INFERRING CROP STAND AGE AND LAND USE DURATION IN THE WILLAMETTE VALLEY FROM REMOTELY SENSED DATA

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Introduction

Ongoing work is being conducted to classify agricultural crops, urban development, and forests in the Willamette Valley through analysis of ground-truth surveys and aerial imagery from 2004 through 2011. The objective is to lay the basis for answering fundamental questions regarding how landscapes are currently managed and how management may evolve in the future.

Previous remote sensing classifications defined 57 land use categories, which included 19 classes of annually disturbed agricultural crops, 20 classes of established perennial crops, 13 classes of forests and other natural landscape elements, and 5 classes of urban development (Mueller-Warrant et al., 2011; Mueller-Warrant et al., under review). The approach was successful in separating these four broad groups of classes from each other at 90 to 95% accuracy. Accuracy in classifying the land use categories varied substantially among the classes and over time, approaching 100% in the best cases and averaging between 64 and 77%.

If classification data are sufficiently accurate, the timing and duration of specific land use sequences can be determined. For a few long-lived crops and most urban development and forests, the eight-year extent of our remotely sensed classifications was too short to determine duration of land use sequences or detect long-term changes. For most crops, however, the eight-year period should be sufficiently long to include establishment, multiple years of production, and transition to rotational crops.

Defining the duration of specific land use practices at a site by identifying beginning and ending years of that land use serves several objectives. First, the process acts as a quality control procedure that finds a valid sequence of crops/land uses or proves that some of the classifications were in error (e.g., established tall fescue in 2005, established orchardgrass in 2006, and established tall fescue in 2007 would not be a feasible cropping sequence). Second, delineation of the landscape into areas that were either disturbed in a given year (to grow an annual crop or to plant a new stand of a perennial crop) or retained in an established perennial crop or other permanent land use is a key input into programs such as the Soil and Water Assessment Tool (SWAT) (Mueller-Warrant et al., 2012). Third, identification of the specific crop rotation patterns and stand durations common to the Willamette Valley enables us to detect outliers where stand lives of crops were unusually long or short. Such cases can be considered for on-site visits with cooperating growers to obtain detailed histories of field management practices, collect soil samples, and measure pest populations (insects, slugs, weeds, foliar and soil-borne diseases) to better understand the roles these factors play in forcing stands out of production or preventing successful establishment of new stands.

Method

The 57 land use categories were regrouped into 50 new categories by merging several cases of similar land use. Three categories of Italian ryegrass (full straw, normal fall-plant, and volunteer pasture) were merged; two categories of bare ground (bare ground in fall not otherwise classified in spring and fallow in spring) were merged; three categories of evergreens (Christmas trees, reforestation, evergreen forest) were also merged; and three categories of urban development (mixed grass and buildings, developed open space, and developed low intensity) were combined.

The reclassified rasters (images and derived data stored in a gridlike format) were compared one year to the next to identify locations where the crops or land uses did not change. The year-to-year rasters were combined to determine locations classified as the same category for multiple years up through a given final year. Raster summaries were used to calculate apparent stand ages for each class. As an alternative approach for data sequences that included 2011 classification results, the restriction that the ends of stand lives had to be identified based on change in land use classification between the final year of a stand and the following year was eliminated. This approach produced minimum stand age estimates because it could not guarantee that the sequence of identical land use would not continue beyond 2011.

Results

Our first objective was to conduct quality control tests of our methods to determine whether our stand age distributions were reasonable or whether they implied the presence of systematic problems in the individual year classifications. The most immediate problem that classification errors would cause is shortening of the apparent stand life/age. The stand ages calculated in Tables 1 and 2 are the number of consecutive years in which a given location was classified as growing the same crop or having the same land use. Our methods for calculating stand age did not include the establishment year for perennial crops.

Problems from misclassifications (such as the sequence perennial ryegrass/Italian ryegrass/perennial ryegrass) were common in our results. For example, only 27% of the Italian ryegrass acreage was even assigned a stand age, indicating that at least some crops classified as Italian ryegrass in one year were sandwiched between other crops, a fairly unlikely situation given that Italian ryegrass is commonly produced on the same fields from year to year (Table 1). Another cause for failure to define Italian ryegrass stand age is that our methods required detection of the apparent end of the string of consecutive crops, and much of the Italian ryegrass acreage in any year simply continued on as Italian ryegrass in the next year (e.g., 77% did so from 2010 to 2011). Despite this limitation, the Italian ryegrass cropping sequences that were identified included approximately even numbers of stands of all ages up to seven years, the maximum we could characterize.

Many of the annual crops and new seedings of perennial crops behaved as expected, with over 90% of the cases identified as single-year events for spring plantings of new grass seed crops, peas, and mint (classes 3, 41); fall plantings of grass seed and legume crops (classes 13, 14, 15, 40, 43); bush beans (class 35); and *Brassica* seed crops (class 55). Small numbers of second-year crops of wheat and meadowfoam were detected, but most of the wheat and meadowfoam crops were grown as single-year-production annuals.

In general, estimated ages for established stands of perennial crops seemed to indicate that too many were identified as single-year stands. Correcting this problem will probably require incorporating knowledge of previous classification of a location as a long-lived crop (e.g., pasture, orchard, blueberries, or vineyard) into subsequent classifications. Removal of single-year occurrences of crops such as Italian ryegrass between multiple years of other established grass seed crops will also help improve our estimates of stand ages of perennial crops.

Relaxing our restriction that land uses had to change in 2011 relative to 2010 to signify the end of a sequence of identical crops/land uses corrected most of the problems of missing classes. Considering all the identical land use sequences ending in 2011, we found that stand age was defined in over 90% of the cases for all but one of the annual disturbed crops. Age was defined in over 99% of the cases for seven of the crops (Table 3). Similarly, stand ages were defined in over 86% of the cases for all but one of the established perennial crops. Again, age was defined in over 96% of the cases for seven of the crops (Table 4). Among grass seed crops, orchardgrass and fine fescue had the largest fractions of stands at least 8 years in age.

Conclusions

The raw individual year classification data clearly possess problems limiting their ability to accurately define true stand ages for many crops in western Oregon. One very critical issue is the challenge of determining when the end of a stand has been reached. Many of the sequences of identical crops extended through 2011, the final year for which remote sensing classifications have been conducted. We have ground-truth data and remote sensing imagery for additional years up through the impending 2014 harvest, and incorporating classifications from those additional years should help better identify the ending time for many additional multiyear stands.

A second critical issue is the presence of single-year classification errors interrupting what would otherwise be recognized as a single longer stand rather than two shorter stands. Systematic approaches for solving this problem should begin with correction of the most obvious errors (such as a single year of one established perennial crop interspersed between multiple years of a different perennial crop) and continue on into more subtle questions of whether a particular land use makes sense as something that could occur in the year immediately prior to an established perennial crop being present. Even though correcting the most clearly obvious single-year errors will not fix all classification errors, doing so will substantially improve the accuracy of stand age measurements in many cases. More robust handling of individual year classification errors might also be achieved through inclusion of prior-year land use data in the classification process itself.

Accurate identification of beginning, end, and duration of multiple-year crop stands was successful in a large number of cases and could be used to find stands of particular ages for further evaluation and research. It will be necessary to improve the accuracy of stand age measurements before the data can be used to identify outliers (unusually long or short stand lives) that will be of particular research interest in terms of possible causes of the departures from normal. It will also be necessary to bring the classifications closer to the present because reasons for shorter or longer stand lives may disappear when fields are subsequently rotated into other crops.

In addition to guiding future agronomic research into factors causing shortened stand lives and difficulties in establishing new grass seed stands, our results may also help policymakers develop improved land use rules, regulations, and incentives based on more complete scientific knowledge of the on- and off-farm impacts of contrasting land use practices (annual versus perennial crops, short- versus long-term rotations, diversity versus simplicity of rotational crops). Sustainability of agriculture cannot be achieved without an effective combination of research, regulation, assessment, and ongoing reconsideration of policies affecting prices of crops and inputs, rules regarding use of inputs, and effective extension of research knowledge to producers. It is our goal to provide valuable contributions to that process through deeper understanding of the reasons for successes and failures experienced by western Oregon grass seed growers.

References

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Table 1. Apparent stand age of 16 crops with annual disturbance.

		Apparent duration of repeated identical crops							
Class No.	Crop/Land use category	Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Total
		(% of total area classified in particular crop/land use)							
1	Bare ground in fall or true fallow	34.4	10.2	5.3	3.6	3.0	2.8	4.8	64.2
2	Full straw Italian ryegrass	9.0	3.8	2.3	2.6	2.9	2.6	4.3	27.6
3	Spring-plant new grass seed stands	92.3	3.3	0.0	0.0	0.0	0.0	0.0	95.7
13	Fall-plant perennial ryegrass	94.2	2.3	0.0	0.0	0.0	0.0	0.0	96.5
14	Fall-plant tall fescue	99.9	0.0	0.0	0.0	0.0	0.0	0.0	100.0
15	Fall-plant clover	92.8	3.0	0.0	0.0	0.0	0.0	0.0	95.8
16	Wheat and oats	58.5	8.8	3.1	0.3	0.1	0.1	0.1	71.1
17	Meadowfoam	72.6	10.1	1.1	0.3	0.0	0.0	0.0	84.2
27	Corn and sudangrass	71.0	3.2	0.1	0.0	0.0	0.0	0.0	74.2
35	Beans	90.1	3.0	0.2	0.1	0.0	0.0	0.0	93.3
36	Flowers	80.1	0.6	0.0	0.0	0.0	0.0	0.0	80.7
40	Other fall-plant/ no-till grass seed crops	99.7	0.0	0.0	0.0	0.0	0.0	0.0	99.7
41	Spring-plant peas or other unidentified	95.4	1.3	0.0	0.0	0.0	0.0	0.0	96.8
42	New planting hops, filberts, blueberries	87.9	2.5	0.0	0.0	0.0	0.0	0.0	90.4
43	New planting alfalfa or vetch	95.9	0.8	0.0	0.0	0.0	0.0	0.0	96.8
55	Brassicaceae	91.4	2.5	0.0	2.1	0.0	0.0	0.0	96.0

Table 2. Apparent stand age of 20 established perennial crops.

Class No.	Crop/Land use category	------------- Apparent age of established stands beyond the seeding year -------------							
		Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Total
		------------------ (% of total area classified in particular crop/land use) ----------------							
4	Established perennial ryegrass	27.4	14.8	8.4	4.4	2.8	2.4	2.3	62.6
5	Established orchardgrass	42.8	7.3	2.6	2.2	1.5	3.0	2.8	62.2
6	Established tall fescue	19.7	6.8	6.6	6.2	4.8	3.4	2.2	49.6
7	Pasture	33.8	10.1	3.5	1.7	1.9	2.0	1.0	53.9
8	Established clover	56.9	13.7	2.6	1.1	0.0	0.0	0.0	74.3
9	Established mint	35.1	12.5	19.2	11.7	2.3	0.0	0.0	80.9
10	Hay crop	46.3	10.6	3.6	2.3	1.3	1.2	1.1	66.4
18	Established bentgrass	56.8	8.7	4.3	2.4	4.6	3.1	0.0	79.9
19	Established fine fescue	29.6	5.7	3.5	4.2	3.1	4.9	4.6	55.5
21	Wild rice paddies	21.1	1.6	0.0	0.0	0.0	0.0	0.0	22.7
22	Wetlands restoration	62.7	3.9	0.8	0.0	0.0	0.2	0.0	67.6
23	Established alfalfa	78.8	4.4	0.1	0.6	0.2	0.1	1.8	86.0
24	Established blueberries	49.7	1.1	0.4	0.0	0.1	0.0	0.0	51.4
25	Filberts	50.8	8.2	2.5	0.9	0.4	0.8	2.7	66.3
26	Caneberry	54.0	10.8	2.3	0.6	0.3	0.6	0.4	69.1
28	Nursery crops	36.5	10.3	4.6	2.3	1.3	1.7	0.4	57.1
29	Orchard crops (apple, cherry)	47.3	3.6	0.8	0.2	0.8	0.2	0.0	52.7
32	Vineyard	53.1	9.5	4.3	1.7	2.3	2.4	1.5	74.8
38	Established hops	55.9	6.5	1.5	0.5	1.4	0.0	0.5	66.3
56	Strawberries	38.6	5.3	14.5	9.5	0.0	0.0	0.0	67.9

Table 3. Minimum apparent stand age from 2011 data only of 16 crops with annual disturbance.

Class No.	Crop/Land use category	--------------------- Apparent duration of repeated identical crops ---------------------								
		Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Eight years	Total
		----------------- (% of total area classified in particular crop/land use) -----------------								
1	Bare ground in fall or true fallow	62.8	17.6	2.7	4.0	1.3	1.4	0.5	7.0	97.3
2	Full straw Italian ryegrass	34.5	9.8	3.5	2.1	2.8	3.6	1.1	42.1	99.5
3	Spring-plant new grass seed stands	97.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	99.0
13	Fall-plant perennial ryegrass	96.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	97.9
14	Fall-plant tall fescue	95.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.5
15	Fall-plant clover	97.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	99.3
16	Wheat and oats	70.2	19.7	4.4	2.6	0.6	0.0	0.0	0.6	98.1
17	Meadowfoam	93.3	6.2	0.0	0.0	0.0	0.0	0.0	0.0	99.5
27	Corn and sudangrass	69.0	18.1	12.1	0.0	0.3	0.0	0.0	0.0	99.6
35	Beans	95.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.2
36	Flowers	65.8	16.6	0.3	0.0	0.0	0.0	0.0	0.0	82.7
40	Other fall-plant/no-till grass seed crops	99.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	99.6
41	Spring-plant peas or other unidentified	91.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	92.0
42	New planting hops, filberts, blueberries	94.9	3.1	0.0	0.0	0.0	0.0	0.0	0.0	97.9
43	New planting alfalfa or vetch	96.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	97.4
55	Brassicaceae	99.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.7

Table 4. Minimum apparent stand age from 2011 data only of 20 established perennial crops.

Class No.	Crop/Land use category	Apparent duration of repeated identical crops: Single year	Two years	Three years	Four years	Five years	Six years	Seven years	Eight years	Total
		(% of total area classified in particular crop/land use)								
4	Established perennial ryegrass	54.4	25.3	6.5	3.7	2.0	1.2	0.5	5.2	98.9
5	Established orchardgrass	65.6	5.2	8.9	2.6	1.1	0.3	0.4	14.8	98.9
6	Established tall fescue	22.7	46.2	9.9	8.5	5.4	2.1	0.4	4.2	99.3
7	Pasture	57.1	5.1	1.3	10.0	4.4	1.6	3.5	5.2	88.2
8	Established clover	79.2	16.2	3.2	0.6	0.0	0.0	0.0	0.0	99.3
9	Established mint	69.5	13.0	10.7	3.5	0.0	0.0	0.0	2.4	99.1
10	Hay crop	62.7	12.3	7.7	1.6	1.3	0.9	0.4	2.1	88.9
18	Established bentgrass	80.7	4.7	3.8	2.4	0.0	0.0	0.0	5.1	96.7
19	Established fine fescue	45.1	12.8	9.1	4.6	4.7	3.3	0.0	13.8	93.4
21	Wild rice paddies	32.2	49.1	6.9	2.0	2.9	1.1	0.0	0.6	94.8
22	Wetlands restoration	29.6	33.2	4.4	27.3	0.0	0.0	0.0	0.0	94.4
23	Established alfalfa	86.0	5.0	0.9	0.0	0.0	0.0	0.0	0.0	91.9
24	Established blueberries	77.9	11.5	2.5	0.7	0.2	0.9	0.0	1.2	94.9
25	Filberts	58.7	6.1	7.8	5.6	0.3	3.4	0.3	5.9	88.1
26	Caneberry	76.6	3.8	3.1	1.3	0.2	0.6	0.0	1.0	86.7
28	Nursery crops	64.4	8.0	5.4	4.7	1.1	1.2	0.8	7.4	93.0
29	Orchard crops (apple, cherry)	63.4	4.0	0.2	0.2	0.1	0.0	0.0	0.0	67.9
32	Vineyard	56.7	9.1	5.4	8.4	1.1	0.7	0.5	9.7	91.5
38	Established hops	66.2	14.1	3.7	0.7	0.0	0.0	0.0	4.2	89.0
56	Strawberries	93.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	97.2