Economics of weed control in broad-acre crops

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There are many ways in which weeds cause economic losses in broad-acre crops. Weed competition resulting in loss of biological yield is the most obvious one, but harvesting difficulties, contaminated produce and increased incidence of disease have all contributed from time to time. In this paper I shall be concerned with weed competition because it is the most important aspect in broad-acre crops and one that has proved difficult to quantify. Before I begin though, the presence of particular weed seeds in imported grain is of major concern to some recipient countries and so, in all cases where zero tolerance limits apply, weed control is necessary regardless of the competitive effect. The same can be said for controlling weeds which interfere with harvesting, but, fortunately, there are few species in this category. For example, in wheat there are *Chondrilla juncea* (but only in the higher rainfall areas), *Polygonum patulum, Polygonum convolvulus* and *Brassica tournifortii*; and in soyabean, *Amaranthus hybridus* (Nave and Wax, 1971).

It is stating the obvious to say that crop yield is determined by many factors such as available moisture, soil fertility, length of growing period and so on, but weed competition affects crop yield by interacting with all these factors. Therefore, the selection of appropriate weed control measures should be considered an integral part of growing the crop and it is one of the most significant management decisions a grower has to make. But how much information has he on which to base that decision? A search of the Australian literature reveals very little data which allows quantitative relationships between crop yield and weed density to be derived (wheat was the only crop). Research overseas has dealt with wheat, maize, sorghum and soyabean, but it is difficult to compare the results because different methods of crop loss assessment have been used. I should like to briefly review these methods and discuss the several relationships which have been derived.

COMPARISON OF METHODS

There are two main approaches to investigations of this nature. Naturally occurring weed infestations can be selected if the crop and site satisfy the experimental conditions required. Alternatively, the seed of a particular weed might be collected and artificial infestations established at the time of sowing the crop. Weed seed collected during the previous season or seasons will most likely have a different germination pattern to that occurring naturally in the field because it will have been exposed to different temperatures and humidity during storage. However, this need not be of concern provided that, in the experiment, the weeds emerge at the same time with respect to the crop as naturally occurring infestations. There are many examples of weed competition having been either increased or decreased by allowing the weeds to emerge either before of after the crop (Nelson and Nylund, 1962; Knake and Slife, 1965).

Where natural infestations have been used, competition can be measured by either sampling quadrats over the whole field or an experiment can be conducted on a small area within the field. Wiese (1965) selected square meter quadrats of weedy and weed-free crop within a number of 15 m diameter circles. Crop yields from the weedy quadrats were expressed as a percentage of the weed-free quadrat and over 3 years the average yield loss was 8% for every 10 weed plants (*Descurainia pinnata*) per m^2. To be successful, this method depends on exceptionally uniform soil type and fertility throughout the field and there must be no interaction between weed density and any soil factor which might influence the relationship.

To overcome some of these deficiencies, a number of paired quadrats can be selected within a field and the weeds removed completely from one quadrat of each pair. Crop yield is again expressed as a percentage of the weed-free quadrat. Gilbey (1974) used this method to study the competition of *Emex australis* in wheat and found a linear relationship between percent yield reduction and weed density. The use of regression analysis in studies of this nature allow interpolation of the data and a much wider application than would be possible with an analysis of variance of individual treatments.

One of the most successful methods of establishing crop yield-weed density relationships is by selecting a small area of uniform crop heavily infested with a particular weed and thinning plots to the required density. In this way, variability within the experiment is likely to be low and crop yield more dependent on weed density than other factors, such as soil type and fertility. Furthermore, extra treatments can be included to study the mechanism of competition involved. Weed infestations can be thinned by hand using scissors, hoeing, hand pulling or herbicides applied with a brush or, alternatively, selective herbicides might be used in various ways. For example, Hammerton (1964) applied different rates of herbicide to weed-infested kale which resulted in a range of weed densities under the crop. It would appear, though, that the growth of the surviving weeds might be affected to some extent by the herbicide and competition towards the crop might be decreased. Despite this, however, he was able to derive a significant curvi-linear relationship accounting for 72% of the variation.

In 1970, I developed a thinning spray boom at Horsham which applies herbicides in narrow bands (4 cm wide) at any given spacing through the crop. Weed density of each plot is determined by the area not sprayed between these bands and so a wide range of densities can be achieved with minimum disturbance to both crop and remaining weeds. It is assumed that the bands of weeds will have a similar competitive effect on the wheat crop as a randomly distributed population of the same density and in practice this seems to be so. Linear or curvi-linear functions are fitted to the data from these experiments and the results will be discussed later in this paper.

Artificially established weed infestations have been used in many experiments. In some, the weed species is sown at the required densities (e.g. Reeves, 1976) while in others, the weed seed is broadcast over the whole site either before or after sowing the crop and the different densities are obtained by hand thinning after emergence (e.g. Moolani et al, 1964). Data can be analysed by an analysis of variance but, when a range of population densities is available, regression analysis is preferred.

ECONOMICS OF WEED CONTROL

Although weeds in some crops can be controlled by well-timed cultivations before sowing and inter-row cultivations after sowing, weed control in the majority of crops requires some form of herbicide treatment. Calculating the economics of such an operation is similar for all crops. In economic terms, spraying for weed control is a variable cost and its relation to crop yield is calculated using the following formula:

cost of herbicide + cost of application + return on capital invested = minimum value of increased crop yield.

The economics of spraying for weed control will therefore change with fluctuations in the cost of herbicides and the price obtained for the crop. The essential point, of course, is knowing whether the yield of the crop will be increased sufficiently to reach this minimum value and this is why the crop yield-weed density relationships are so important. The minimum value is converted to actual crop yield which is then subtracted from the potential weed-free yield. The critical weed density, above which spraying is economical, is then read from the graph as shown in Figure 1.

In this experiment (Figure 1), the curves fitted to data from individual years were very similar even though the weed-free yields varied from 1.6 to 4.6 t/ha. This indicates that, for this weed and this crop, the absolute level of weed competition does not vary greatly from year to year or from one paddock to another and so the critical weed density (18 plants/m^2) could be used as a reliable guide for spraying. Similar relationships hold for other broad-leaved weeds competing with wheat.

Several workers have expressed their crop loss equations in terms of percentage rather than absolute units (Gilbey, 1974; Reeves, 1976). Unfortunately, when using their equations to determine the economics of spraying, an estimate of crop yield in the absence of weed competition is necessary and this is very difficult to determine in most of the Australian wheatbelt. Where weed competition is highly dependent on crop yield, it might be possible to determine which factors are responsible and include them in the yield loss equation. For example, if the level of soil fertility was shown to affect the relationship, it would be quite simple to measure this at the appropriate time and the critical weed density could still be predicted.

CURRENT SITUATION

Wheat - Several Australian workers have assessed weed competition in wheat crops. The main weed studied was *Lolium rigidum*. Using data from Smith and Levick (1974), Reeves (1976) and my own, critical weed densities were calculated for both pre- and post-emergence herbicides. Assuming that the pre-emergence herbicide trifluralin costs \$5/ℓ/ha applied and wheat is valued at \$100/t and 50% return on capital invested is required, the critical weed density for *L. rigidum* varies from 20 to 75 plants/m^2. If the more expensive post-emergence herbicide diclofop methyl, costing \$18/ℓ/ha, is used, the critical weed density varies from 90 to 390 plants/m^2. The high densities in each case were associated with very low yielding crops in drought years and hence in more normal seasons the range would not be so great.

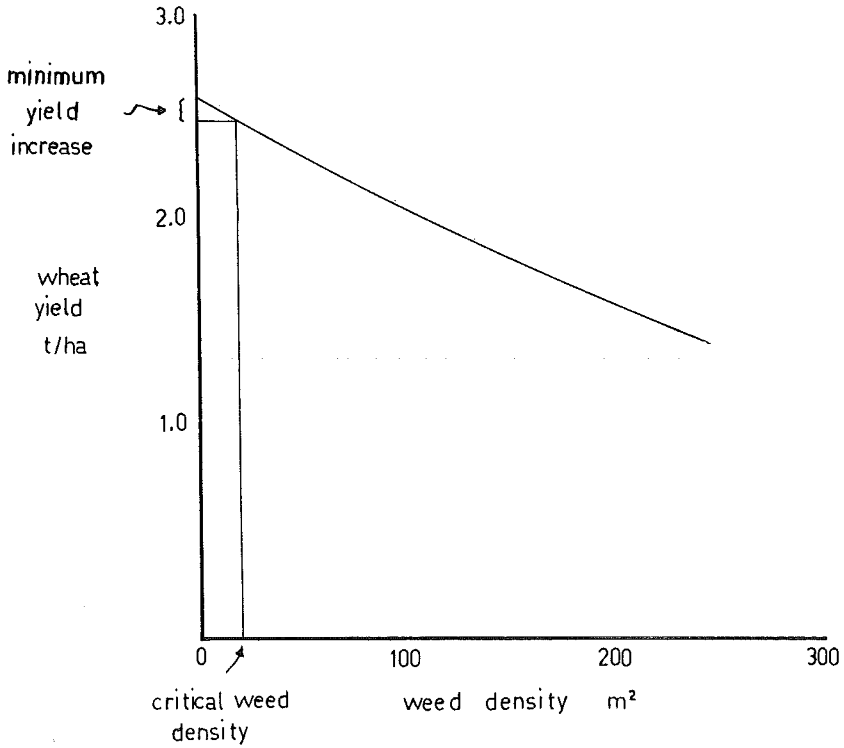

Figure 1. Relationship between wheat yield and weed density.

Other weeds in wheat for which data are available are *Emex australis* (Gilbey, 1974), *Polygonum convolvulus* (Messersmith, 1970), *Amsinckia hispida, Fumaria parviflora, Lamium amplexicaule* and *Lithospermum arvense* (Wells, unpublished) and *Avena fatua* (Dew, 1972) (Table 1).

Table 1. Data on weeds occurring in wheat

Weed sp.	Weed control		Weed-free yield of crop t/ha	Suggested critical weed density/m^2
	Herbicide	Variable cost $		
E. australis	Tribunil	5.00	1.4	12
P. convolvulus	Bromoxynil + MCPA	10.00	1.6	158
A. hispida	Igran	6.50	1.7 - 4.0	18
F. parviflora	Igran	6.50	1.5 - 5.5	20
L. amplexicaule	Igran	6.50	1.6 - 4.4	72
L. arvense	Igran	6.50	0.8 - 3.4	14
A. fatua	Avadex	8.00	2.0	4

Competition from perennial weeds in wheat is more difficult to assess than that from annuals because one is not sure what soil resources the weed has used prior to sowing the crop. For example, in Victoria, the control of *Chondrilla juncea* in the actual wheat crop increased grain yield only once in 8 years and it was concluded that the main effect of the weed was to reduce soil moisture and nitrogen during the pasture (unimproved) and fallow periods (Wells, 1971). The economic solution to this problem was to sow improved pastures which reduced the weed density and increased soil fertility at the same time, thus enabling successful wheat crops to be grown once again. The rust fungus (*Puccinia chondrillina*) has been very effective also in reducing *C. juncea* populations but it is interesting that where improved pastures have not been sown, weeds such as *Marrubium vulgare* and *Inula graveolens* have colonized the areas once occupied by *C. juncea*.

Grain legumes - Field peas and lupins are very susceptible to weed competition and it is doubtful whether these crops could be grown without some form of weed control. High prices are received for both grains and therefore any weed control costs incurred should be easily recovered. Using paired plots of 1 ha each, Demby and Turowski (1967) obtained an economic increase in the yield of peas (86 kg/ha) when annual weeds (*Chenopodium album, Polygonum* spp. and *Centaurea cyanus*) at 46 plants/m^2 were controlled. The same weeds at 110 plants/m^2 reduced the yield of lupins by 153 kg/ha and their removal also was economic even though the weed control costs were higher. Nelson and Nylund (1962) found competition between peas and either *Setaria italica* or *Brassica hirta* to be extremely variable (due mainly to time of weed emergence) and pea yields were decreased by up to 64%. In one direct comparison, 290 plants of *S. italicum* per m^2 were equivalent to 32 plants of *B. hirta* per m^2 in competitive ability. Preliminary data from Victoria (Reeves and Brooke, unpublished) suggest that the critical weed density of *L. rigidum* in lupins is approximately 40 plants/m^2.

Summer grain crops - Two sets of data are available for the effect of annual weeds on sorghum yields. Shipley and Wiese (1969) derived a quadratic equation which related sorghum yield to the density of *Amaranthus* spp. Using atrazine pre-emergence at 3 kg/ha (Wylie and Stirling, 1977) and assuming a price of $80/t for the crop, the critical weed density was 0.5 plants/m^2. Burnside and Wicks (1967) obtained data over 4 years but, instead of varying weed density, they varied the time and duration of weed competition and measured weed dry weight instead. Their data, for four annual weeds including *Amaranthus* spp., indicated a critical weed dry weight of 600 kg/ha for economic weed control. Unfortunately, without further experiments, this is of little predictive value.

Atrazine is also used for weed control in maize and, as with other crops, the decision whether to spray or not often depends on the weed species involved. Knake and Slife (1962) showed that the critical weed dry weight for *Setaria faberii* was 1200 kg/ha which was produced when the weeds were spaced 2 cm apart along the crop row. A similar density of *Amaranthus hybridus*, however, produced 3800 kg d.m./ha (Moolani et al, 1964) and so the critical weed density for this species was a spacing of 50 cm between plants, producing 1100 kg/ha. In Queensland, Kilpatrick and Hawton (1975) stated that *Nicandra physalodes* was a serious competitor in maize and yield losses of up to 1.4 t/ha (valued at $84) can be caused by as few as 5 plants/m^2.

Soyabean at $160/t is a more valuable crop than either sorghum or maize and so fewer weeds can be tolerated. Also, weed control is cheaper since trifluralin at 2 ℓ/ha controls most weeds (Williamson, 1976). From data reported by Knake and Slife (1962) and Moolani et al (1964), critical weed dry weights for *Setaria* spp. and *Amaranthus* spp. were 120 and 200 kg/ha, respectively. These dry weights corresponded to plant spacings of 35 cm and >100 cm, respectively. Clearly, *Amaranthus* spp. are much more competitive than *Setaria* spp. in these crops and if a choice has to be made, control methods should be directed towards the more competitive species.

Oilseed crops - Although no weed density experiments have been carried out in crops such as sunflower, safflower and rapeseed, it is generally believed that weed control is necessary. The crops are poor competitors with weeds but, fortunately, the herbicide trifluralin is most effective and not too expensive and so the risk factor is low.

Rice - Finlay (1975) states that most grasses and broadleafed weeds can be controlled by propanil but that in ratoon crops weed control should be restricted to the use of 2,4-D for broadleaved species. Again, there is no data available from weed density experiments but Sing (1975) suggests that only two out of every three crops need spraying inferring that weeds are not a problem in some years. Propanil costs $25/ha and represents about 10% of the variable costs of growing the rice crop. For weed control in upland rice in India, Chakraborty and Majumdar (1973) found that the highest net profit was obtained when propanil + 2,4-D was used compared with other herbicide mixtures, hand weeding and no control at all.

Cotton - There is little doubt that cotton crops are susceptible to weed competition. In Australia, progress within the industry was delayed for some time while effective control methods were being developed. Hazard (1973) recommended a pre-plant application of trifluralin, or a band application together with inter-row cultivation or flaming. This would appear to be economic at current prices and illustrates the important point that all forms of weed control should be constantly reviewed as costs and prices change relative to each other.

CONCLUSION

Effective weed control methods have been developed for most crops and there is ample evidence that the control of dense infestations in broad-acre crops is economically justified. However, the decision becomes more difficult to make when weed densities are low and their competitive effect is much less. The cost of weed control is increasing and it is therefore important that the effect of a particular weed infestation can be predicted early in the growth of the crop so that appropriate action can be taken. This review was highlighted a serious deficiency in our current knowledge of the economics of weed control and detailed work is now needed in the major crops and environments to assist the grower in his decision to control weeds.

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