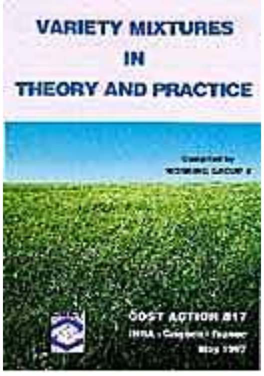
Variety Mixtures in Theory and Practice



Some case studies compiled by the Variety and Species Mixtures working group (WG2) of COST Action 817 (Agriculture and biotechnology) entitled: 'Population studies of airborne pathogens on cereals as means as of improving strategies for disease control.'

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Variety Mixtures: Concept And Value

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Crop monoculture and diversity

It is only in the last hundred years or so that crop monoculture has become predominant in industrialised agriculture for field and plantation crops. The reasons were for simplicity of planting, harvesting and other operations, which could all be mechanised, and for uniform quality of the crop product. However, monoculture produced severe disadvantages, such as vulnerability to diseases, pests and weeds, and yield instability, which necessitated, for example, the large-scale use of pesticides, fertilisers and growth regulators.

Breeders, of course, have tried to breed for disease and pest resistance, but success has often been short-lived, because of the scale of monoculture and the poor management of resistant varieties after their release into agricultural production. Poor management in this case means the use of individual resistant varieties on a large scale which usually leads rapidly to selection of new pathogen races able to overcome the resistance.

Levels of monoculture

From the point-of-view of disease, we need to think of monoculture at three levels.

- Species monoculture: the production of, say, wheat, as a single species on large areas, often in continuous cultivation or in wheat-dominated rotations.
- Variety monoculture: within the species monoculture, single varieties are often used continuously on large areas, providing maximum opportunity for selection of pathogens and pests that are well-adapted to growing on the particular variety.
- Resistance monoculture: even though different varieties may be used simultaneously, they may have the same disease resistance so that they appear identical to a particular pathogen.

To avoid or reduce some of the problems of monoculture, we need to introduce and manage diversity in better ways. At the highest level, species monoculture is difficult to change, at least in the short term. At the variety level, diversification is easy to manage, in the form of variety mixtures within the field. Variety mixtures can be produced commercially or by the farmer at low cost, to produce good disease control and yield stability. Composition of mixtures can be changed to delay selection of pathogen races able to overcome more than one component of each mixture. The main disadvantage is that the quality of the mixture may not be acceptable to the end-user of the crop product.

Breeders can diversify at the resistance level, to produce lines of a single variety that possess different resistance genes (multiline varieties), but this is difficult, time-consuming and often not legally acceptable. Also, the differences in disease resistance among the component lines may be small relative to differences among varieties. On the other hand, the lines can be selected to vary in disease resistance but to be uniform for good quality.

Variety mixtures or multilines can improve significantly the control of any disease that has an air-borne dispersal phase (rusts, mildews, *septorioses, helminthosporioses, Rhynchosporium* and even *Pseudocercosporella herpotrichoides)*, often to the extent that the use of fungicide becomes uneconomic. Because of this and other interactions among the components, mixtures provide a buffer against environmental variation so that yield is stable among environments.

Stability of yield is extremely important for the farmer. Because of environmental variation among mixture components, it is not possible to forecast which component will give the best yield in the next season. The safest gamble, therefore, is always to grow the mixture.

Malting barley mixtures in the German Democratic Republic

One of the most remarkable examples of the large-scale use of variety mixtures in industrialised agriculture was the development during the 1980's of the use of spring barley mixtures in the former German Democratic Republic. Following the recognition of the problems caused by the powdery mildew pathogen in monoculture of barley varieties, and of the high cost of western fungicides, the Government implemented the use of barley mixtures nationwide. As the acreage increased, the average national incidence of mildew declined from more than 50% to little more than 10%, leading to a massive reduction in fungicide use for mildew control. At the same time, national yield levels remained high and the crops were used successfully for malting and brewing, with much of the production being exported to west European countries. This was achieved because the breeders produced only high malting quality varieties and they were careful to ensure that the mixtures contained components that were well-matched for quality characteristics.

Management for disease resistance was less than optimal; many different varieties were used to produce a range of mixtures, but we found that many of the varieties contained the same resistance genes, i.e. variety diversity was far greater than resistance diversity. Despite this disadvantage, the mixtures were effective until the time of political re-unification in Germany when the whole project was stopped. Variety and resistance monoculture has now been re-established at the cost of a large-scale expansion of fungicide use combined with over-dependence on the single Mlo resistance gene.

The way forward

From this and other examples, it is clear that variety mixtures can be used successfully on a large scale, but to do so requires more publicity and information on the potential value and advantages of mixtures for individual farmers, together with incentives related to the benefits for the environment as a whole.

The following short articles summarise some information on how mixtures work to control disease, together with some of the ways in which mixtures are being used at present to improve monoculture in industrialised agriculture.

Mechanisms of Variety Mixtures for Reducing Epidemics

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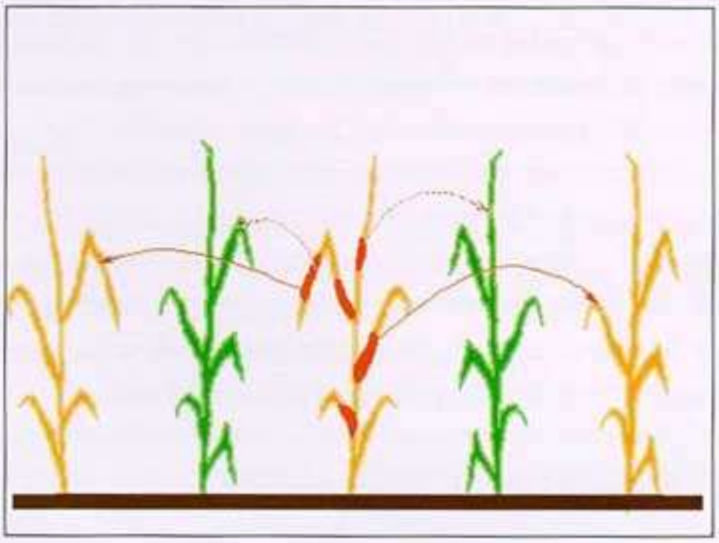
The use of varietal mixtures is an epidemic control strategy that has been shown to be effective against air-borne pathogens of crops developing polycyclic epidemics. Basically, and this is a generality for pathosystems, host mixtures may restrict the spread of diseases relative to the mean of their components, provided that the components differ in their susceptibility. Most studies, however, have been developed for specialised pathogens and specific resistance genes, When a pathogen develops epidemic cycles in a mixture, the numbers of new lesions generated for each cycle is considerably reduced compared to what would happen in a pure stand. This operates in three principal ways that have been identified through both experimental and theoretical work.



In a mixture, a part of the spores released from an infected plant is lost on resistant plants (in green). The number of spores producing new infections on susceptible plants (in yellow) is considerably reduced due to the lower density of susceptible plants and barrier effect of resistant plants

The first mechanism of disease reduction is the decrease in the spatial density of susceptible plants. In a mixture, the probability of a spore released from a lesion to be deposited on susceptible tissue is reduced in relation to the density of susceptible plants. When the distance between susceptible plants increases, it becomes increasingly unlikely for a spore to land on a suitable host. In addition to host density, the presence of resistant plants in the canopy provides a physical barrier against spore dispersal.

These two mechanisms appear to be mechanical effects related to the way the pathogen spores are spread and to the distribution of resistant and susceptible hosts. Therefore, the magnitude of disease reduction that can be expected depends on parameters such as the spore dispersal gradient, the lesion growth rate, plant size, distribution of the plant genotypes (groups of plants or random distribution) etc. Pathosystems with the best characteristics for effective use of mixtures include particularly the air-borne pathogens of small-grain cereals (for example, barley powdery mildew). In host mixtures, the genetic diversity of the pathogen population is greater than in a cultivar stand and, for a given host component, pathogen and non-pathogen spores coexist. Therefore a third mechanism of disease reduction in mixtures is the resistance induced by non-pathogenic spores on host tissue that prevents or reduces infections from normally pathogenic spores that are deposited in the same area. Either the infection efficacy or the lesion productivity can be reduced. Induced resistance is a general mechanism in pathosystems and its characteristics may vary from case to case. It has been suggested however, that even very localised effects in terms of susceptible tissue area protected by a non-pathogenic spore may result in significant disease reduction at the epidemic level. Experimental studies have shown that induced resistance could account for 20% to 40% of the disease reduction in mixtures.

Variety mixtures do not eliminate the pathogen as a fungicide might. Rather, they reduce the rate of disease progress by eliminating large numbers of spores at each cycle of pathogen multiplication. Spores are lost on resistant plants or because of the larger distance between susceptible plants and the infection processes are perturbed by induced resistance. The result is a high level of partial resistance.

Focal development of disease in a field plot of pure line of wheat inoculated with yellow rust at the centre.

Disease development of yellow rust in field plot of mixture of wheat varieties whith different resistance genes.

Variety and Species Mixtures in Practice

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Who grows mixtures where?

Variety and species mixtures are not only being used extensively in small-scale subsistence agriculture worldwide but also in large-scale systems. In 1996 we sent an informal questionnaire to researchers worldwide who we thought were interested in mixture production: we received a total of 12 replies from 10 countries. Areas grown are substantial.

Why do growers grow mixtures?

Growers grow mixtures for many reasons, for example:

- Protection from air-borne diseases such as rusts and powdery mildews.

But also:

- *Rhynchosporium, Septoria,* and *Pseudocercosporella* (cultivar and species mixtures).
- Protection from cold injury (in the US, Pakistan and Poland).
- To achieve better quality (Switzerland, Coffee in Colombia).
- To achieve higher yield stability.

What are mixtures used for?

Part of mixture production is for animal feed, however, cereal cultivar mixtures in Switzerland, Poland and the US are used for bread and beer production. Most interesting is the fact that the highest quality coffee of Colombia is almost all produced in cultivar mixtures to protect the coffee from the coffee rust disease. These mixtures are perennial and have been successful since 1982 on a large scale.

Variety Mixtures: 19 Years of Experience in Denmark

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In 1979, seed companies were allowed for the first time to produce and sell variety mixtures of spring barley in Denmark. A committee appointed by the Danish State Seed Testing Station (now Danish plant Directorate) approved the mixtures according to the following criteria:

- Only varieties from the Danish National List of Varieties could be used as components
- Mixtures should be composed so as to reduce harmful organisms (mainly powdery mildew, rust and nematodes)
- A mixture should be composed of at least four varieties representing at least three different sources of resistance to powdery mildew
- The components should be uniform with respect to maturity
- A mixture should be composed of equal amounts of the component varieties.

A major revision of the criteria is under preparation in 1997. In the first years, only few mixtures were registered. For instance in 1981, six mixtures were approved, all of which included at least one variety with *Laevigatum* resistance. For the growing season 1997, 49 different mixtures have been approved, involving

20 different varieties from six resistance groups (Algerian, Arabische, Monte Cristo (+lm9), Mlo, Ricardo and Rupee). The most frequently-occurring varieties are Lamba (Ri,Tu2) in 71% of the mixtures and Meltan (Ru,lm9,Hu4) and Goldie (Ar,La,U), respectively, in 51 and 57%. Three-quarters of the mixtures include a variety possessing Mlo-resistance.

In the mid-80s, winter barley varieties with powdery mildew resistance were released and an increasing interest for winter barley mixtures led to a law which allowed mixtures from 1987. The criteria for winter barley mixtures were similar to those for spring barley: only varieties from the Danish National or EU List of Varieties can be mixed and only with equal amounts of the components. The mixtures may be composed of three or four varieties, which are uniform with respect to maturity. In addition, information on winter-hardiness and resistance to powdery mildew is considered. Eight mixtures were approved for the season 1996/97.

Area of variety mixtures

Based on information from second generation certified seed, mixtures were grown on 6 to 15% of the spring barley area in the years 1980 to 1997; from 1986 it was 11% or more. The actual area was probably 2-3% greater because some farmers use their own seed for mixing. During the last two years, the area has decreased slightly, possibly due to lesser mixing effects and increasing areas with malting barleys, which are grown only in monoculture. In 1996, 62,000 ha (9.7%) were grown with spring barley mixtures. The area with winter barley mixtures was considerably less, that is up to 4%, and in 1995/96 the area was 2,400 ha (1.2%).

Grain yield and powdery mildew in barley mixtures

From 1979 to 1991, The Danish Agricultural Advisory Centre conducted more than 230 trials with spring barley mixtures in sprayed and unsprayed trials. In summary, the mixtures yielded from 1 to 7% (average 3%), more than the mean of the varieties in pure stand in unsprayed trials. In the same period, the powdery mildew score (0-10 with 0 = no powdery mildew) varied between 0, 1 and 7 in the mixtures. The mean powdery mildew scores of the component varieties were equal to the mixture scores in years with low levels of powdery mildew, or higher in years with high levels. Since 1983, a mixture has been used as a standard in the National trials, The mixture changed over the years as single component varieties were replaced with more up-to-date varieties. Using this scheme, greater stability over years is expected. When comparing the variation in yield of variety mixtures with that of the highest yielding variety it is clear that the stability of mixtures is greater over years than that of varieties in pure stand. In the last 2-3 years, the yields of mixtures compared to the means of components has declined, probably because component resistances such as Mlo, Tu2 and lm9, are still effective.

Grain yield, yield increase in sprayed plots, pct. powdery mildew and scald in spring barley mixtures and their components, 1995 and 1996 (Data from The Danish Agricultural Advisory Centre)

	Powdery mildew resistance	Yield in unsprayed plots hkg/ha 1995	1996	Yield incr. in sprayed plots hkg/ha 1995	1996	Pct. powdery mildew 1995	1996	Pct. scald 1995	1996
No. of trials		5	4	5	4	4	4	4	4
Mixture		62.5	69.0	2.3	0.4	0.1	0.0	3.4	0.1
Alexis	Mlo	61.5	69.4	3.0	1.1	0.0	0.0	5.0	0.2
Meltan	Ru,Im9, Hu4	63.9	64.9	-0.1	1.2	0.0	0.0	1.9	0.1
Goldie	Ar,La,U	63.1	69.7	1.6	1.5	0.0	0.0	4.3	0.1
Canut	Ly,La	60.1		4.7		1.6		10.6	
Lambda	Ri,Tu2		70.2		1.5		0.0		0.1

From 1983-86, trials with winter barley mixtures were conducted at the Danish Government Research Stations. In unsprayed plots, the levels of leaf blotch and scald were reduced significantly and small but non-significant yield increases were obtained commonly in the mixtures compared with the mean yields of the component varieties grown alone. It was concluded that the winter barley mixtures had a greater ability to utilise growth factors than did pure varieties.

Other mixture trials

During the last five years, The Danish Agricultural Advisory Centre has tested four variety mixtures of winter wheat. The results obtained on disease reduction and yield increase are similar to those from trials with barley mixtures. Mixtures of pea varieties have been tested for three years and in each year the mixtures yielded more than the means of the four components (2 to 4%). However, sales of winter wheat or pea mixtures are not yet allowed in Denmark.

Interspecies mixture: Wheat, Oat and Barley

Wheat varietal mixture

'Extenso' Production and Cereal Mixtures in Switzerland

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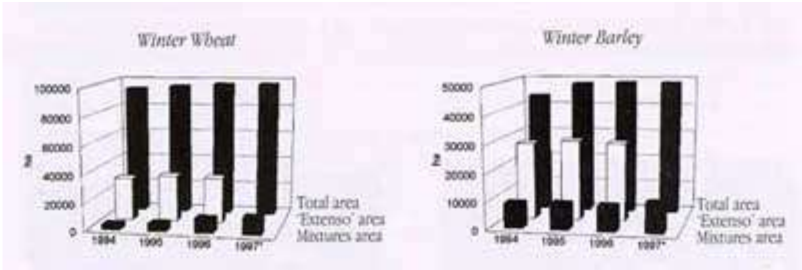
Intensification of agriculture in Switzerland after World War II increased production too far and led to problems such as high financial input and negative impact on the environment, The government therefore introduced new agricultural policies. An essential part was a shift from price support to direct payments, linked increasingly to IP (Integrated Production). In 1992, financial support for extensive cereal production ('Extenso') was introduced (800 SFr./ha). 'Extenso'-production means no application of fungicides, insecticides or growth regulators. Many farmers realise that 'Extenso' is an economical and ecological alternative, particularly where mixtures are used to provide disease control in place of fungicides. As a consequence, the importance of mixtures has increased since 1992.



The list of recommended barley varieties, which all originate from outside Switzerland, changes every year. The seed suppliers offer pre-made mixtures, mostly with two components only, which are tested and recommended by the research stations, advisers or farm schools, Other variety mixtures are made up by the farmers themselves.

In contrast, the wheat seed market is more stable; for example, today's most popular variety has covered 60-70% of the wheat area for more than ten years. Most wheat varieties used are bred in Switzerland in programmes in which disease resistance is the first criterion for selection, followed by baking quality, lodging resistance and yield; fungicides, insecticides and growth regulators are never used during the breeding and recommendation process. As wheat price is based on quality and there are only few varieties within the highest class, there is currently only one favourable combination available for use as a variety mixture.

Legislation to allow for the legal maintenance and sale of 'population varieties' was initiated through the revision of the 'Ordinance on Production and Circulation of Cereal Seed'. Since 1995, registration of breeding lines for the sole purpose of use as mixture components has become possible. Such breeding lines are subject to the same protection rules as varieties. So far, however, no breeding line mixture has been submitted for homologation.

Summarised Variety Mixture Information Given to Polish Farmers

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The use of variety mixtures in barley cultivation has been introduced widely into practice during the nineties and has now reached about 80-90,000 hectares. So far, the main concentration has been on spring-sown feed barley mixtures (eight mixtures recommended), but two spring-sown malting mixtures and three winter barley mixtures have also been recommended, The following two paragraphs and table summarise the information given to farmers on these mixtures.

The mixtures are designed particularly for control of powdery mildew, but more general recommendations for their use are given to farmers:

- because of their broad genetic variation, variety mixtures have greater environmental plasticity than pure varieties and are therefore recommended for use in the country as a whole
- yields of the mixtures are greater and more stable than those of pure varieties
- crops are healthier, mainly through reduced mildew infection, and less likely to lodge
- the reduced need for fungicides lowers production costs and reduces contamination of the environment
- variety mixtures should be cultivated in the same way as pure varieties.

Before introduction into commercial production, candidate mixtures and their variety components are grown in replicated, small plot (10 M2) field trials for three years at three or four sites. The best performing mixtures are selected for multiplication (initially as pure varieties with the final year as a mixture). Examples of trial performance of four recently selected barley mixtures are as follows.

JP5		JP6		JP7		JP8	
Boss	63.6	Boss	56.4	Boss	64.7	Boss	64.7
Edgar	62.2	Ekol	55.2	Rambo	64.1	Rambo	64.1
Ekol	61.6	Rabel	57.1	Rabel	65.4	Bryl	64.7
Mean	62.5	Mean	56.2	Mean	64.7	Mean	64.5
Mix	64.5	Mix	57.0	Mix	67.0	Mix	67.0
%	103	%	101	%	104	%	104

Future research on variety mixtures will include practical aspects such as control of pests and weeds and pre-breeding for mixing ability together with longer-term investigation of plant development and inter-plant interactions. There will also be further investigation of cereal species mixtures, which are even more widely used by Polish farmers.

Crop Mixtures Peer-Reviewed Publications from the James Hutton Institute

Newton, A.C., Guy, D.C., Bengough, A.G., Gordon, D.C., McKenzie, B.M., Sun, B., Valentine, T., Hallett, P.D. 2012 Soil tillage effects on the efficacy of cultivar and their mixtures in winter barley. Field Crops Research 128, 91-100.

Newton, A.C., Guy, D.C. 2011 Scale and spatial structure effects on the outcome of barley cultivar mixture trials for disease control. Field Crops Research 123, 74-79.

Marshall, B., Newton, A.C., Zhan, J., 2009. Quantitative evolution of aggressiveness of powdery mildew in a two-cultivar barley mixture. Plant Pathology 58, 378-388.

Newton, A.C., Guy, D.C., 2009. The effects of uneven, patchy cultivar mixtures on disease control and yield in winter barley. Field Crops Research 110, 225-228.

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Newton, A.C., Swanston, J.S., Guy, D.C., Ellis, R.P. 1998. The effect of cultivar mixtures on malting quality in winter barley. Journal of the Institute of Brewing 104, 41-45.

Newton, A.C., Ellis, R.P., Hackett, C.A., Guy, D.C. 1997. The effect of component number on *Rhynchosporium secalis* infection and yield in mixtures of winter barley cultivars. Plant Pathology 46, 930-938.

Goleniewski, G., Newton, A.C. 1994. Modelling the spread of fungal diseases using a nearest neighbour approach: the effect of geometrical arrangement. Plant Pathology 43, 631-643.

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Newton, A.C., Thomas, W.T.B. 1992. The effect of specific and non-specific resistance in mixtures of barley phenotypes on infection by mildew (*Erysiphe graminis* f.sp. *hordei*) and on yield. Euphytica 59, 73-81.

Related SCRI (Scottish Crop Research Insitute) Annual Report Articles

Crop diversity - new opportunities for low-input industrial crops? A.C. Newton and J.S. Swanston (SCRI Annual Report 2003/04)

The role and importance of canopy heterogeneity A.C. Newton, G. Bengough, G. Begg, J.S. Swanston and C. Hawes (SCRI Annual Report 2002/03)
Cereal variety mixtures reduce inputs and improve yield and quality - why isn't everybody growing them? A.C. Newton and J.S. Swanston (SCRI Annual Report 1998/99)