Weed competition and interference in cropping systems

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Summary

Although we have accumulated a considerable volume of data on weed-crop competition, it has so far had less influence on the practice of weed control than anticipated. More attention needs to be given to species comparisons, multispecies losses, effects of crops on weeds and variability of yield loss between sites and years. Critical period studies have had little effect on our understanding of competition; instead, future research is needed in the area of comparative temporal development of weeds and crops. A better understanding of the topic should lead to more efficient and thus environmentally sensitive weed control.

Introduction

Over the last 30 years, we have accumulated a considerable volume of literature on the interaction between weeds and crops. Zimdahl (15) summarized a considerable amount of this, and since his review the proliferation of studies has continued. Why so many studies? Papers on weed-crop interference are usually justified by (a) the need to measure how much yield loss a given species causes on a given crop (though it is seldom stated explicitly why the data are needed), (b) the need to calculate economic (or other) thresholds (though the thresholds are often not calculated in the papers), (c) the information being useful for improving the efficiency of weed control (again, in unspecified ways), or (d) the need to know the effects of various factors on weed-crop interference. Perhaps we might categorize the studies more simply into those which aim to develop understanding of the nature of particular weed-crop interactions, and those which seek to generate useful data.

As long ago as 1934, Pavlychenko and Harrington (9) stated that: "Competition between weeds and crop plants presents a useful field of research which, if carried out in great detail, should be of considerable practical significance". As a result of all the research since that date, how useful has it actually been: how far has our understanding developed, and has it been of practical significance? These questions will be the focus of this paper.

Processes involved in interference

It has been appreciated for some time that when two plants interact, there are a number of processes which may occur. They may lead to one, both or neither plant benefiting or suffering as a result. The possible processes include competition, allelopathy, parasitism and commensalism (10). Competition is strictly defined as the capture of limited resources by one individual at the expense of another. It was probably the first interference process postulated, and as a result the term "competition" is often used synonymously as "interference" (without any assumption of processes involved).

When doing an experiment on a mixture of species, however, we can never be sure from measurements of plant size alone what the underlying processes are. We cannot tell categorically whether a given case is mainly competition, mainly allelopathy, or some combination of these and other processes. Because of this, the use of the term "interference" is becoming more popular.

Of those authors using the term competition to refer to interference in general, a proportion probably do so because they feel that the competitive process is dominant. It is, for example, easy to show that nutrients, water or light are limited in a particular case, by adding more of them. To such people, competition is (in statistical terms) the null hypothesis to be disproved, to be assumed until someone can prove otherwise. This attitude has resulted in a conflict with the passionate believers in allelopathy, who have found that leachates from many plants are capable of suppressing the germination or growth of other plants. They believe that allelopathy is important, perhaps even dominant: why should they have to prove their case when the same is not demanded of the competition-assumers? The problem is that there is not yet a technique for separating out the relative effects of the two processes *in situ*. Until then, we can only guess at which are acting, and continue to measure their combined effects reflected in plant weights. In which case, the term interference should be used more widely.

There has been a certain amount of work done to determine how much interference is above-ground (competition for light) and how much takes place below ground (most other processes). Experiments using partitions in boxes have been used to keep roots and/or shoots from interacting. Snaydon (11) has pointed out that most such studies show below-ground interference to be more important than above-ground. However, partitions restrict growth, in addition to preventing interference, and alter other aspects of the environment. As a result, many researchers will remain dubious of Snaydon's generalization. Again, since there is no way that we can separate out above- and below-ground components *in situ*, arguments will remain unresolved. Since the availability of different resources varies during the year, as do leaf canopy and root development, we would expect the relative importance of above- and below-ground interference to change during the course of growth. We would also expect above and below ground processes to interact.

Effects of Interference on Crop Yield

Single species of weed

For whatever reasons, a question asked repeatedly is "how much yield reduction does a given density of a weed cause?". This has resulted in many experiments using the additive design (a fixed crop density and a range of increasing densities of a weed) for different species of weeds in different crops. A comprehensive review of data (2) has shown that when yields are plotted against weed density, the resulting curve falls steeply at first and curves asymptotically towards the density axis. This is well described by an exponential or hyperbolic equation. Dew (6) was one of the first to recognize the shape of the curve, in fitting a square root model to data from additive designs. Many studies have shown that at low densities the curve approximates to a straight line, intersecting with the yield axis at the "weed-free yield".

At the same time, it has been argued by many that (a) a few weeds in a large field cannot possibly reduce yield, (b) at some density yields must start to be affected, and (c) yield loss cannot exceed 100%. Hence, the relationship between yield and weed density must be sigmoidal; figures depicting this have appeared in several text books. The sigmoidal model is "supported" by statistical analyses of data. A high proportion of interference experiments have been presented as tables of means, with letters indicating results of a multiple comparison test.

The apparent contradiction between graphical appearance and multiple range tests is easily explained by the common misconception that "non-significant" in a comparison of two means proves no difference between them (3). The point at which yield differences become large enough to be conclusively confirmed is not the same as a point at which differences begin. Statisticians have repeatedly published papers reiterating that multiple comparison tests, such as Duncan's or the LSD, should not be used to interpret response curves. The appropriate approach is graphical presentation combined with regression.

Despite the mounting evidence that yield-density curves are seldom, if ever, sigmoidal, statements that there is a point below which weeds do not affect yield are still frequent. Proponents "know" that this must be the case (even some who are happy to fit non-sigmoidal lines to their data). One explanation of this may be confusion between a "biological threshold" and the "economic threshold", above which yields are great enough to warrant weed control. However, although our philosophical basis for weed control decision making may have been flawed, little damage has probably been done to weed science, but has loss of income by farmers resulted from it? Some recent economic models have been based on a sigmoidal loss function, and predictions from these models may be sensitive to this assumption (D. Pannell, personal communication). Future modelling should surely be based on relationships shown by the data, rather than those assumed by folklore. To avoid similar misinterpretations for other response curves, we need better statistical education on the analysis of response curves, more relevant techniques such as non-linear regression (rather than just polynomial regression), less reliance on tables of means, less emphasis on hypothesis-testing and multiple range tests, and more attention to the philosophical understanding of statistics.

Despite the volume of work on density responses, we have catalogued only a small range of species in a small number of major crops. There have been few comparative studies of different species or different crops (though see 14). Hence, for many weeds in many crops we still have no reliable data on yield losses.

We also know that weed density effects can change considerably with crop density, crop variety, relative time of emergence of weed and crop, fertilizer use, etc. etc.. Again, there have been few studies of these. As a result, predictions of the loss caused by a single species in a crop are very imprecise and we should expect considerable inaccuracies if we try to predict from one (or more) experiments to a particular field in a particular year. How reliable would such predictions be? Far more studies are needed of the variability in yield-density curves.

Multiple species of weeds

Few fields have a single weed in them, and most spray decisions for farmers concern more than one weed. There have been few attempts to study the effects of mixtures of weeds on crop yield. A few studies have looked at mixtures of two or three weeds, but mixtures of more species have not been studied in a systematic way.

In developing realistic spray decision support models, a number of multispecies yield models have been developed:

$$\%\,y_L = 0.5\,\Sigma c_i\,D_i \qquad \text{Coble (1)}$$

$$\%\,y_L = a + \Sigma c_i \log D_i \qquad \text{Keisling \textit{et al.} (7)}$$

$$\%\,y_L = \frac{100\,\Sigma c_i\,D_i}{(C + \Sigma c_i\,D_i)} \qquad \text{Wilson (13)}$$

$$y = \frac{aC}{(1 + b\,(C + \Sigma c_i\,D_i))} \qquad \text{Spitters (12)}$$

where **C** is crop density, $\mathbf{D}_i$ is density of weed species ***i***, $\mathbf{c}_i$ is a measure of the effect of species ***i*** on the crop variously called the "crop equivalent" or "competitive index". Most of these models have been assigned parameter values on the basis of single species competition studies. For example, Coble's model treats all species as additive (low weed densities), and it is therefore a simple matter to combine species effects. For some species, no measures of yield loss may be available and parameter values may be derived in other ways. Wilson (13) assumed that the weight of a weed plant in relation to weed-free crop plant weight gave an estimate of competitive ability. Weeds may also be classified into groups of similar perceived competitiveness (such as "grasses") and given the same parameter value.

Of the models so far proposed, Spitters (12) model appears to best describe yields when only one weed species is present. Keisling *et al.*'s (7) model has difficulties arising at low weed densities (log 0 cannot be calculated). Although some of these models are being used for decision support systems, only one of them (13) appears to have been thoroughly tested on multispecies yield loss data. Wilson's (13) model, when applied to multi-site data, gave poor accuracy and left considerable unexplained variance. There has been a vast number of experiments on weed control of multispecies communities. Published reports of these do not usually give densities of the component weeds. Testing of models on such experiments, if available, may be worthwhile. However, the data are confounded by the use of herbicides and we cannot be sure that there have been no phytotoxic effects on the crops or on the surviving weeds. Far more work is required on multispecies competition before we can accurately predict losses on the field.

Time of weed removal

A popular experimental design has been that used to determine the "critical period" for weed removal (8). In one set of treatments, plots are allowed to be weedy for different lengths of time and then kept weed-free until harvest. In another set of treatments, plots are kept weed-free for various periods and then left to become weedy until harvest. If yield is plotted against duration left weedy and duration weed-free, the result is two intersecting curves which reveal the period when crop yield is most sensitive to weed presence and during which weeds should be kept out.

It has been a widespread belief that the critical period should help to make timing of weed control more efficient. However, there are few cases where this has occurred. Most studies of critical periods ignore the economics of control and the "windows" available for crop safety and efficacy of the herbicides available. Unless hand-weeding using cheap labour is to be used, critical period studies will produce little more than a simple range of optimum times of application for particular chemicals. Although such data are worthwhile and can help us to use chemicals more effectively, the current application of the critical period per se is limited. Knowledge of the effects of application time will be of little use in situations where the available chemicals are restricted to a narrow range of growth stages by manufactures recommendations.

The critical period experiments draw at least some attention to the temporal development of competition, though only final yields are measured. If we are to understand why some crops, some varieties and some weeds are more competitive than others, we need more work on how competition develops through time, especially in relation to crop phenological development.

Effects of interference on weed seed production

Traditionally, attention has been given to crop yield. The main reason agronomists have studied weeds has been learn how best to kill them, to maximize yields or profits. In more recent times, there has been a greater awareness of weed population dynamics. If we are to predict changes in weed density from year to year, we need to predict, amongst other things, weed seed production. The same factors affecting crop yield are likely to affect weed seed yield. To date, however, there have been a relatively small number of case studies of seed production by single weeds, and few comparisons since E.J. Salisbury's classic works.

Practical applications

It is difficult to see many areas in which interference studies have impinged on farming practices. Multispecies models are being incorporated into computer packages to help farmers decide whether or not to spray and with what to spray (5). Several packages are based on the concept of an economic threshold. Densities of different weeds are entered and an estimate of yield is calculated. The estimated costs and benefits of spraying are then compared. To do this, assumptions must be made about the weed control achieved for each species. Since few quantitative data on herbicide efficacy to multispecies weed communities are published, (most are held in confidence by herbicide companies) considerable guesses must be made. When considered alongside the guesses which are made of many interference parameters, the confidence in the cost/benefit analysis must be low. Are such packages, therefore, to be trusted? In Germany (B. Gerowitt, personal communication), it has been found that the frequency of false decisions (i.e., the qualitative predictive ability) is quite low in practise. The decision packages are constantly being updated in light of new information. For example, a German system now includes crop and weed growth stages and relative weed and crop cover values. They will certainly improve; however, more attention is required for their validation using on-farm data. At present, thresholds are being used in very few countries, and by few farmers even within those.

For a number of reasons, average loss in yield in the current year is not the only thing which goes into a farmer's decision on whether or not to spray. Weed seed production, leading to future problems, is considered to be important. We should, therefore, be linking interference studies with research on long-term population dynamics (e.g., (4)). Also, farmers are as much risk-averters as they are profit-maximizers. Our predictive models to date are deterministic, giving a single figure without confidence intervals. We need to know more about year to year variability: what is the risk (probability) of a given level of loss?

Conclusions

There can be little doubt that, to date, interference research has had less influence on farming practice than they should. Have we therefore wasted our time and money? Our scientific understanding has become more extensive, though knowledge would be extended much faster if there was less emphasis on simply generating case study data on crop yields and more emphasis on growth studies of weed and crop. More work is needed on causes of variability (site to site and year to year) in yield loss – weed density curves, on multispecies interference, on factors other than density (timing of emergence, crop variety, etc.), and on comparisons of species. No space was available here to review weed-crop growth models, which are becoming more common and more sophisticated. However, more attention needs to be given to the testing of such models in a range of environments, and in general a closer interplay between experimental studies and modelling.

Will interference studies have direct practical applications? Perhaps, as we place more emphasis on reduction of herbicide usage. One immediate application can come from comparative studies of crop varieties, so that farmers can choose those varieties which give greatest suppression of weeds. We already know that we can obtain large differences in yield losses between varieties; we now need to generate advice on this in the same way that we distribute advice on potential (weed free) yields and disease resistance. Even if few practical applications ensue, there is still a powerful esoteric argument that we should understand what it is that we are trying so hard to kill. If we understand how to minimize interference, we can perhaps, as a result, reduce our requirements for weed control.

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