Tillage and Herbicide Indices Illustrate Relationships among Cropping Systems

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Abstract

Farming systems based on reduced inputs and increased diversity of crop types are of interest to producers as alternatives to conventional systems. Indices can be derived to estimate the impact of various farming practices on the system and its environment. The paper presents methods for calculating simple, weighted and modeled herbicide and tillage indices. The simple indices are based solely on farm input use records. The simple indices illustrated in the paper are number of herbicide applications and number of tillage operations. The weighted indices incorporate some knowledge about the operations using external data sources. The examples illustrated are herbicide active ingredient and cumulative disturbance. The third level of complexity is to model the impact of the operations on the environment using several external sources. The paper calculates environmental exposure to herbicides and residue removed. All indices are calculated for nine cropping systems included in the Scott Alternative Cropping System Study. Each index ranked the cropping systems differently. Number of herbicide applications underestimated the relative amount of active ingredient applied in the high input systems as compared to the reduced input (minimum tillage) systems. The types of herbicide necessary to control weeds in high input systems tended to result in higher environmental exposure to herbicides. The number of tillage passes also underestimated the relative amount of disturbance in the high input systems as compared to the organic systems. The amount of residue removed in the organic and high input systems was similar.

Introduction

Farming systems based on reduced inputs and increased diversity of crop types are of interest to producers as alternatives to conventional systems. For the development of alternative approaches to farming, tools are needed to evaluate and optimize the performance of these cropping systems. Economic indicators are important, but the agronomic and environmental aspects of the systems also need to be considered. Indices can be derived to estimate the impact of various farming practices on the system and its environment. The simplest approach is to construct an index based solely on farm input use records. The next level of complexity is weighted indices that incorporate some knowledge about the farming practices using external data sources. The third level of complexity is to model the impact of the farming practices on the environment using several external sources.

The paper presents various methods for calculating herbicide and tillage indices. These indices are used for ranking nine cropping systems found in the Alternative Cropping System Study.

Alternative Cropping Systems Study

The study site occupies 16 ha at Scott, SK utilizing 12.8 m by 40 m plots in a split-plot factorial design with four replicates (Ulrich *et al.* 2001). The experimental framework is a matrix representing three levels of input use and three levels of cropping diversity. The design is based on a 6-year rotation and includes all phases each year. The study has just completed the first 6-year cycle (1995 to 2000).

Cropping Systems

Three input levels are organic (ORG), reduced (RED) and High (HIGH). In the organic systems, management is based on non-chemical means to mimic what an organic grower might do. In the reduced input systems, long-term management and reduced tillage are used to reduce non-renewable inputs while chemicals are used to supplement management practices. In the high input systems, inputs are based on pest thresholds and soil tests. In this system, chemical inputs compliment conventional tillage practices.

The three levels of cropping diversity are low (LOW), diversified annual grains (DAG), and diversified annual and perennial (DAP). The low diversity system is a traditional rotation of fallow-wheat-wheat-fallow-canola-wheat. The organic input level uses green manure fallow, the reduced input level has one green manure fallow and one chemical fallow and the high input level has tillage fallow. The diversified annual grains rotation has a diversity of cereal, oilseed and pulse grains. The reduced and high input systems follow the same rotation (canola-fall rye-pea-barley-flax-wheat), while the organic input system incorporates green manure fallow for nitrogen fixation (green manure fallow-wheat-pea-barley-green manure fallow-canola). The diversified annual and perennial rotation mixes grains and perennials (canola-wheat-barley-oat under seeded to brome alfalfa-brome alfalfa-brome alfalfa).

Indices

All indices represent average values per plot per year. System averages represent averages of 24 plots in each of the last six years.

The simplest herbicide index is a count of the number of herbicide applications in one year. Tank mixes are considered one application. The weighted herbicide index included in the paper is kilograms of active ingredient per hectare per year. The modeled index is the Environmental Exposure to Herbicides (EEH). This index accounts for the environmental exposure of the air, soil and groundwater as proposed by the Environmental Exposure to Pesticides index (Vereijken *et al.* 1995), except that the calculation for the air environmental exposure is based on Henry's Law constant rather than vapour pressure (van der Werf 1996).

EEH_{air} = active ingredient (kg/ha) * Henry's Law constant (Pa m^3/moles)

EEH_{soil} = active ingredient (kg/ha) * soil half life

$EEH_{groundwater} = EEH_{soil}$ / mobility (K_{oc})

Each component of the EEH (air, soil and water) is weighted equally in the final index. The values for herbicides in each component are standardized by the maximum value out of all the herbicides applied in the study.

$$EEH = EEH_{air}/\text{ maximum } EEH_{air} + EEH_{soil}/\text{maximum } EEH_{soil} + EEH_{groundwater}/\text{maximum } EEH_{groundwater}$$

The simple tillage index is a count of the number of tillage operations per year. In this index, mounted tine harrows and trailed rod were not counted as a separate tillage operations. Also, seeding and banding fertilizer were not included as tillage operations. The weighted index measured the cumulative disturbance in the plots. Additive index of disturbance per year is based on relative disturbance caused by each implement (a value between 0 and 1) as rated by ability to remove fragile residue (Bull 1993). The modeled tillage index measures the percent of crop residue removed per year. This index reflects the relative vulnerability of the cropping system to erosion. The percentage of residue removed is based on residue type (fragile or non-fragile) and type of tillage operation (Bull 1993).

To illustrate the relative usage of tillage and herbicide inputs simultaneously, each index complexity level is plotted against each other. In order to rank the systems, a perpendicular is dropped to a line at 45^o between the two axes. This ranking gives the tillage and herbicide indices equal weight.

Results and Discussion

All herbicide indices ranked the systems differently (Fig. 1). Reduced input systems applied herbicides more frequently than the high input systems. In general, the reduced input systems included a fall and spring burn-off as well as an in-crop herbicide application.

The number of applications underestimated the relative amount of herbicide active ingredients applied in the high input systems (Fig. 1). The in-crop herbicide products necessary to control weed populations in the high input systems tended to contain more active ingredients than the in-crop herbicides used in the reduced input systems. Nevertheless, the reduced input systems still applied more active ingredient than the equivalent high input systems.

Herbicides used in the high input diversified annual grains and high input diversified annual and perennial systems result in higher environmental exposure values than those used in the equivalent reduced input systems (Fig. 1). Herbicides in the reduced low diversity system result in higher EEH values than those in the high input low diversity systems, primarily due to chemical fallow in the reduced input low diversity system.

All tillage indices ranked the systems differently (Fig. 2). The main differences between indices were seen in the relative ranking of the high input systems. Number of operations underestimated the amount of disturbance in the high input systems. Amount of residue removed was similar in the organic and high input systems.

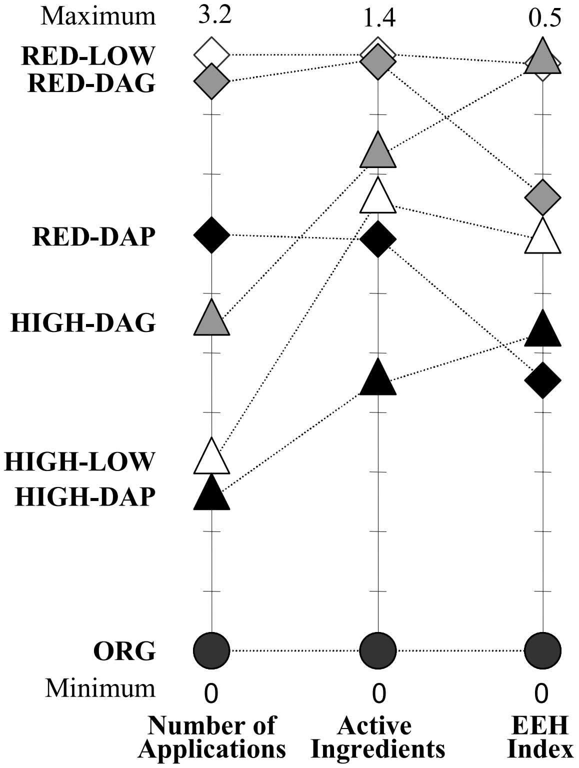

Figure 1. Herbicide indices.

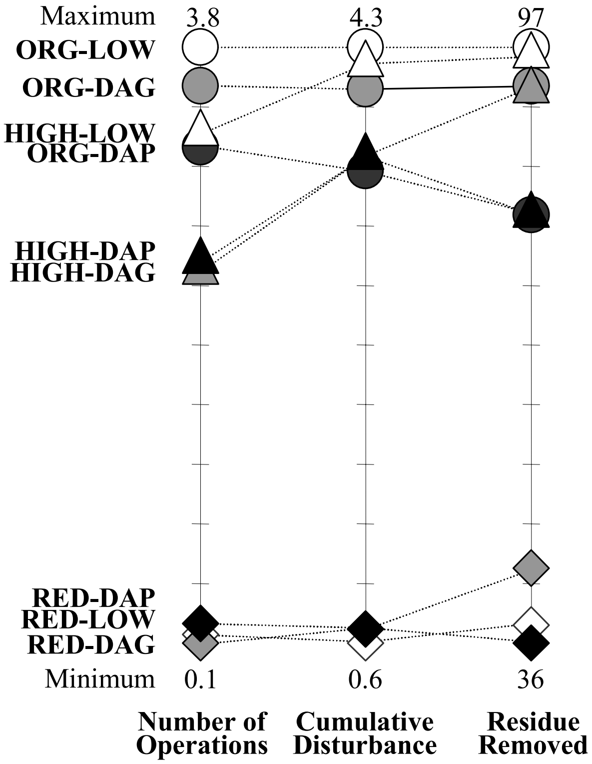

Figure 2. Tillage indices.

The combination of the simple indices indicated that the lowest inputs were found in the DAP systems, followed by the other organic, reduced and high input systems (Fig. 3). The combination of the weighted indices indicate that all the high input systems had higher combined use of herbicide and tillage than the other input levels (Fig. 3). The high overall input levels in the high input system indicate that herbicides were used in addition to tillage rather than as a substitution for tillage. When the modeled indices are combined, the high input DAG system has the highest combined input level and reduced input DAP system has the lowest combined input level.

Summary

These indices assist in an understanding and interpretation of complex farming systems by synthesizing data for farm input use and environmental risk enabling quantification of the current state of the system. These indices allow the evaluation of the systems in terms of target levels that need to be achieved as well as thresholds that should not be exceeded. Therefore, indices can be used as a tool for management decisions.

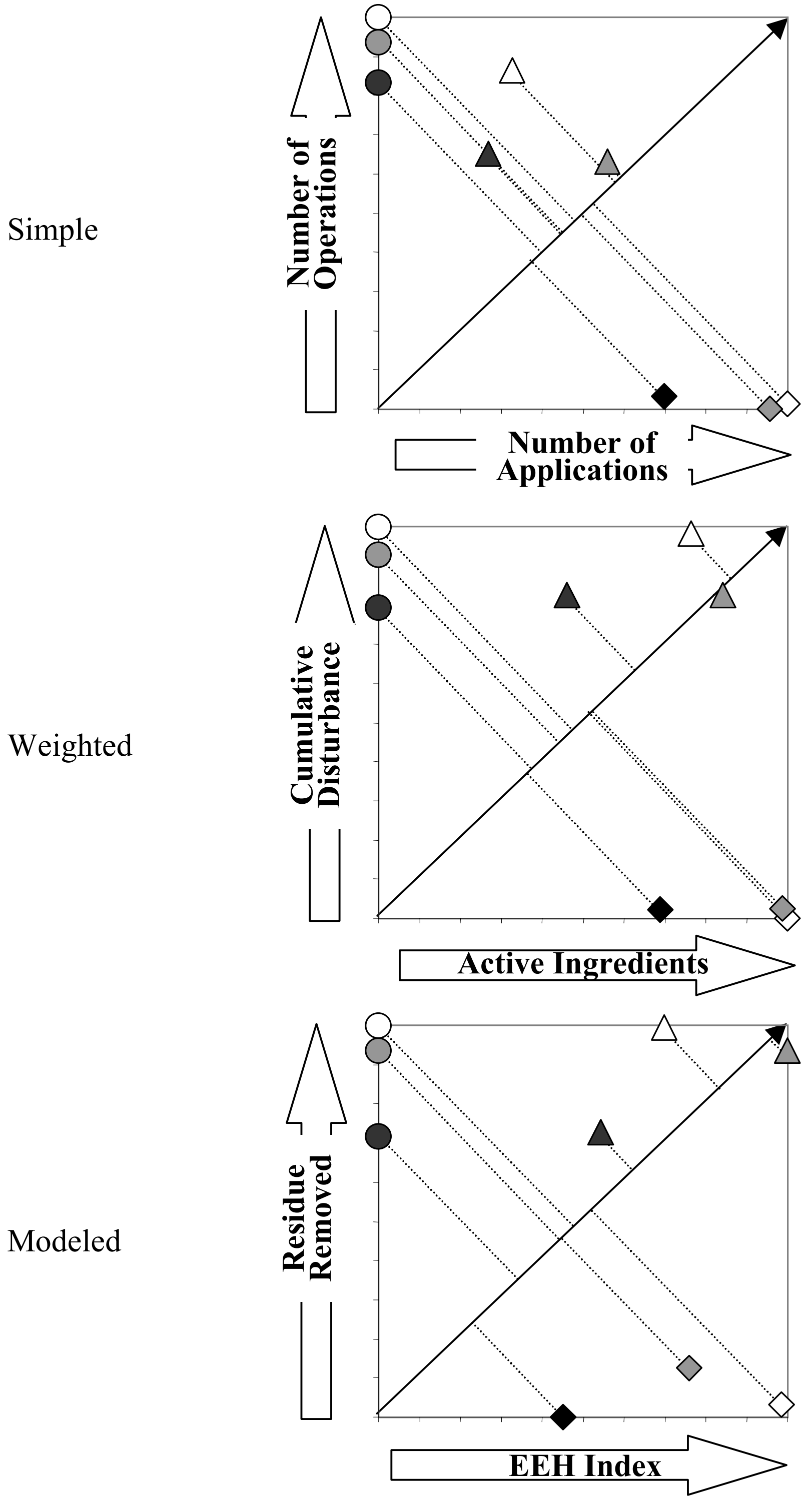

Figure 3. Combined tillage and herbicide indices. Values are scaled identically to Fig. 1 and Fig. 2 and the same symbols are used to identify systems. Ranking along arrow placed at 45^o indicates relative combined input levels.

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