The value of break crops for wheat

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Abstract

The yield of wheat growing after a broadleaf break crop generally exceeds that of wheat growing after wheat or other cereals. The presumed reasons for the yield benefit vary between break crops. They include reduced root and foliar disease, increased supply of soil water and mineral N, reduced assimilate loss to mycorrhizas, and, after legumes, growth stimulation following hydrogen gas release. To quantify the value of break crops, we compiled data from published experiments on the additional yield of wheat following oilseeds, grain legumes or alternative cereals grown in the previous year. The yield increase was not generally proportional to yield, so the yield contribution of break crops is best expressed in absolute, not percentage terms. For a 4 t/ha wheat crop the additional yield after an oat break crop was 0.47 t/ha, after canola and linseed 0.85 t/ha, and after grain legumes between 1.81 t/ha for lupin and 1.10 t/ha for field pea. These data are used to evaluate the reasons for yield increase. They suggest that control of take-all and residual nitrogen after legumes are the largest benefits of break crops.

Key Words

break crop, root disease, legumes, mycorrhizas, nitrogen, hydrogen fertilisation

Introduction

A crop grown after a different species generally produces higher yields than one grown after the same species. This break-crop effect has been recognized since ancient times and in some wheat-based farming systems gave rise to more or less regular sequences of pastures, fallows and crops of different species which, when followed inflexibly, are called rotations. The means by which a crop affects following crops include well recognised processes related to disease, weeds, rhizosphere microorganisms, herbicide residues and residual soil water and mineral nitrogen. They may also include two recently discovered processes. One is growth stimulation following hydrogen gas released into the soil by the legume-rhizobial symbiosis (Peoples et al. 2008). The other is a drain on assimilates when its roots are strongly colonised by the hyphae of arbuscular mycorrhizal fungi (AMF) built up by a previous colonised host crop (Ryan and Graham 2002).

In contrast to the diverse and complex systems of different crops grown in sequence there has been a trend, in other farming systems, towards wheat monoculture, made possible by the availability of nitrogen fertiliser and selective herbicides. An alternative to both rotations and continuous monoculture is an opportunistic system in which farmers respond to changing circumstances by selecting crops on the basis of grain price, production costs and the expected effect of the previous crop on yield. Reliable estimates of the break-crop benefits of different crops and better understanding of the processes by which they affect yield of following crops could lead to improved tactical methods of crop selection.

Previous reviews of the benefit of break crops by Angus et al. (2001) and Kirkegaard et al. (2008) compared yield of wheat after wheat with wheat after break crops. These reviews showed that wheat after canola exceeded the yield of wheat after wheat by about 20% and wheat after grain legumes (field pea, lupin, chickpea and faba bean) outyielded wheat after wheat by 40-50%. The results of recent experiments enable us to better quantify the effects of different break crops. The aim of this paper is to review all available experimental evidence to evaluate the magnitude of the break crop effect of different species and the processes by which one crop affects the yield of following wheat crops. It is possible that a break crop affects several following crops but only the first is discussed here.

Methods

We reviewed experiments comparing yields of wheat after wheat with wheat after one or more break crops. Some were long-term experiments but most lasted two seasons. The data are presented in graphs in which each point represents the results of two treatments in a replicated experiment in one season. The data sources are not cited because of space restriction but will be presented in a larger report; they are mostly from Australia and Sweden, with some other parts of Europe and North America.

Results and discussion

Wheat after oats

Yield of wheat after oats (OW) exceeded wheat after wheat (WW) in 90 out of 115 comparisons reported in Fig. 1. This relationship shows that on average, wheat after oats yielded 0.47 t/ha more than wheat after wheat, and that the increase was not proportional to yield. Oats was widely grown in wheat rotations, before well-adapted broadleaf crops became available, because it is not host to take-all. However oats is host to other wheat root pathogens so its effect on wheat yield, compared to wheat after wheat, indicates the importance of take-all.

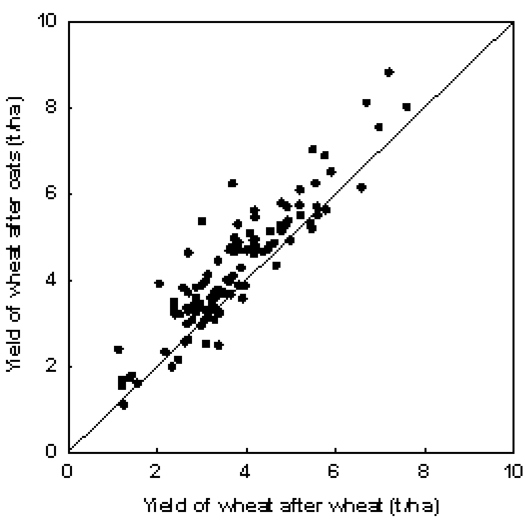

Figure 1. Comparison of yield of wheat growing after oats (OW) with wheat growing after wheat (WW) in 115 experiments. The relationship between the yields was OW = 0.47 + 1.00WW (R^2 = 0.84).

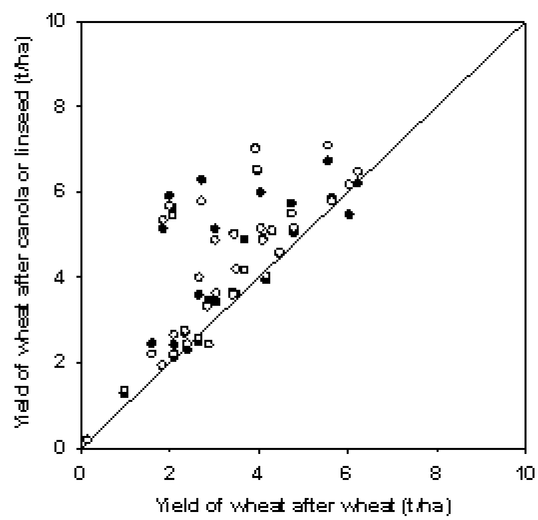

Figure 2. Comparison of yield of wheat growing after canola (CW,●) and linseed (LW,○) with wheat growing after wheat (WW) in 35 experiments. The relationships were CW=1.49 + 0.84WW, (R^2=0.59); LW=1.33 + 0.88 WW (R^2=0.53).

Oilseeds and suppression of mycorrhizas

The most important oilseed in Australia is canola, partly because it breaks the life cycle of most wheat-root pathogens. Canola provides an additional benefit of high levels of soil mineral N, apparently because of the composition of the residues (Kirkegaard et al. 1999). There is also some evidence of a break-crop benefit even when root disease is controlled and N supply is adequate. For example Harris et al. (2002) showed that wheat following canola yielded 11% more than wheat after wheat, even after precautions were taken to supply high levels of N and minimise root disease with a previous legume crop. Canola, like other crucifers, contains glucosinolates that are hydrolysed during tissue breakdown to release isothiocyanates into the soil, where they suppress a wide range of pathogens in the process of biofumigation, but it is doubtful that this effect provides more disease suppression than the absence of a host (Smith et al. 2004).

Linseed (including Linola which differs from linseed only in the oil composition of the seed), also does not host the main root pathogens of wheat and has an analogous biofumigation mechanism to crucifers by which a conjugated glycoside, linamarin, hydolyses and releases cyanide when tissue is disrupted. While canola and linseed appear to have similar effects on wheat pathogens, they differ in that canola is not a host of AMF while linseed is a strong host. There is evidence that growing a non-host of AMF leads to a reduced level of AMF-colonisation in a following AMF host crop. There is also some evidence that, provided the crop is well supplied with nutrients, reduced AMF colonisation leads to increased growth of a following crop, apparently because the loss of assimilates to the AMF is staunched (Ryan and Graham 2002). Comparing the break-crop effect of canola and linseed is a way to assess this effect.

Figure 2 shows a comparison of the break-crop effects of canola and linseed from 35 experiments. In simple terms, the yield of wheat after canola was 36% greater than wheat after wheat and not significantly different from the 38% yield advantage of wheat after linseed. These yield improvements are greater than those reported in previous reviews (Angus et al. 2001; Kirkegaard et al. 2008) and are probably unrepresentative because of unusually high levels of root disease in some experiments. Expressing the yield increased in percentage terms is not justified by the regression equations, where the slope coefficients are <1.0. For both canola and linseed, it is more correct to express the yield increase as an additional amount rather as an additional percentage, as shown for the oats data. At a wheat yield level of 4 t/ha, the break-crop benefit was 0.85 t/ha for both canola and linseed, indicating that there was no yield advantage to wheat following canola due to reduced AMF colonisation. Suppressing AMF may take more than a single growing season without a host, as suggested by Harris et al. (2002).

Another test of the effects of suppressing AMF colonisation was from a field experiment at Stockinbingal in southern NSW from 2002 to 2004. The site had grown field pea in 2001 and, as expected, wheat growing on the site showed no symptoms of root disease over the next 3 years. Soil levels of mineral N were adequate for the relatively small yields during a series of dry seasons. Wheat was grown after the break crops canola, linola, narrow-leaf lupin and faba bean, with control treatments of wheat after wheat and fallow. Of these, canola and narrow-leaf lupin are non-hosts of AMF while linola and faba bean are hosts. In 2002 and 2003 we grew the AMF non-host sequences of canola-lupin and lupin-canola and the AMF host sequences of linola-faba bean and faba bean-linola. There were 5 replicates. Yields of wheat in 2004 after these sequences and the controls are shown in Table 1.

Table 1. Yield of wheat (t/ha) after previous wheat, fallow, or single or double break crops that are host to arbuscular mycorrhizal fungi (AMF) (linseed and faba bean) or non-host to AMF (canola and lupin)

2002 crop	2003 crop	2004 wheat yield
Wheat	Wheat	2.39
Wheat	Fallow	2.88
Wheat	Non-AMF hosts	3.12

Wheat	AMF hosts	3.01
Non-AMF hosts	Non-AMF hosts	3.24
AMF hosts	AMF hosts	2.96
l.s.d.		0.32

Yields of wheat after the break crops were significantly greater than wheat after wheat but there was no difference between yield after one year of AMF host or non-host crops. However the yields of wheat grown after 2 years of AMF non-hosts were significantly greater than after a fallow while after the AMF host crops they were not. These data show a break-crop benefit from broad-leaf crops even when root disease was controlled but they do not provide evidence that AMF suppression is involved in the process.

Grain legumes

The species and number of experiments reviewed were field pea (57), faba bean (19), lupin (49) and chickpea (26). Unlike the oilseed comparisons not all species were compared at the same sites (Figure 3). When the data for the 4 legume species were combined the relationship, as with the oats and oilseeds, showed a greater yield than wheat after legume (LW) than wheat after wheat (WW) and the increase was not proportional to yield. The variability of the data was greater than for oats or the oilseeds, possibly reflecting differences in the level of residual N and the seasonal conditions affecting mineralisation. The 4 legume

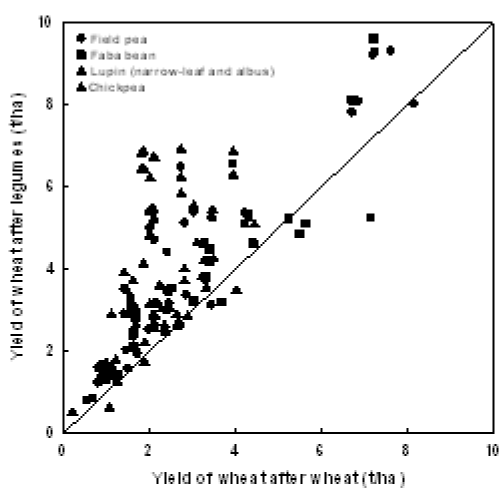

Figure 3. Comparison of yield of wheat growing after grain legumes, with wheat after wheat in 150 experiments.
(LW=1.49+0.93WW, R^2=0.53).

species had different effects on the yield of the following wheat: using a reference yield of 4t/ha for wheat after wheat, the advantage varied from 1.81 t/ha after lupin to 1.10 t/ha after field pea. The low value for field pea may reflect the dry regions where many of the experiments were conducted. The yield advantage of legumes is made up of growth stimulation by hydrogen gas released into the rhizosphere (Peoples et al. 2008) as well as a disease break and additional residual nitrogen. The yield responses are much greater than for oats or oilseeds, possibly reflecting differences in residual N. The few studies of the effect of hydrogen gas suggest that it contributes up to 15% additional growth of a following cereal (Peoples et al.2008).

Conclusion

The yield increase of wheat following a break crop is not a percentage of yield, as usually reported, but is a relatively constant amount for a particular break-crop species. The reason for a constant increase may be because the healthy roots of wheat following a break crop are able to extract more soil water and nutrients than wheat after wheat, as reported by Angus and van Herwaarden (2001). The limit to additional extraction of water and nutrients is presumably the duration of the crop.

Based on the increases in wheat yield after different break crops, we summarized the different sources of additional yield and rounded them to emphasise the approximations involved (Table 2). We classified the sources so that they can be added where appropriate, for example adding disease control to the other benefits of legumes. The yield benefit from take-all suppression is estimated from the oats data and the suppression of other root diseases from the additional benefit after canola. A separate allowance is made for stimulation of N mineralisation by canola. Estimates of the yield effect of hydrogen fertilisation by legumes vary from 0 to 15% (Peoples et al. 2008) and we have assumed a value of 10%. There is little hard evidence for a yield benefit from suppression of AMF after a single break crop but is included because of previous evidence from double break crops and the extraordinarily high yield of wheat after lupin, a non-host of AMF. The N benefit from legumes is estimated as the residual needed to explain the average break-crop effect shown in Figure 3.

Table 2. Sources of the break-crop effect and estimates of their value at a wheat yield level of 4 t/ha.

Mechanism	Additional wheat yield (t/ha)
Take-all suppression	0.5
Suppression of other root diseases	0.3
Net nitrogen benefit of canola	0.1
Hydrogen fertilisation by legumes	0.4 ?
Suppression of AMF by non-host crops	0-0.1
Net nitrogen benefit of legumes	0.5

The estimates in Table 2 explain average effects of break crops reviewed here. The variation between experiments is not explained and presumably reflects interactions between environment and break-crop effects. Research to better explain and quantify the mechanisms, particularly for the different legume species, will assist farmers in selecting crops to grow in sequence.

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