Field evaluation and selection of winter wheat for competitiveness against weeds

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Abstract
The evaluation of new winter wheat varieties in relation weed suppression should consider characteristics such as growth habit, speed of early development and tillering ability. Weed suppression cannot be attributed to a single characteristic. Instead the interaction between a series of desirable characteristics has been shown to be important, with varieties compensating for weakness in certain characteristics with strengths in others. Generally, a high season-long crop ground cover is important. The balance between different characteristics for weed suppression will determine the value of the variety for early, late and season-long weed control, and for the climatic zone. Selection for general growth habits is based on understanding the role of different characteristics in weed competition. These will be of value under different circumstances or locations in Organic Farming. Defined growth habits are: (1) The continuous planophile habit which has a clear advantage for weed suppression over the erectophile type at a given plant or shoot population density. (2) The early season erectophile to late season planophile habit is a good model when crop establishment is high. (3) The early planophile to late erectophile habit can compensate more for lower crop establishment than the early erectophiles. (4) A continuous erectophile habit is only beneficial when weed levels are low, crop establishment is sufficiently high or crop row widths are very narrow.

Background
Selection of new cereal varieties for competitiveness of against weeds under organic conditions requires identification of crop characteristics (or traits) and development of routine methodologies to indicate their potential usefulness. The EU funded project on Strategies of Weed Control in Organic Farming (WECOF) has examined the key morphological characteristics which are involved in the ability of winter wheat to reduce weed growth through light interception and shading so as to determine their relative importance. Particular emphasis was on the determination of the wheat ideotypes to optimise weed suppression. This paper focuses on variety trials carried out in south east Scotland that consisted of a wide range of genotypes considered as having potential for weed suppression in Organic Farming. The following discussion is supported by information drawn from the WECOF Core Trials carried over three years in Germany, Poland, Spain and Scotland, covering Mediterranean, Continental and cool, temperate climates. Evaluation and selection for weed suppression will be of advantage for organic farmers, and farmers practicing integrated methods of farming, as well as benefiting breeders of suitable varieties.

Plant characteristics for weed suppression
Although some varieties have higher weed suppression than others, this is usually not attributed to a single characteristic, either within or between varieties. The interaction between a series of desirable characteristics is important is weed competition (Eisele & Köpke, 1997) and this will include strengths in some characteristics compensating for weaknesses in others. Certain key characteristics are indicated as generically desirable for organic wheat varieties to improve weed suppression: (1) good establishment ability, (2) high tillering ability, (3) increasing plant height (Wicks et al., 1986; Korr et al., 1996; Didon & Hansson, 2002), (4) planophile leaf habit and high leaf area index through production of large leaves (Niemann, 1992; Huel & Hucl, 1996; Seavers & Wright, 1999), (5) plant growth habit and leaf inclination (Eisele, 1992; Niemann, 1992; Lemerle et al., 1996) and (6) high yield potential. Many of the individual plant traits in (1) to (5) can be used to define plant growth habits (which are discussed later in this paper). These characteristics also determine whole crop measures such as leaf canopy size and light interception. Thus, crop ground cover also comprises a broad range of plant characteristics (e.g. Huel & Hucl, 1996; Ogg & Seefeldt; Didon & Hansson, 2002).

Our results from the variety trails strongly suggest that crop ground cover is the most important crop feature for competing against weeds (Davies et al., 2004). This view is supported by results from WECOF Core Trials (Drews, 2005) and other research (Richards and Whytock, 1993; Lemerle et al., 1996). Figure 1 demonstrates how crop ground cover is inversely (and significantly) related to weed ground cover. The affect of the crop on later weed growth was evident in much of our work (Figure 1). When a variety

competed well against weeds this was associated with a relatively high fractional light interception. For example light interception at ear emergence was significantly and negatively correlated with subsequent weed growth (R^2 = 0.45; data not shown). Other work has shown that higher weed suppression was associated with relatively high light interception in the upper leaf canopy of tall, planophile cultivars (Verschwele, 1994; Christensen, 1995; Amesbaur & Hartl, 1999). Seasonal variations in plant establishment and individual genotype responses in tiller production and/or tiller retention can make it difficult to group varieties in field trials into consistently good or poor for ground cover and light interception. However, it is possible to describe general growth habits of current varieties in such a way that will benefit the selection of weed suppression ability in new genotypes.

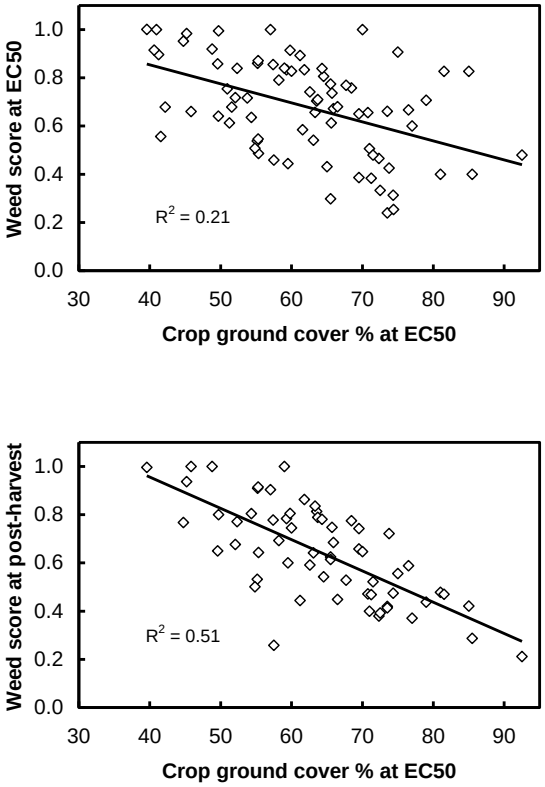

Figure 1. Relationship between crop ground cover (%) at EC50 and weed ground cover at EC50 (upper figure) and post-harvest (lower figure). Data represent all varieties across four seasons (2000/01 to 2003/04). Weed ground cover is scored as the percentage weed cover for each variety in each season expressed as a fraction of maximum weed cover at the relevant growth stage, thus enabling each season's data to be placed on the same scale.

Working towards defining growth habits and cereal ideotypes

The use of a wide range of genotypes has enabled us to develop guidelines for the types of variety that are best suited to weed suppression in Organic Farming. The balance between the characteristics will determine the value of the variety for early, late and season long weed suppression, and for the climatic zone. For example, in very dry zones, highly erectophile habits (especially after stem extension) may be preferred for later moisture conservation; in such situations early ground cover, height and yield may be of greater consequence for weed suppression, along with leaf size, and possibly tillering ability. In such zones, early weed suppression is generally the requirement anyway and the characteristics indicated would provide that benefit. In cool, moist climates, season long weed suppression may be required with a combination of an early prostrate (i.e very flat) and later planophile habit with large leaves. High tillering ability is also important because of greater establishment risks, and additional compensation is possible with height increase. High yielding potential also appears to be important.

A key factor for all these characteristics is a robust consistency in weed suppression and yield required for organic varieties. It is clear that some varieties are more robust than others, though it is not always clear why this is so. Our own results suggests that about 40% of the variation in ability to suppress weeds appears not to be linked to the measured characteristics. This leads to hypothesise what characteristics should also be assessed after suitable research. Root competition was not evaluated and is relatively poorly understood; particularly genotypic variation between varieties. The potential for allelopathic differences between varieties has been alluded to in the literature (Didon, 2002; Didon & Hansson, 2002) derived from in-vitro testing, but little is known about in-vivo behaviour.

For plant breeders, targets for plant and crop characteristics should be considered in relation to generalised growth habits that are of value under different circumstances or locations in Organic Farming. Examples of current varieties that provide a basis for developing future ideotypes are highlighted in Table 1. The types described below represent a wide range suited to different situations of climate and weed development. All types benefit from good crop emergence. An early planophile type can provide earlier canopy closure and a degree of buffering against poor to moderate crop establishment.

Table 1. Leaf characteristics and general plant growth habit of selected wheat varieties from WECOF. The leaf angles were measured from the stem at anthesis (i.e. a more erect leaf has a low angle). Mean leaf width and length were measured at ear emergence and are defined below. Plant growth habit refers to the change in leaf habit from pre-tillering to post-anthesis.

Variety	Angle of flag leaf (°)	Mean angle of all leaves (°)	Mean leaf width	Mean Leaf length	Plant growth habit
Chablis	76	52	N	S	Continuous planophile
Maris Widgeon	55	44	M	M	Erectophile to planophile
Rialto	31	35	W	M	Planophile to erectophile
Zyta	23	26	M	S	Continuous erectophile

Leaf width: Narrow < 14 mm; Medium = 14-15 mm; Wide > 15 mm
Leaf length: Short < 22 mm; Medium = 22-25 mm (Long > 25 mm, e.g. oat leaves, not shown above).

A continuous planophile habit has a clear advantage over the erectophile habit at a given plant or shoot population density. This habit appears to be particularly beneficial in shorter varieties and under circumstances where a crop requires sustained weed suppression, especially during the autumn and stem extension. An early planophile to later erectophile habit can compensate better for lower crop establishment than early erectophiles, though rapid leaf development or large leaves would enable varieties of this type to take full advantage of their leaf habit. The early erectophile to later planophile habit is a good model when crop establishment is high and if crops are sown in narrow rows. This structure, can provide high fractional light interception throughout the season. The later planophile habit is the most beneficial habit where there is late weed growth i.e. from stem extension onwards. The erectophile habit has been the long established ideotype for high yields in cereals for high-input agriculture and unlimited nutient supply. This habit can be an advantage when weed levels are low, but it is a risky strategy when competition from weeds is high, especially early in the growing season. If an erectophile is desired then increased height may be of value. Shorter vartieties would benefit from an ability to produce and retain a high number of shoots per plant.

Genotype selection in plant breeding programmes
One of the outcomes of the WECOF project was a guide to genotype selection for plant breeders. The following descriptors are derived from this study plus literature reviews and field observations. We list the key characteristics, and how important they are in weed suppression for different climatic regions.

Early growth habit
An early prostrate habit (at the start of tillering) combined with a moderate to high leaf area index (either through rapid leaf development or good crop establishment) has been determined as being closely linked with reduced weed growth, despite the fact that shading is at a low level at this stage. Other competitive characteristics such as nutrient and water competition are suspected to play an important part, as may

allelopathy, at this early stage. However, an early prostrate habit appears to be a good indicator of such competition. Ground cover at earlt tillering is strongly correlated with weed suppression throughout the season Richards & Davies, 1991). An erectophile habit at early tillering tends to require a higher crop establishment to be as equally competitive as an early planophile.

Although plant characteristics such as the amount of ground cover per plant and the amount of leaf area per unit of ground cover are only weakly correlated with weed ground cover, our results suggest that these measures are useful indicators of competitive ability for crops at equivalent plant population densities. This would be a particularly useful feature for plants to retain at moderate to high plant population densities, rather than simply used to compensate for poor establishment. Optimising the early growth is likely to be very important in reducing autumn and winter weed emergence in cool temperate climates.

High tillering capacity
Shoot population density is a function of plant number and the ability of a plant to produce and maintain tillers. Consequently, some varieties have a relatively high shoot population because of good establishment, whilst others produce a higher than average number of shoots per plant: some varieties may have both characteristics. High tillering ability is likely to be most important at low plant populations i.e. 150-160 plants per square metre or less. As organic seed is not treated for disease and pest control, establishment in adverse conditions can be reduced significantly. Data from our own trials and from farm crops indicates that the percentage of plants established is less under organic than under conventional conditions. Therefore high and consistent establishment across a range of soil conditions is a particular requirement for organic varieties. The selected varieties should be high tillering types to cope with such situations. High tillering capacity is essential in cool temperate conditions, but perhaps less important in mediterranean regions where establishment conditions are usually more favourable.

Rapid early growth to stem extension
Rapid early growth allows the crop to maintain a light interception lead over the rapidly growing weeds, and with the right habit, shade newly emerging weeds. Ground cover by the crop at the end of tillering is strongly correlated with weed suppression up to full canopy cover and up to harvest. In Mediterranean regions, rapid autumn and early spring growth is required to cope with weed emergence with the crop and a further emergence in early spring. In continental regions or in late sown crops in cool temperate regions a rapid early spring growth is particularly required to shade a largely spring emerging weed flora. In early sown crops rapid autumn tillering is required, as well as rapid early spring growth.

Plant habit
We have determined that the habit is considered planophile when the leaf angle from the main stem and tillers exceed 30º to 45º from the vertical. A leaf may be relatively straight or slightly curved. A highly curved or extended leaf in which the leaf tips exceed an angle of 60º from the stem can also be described as planophile. In general, highly planophile morphologies increase light interception and shading of weeds, and this compensates significantly for lack of height. Some varieties change from planophile to erectophile (leaf angle is less than 30º from the vertical, straight or curved) over the season. The WECOF project has devised several scoring systems for assessing plant growth habit in the field. An example of a five-point scale or scoring system will be demonstrated in the oral presentation of this paper. These assessments take into account plant structure based on leaf inclination and estimates such as plant height to width ratio. This type of scale can be used to indicate extremes of plant habit, as well as potentially useful growth habit in between. The four varieties highlighted in Table 1 provide examples of the growth habits identified in the WECOF project. Although each of these types can provide good suppression against weeds under different conditions for crop establishment, or timing and amount of weed emergence and growth, it appears that the competiveness of the continuous erectophiles and late erectophiles is compromised when plant populations are poor. Where breeding lines are exclusively of erectophile types, then it should be possible to improve weed suppression through shading by increasing LAI with increased height and leaf size.

Therefore a continuous planophile or a more rapid growing early-erectophile with a later planophile habit is more robust. Types that maintain either a planophile or erectophile habit for the whole season appear to best suit conditions of poor or good crop establishment, respectively. Organic farmers may sow in narrow or wide rows. In general wide rows are used to aid hoeing for control of difficult perennial weeds, such as docks, thistles, common couch and scrambling weeds such as cleavers. Narrow rows are preferred for general weed suppression as shading is increased. Where narrow (10-16cm) rows are used both planophiles (short or tall) and tall erectophiles with large leaves are successful. Where rows are over 20 cm then

erectophiles have to be very tall with large leaves to give a comparable shading ability as planophile varieties.

Plant height
Although there was no clear indication of height alone being useful in competition against weeds, very tall varieties would appear to be competitive at moderate to good plant population densities. Height can compensate for an erectophile leaf habit, but a relatively short planophile can give the same shading ability and weed suppression of shorter weeds. Tall varieties may have an advantage for some very tall grasses and scrambling weeds (Baylan et al., 1991; Blackshaw, 1994; Ogg & Seefeldt, 1999; Cousens et al., 2003). Leaf size is an important factor in shading, with larger leaves of particular assistance in erectophile varieties. The varieties that have the poorest weed suppression are short, erectophile varieties or planophile varieties with small or narrow leaves.

Considering crop ground cover in plant selection
As stated earlier, crop ground cover integrates several plant and crop characteristics. Cover measured from directly above the crop is a good indicator of shading characteristics and can be used as a guide. However, total leaf area index (LAI) or green area index (GAI) are also good correlants with shading and weed suppression. So, a tall, large-leaved erectophile may have similar shading ability, or possibly even greater ability later in the season, than a short planophile variety. So a variety that changes from planophile to erectophile over the season will give continuous good shading so long as it is tall later on. Some varieties have a consistently higher leaf area index than others. This is influenced by plant and crop factors such as leaf size and percent establishment. When a variety competes well against weeds this tends to be associated with a relatively high fractional light interception (Verschwele, 1994; Christensen, 1995). In the Mediterranean region a planophile habit in autumn and early spring would be useful. Later weed growth is reduced by the hot, dry conditions, so later wheat growth may be erectophile. Most varieties in this region are erectophile at present, so large leaves and height become more important characters in maintaining shading. In continental regions a planophile habit in the spring is useful; dry and warm conditions in summer reduce weed growth, so later growth may be erectophile. A tall early erectophile with large leaves may be suitable. In cool, temperate regions a planophile habit is useful throughout the season as weed growth may continue through to canopy closure and beyond in some cooler, wetter summers. If the variety is, or becomes, erectophile then it should also be tall with large leaves.

Selection for yield
From the WECOF trials and trials elsewhere, there is an indication that the best weed suppressors tend to be amongst the better yielding varieties. Our own work indicates a significant negative correlation between yield and weed cover immediately post-harvest ($R^2 = 0.46$, data not shown). It is clear that yield benefits are not lost in selecting for weed suppression in winter wheat. This has implications for plant breeding programmes, because the development of competitiveness against weeds does not exclude development of high yielding varieties.

Concluding remarks
The information we have leads us to conclude that new varieties for organic agriculture need to be more robust in both their percentage establishment under contrasting conditions and in their ability to produce as high as possible number of shoots per plant: either through tiller production or tiller retention. The balance between different characteristics for weed suppression will determine the value of the variety for early, late and season-long weed control. The continuous planophile habit has a clear advantage for weed suppression over the erectophile type at a given plant or shoot population density, but there are also benefits of early and late planophile habits depending on the relative establishment of crop and weeds during the season. It is clear that selection for variety types should be considered in relation to climatic factors that affect both crop and weed growth.

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