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Evidence for the influence of agriculture on weather and climate through the transformation and management of vegetation: Illustrated by examples from the Canadian Prairies

R.L. Raddatz

Department of Geography, The University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, Canada R3B 2E9

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Abstract

This paper lists selected observational and modeling studies which provide evidence that agriculture, through the transformation and management of vegetation, has had, and continues to have, an impact upon the weather and climate on the local, regional and global scales. The influence of agriculture on weather and climate, through the alteration of the physiological properties of the land cover, is illustrated by examples from the cropped grassland of the Canadian Prairies.

The physiological and physical properties of the vegetation, along with the land cover's impact upon the level of available soil moisture, affect the weather and climate by influencing the transfer of heat, moisture and momentum from the land surface to the overlying air. The principle physiological properties are leaf area, stomatal resistance, and rooting depth; the main physical properties are albedo and surface roughness. By land clearing, cultivation and the grazing of domesticated animals, man has transformed and now manages the vegetation over vast areas of the globe. Agriculture influences the availability of energy and water vapour mass for moist deep convection on the local and regional scales. By creating latent heat flux discontinuities, it may induce mesoscale circulations that initiate moist deep convection. Agriculture, by affecting the level of stored soil moisture, moisture that is available to the vegetation during a later period, may influence the level of convective activity within a region during a subsequent season. Thus agriculture, through the physiological and physical properties of the land cover, has had, and continues to have, an impact upon near surface weather elements and, more significantly, upon the regional hydrologic cycle.

Spatially coherent and persistent patterns of thunderstorms play a role in the export of heat and moisture from lower to higher latitudes—this may effect the general circulation. Thus agriculture, by influencing the occurrence, location and intensity of moist deep convection, particularly in the tropics, may also influence global weather and climate.

Keywords: Land-surface forcing; Local effects; Regional hydrologic cycle; Tele-connections

1. Introduction

Near surface weather elements and, more significantly the regional hydrologic cycle and even global weather patterns, are affected by: (1) the energy budget of the land surface, and (2) the moisture (mass) balance of the surface layer of the land, and the moisture (mass) balance of the atmosphere (Pielke and Avissar, 1990; Betts et al., 1996; Pielke et al., 1998; Chase et al., 2000; Douville et al., 2000; Pielke, 2001; Lu et al., 2001; Bounoua et al., 2002). The simplified equation for the

E-mail address: rick.raddatz@shaw.ca.

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partitioning of the net radiative energy at the land surface–atmosphere interface can be written as (Oke, 1987):

$$R_n = \lambda E + H + G \quad (1)$$

where R_n represents the net radiative flux; λE the convective flux of latent heat (evaporation and transpiration); H the convective flux of sensible heat; G is the heat conducted into the soil and vegetation. The moisture (mass) balances for the surface layer of the land and for the atmosphere can, respectively, be written as (Budyko, 1982; Brubaker et al., 1993; Oke, 1997):

$$P = I + E + T + R + D + \Delta S_W \quad (2a)$$

$$P = E + T + (F^+ - F^-) + \Delta S_V \quad (2b)$$

where P is precipitation; I the infiltration; E the evaporation from the soil and from the surfaces of the vegetation; T the transpiration (water vapour flux via the stomata of plants); R the runoff by horizontal flow, and D the vertical drainage or deep peculation, ΔS_W the change in soil moisture – the water stored in the surface layer of the land, and ΔS_V is the change in atmospheric moisture – the water vapour stored in the total atmospheric column; F^+ and F^- are, respectively, the horizontal influx and efflux of moisture. Snow and ice covered surfaces are not considered in this discussion.

The physiological and physical properties of the vegetation, along with the land cover's impact upon soil moisture, affect the weather and climate by influencing the transfer of heat, moisture and momentum from the land surface to the overlying air. The principle physiological properties are leaf area, stomatal resistance, and rooting depth; the main physical properties are albedo and surface roughness (Arora, 2002). These properties generally vary with the type, phenological stage, and structure of the vegetation. They are dynamic—changing through the seasons and exhibiting inter-annual and longer-term variability. For example, an increase in transpiration or λE, brought about by the seasonal expansion of annual foliage with the associated decrease in the bulk stomatal or canopy resistance, decreases H, if R_n and G remain the same. The seasonal senescence of annual foliage has the reverse effect. Root growth defines the soil moisture reservoir, and the level of plant-available moisture in the root zone limits λE. A change in albedo, associated with a change in the vegetation, changes Rn and, thus the heat available for H, λE and G. The structure of the vegetation affects the surface roughness, and thus, the aerodynamic coupling of the atmosphere to the land surface. Thus, a change in roughness length not only influences the turbulent momentum flux, but also the convective fluxes—H and λE (Gillespie, 1997).

Through agriculture (land clearing, cultivation and the grazing of domesticated animals), man has altered, and now manages to varying degrees, the vegetation (i.e., the physiological and physical properties of the land cover), and directly (via irrigation) or indirectly (via the vegetation) the soil moisture over large tracks of land. From census data and satellite imagery, it is estimate that agricultural cultivation has transformed about 12% of the earth's land surface into cropland—15–18 million km^2 or an area roughly the size of South America. Pastures and rangelands now cover about 22% of the land surface area—about 34 million km^2 or an area roughly the size of Africa. These vegetation alterations or complete transformations have taken place at the expense of natural grasslands, and to a lesser extent of forests (Goldewijk, 2001; Leff et al., 2004). It follows that crops and pastures now play a significant role in the interactions between the land surface and the atmosphere, and thereby, routinely influence the weather and climate. Land cover effects may reinforce climate variability enhancing and/or extending extremes such as floods and droughts (Trenberth and Guillemot, 1996; Nicholson et al., 1998).

This paper is a compilation of selected observational and modeling studies which document the influence of agriculture, through the transformation and management of vegetation, on: (1) some near surface weather elements, (2) the regional hydrologic cycle, and (3) the global weather patterns. While this compilation is extensive, it is not a comprehensive documentation of all relevant studies. The impact of agriculture upon weather and climate, through the alteration of the physiological properties of the land cover, is illustrated by examples from the cropped grassland of the Canadian Prairies.

2. Cropped grassland eco-climatic region of the Canadian Prairies

The grasslands of the Canadian Prairie provinces occupy about 520,000 km^2 of Manitoba, Saskatchewan and Alberta (Fig. 1). This eco-climatic region consists of a vast arid core and a border zone of transitional grassland (Canada Committee on Ecological Land Classification, 1989). Today, cultivation has transformed 50–60% of area from perennial mixed native grasses (*Stripa-Bouteloua* association), with groves of deciduous aspen (*Populous tremuloides* Michx.) in the transition zone, to annual field crops (Environment Canada, 1991)—primarily spring wheat (*Triticum*