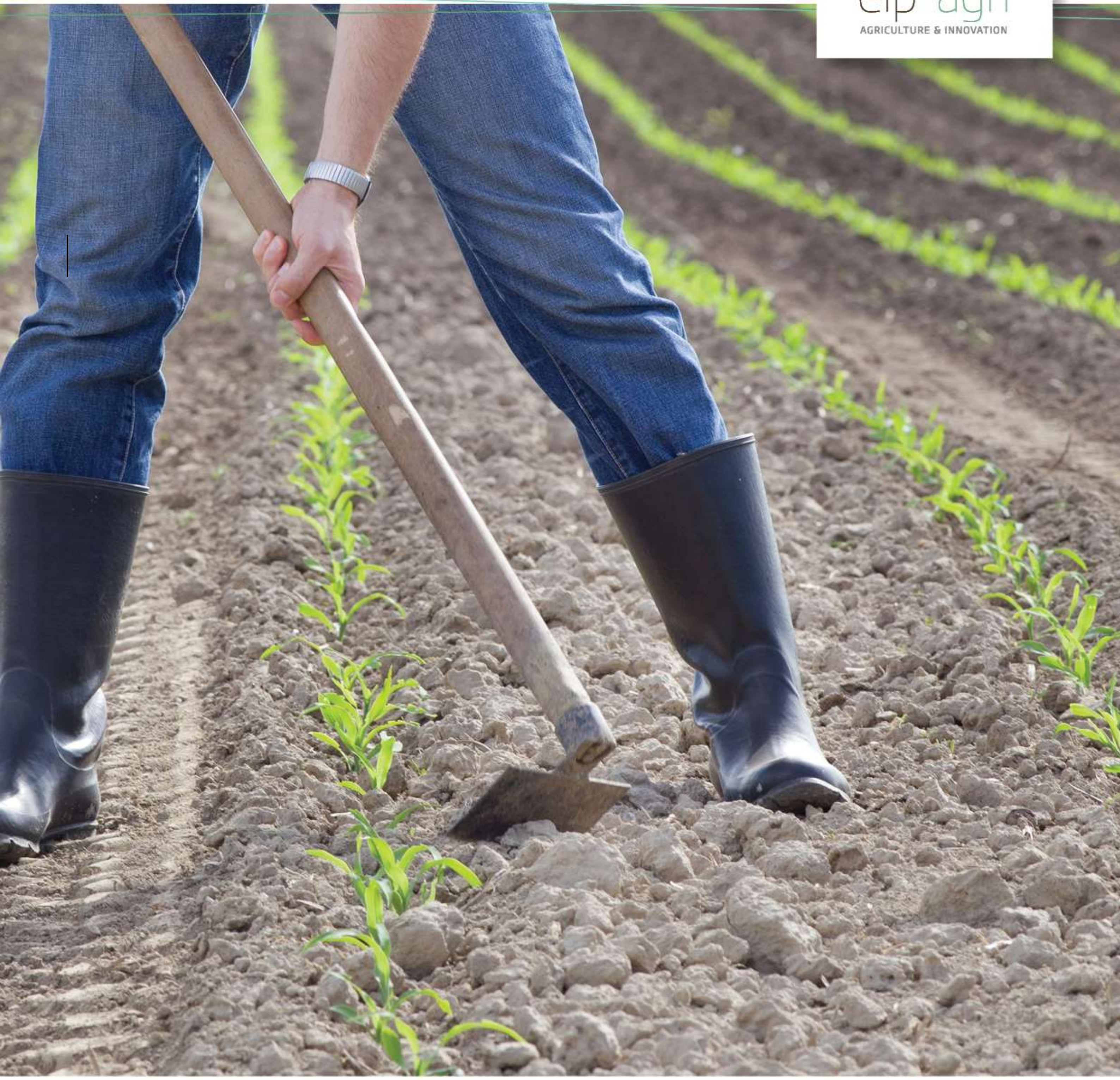
EIP-AGRI Focus Group

Non-chemical weed management in arable cropping systems



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Breeding for weed suppressive and tolerant varieties/crops

Ilse A. Rasmussen[1] & Hansueli Dierauer[2]& Marleen Riemens[3]

Herbicide resistance has been the major focus of many breeding programs. The introduction of herbicide resistant crops has resulted in an increased global dependence on herbicides in arable systems (Madsen & Streibig, 2003). Using the competitiveness of a crop or of crop mixtures either for being weed suppressive or weed tolerant is a relevant way to reduce the need for more invasive types of weed management (Andrew *et al.*, 2014). A shift towards breeding programs selecting for weed-suppressive genotypes can potentially reduce the need for weed management and direct weed control without the environmental malign side effects of herbicides. Early soil coverage, optimal use of light, water and nutrients for a high competitive ability and the ability to grow in intercropping or cover crop systems (matching niches) are important elements to be included in these programs that help reduce the need for weed control with herbicides.

An example are short season maize cultivars that allow for a delay in sowing date enabling the use of a stale seedbed prior to sowing the main crop or allow for early harvest and the growth of a competitive cover crop afterwards.

Adjusting sowing patterns and seed rates can be used to allow mechanical weed control in crops in which this option normally does not exist. For instance, an increased row distance in cereals of 18-23 cm combined with an increased seed density allows mechanical weeding during crop growth and increases the competitive ability of crops curing the early growth stages (Melander, 2003; Kolb, 2012). However, trade-offs with other crop management objectives need to be taken into account, such as the enhancement of organic matter in the soils through no or low till.

A crop cultivar that reduces the fitness of a weed or other plant is called suppressive, a crop cultivar that does not react with yield loss – or only to a small degree – when faced with competition from weeds (or other crop plants) is called tolerant, see fig. 1 (Basstiaans & Storkey, 2017; Hansen *et al.*, 2008). If a weed is suppressed by a crop, it will have reduced seed or other propagule production, which will aid the long-term management of the weed (Andrew *et al.*, 2014). This might not be the case if the crop is tolerant, but does not suppress weeds.

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[1] International Centre for Research in Organic Food Systems
[2] FiBL
[3] WUR

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Less suppressive, more weed biomass	*More suppressive, less weed biomass*	*Tolerant to weed biomass*

Fig. 1. Suppressiveness vs. tolerance. Drawing by M.S. Jørgensen

The goals of breeding for weed suppressive and/or tolerant varieties/crops could be

- Higher/stable yields with reduced or no use of herbicides or non-chemical weed control methods
- Less weeds in the field in the current year
- Less weeds in the future
- Crops/varieties adapted to non-chemical weed control methods
- Capacity of crops to perform in mixtures (including intercropping).

<u>Crop traits associated with suppressiveness, tolerance or both</u>

There is a range of crop traits that are associated with suppressivenes, tolerance or both, often defined together as competitiveness. Tolerance can be measured as percentage yield reduction under weedy conditions, whereas suppressiveness can be measured as relative weed biomass in the presence of different cultivars (Bastiaans & Storkey, 2017).

Research has indicated that a screening programme for crop variety suppressiveness would ideally be based on only a few, non-destructive measurements of key growth traits. In one study they measured the weed suppressive ability of 79 varieties of spring barley in two ways: 1) directly, by weed coverage assessments under weedy conditions at three Danish locations in 2002-2004, and 2) indirectly, by non-destructive measurements of varietal growth traits under weed-free conditions in 17 other experiments in Denmark in 2001-2003. Based on just four varietal growth traits, see fig. 2 (reflectance, leaf area index, leaf angle and culm length), they successfully developed a method for indexing the weed suppressive ability of spring barley varieties. The suppressive index ranged from 12% in variety 'Lux' to 55% in variety 'Modena'. The index was validated against independent data from two locations in 2005 with 14 and 24 varieties and found valuable for future use in regular screening programmes (Hansen *et al.*, 2008).

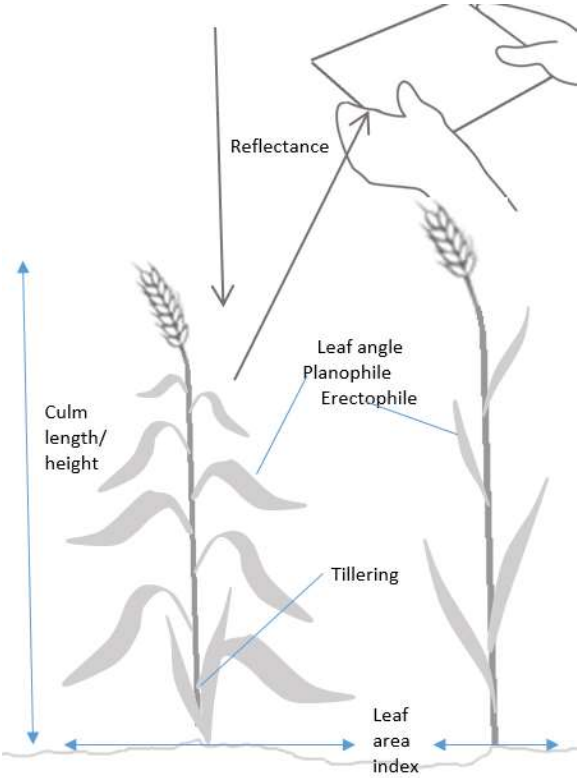

Fig. 2. Varietal traits measured for weed suppressive index. Drawing by M.S. Jørgensen

Weed suppression increased with culm length, ratio vegetation index and leaf area index, whereas increased leaf angle, where 0° is horizontal (planophile) and 90° vertical (erectophile) leaves, decreased weed suppression (Hansen *et al.*, 2008).

Similar results were found in a study in Germany, where tall cultivars with planophile leaf inclination and leaf area index resulted in higher ground cover and light interception. This had an effect on ground covering by the weeds, reducing it by up to 73 % when combined with narrow row spacing (12 cm). However the efficacy of the shading was influenced by weed characteristics like time of development, plant height and tolerance to shading, where small or late developing weeds were more susceptible to shading than tall or early developing weeds (Drews *et al.*, 2009).

Traits such as early vigour/RGR (Christensen, 1995; Olesen *et al.*, 2004; Colbach *et al.*, 2018) or early leaf area development (Bastiaans & Storkey, 2017), tillering (rate of tillering and final tiller number) (Lemerle *et al.*, 1996; Seavers & Wright, 1997), canopy height (culm length)(Christensen, 1995; Lemerle *et al.*, 1996) as well as early height growth-rate (Bastiaans & Storkey, 2017), canopy architechture, often measured by light penetration through the canopy (PAR) (leaf area index, leaf size, growth form/leaf inclination erect vs. planophile) (Didon & Hansson, 2002; Hansen *et al.*, 2008; Coleman *et al.*, 2001; Drews *et al.*, 2009; Colbach *et al.*, 2018) are often used as indicators of competitiveness/suppression/tolerance, although Bastiaans & Storkey (2017) indicate that specific leaf area, crop growth rate and light extinction coefficient only resulted in small reductions in weed biomass in rice. Another important trait may be underground structures such as root length/density and other root associated traits, however, up till now these have been too difficult to include in breeding programmes (Andrew *et al.*,

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2015). Colbach et al. (2018) working in the REMIX project indicate that allocation of biomass to stems rather than leaves contributed to crop species decreasing weed impact.

Other traits that may affect weed competitiveness/suppression/tolerance is lodging, as weeds may continue to grow, once the crop has lodged. Traits that may be associated to competitiveness/suppression/tolerance, but may be difficult to seperate from effects on yield, are e.g. nutrient and water efficiency (see e.g. Lemerle *et al.*, 2006).

Instead of – or in addition to – breeding for higher suppressiveness, it is also relevant to breed for higher tolerance, so that the crop will maintain yield level at higher weed densities. This could also be relevant for tolerance towards catch crops/cover crops/green manures undersown or intersown with the crop or for intercropping with other crops.

In an Australian study, research examined the feasibility of selecting for wheat tolerance to weeds by crossing varieties differing for traits associated with competitiveness. Competitive ability and yield potential were treated as separate traits for selection. Previously measures of crop tolerance to weed competition often did not separate the two traits so that selection based on these measures was often synonymous with selection for yield potential rather than pure tolerance. They proposed a measure, termed Incremental Crop Tolerance (ICT) that reflects the incremental yield difference between genotypes associated with tolerance, over and above differences in underlying yield potential (Lemerle *et al.*, 2006).

<u>Cultural methods to increase competitiveness of crops</u>

As increasing the seeding rates of a crop will increase the competitiveness towards weeds, it is also important that the crop is tolerant to high seeding rates without reducing yield or quality. There are drawbacks to using high seed rates, many diseases will have increased potential at high crop densities, and drought effects may be more severe than at lower densities. High densities may also increase the need for nutrients. The cost of establishing the crop will increase at high seeding rates, and must be balanced with the positive effect against weeds. Technological developments may make it possible to use the high seed rates only in areas of the field with high weed infestations, however, there is also a risk that the weeds will adapt and become more competitive at high crop seeding rates.

Intercropping is a strategy for increasing agricultural productivity per unit land that is based on ecological mechanisms for improved ressource capture (Yu *et al.*, 2015). Mixtures of crop species or of varieties within the same species may also be used to increase competitiveness against weeds, see fig. 3. While the best mixture is rarely better than the best variety/species measure in competitiveness, the combination may yield other benefits in the shape of yield, disease resistance and resilience against physical environment such as drought, frost, water logging etc. (Lithourgidis et al., 2011) and intercropping may improve uptake of nutrients in the intercroppped species (Zhang & Li, 2003). A drawback of mixtures may be that they don’t mature at the same time. The efficiency of intercrops is often compared to pure crop stands using the land equivalent ratio (LER), which is calculated as the sum of the relative yields of component species in an intercrop as compared to their respective sole crops (Yu *et al.*, 2015). LER may be below one, showing no benefit or indeed a reduction in yield due to intercropping, or above one, showing a yield benefit of intercropping. Yu et al. (2015) found that a combination of C3 and C4 species gave a higher LER than a combination of C3-species only.

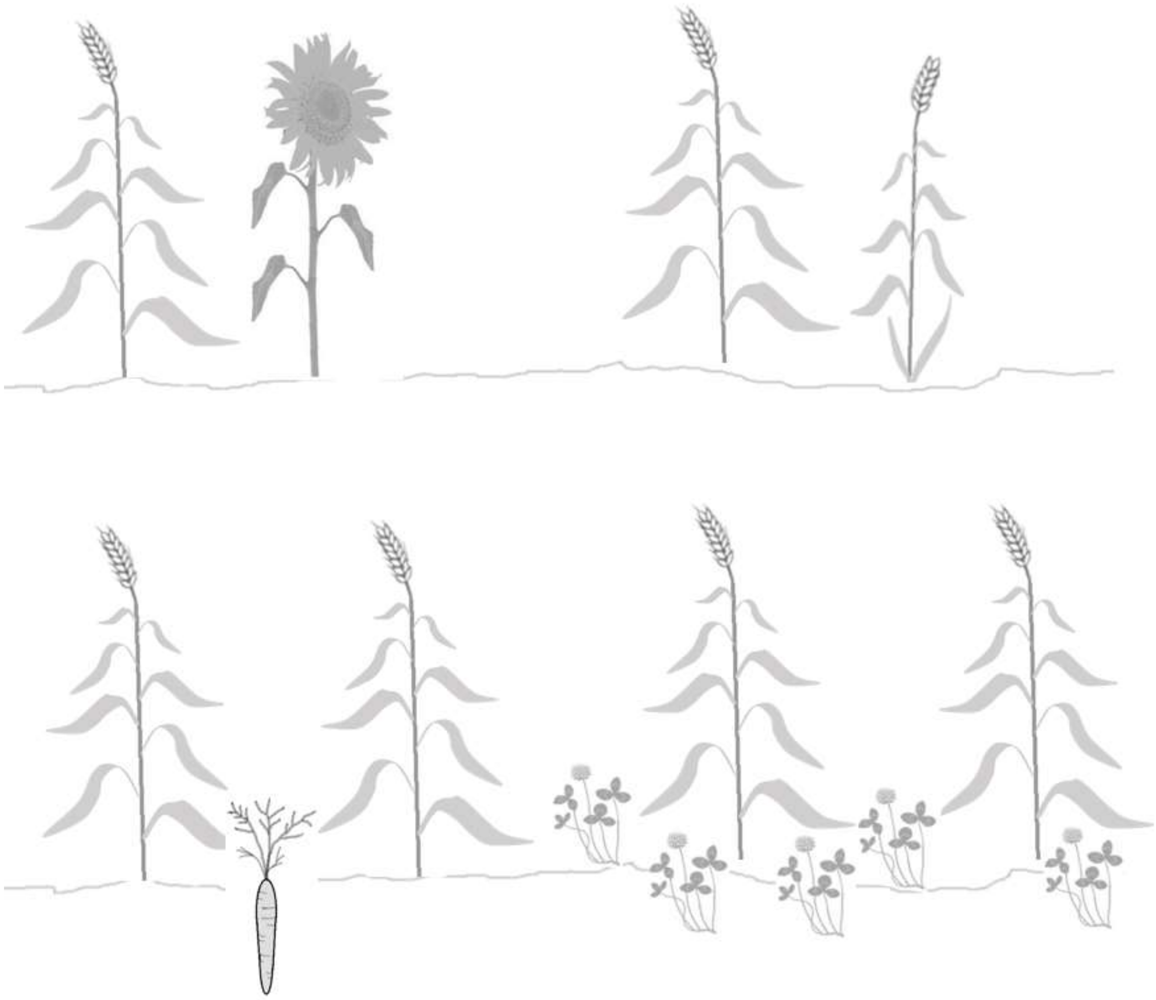

Fig. 3. Intercropping species (top left) or varieties (top right), intercropping rows of species (lower left), cover/catch crops undersown in crops (lower right). Drawing by M.S. Jørgensen

A special type of breeding called evolutionary breeding (composite cross populations) could be utilized in order to breed for competitiveness amongst other goals (Murphy *et al.*, 2005; Phillips & Wolfe, 2005). Döring *et al.* (2015) found higher yield as well as earlier ground cover and final plant height in composite crosses than in pure stands or mixtures, however, this did not result in significant effects on weed cover. This type of breeding would be very well adapted to the location, where it is carried out, however farm-saved seed gives higher risk of seed-borne diseases. There are also legal issues about seed certification.

Late sowing of winter crops (cereals) will reduce weed pressure, so breeding for varieties that tolerate late sowing without yield loss would be relevant (Rasmussen,

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2004). However, late sowing gives higher risk of bad soil conditions, wet soil etc. and also a risk for lower yield, especially in weed-free conditions. But any short season variety would give the possibility to include sowing date, stale seed bed, different weeding/tillage techniques etc.

Fig. 4. Allelopathic effects of live crops or crop residues incorporated in the soil. Drawing by M.S. Jørgensen

Crop species or varieties that have allelopathic characteristics may contribute to reducing the weed pressure. While some species excrete compounds from the roots during the growth of the crop (Reiss *et al.*, 2018), others release compounds after termination of the crop, see fig. 4 (Mathiassen *et al.*, 2006). However, the allelopathic compounds are poisonous and may leave residues in the ground that are polluting in the same way as pesticides (Krogh *et al.*, 2006) The allelopathic effect may also give adverse effects on the subsequent crops with lower germination.

<u>Overview of combination of breeding goals and cultural methods</u>

Table 1. Combination of breeding goals with other cultural and mechanical weed control methods

To use	**Breed for**		**Effect on**			**Trade-offs**
Cultural weed control	Suppress-iveness	Tole-rance	Yield	Less weeds	Next season	
High seed rates		x	X	X		€, nutrients, disease
<u>*Seeding pattern:*</u>						
Row width narrow		X	X	X		
Row width wide	X		X	*		Soil organic matter if high intensity mechanical weed control
Mixtures		x	X	X		maturity
Intercropping		x	X	X		
Cover/catch crops	X	X	X	X		€
Sowing time			X	X		Soil conditions
<u>*Short season:*</u>						
False seedbed			X	x		
Early harvest			X		¤	
Allelopathy				x	x	residues

* only if mechanical weed control is efficient

¤ cover crops or tillage to reduce weeds.

Discussion

There are many possibilities for breeding for increased competitiveness in crops. However, traditionally breeding has mainly been focussed at yield, quality and disease resistance, and it may be difficult to change this towards breeding for increased competitiveness.

As breeding is carried out by commercial breeders in most countries, they will only breed for traits that the farmers will pay for. As organic farmers is a small community and conventional farmers are not likely to pay for varieties that may only marginally reduce the weed problem, it is difficult to promote this.

Taking into account the results mentioned above, it could be possible to include at least an evaluation of the competitive characteristics of varieties in breeding programs, so that farmers could have this information included in their choice of variety. This could be a role for policy makers to require. E.g. an organic farmer may find it more important to have a competitive species, because it may yield higher under conditions with more weeds, than the weed-free herbicide applied conditions varieties are usually tested under.

References

Andrew IKS, Storkey J & Sparkes DL (2014): A review of the potential for competitive cereal cultivars as a tool in integrated weed management. Weed Research 55, 239-248.

Bastiaans L & Storkey J (2017) Descriptive and Mechanistic Models of Crop-Weed Competition in: Weed Research: Expanding Horizons, p. 33-60.

Colbach N, Dugué F, Gardarin A, Strbik F, Munier-Jolain N, Moreau D (2018): The response of weed and crop species to shading: measurement and prediction from trais. In: New approaches for smarter weed management, Book of Abstracts, 18th European Weed Research Society Symposium, EWRS 2018, 17-21 June 2018, Ljubljana, Slovenia, p. 236.

DIVERSIFY – Designing Innovative plant teams for ecosystem resilience and agricultural sustainability. https://www.plant-teams.eu/

Döring TF, Annicchiarico P, Clarke S, Haigh Z, Jones HE, Pearce H, Snape J, Zhan J, Wolfe MS (2015): Comparative analysis of perfomance and stability amon composite cross populations, variety mixtures and pure lines of winter wheat in organic and conventional cropping systems. Field Crops Research 183, 235-245.

Drews S, Neuhoff D & Köpke U (2009): Weed suppression ability of three winter wheat varieties at different row spacing under organic farming conditions. Weed Research, 49, 526-533.

Hansen PK, Willas J & Kristensen K (2008) A weed suppressive index for spring barley (Hordeum vulgare L.) varieties. Weed Research Oxford, 48, pp. 225-236.

Kolb LN, Gallandt ER & Mallory EB (2012): Impact of Spring Wheat Planting Density, Row Spacing and Mechanical Weed Control on Yield, Grain Protein, and Economic Return in Maine. Weed Science 60 (2), 244-253.

Krogh SS, Mensz SJM, Nielsen ST, Mortensen AG, Christophersen C & Fomsgaard IS (2006): Fate of benzoxazinone allelochemicals in soil after incorporation of wheat and rye sprouts. Journal of Agricultural Food Chemistry 54, 1064-1074.

Lemerle D, Smith A, Verbeek B, Koetz E, Lockley P & Martin P (2006) Incremental crop tolerance to weeds: A measure for selecting competitive ability in Australian wheats. Euphytica 149: 85. https://doi.org/10.1007/s10681-005-9056-5

Madsen KH & Streibig JC (2003) Benefits and risks of the use of herbicide-resistant crops. In: Ricardo Labrada (ed.) *Weed Management for Developing Countries* Addendum 1. FAO Plant production and protection paper 120 Add. 1. Food and Agricultural Organisation, United Nations, Rome, 2003, pp. 245-55.

Mathiassen S, Kudsk P & Mogensen BB (2006): Herbicidal effects of soil-incorporated wheat. Journal of Agricultural Food Chemistry 54, 1058-1063.

Melander B, Cirujeda A, Jørgensen MH (2003): Effects of inter-row hoeing and fertilizer placement on weed growth and yield of winter wheat. Weed Research 43: 428-438.

Murphy K, Lammer D, Lyon S, Carter B & Jones SS (2005): Breeding for organic and low-input farming systems: An evolutionary-participatory breeding method for inbred cereal grains. Renewable Agriculture and Food Systems 20 (1), 48-55.

Phillips SL & Wolfe MS (2005): Evolutionary plant breeding for low input systems. Journal of Agricultural Scince 143, 245-254.

Rasmussen I (2004): The effect of sowing date, stale seedbed, row width and mechanical weed control on weeds and yields of organic winter winter. Weed Research 44 (1), 12-20.

Reiss A, Fomsgaard IS, Mathiassen S & Kudsk P (2018): Weed suppressive traits of winter cereals: allelopathy and competition. Biochemical Systematics and Ecology 86, 35-41.

REMIX – Redesigning European cropping systems based on species mixtures. https://www.remix-intercrops.eu/

Yu Y, Stomph T-J, Makowski D & van der Werf W (2015): Temporal niche differentiation increases the land equivalent ration ofo annual intercrops: a meta-analysis. Field Crops Research 184, 133-144.

Zhang F & Li L (2003): Using competitive an facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. Plant and Soil 248, 305-312.

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