THE EFFECTS OF LANDSCAPE RESTORATION ON GREENHOUSE GAS EMISSIONS AND PLANT SPECIES AND ABUNDANCE

BY

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ABSTRACT

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The objective of this study was to investigate the effects of landscape restoration on two main parameters: greenhouse gas emissions (GHG; carbon dioxide, methane and nitrous oxide) and plants (species - including crop and weed species - and abundance). Two field experiments and two growth chamber experiments were completed over a two-year period to fulfill this objective. The two field experiments were similar in nature and examined the impacts of landscape restoration on both parameters under field-scale conditions. Greenhouse gases and plants were studied in separate growth chamber experiments. The growth chamber experiments complemented the field experiments but focused on one of the two parameters.

In the field, soil was removed from the lower slope riparian area of the landscape where soil had accumulated due to past tillage erosion, and was added to the eroded upper slope area. Nitrous oxide (N_2O), and methane (CH_4) emissions were not influenced by the removal of soil; however, carbon dioxide (CO_2) emissions were reduced in the first year following soil removal. In the upper slope area where soil was added, greenhouse gas emissions were not impacted. The growth chamber experiments assessed varying depths of soil removal and addition and the effects on GHG emissions. The depth of soil removal did not influence cumulative gas flux but in general, and similar to field results, soil removal reduced CO_2 emissions. Reductions in N_2O

emissions following soil removal were also found in the growth chamber. Soil addition did not impact GHG emissions by depth.

To address the question of landscape restoration effects on plants, plant emergence, abundance, and species composition was monitored in the field. In the first year following soil addition, weed emergence increased where soil was added. In one of the two study areas, crop yield was greater where soil was added despite the increase in weed emergence. The number of weed species present following soil addition remained the same as the controls. In year two following the addition of soil, weed emergence numbers where soil was added were similar to the control. The number of weed species present did increase. Because the area from which soil was removed was not part of the cropland, the type (weedy vs. native or wetland) of species revegetating the lower slope removal area was the primary interest. The species observed in the lower slope area were predominantly weeds and similar to those found in the adjacent cropland. In the growth chamber, the soil seed bank was examined to assess the viability of the seed bank within the soil profile and assess the species present; this information may be useful for predicting potential impacts of landscape restoration on weed populations in the restored cropland. It was found that the most viable seeds exist near the soil surface (within the top 5 cm of soil) and that the species were predominantly weeds. The species found in the seed bank correspond with those found in the field experiments in both the upper and lower slope areas.

In summary, this study demonstrated that in the medium-term, landscape restoration does not increase greenhouse gas emissions from soil. In fact, the removal of soil will benefit atmospheric CO_2 levels by reducing CO_2 emissions from the lower slope removal areas. Weed emergence will likely increase in the first year following the addition of soil; which may or may not adversely affect crop yield depending on the crop type. The overall impact of increased weed pressures can be reduced by planting a competitive crop, and using the appropriate herbicide in correct rotation.

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FOREWORD

This thesis has been prepared in the manuscript format in adherence with the guidelines established by the Department of Soil Science at the University of Manitoba. The Canadian Journal of Soil Science was the reference style used in this document. Chapters 3 and 4 will be submitted to Journal of Soil and Water Conservation. For all papers, I will be the lead author and co-authorship will be designated accordingly.

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1. INTRODUCTION

Soil erosion by wind, water and tillage results in the redistribution of soil within the landscape. In topographically complex landscapes where conventional tillage is practiced, organic-rich topsoil becomes redistributed from hilltops (or convexities) to lower slope and depressional areas (or concavities). When hilltops become eroded they lose productivity while the lower slope and depressional areas often become more productive. The yield variability within the landscape resulting from soil erosion makes agricultural land management difficult and reduces the economic viability of the cropping system.

There are several ways hilltops can be managed to improve their productivity. These include increasing the fertility of the hilltop via chemical or organic fertilizers, increasing the organic matter content of the hilltop by using manure, green manures or altering the crop rotation, and by implementing conservation tillage practices. Adding fertilizer or manure may improve the short-term productivity of the eroded hilltops, but may have limited economic return. Using crop rotation or conservation tillage requires many years of implementation to improve soil productivity. An innovative approach to improving eroded hilltops quickly and effectively is landscape restoration.

Landscape restoration is a land management practice whereby soil that has accumulated in lower slopes and depressions is returned to the adjacent eroded hilltops. This technique has been practiced for many years by farmers in China and some parts of the U.S. and Canada, but has not been documented. Some researchers have looked at crop response to the application of soil and have found optimistic results, however, landscape restoration as a general management practice has not been studied. General agronomic, economic and environmental factors of landscape restoration should be considered. For example, there are many potential environmental impacts that may be associated with the movement of organic-rich soil within a landscape that have not been considered. These include pesticide fate, nutrient cycling as it relates to runoff, leaching, and greenhouse gas emissions, as well as impacts on plant species and abundance including crops, weeds, and native plants. The latter two topics are the focus of this study.

The purpose of this thesis project was to determine the medium-term effects of landscape restoration on greenhouse gas emissions and on plant species and abundance.

The objectives of this study were:

1) To study greenhouse gas emissions (carbon dioxide, methane and nitrous oxide) following landscape restoration comparing the restored areas to the eroded area in the upper slope area, and comparing removal areas to the accumulated areas in the lower slope area.

2) To study plant emergence (including crop and weeds) and examine weed composition in the area that is restored, and monitor plant species composition where soil was removed.

Several experiments were conducted to fulfill each of these objectives. Two field experiments were initiated to address both objectives, while one growth chamber experiment used intact soil cores to address objective 1, and a second growth chamber experiment looked at the seed bank within the soil profile to address objective 2. The findings from the growth chamber studies were compared with field experiment findings.

2. LITERATURE REVIEW

Erosion processes and erosion effects on crop productivity are outlined in this chapter. A review of the current methods for improving soil quality on eroded hilltops is included. Past research on landscape restoration and its effects on plant species and emergence, including crop, weeds and native plants, and on greenhouse gas emissions is summarized.

2.1 Soil Erosion in Topographically Complex Landscapes

The three predominant forms of soil erosion reported in the literature include water, wind and tillage erosion. Each form of erosion acts on the soil in different ways; each are predominant in different types of landscapes and may cause the redistribution of soil from and to different parts of the landscape. This section briefly describes the three types of soil erosion including soil and landscape factors affecting erosion.

2.1.1 Water and Wind Erosion

Water erosion occurs in moderately to strongly sloping landscapes and is most severe on soils of silty texture and with poor aggregate stability (Troeh et al.1980). When considering landform, soil tends to be lost from concave curvatures or backslopes (Lobb and Kachanoski 1999).

Wind erosion is most common on level landscapes. Fine sands and silts are prone to wind erosion, especially when soil moisture is low. When the landscape is topographically complex, wind erosion is most severe on exposed hilltops within the landscape (Lobb 1999). Although wind erosion is responsible for the loss of soil from hilltops, it is not the predominant erosion acting on hilltops of the prairie pothole region of Canada. The losses from hilltops are equally severe on a range of soil types on both sheltered and unsheltered hilltops indicating wind erosion cannot be the only cause (Lobb 1999).

Brady and Weil (2002) report 4 billion Mg soil per year is moved by water and wind erosion in the U.S. Both wind and water erosion are thought to be the predominant forces degrading agricultural soils, including the loss of soil from hilltops and ridges. However, there is little experimental or theoretical evidence that can adequately explain the degree of soil erosion on hilltops (Lobb et al.1995). Recent research has found that tillage erosion is in fact the cause (Govers et al. 1999).

2.1.2 Tillage Erosion

Tillage erosion is responsible for the loss of large quantities of soil from crest and shoulder slope landscape positions (Lobb et al.1995; Govers et al.1999;). Soil lost from these convexities accumulates in the concave footslopes and hollows (or depressions) downlsope (Govers et. al.1999). Slope gradient strongly affects tillage erosion (Van Muysen and Govers 2002) while other factors such as tillage depth, tillage speed, tillage direction (upslope vs. downslope tillage), and soil condition also play an important role (Lobb et al. 1995; Lobb et al. 1999; Govers et al. 1999; Van Muysen et al. 2002).

Tillage erosion has been reported to account for soil losses of 54 t ha^{-1} $year^{-1}$ from upland shoulder slope positions in Southern Ontario (Lobb et al. 1995). This level far exceeds Canada's Agri-Environmental Indicator - Risk of Tillage Erosion tolerable level of 6 t ha^{-1} yr^{-1} (King et al. 2000). In Manitoba it was estimated that 56% of cropland fell under unsustainable soil conditions in terms of tillage erosion risk (King et al. 2000). It is clear that tillage erosion is an important process affecting soil quality and crop productivity in agricultural landscapes (Li and Lindstrom 2001).

2.2 Effects of Soil Loss on Crop Productivity

'The effects of erosion depend largely on the thickness and the quality of the topsoil (being lost) and the nature of the subsoil' being exposed (Frye et al.1985). The loss of topsoil from hilltops can dramatically reduce the productivity of those hilltops for various reasons.

When topsoil is lost, the total amount of soil organic matter[1] is reduced on the eroded areas (Lal 2000; Frye 1985; Lobb1995; Tanaka 1989). The loss of organic matter brings with it altered chemical and physical properties, such as reduced fertility and lower soil water holding capacity (Lal 2000; Langdale 1982).

Soil fertility is reduced in eroded soils (Fry et al. 1985). With each Mg ha^{-1} of lost organic matter, approximately 60 kg of nitrogen (N) is also lost (Frye et al. 1985). Phosphorus concentrations of soil may also be lowered. Larney et al. (2000a) found the extractable phosphorus (P) concentration decreased with increasing depth of soil removal at two of three sites while Tanaka and Aase (1989) also found extractable P significantly decreased when soil was removed.

In addition to influencing soil fertility, soil organic matter content influences the soil's water holding capacity by retaining water that is much more plant available than that held in the mineral fraction (Brady and Weil 2002). When organic matter is lost, so is

[1] The term organic matter refers to the organic fraction of soil consisting of all organic elements including carbon, nitrogen, phosphorus, sulphur, hydrogen and oxygen; the terms organic matter and organic carbon are sometimes used interchangeably in the literature but here, when the term organic matter is used, the organic compounds in general are being reported; when the term organic carbon is used, the measured organic carbon fraction is being reported.