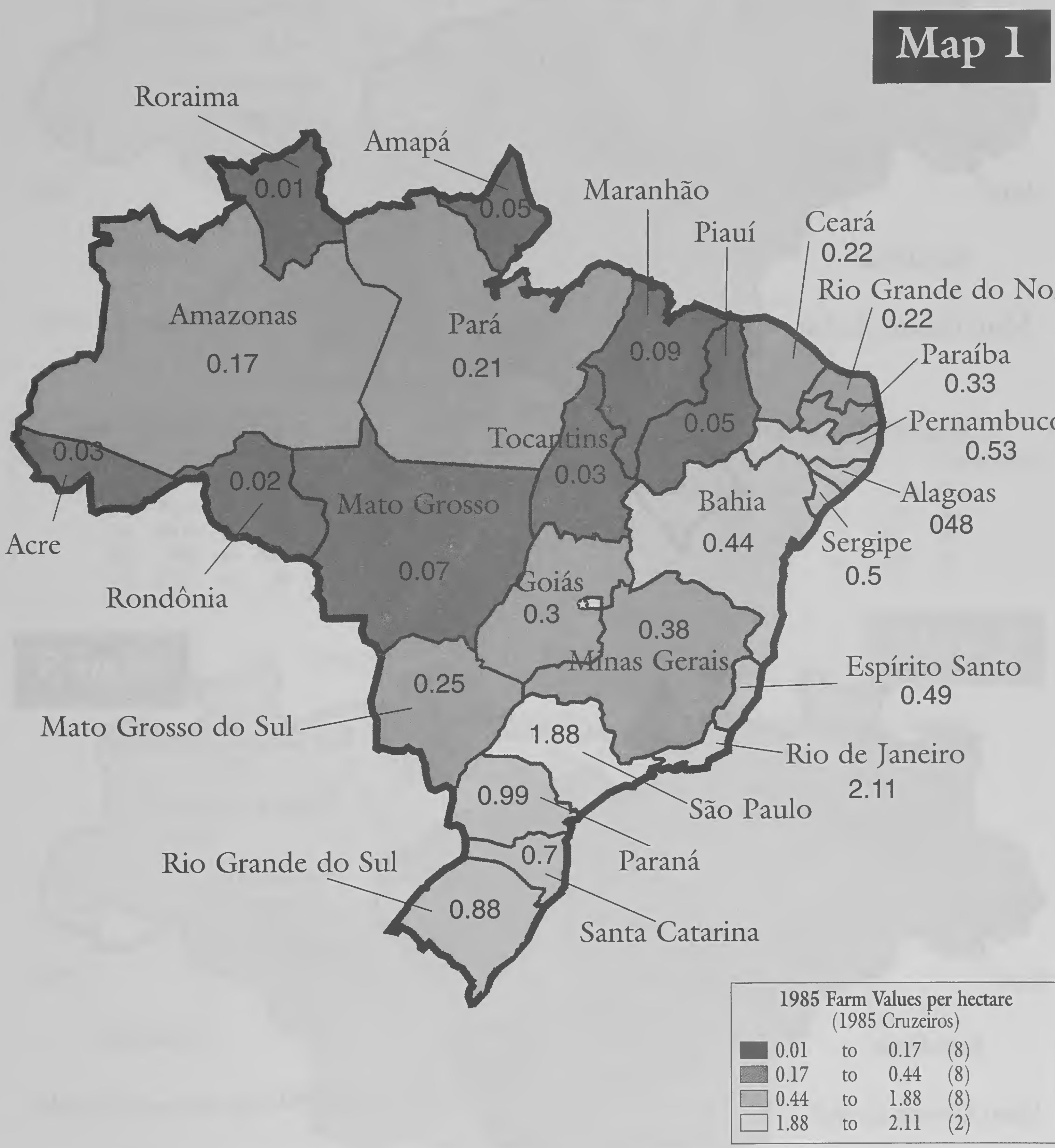
The first category DM511 corresponds to Latossols which are very old, highly weathered, acidic soils with low to moderate base saturation and exchange capacity. DM512 groups the Podzolicos which too are old, highly acidic, and not productive. DM513 groups rocky soils and bedrocks. DM514 groups the Areias which are sandy in nature and can be productive in conjunction with water. DM515 corresponds to the Plintosols which have low Ph content. DM516 groups Reggosols which can range from dry and sandy to very good in terms of potential productivity. DM517 refers to Cambissols, Gleyssols, and Rendzinas, all intermediate and young soils which could be productive but are slightly impermeable. DM5110 is the category of soils with the highest base saturation. Brunizems contain the most dark organic matter, and Alluvial soil is very fertile. The Terras Brunas are brown forest soils with relatively good productivity.

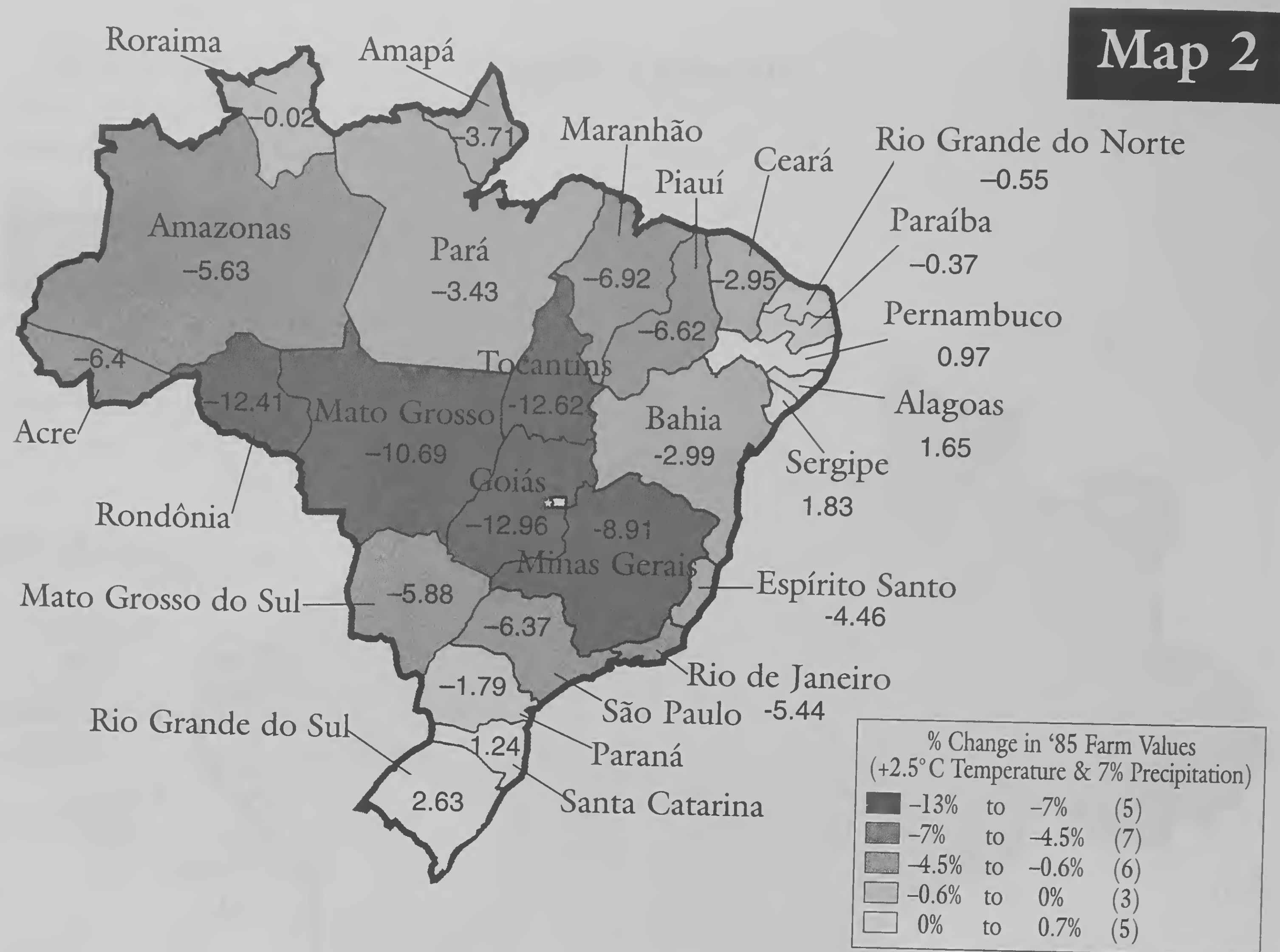
Index V2: Erosion Potential

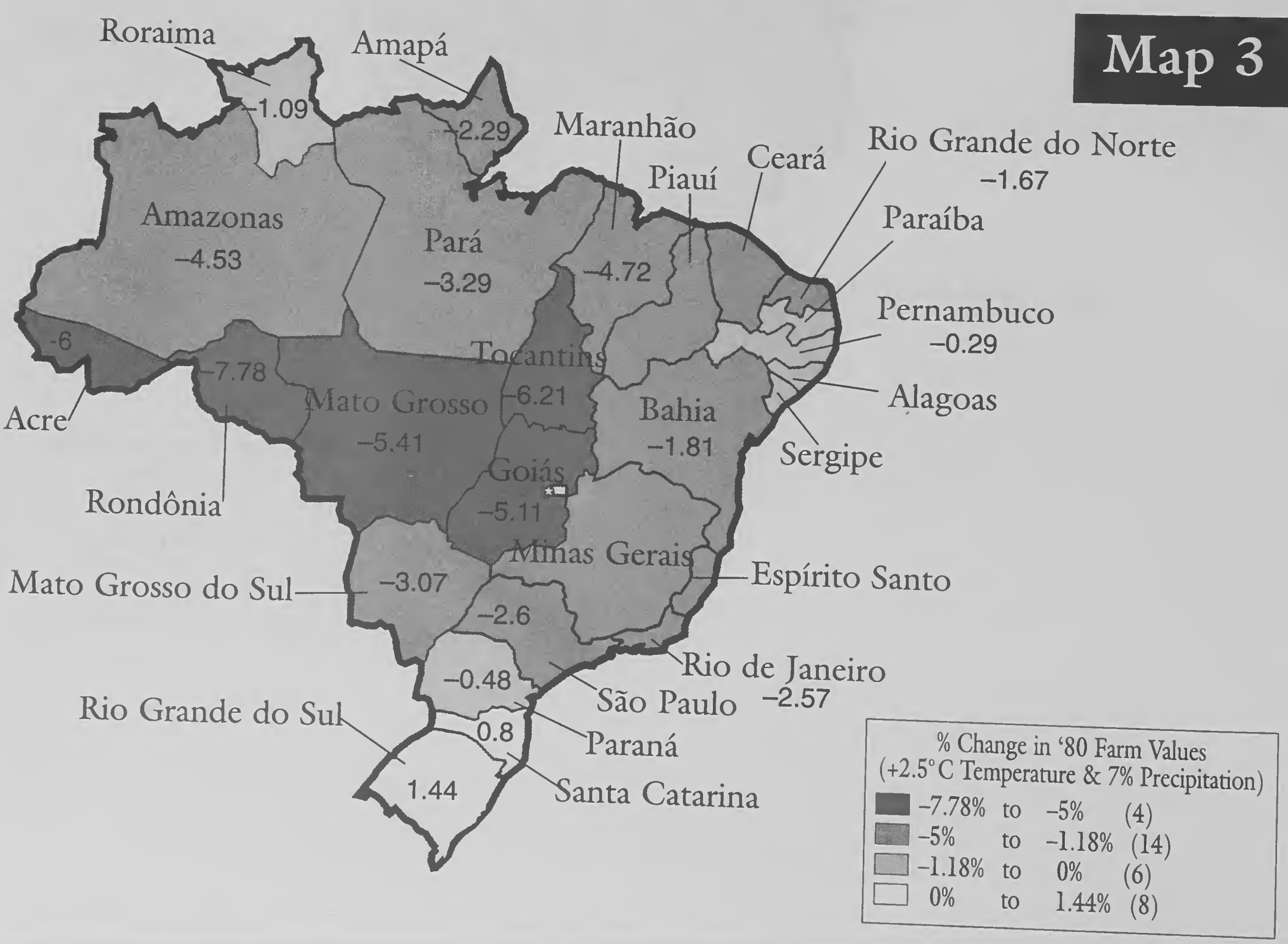
Category	Predisposition to Erosion
DM521	Moderate predisposition to erosion
DM522	Strong predisposition
DM523	Very strong predisposition
DM524	Extreme predisposition
DM525*	Light to moderate erosion potential

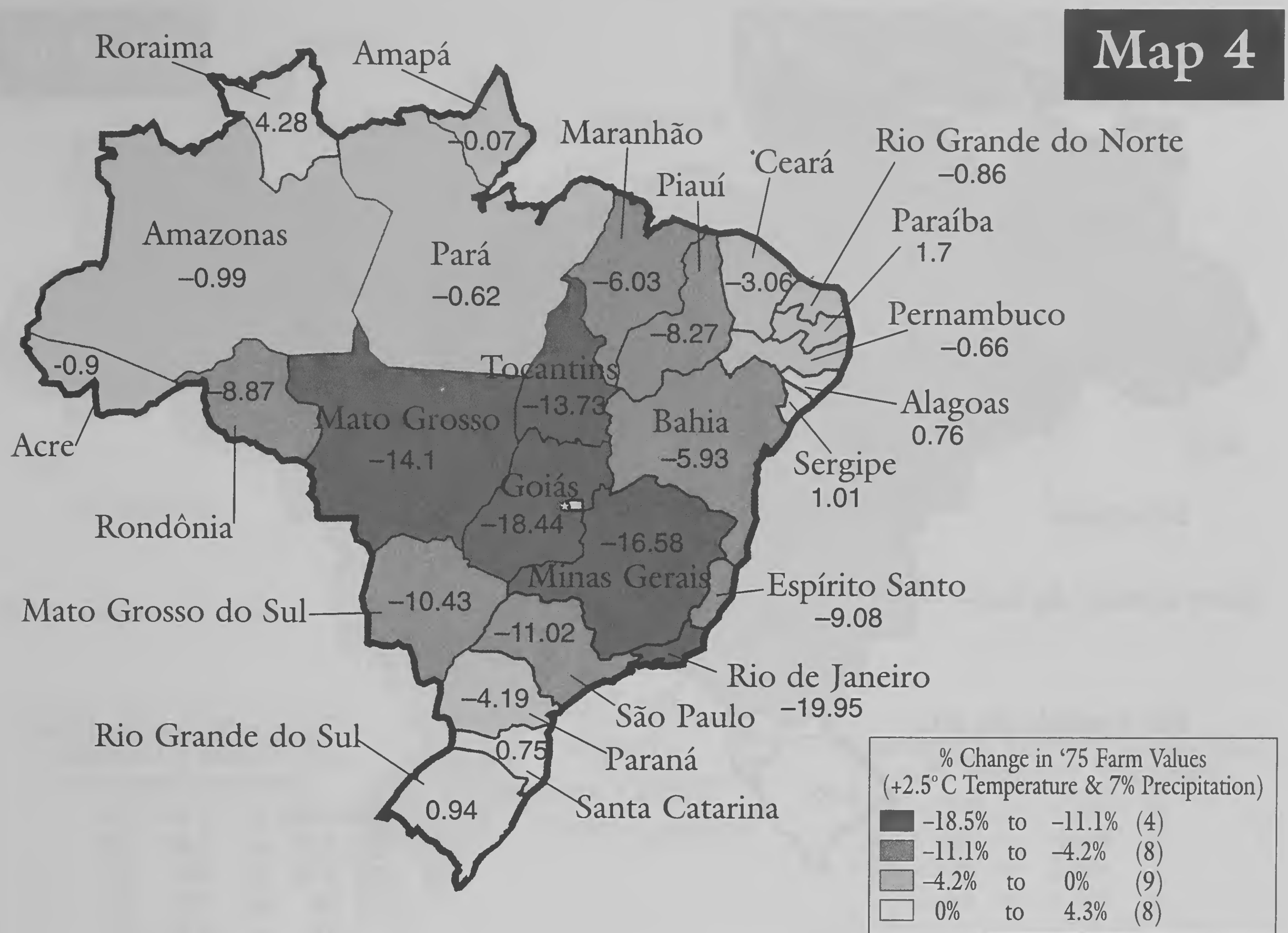
(* omitted category in land value regressions)

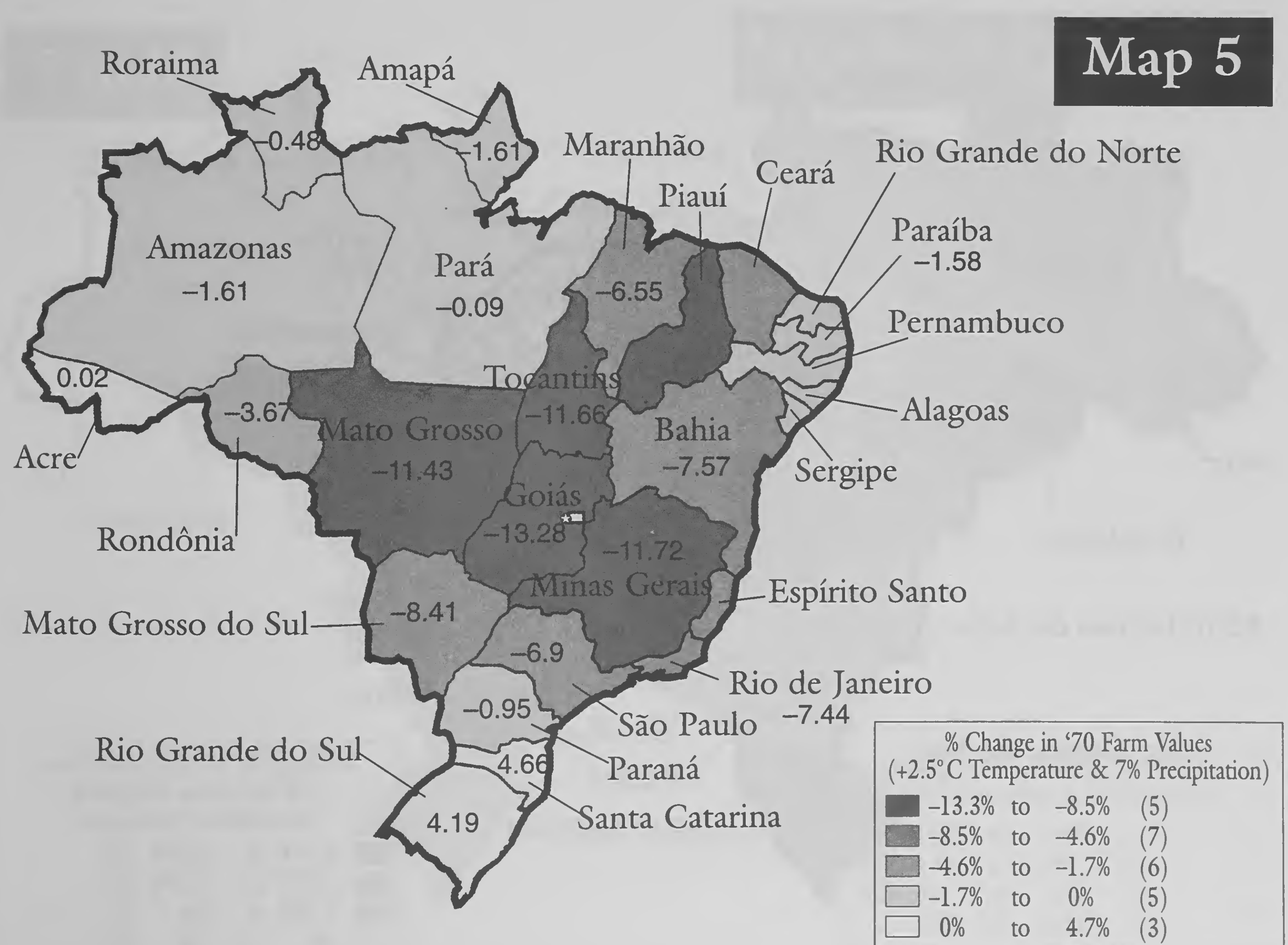
Appendix C: Maps

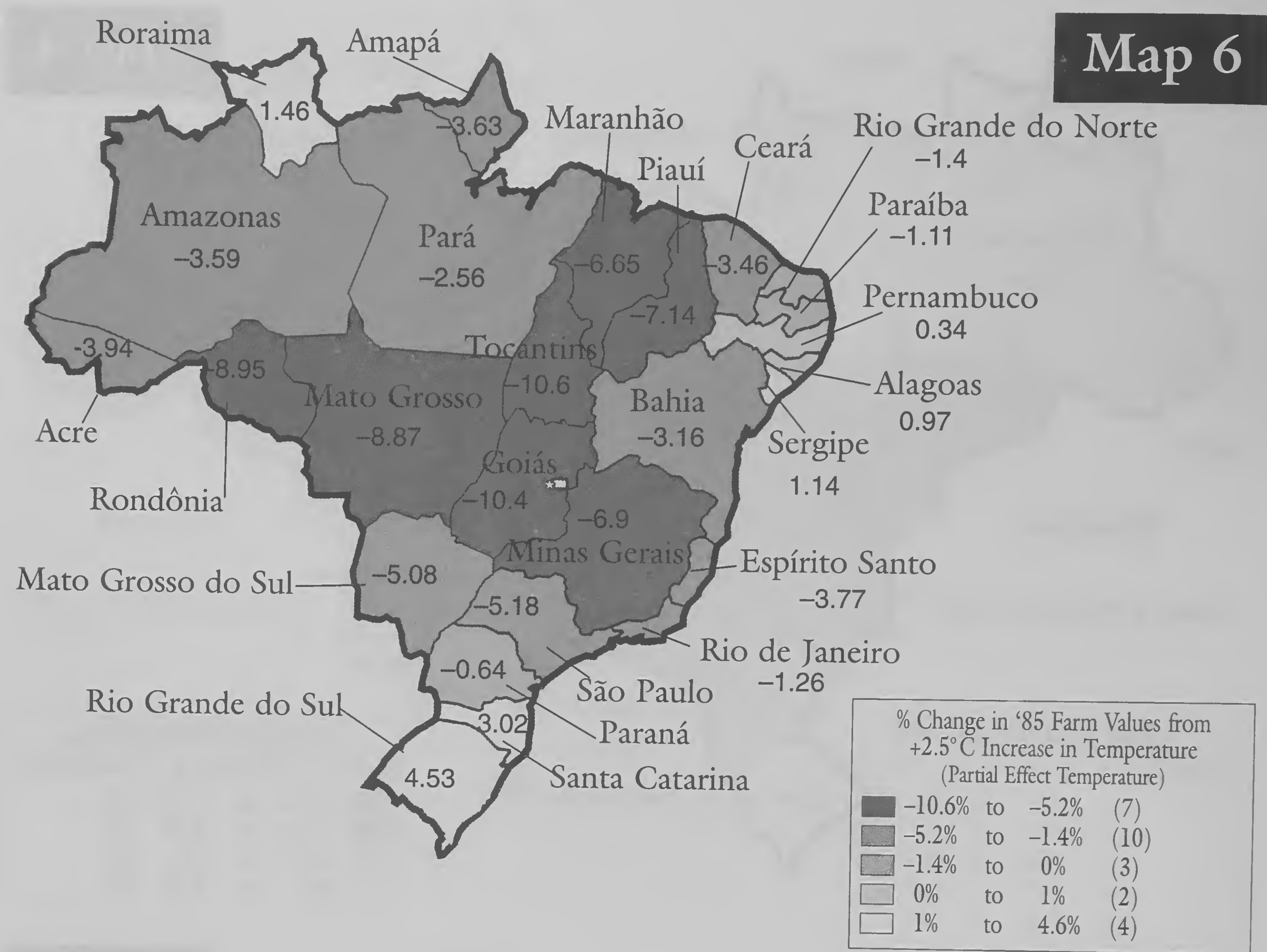


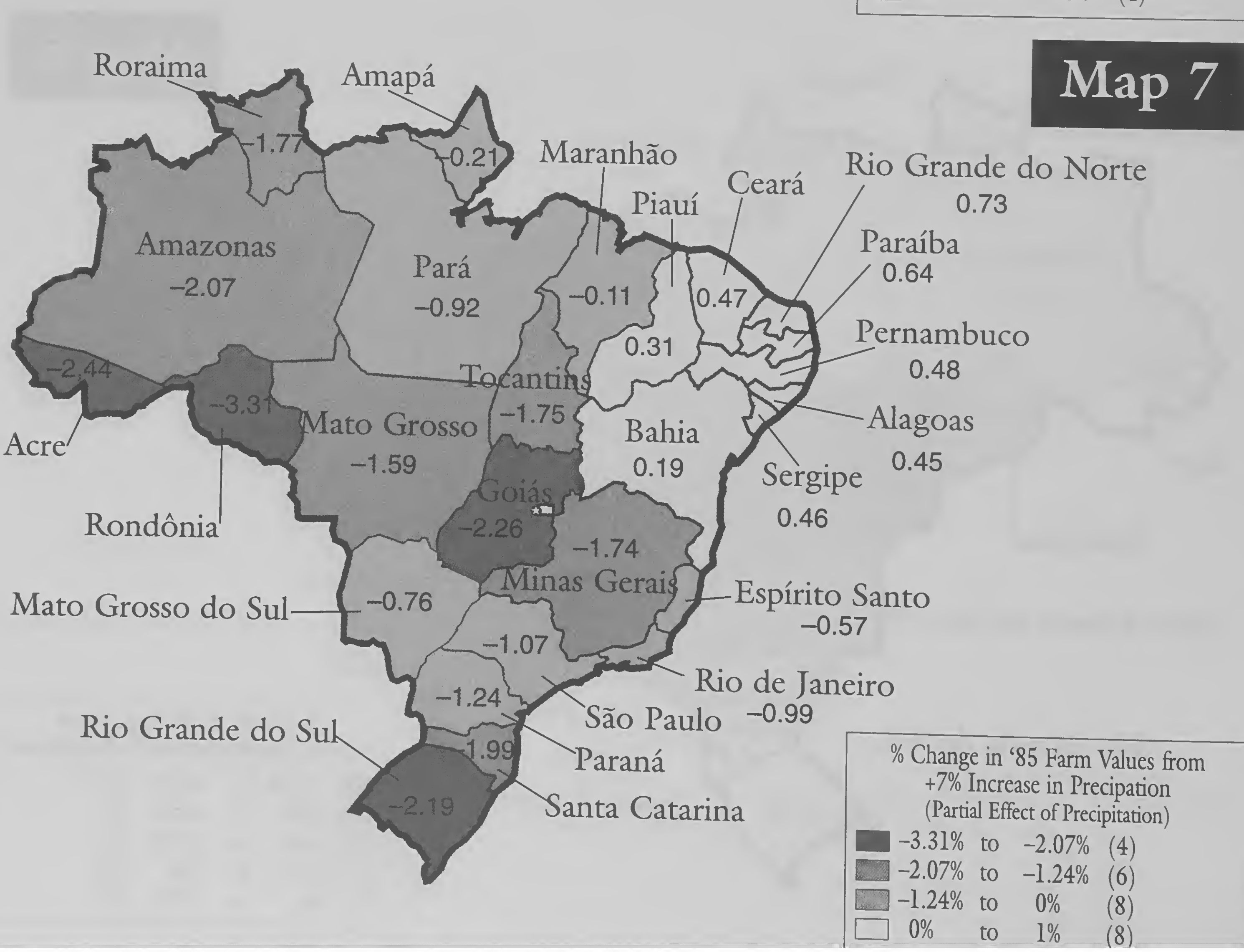

Map 2
Roraima
-0.02
Amapá
-3.71
Maranhão
-6.92
Piauí
-6.62
Ceará
-2.95
Rio Grande do Norte
–0.55
Paraíba
–0.37
Pernambuco
0.97
Alagoas
1.65
Sergipe
1.83
Amazonas
–5.63
Pará
–3.43
Acre
-6.4
Rondônia
-12.41
Tocantins
-12.62
Mato Grosso
–10.69
Bahia
-2.99
Goiás
-12.96
-8.91
Minas Gerais
Mato Grosso do Sul
-5.88
-6.37
Espírito Santo
-4.46
Rio de Janeiro
-5.44
São Paulo
-1.79
Paraná
1.24
Rio Grande do Sul
2.63
Santa Catarina
% Change in '85 Farm Values
(+2.5° C Temperature & 7% Precipitation)
–13% to –7% (5)
–7% to –4.5% (7)
–4.5% to –0.6% (6)
–0.6% to 0% (3)
0% to 0.7% (5)


Map 3
Roraima
-1.09
Amapá
-2.29
Maranhão
-4.72
Piauí
Ceará
Rio Grande do Norte
–1.67
Paraíba
Pernambuco
–0.29
Alagoas
Sergipe
Amazonas
-4.53
Pará
–3.29
Acre
-6
Rondônia
-7.78
Tocantins
-6.21
Mato Grosso
–5.41
Bahia
–1.81
Goiás
–5.11
Minas Gerais
Mato Grosso do Sul
-3.07
–2.6
Espírito Santo
Rio de Janeiro
–2.57
São Paulo
–0.48
Paraná
0.8
Rio Grande do Sul
1.44
Santa Catarina
% Change in '80 Farm Values
(+2.5° C Temperature & 7% Precipitation)
–7.78% to –5% (4)
–5% to –1.18% (14)
–1.18% to 0% (6)
0% to 1.44% (8)

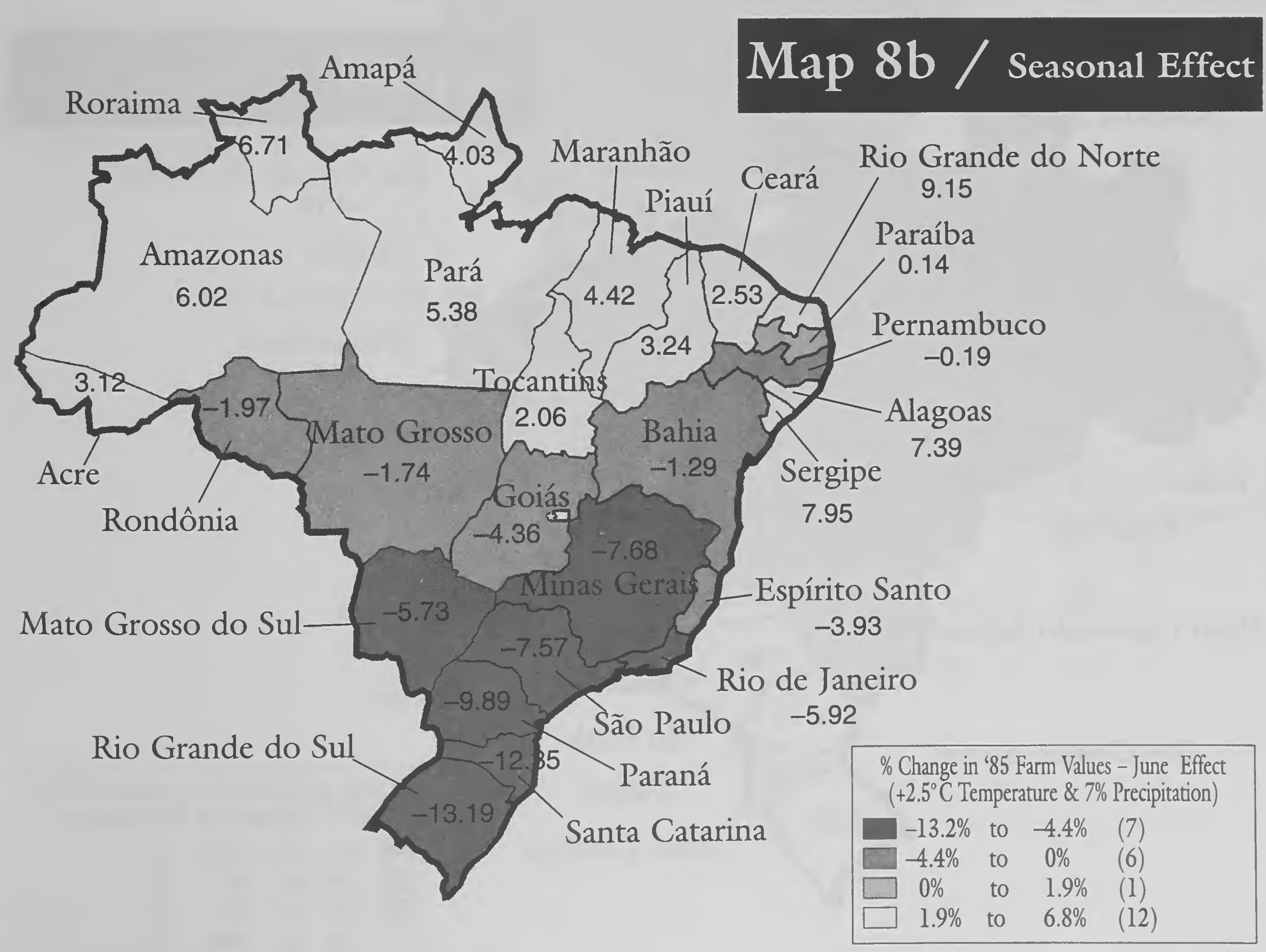

Map 4
Roraima
4.28
Amapá
0.07
Maranhão
Piauí
Ceará
Rio Grande do Norte
–0.86
Paraíba
1.7
Amazonas
–0.99
Pará
–0.62
–6.03
–3.06
–8.27
Pernambuco
–0.66
–0.9
–8.87
Tocantins
–13.73
Alagoas
0.76
Acre
Mato Grosso
–14.1
Bahia
–5.93
Sergipe
1.01
Goiás
–18.44
–16.58
Rondônia
Minas Gerais
Espírito Santo
–9.08
Mato Grosso do Sul
–10.43
–11.02
Rio de Janeiro
–19.95
–4.19
São Paulo
Rio Grande do Sul
0.75
Paraná
0.94
Santa Catarina
% Change in '75 Farm Values
(+2.5° C Temperature & 7% Precipitation)
–18.5% to –11.1% (4)
–11.1% to –4.2% (8)
–4.2% to 0% (9)
0% to 4.3% (8)


Map 5
Roraima
0.48
Amapá
1.61
Maranhão
Ceará
Rio Grande do Norte
Piauí
Paraíba
–1.58
Amazonas
–1.61
Pará
–0.09
–6.55
Pernambuco
0.02
Tocantins
–3.67
–11.66
Alagoas
Acre
Mato Grosso
–11.43
Bahia
–7.57
Sergipe
Goiás
–13.28
–11.72
Rondônia
Minas Gerais
Espírito Santo
Mato Grosso do Sul
–8.41
–6.9
Rio de Janeiro
–7.44
–0.95
São Paulo
Rio Grande do Sul
4.66
Paraná
4.19
Santa Catarina
% Change in '70 Farm Values
(+2.5° C Temperature & 7% Precipitation)
–13.3% to –8.5% (5)
–8.5% to –4.6% (7)
–4.6% to –1.7% (6)
–1.7% to 0% (5)
0% to 4.7% (3)

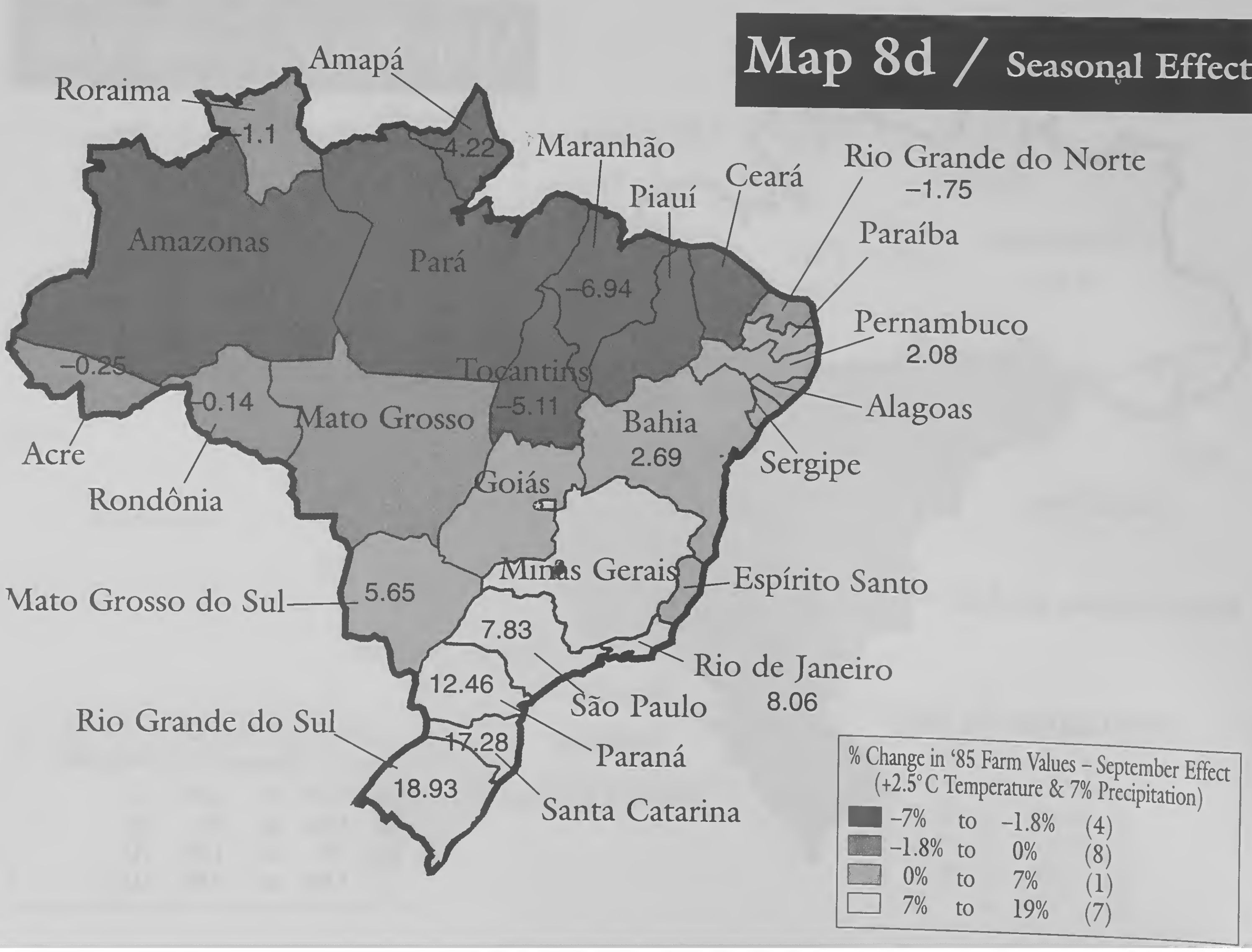

Map 6
Roraima
1.46
Amapá
-3.63
Maranhão
-6.65
Piauí
-7.14
Ceará
-3.46
Rio Grande do Norte
–1.4
Paraíba
–1.11
Pernambuco
0.34
Alagoas
0.97
Sergipe
1.14
Amazonas
–3.59
Pará
–2.56
Acre
-3.94
Rondônia
-8.95
Mato Grosso
–8.87
Tocantins
–10.6
Bahia
–3.16
Goiás
–10.4
Minas Gerais
–6.9
Espírito Santo
–3.77
Mato Grosso do Sul
–5.08
São Paulo
–5.18
Rio de Janeiro
–1.26
Paraná
–0.64
Santa Catarina
3.02
Rio Grande do Sul
4.53
% Change in '85 Farm Values from +2.5° C Increase in Temperature (Partial Effect Temperature)
–10.6% to –5.2% (7)
–5.2% to –1.4% (10)
–1.4% to 0% (3)
0% to 1% (2)
1% to 4.6% (4)


Map 7
Roraima
-1.77
Amapá
-0.21
Maranhão
–0.11
Piauí
0.31
Ceará
0.47
Rio Grande do Norte
0.73
Paraíba
0.64
Pernambuco
0.48
Alagoas
0.45
Sergipe
0.46
Amazonas
–2.07
Pará
–0.92
Acre
-2.44
Rondônia
-3.31
Mato Grosso
–1.59
Tocantins
–1.75
Bahia
0.19
Goiás
–2.26
Minas Gerais
–1.74
Espírito Santo
–0.57
Mato Grosso do Sul
–0.76
São Paulo
–1.07
Rio de Janeiro
–0.99
Paraná
–1.24
Santa Catarina
-1.99
Rio Grande do Sul
-2.19
% Change in '85 Farm Values from +7% Increase in Precipation (Partial Effect of Precipitation)
–3.31% to –2.07% (4)
–2.07% to –1.24% (6)
–1.24% to 0% (8)
0% to 1% (8)


Map 8a / Seasonal Effect
Roraima
-5.65
Amapá
-3.8
Maranhão
Ceará
Rio Grande do Norte
-1.53
Piauí
Amazonas
-7.44
Pará
-3.88
Paraíba
-1.95
-2.85
-1.83
-3.26
Pernambuco
-2.34
-8.79
Tocantins
-10.19
-9.03
Alagoas
-1.94
Mato Grosso
-8.55
Bahia
-4.66
Acre
Sergipe
-2.34
Rondônia
Goiás
-10.94
-10.13
Minas Gerais
Espírito Santo
-7.13
Mato Grosso do Sul
-6.42
-8.02
Rio de Janeiro
-8.26
-6.64
São Paulo
Rio Grande do Sul
-6.7
Paraná
-6.16
Santa Catarina
% Change in '85 Farm Values – December Effect
(+2.5°C Temperature & 7% Precipitation)
-10.94% to -7.44% (8)
-7.44% to -4.66% (7)
-4.66% to -2.34% (5)
-2.34% to -1.53% (6)


Map 8b / Seasonal Effect
Roraima
6.71
Amapá
4.03
Maranhão
Ceará
Rio Grande do Norte
9.15
Piauí
Paraíba
0.14
Amazonas
6.02
Pará
5.38
4.42
2.53
3.24
Pernambuco
-0.19
3.12
Tocantins
-1.97
2.06
Alagoas
7.39
Mato Grosso
-1.74
Bahia
-1.29
Acre
Sergipe
7.95
Rondônia
Goiás
-4.36
-7.68
Minas Gerais
Espírito Santo
-3.93
Mato Grosso do Sul
-5.73
-7.57
Rio de Janeiro
-5.92
-9.89
São Paulo
Rio Grande do Sul
-12.85
Paraná
-13.19
Santa Catarina
% Change in '85 Farm Values – June Effect
(+2.5°C Temperature & 7% Precipitation)
-13.2% to -4.4% (7)
-4.4% to 0% (6)
0% to 1.9% (1)
1.9% to 6.8% (12)


Map 8c / Seasonal Effect
Roraima
-0.27
Amapá
0.15
Maranhão
Piauí
Ceará
Rio Grande do Norte
-0.54
Paraíba
Amazonas
-1.07
Pará
-1.55
-1.39
Pernambuco
0.26
-0.45
Tocantins
-0.27
Alagoas
-0.86
Mato Grosso
0.09
Bahia
0.4
Acre
Sergipe
-0.54
Rondônia
Goiás
1.25
1.69
Minas Gerais
Espírito Santo
0.44
Mato Grosso do Sul
0.68
1.51
Rio de Janeiro
0.85
2.19
São Paulo
Rio Grande do Sul
2.79
Paraná
2.76
Santa Catarina
% Change in '85 Farm Values – March Effect
(+2.5°C Temperature & 7% Precipitation)
-1.55% to -0.71% (4)
-0.71% to -0.03% (8)
-0.03% to 0% (1)
0% to 2.79% (7)


Map 8d / Seasonal Effect
Roraima
-1.1
Amapá
4.22
Maranhão
Piauí
Ceará
Rio Grande do Norte
-1.75
Amazonas
Pará
Paraíba
-6.94
Pernambuco
2.08
-0.25
Tocantins
-0.14
-5.11
Alagoas
Mato Grosso
Bahia
2.69
Acre
Sergipe
Rondônia
Goiás
Minas Gerais
Espírito Santo
Mato Grosso do Sul
5.65
7.83
Rio de Janeiro
8.06
12.46
São Paulo
Rio Grande do Sul
17.28
Paraná
18.93
Santa Catarina
% Change in '85 Farm Values – September Effect
(+2.5°C Temperature & 7% Precipitation)
-7% to -1.8% (4)
-1.8% to 0% (8)
0% to 7% (1)
7% to 19% (7)

Net Impact of Benchmark Warming on 1985 Farm Values