STATE OF WEED EMERGENCE PREDICTIONS

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Introduction

There are two general strategies used in formulating weed management plans that can be characterized by sports analogy as either a "zone" or "man-to-man" defenses. The zone defense is designed to handle many different types of offense and is robust to the hazard of getting tricked into a misallocation of resources. The primary factor responsible for the choice is not effectiveness of the strategy in general, for one cannot dispute the logic that if every "man" is covered, then scoring will be difficult or impossible. The primary impediments to tailoring solutions to particular problems are: (1) time and labor costs associated with determining appropriate solutions, i.e. the solutions are too complex, and (2) uncertainties about the current state or process, e.g. we may not know which weed species are present, whether we have resistant genotypes, or when a species is vulnerable to control tactics.

Despite the appeal of the simplicity of a "zone" defense, there are many good reasons to advocate moving beyond this approach. First and foremost, this strategy is wasteful of resources; resources that have both economic value and broader social impact. The second undesirable consequence of a "zone" defense is that weed communities will learn how to outplay any particular strategy we confront them with. We can think about this as a sort of evolutionary Newton's third law: for every (weed control) action, there is an equal and opposite (weed community) reaction. In this way weeds are very different from typical sports opponents.

Given the existence of incentives to develop more situation-specific weed management plans, what can researchers contribute to these efforts?

- **SIMPLICITY**. The first contribution researchers can make is in simplifying, in as much as possible, the assignment of solutions to specific situations. Information technologies make this problem almost non-existent.
- **INFORMATION REQUIREMENTS.** The second task faced by researchers to determine sufficiently accurate, practical and cost-effective means to determine the current state of a system. How do we know what weeds are there? How do we know when they will emerge? Technologies can potentially help to solve both of these problems as well.
- **SYSTEM DYNAMICS.** The third and most difficult task faced by researchers is to understand our agricultural systems well enough to be able to assess the relative advantages and disadvantages of different tactics in specific situations.

Understanding weed emergence is vitally important to both monitoring and our understanding of system dynamics.

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Current State of Knowledge

The oldest embodiment of knowledge about when weeds emerge is experienced-based. By keeping mental note or written records, one can establish the usual time of a weed's yearly emergence and perhaps a range within which year-to-year deviation tend to occur. When enough information is compiled about a weed in an area, a timeline can be constructed. Using Dr. Jerry Doll's extensive data set from the Arlington Research Station's weed garden, I have developed such a timeline, wrapped in a circle like a speedometer.

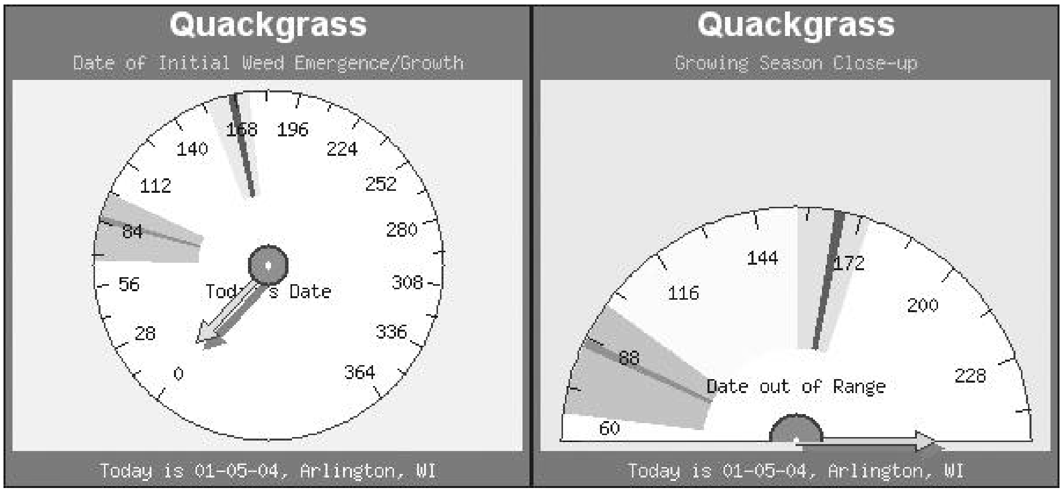

Figure 1: Graphical presentation of historic first emergence times of Quackgrass at the Arlington weed garden. Date is by day-of-year, the first bands represent the range and average first emergence times, the second bands represent the range and average first-flower dates. Over 80 species can be seen at http://weedecology.wisc.edu/weedgarden.

Although the historical approach can provide information on the typical emergence order of weeds, it would be extraordinarily useful to know more about when they will show up in any given year. One way to do this is to attempt to correlate the event with other biological growth-related events occurring earlier in the year. The earlier events can serve and indicators of the relative earliness or lateness of the biological season in that particular year. While some research has been done into 'biotechnological' indicators, no decision aid applications currently exist.

As with crops we know the major factors influencing early growth, and to some extent, germination of weeds. It stands to reason that we might therefore be able to predict germination, emergence and early growth from information about the soil and weather. Unfortunately, charting the physiological development of weeds is substantially more difficult than it is for crops. For one, germination timing is incredibly important to the survival and reproductive potential of weeds. The frequent massive mortality suffered to management has reinforced the importance of maintaining variability in germination timing. The consequence is that there is a great deal of randomness associated with how weeds of the same species respond to identical environments.

In addition to variation in the effect of a weather signal on weed seed behavior, there is also a great deal of variation due to positioning in the soil. While crop seeds tend to be large and are planted at a relatively uniform depth, weed seeds vary in size and in placement within the soil. Some seeds sit on surface while others hibernate beneath the plow layer. Some seeds are encased in clays or aggregates while others loosely contact sand grains. All of these differences relating to burial and soil contact affect the environmental signal to which the seed is exposed. In summary, there are both internal and external sources of variability in the response of seeds to the primary weather signal.

Needless to say, knowing the positions of seeds in the soil is impossible in practice. However, we can proceed as if the weed emergence and growth were as regular as a crop and attempt to determine how exogenous influences, such as the weather, alter emergence timing. Growth models of this sort fall into one of an increasingly complex series of categories:

1. **Temperature accumulator.** As with crops and insects, many physiological processes within seeds operate at rates roughly proportional to temperatures above a physiological minimum. If we keep track of the temperature, we can attempt to describe the number of growing-degree-days necessary for emergence.

2. **Moisture-threshold regulated temperature accumulator**. Larger organisms can often buffer local water supply variation with extensive root systems or larger surface contact areas. Weed seeds often have very little moisture buffering capacity, particularly when they reside at or near the soil surface. The moisture threshold models will shut off the accumulation of temperate units when the moisture availability falls below a certain level. A current example of such a model is the USDA ARS model WeedCast. Figure 2 show an example output from the web version of this model.

3. **Hydro-thermal time accumulator**. Some researchers have treated moisture in a manner similar to temperature where, above a minimum base moisture potential, the rate of progress is proportional to the deviation above the minimum. While undoubtedly rates are moisture dependent, in practice it is more difficult to describe both the signal and the response-model for this type of driver. The difficulty has impeded the development of any useable application.

4. **Gas-limited hydro-thermal time accumulator**. Other than moisture and temperature, variations in gas concentrations, particularly oxygen and carbon dioxide, have been shown to strongly affect germination of many weed seeds. There is currently research in progress to explore the possibility of forecasting germination response to gas-limiting situations. In particular this mechanism is designed to cope with moisture situations that become limiting due to excess moisture, where hydro-time models would become extremely inaccurate.

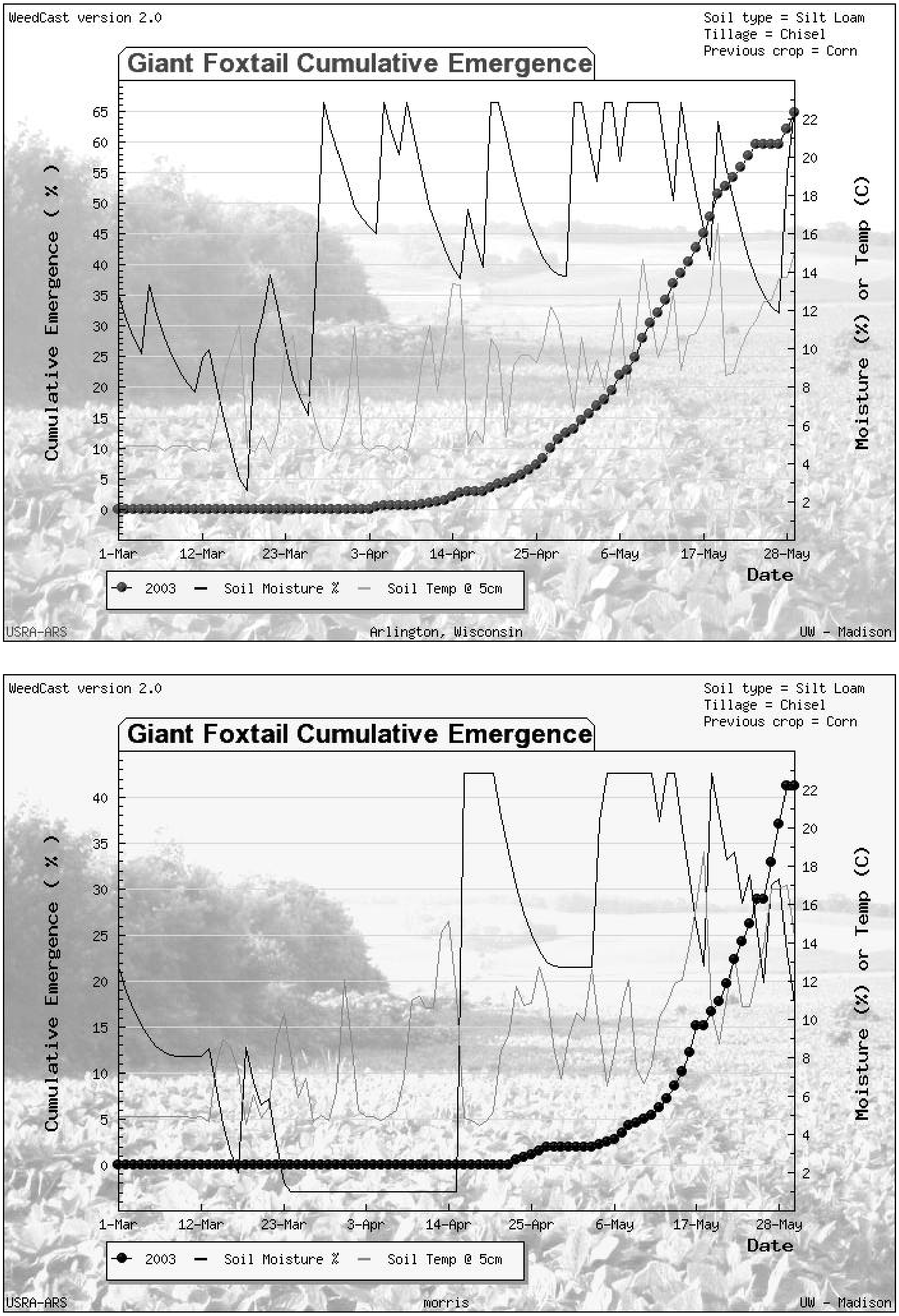

Figure 2. Weedcast on the Web, 2003 data from Arlington, WI (top) and Morris, MN (bottom). Soil moisture or temperature can be shown simulataneously on each plot. Real-time tool available at: http://weedecology.us/weedcast/.

Conclusions

Of the impediments to moving to more resource-efficient weed control programs, model complexity and information requirements will probably be solved by increasingly inexpensive information technologies. The technologies will be able to mask the complexity of any model and will, eventually, present the user with any level of apparent complexity that they desire.

The major limitations to developing robust applications are uncertainty in state of the system and uncertainty in biological processes. Uncertainty in state results from the high cost of knowing what seeds are present and where they are present in the soil profile. Also uncertain is the intrinsic responsiveness of a seed and the fine-grained environment that drives the responsiveness. Uncertainty in process arises because every model is necessarily a simplification of reality and many times that simplification may be overdone. Although we know that thermal-time or hydro-thermal-time model describe important drivers of progress toward germination or growth, many other sources are also known to affect early life processes in weeds. For example, variations in nitrate concentrations and background pH can influence the performance of accumulator models.