THE ROLE OF HOST PLANT RESISTANCE TO PESTS IN ORGANIC AND LOW INPUT AGRICULTURE

P.R. ELLIS

Institute of Horticultural Research, Wellesbourne, Warwick, CV35 9EF, Great Britain.

ABSTRACT

Resistant varieties of crops offer a cheap, long-lasting and environmentally-acceptable method of crop protection which is particularly suitable for organic and low input agriculture. The role that resistant varieties can play in these methods of agriculture is illustrated by reference to examples from several different crops. The advantages and disadvantages of resistant varieties in crop protection are discussed.

INTRODUCTION

Growers' dependence on insecticides to control important pests of agricultural crops has long been the concern of research workers at many centres throughout the world. It has been considered unwise to rely on a single method of control including, for example, conventional pesticides because of problems such as the development of insecticide-resistant strains of pests. In addition, concern has increased because of the adverse side effects of many compounds which may lead to the destruction of natural enemies of pests and other wildlife and may also lead, through their residues, to undesirable levels of contamination of crops, soil and rivers. Therefore research efforts have concentrated on a wide range of alternative crop protection measures which may ultimately be integrated in a more balanced programme of pest management. The pressures from consumers to reduce chemical use and the dramatic media attention attracted by pest control issues have contributed to a wider concern over insecticides which has vindicated the objectives of many long-established research programmes.

At this conference several different alternatives to insecticides are being discussed including, for example, mixed cropping and biological control (see earlier reports); in this paper I will concentrate on the potential of host plant resistance to contribute to crop protection in organic and low input agriculture. Knowledge in this area of crop protection has increased greatly over the last two decades and the full potential of resistant varieties is only now being appreciated as complex interactions between crop, pest and the environment are unravelled. The use of resistant varieties has great advantages over many other crop protection measures but, like all approaches, it also has certain drawbacks and complications. In this presentation I will discuss these points by referring to examples selected mainly from the work of my Institute.

THE NATURE OF PLANT RESISTANCE

In the wild state, plants grow in diverse ecosystems in which large numbers of animal and plant species co-exist; under these conditions, a balance is achieved between herbivores and host-plants, each species evolving to survive and reproduce in a constantly-changing environment. Man's agricultural practices have disrupted this balance and have led to the development of cropping systems in which plants are often grown in monocultures aimed at maximising yields and eliminating all other organisms, whether they are animal or plant. Any animal species which can invade this totally alien niche and survive has discovered an abundance of food which has enabled it to multiply and compete for the resource. There is evidence that the crop varieties which have been bred to occupy monocultures enriched with high levels of fertilizers are 'soft' and much more susceptible than their wild relatives to attack by pests and diseases (Russell, 1978). This ultra-susceptibility may have been enhanced by the practice of seed companies to use insecticides to protect seeding crops from pest attack, thus preventing natural selection from favouring the survival of the most resistant plants in the field. More recently, attempts have been made to reverse these trends by re-introducing genes for resistance to pests into modern varieties.

Plant resistance has been defined as the expression of the variable interaction between the physiology or anatomy of a plant and the physiology or behaviour of the pest (van Emden, 1987). Most resistance characters are heritable and they can be selected for and bred into new varieties. However, it must not be forgotten that, by manipulating the environment of the plant or its physiological state, it may be possible to favour the plant and reduce insect attack. In this way, components which may not be heritable are exploited. The aim of the plant resistance specialist is to tip the balance between crop plants and their insect pests in favour of the plants. Resistance levels vary from very low, where there are slight adverse effects on the insects' development and survival, to levels of immunity where the pest is not supported - such is the variable nature of resistance. Even partial levels of resistance can make a valuable contribution to crop protection. In certain cases, we may not be aware that partial levels of resistance exist in commercially-acceptable varieties of a crop, particularly where the crop is treated routinely with insecticides; there is little chance for slight differences in susceptibility to be manifested under these circumstances. It would be worthwhile evaluating existing varieties of these crops to determine their level of resistance to a particular pest. Indeed, in most resistance breeding projects, the first phase of screening for sources of resistance concentrates on crop varieties because this material requires the minimum adaptation by plant breeders. The search extends wider and wider towards wild species if no valuable sources of resistance are found in crop varieties. At Wellesbourne, we have discovered varieties of carrots which provide partial levels of resistance to the carrot fly (*Psila rosae*). This resistance can provide a 50% reduction in damage and a 50% reduction in the numbers of carrot fly colonising the crop when compared with very susceptible varieties (Ellis *et al.*, 1984). In an integrated programme of carrot fly control, this level of resistance can lead to substantial reductions in insecticide use (Thompson *et al.*, 1980). Prior to our research, seed companies and growers had not been aware of the existence of this resistance in carrots to carrot fly. In the future, we are likely to be more aware of the existence of partial levels of resistance as increasing numbers of seed companies treat the resistance of crops to insect pests as a major objective of their breeding programmes. This is encouraging news for the exponents of organic and low input agriculture.

Most research on crop resistance, and its subsequent development, concentrates on genetic variation in plants. However, it was emphasised earlier that considerable variation in susceptibility can arise from environmental or physiological factors. These factors should not be overlooked as they may contribute significantly to crop protection in organic and low input agriculture. Thus, certain management practices can influence the degree of plant resistance. For example, levels of the three major plant nutrients (nitrogen, potassium and phosphorus) often have far-reaching effects on the physiology of plants and, in turn, this may influence insect behaviour. In particular, many pests have been shown to develop faster in crops with increased rates of nitrogen fertilisation; van Emden (1987) quotes several examples of this. The literature also includes some conflicting reports on this phenomenon but, in most cases, an increase in pest numbers is associated with increased fertiliser levels. It follows therefore that reduced use of fertilisers in organic and low input agriculture is likely to lead to reduced numbers of pest insects.

RESISTANT VARIETIES AS THE PRINCIPAL METHOD OF CROP PROTECTION

Resistant varieties of crops offer the organic and low input farmer a most valuable crop protection measure. If the level of crop resistance to a pest is high enough on its own to permit the crop to be grown economically, this approach may be the principal method used to solve the pest problem. However, as I stressed earlier, to rely on a single method of control is unwise as the pest may adapt to the high selection pressure imposed by the method of crop protection. Therefore, even where completely resistant varieties are available, it is wise to integrate their use with some other measure. Very good examples of this exist. Some lettuce varieties, bred at Wellesbourne and by seed companies, are available which possess immunity to attack by the lettuce root aphid (*Pemphigus bursarius*). As these varieties provide a degree of protection which is better than that provided by insecticides (Dunn & Kempton, 1974), they offer to growers, whether they are organic, low input or conventional, the perfect answer to this pest problem. Despite this level of crop protection, growers would be well advised to adopt a course of rotation, in time and space, so that build-up of the lettuce root aphid is discouraged. The protection of lettuce against this pest with resistant varieties/cultivars illustrates some of the advantages of plant resistance over the use of chemicals. No special equipment is required in using the resistant varieties and no extra cost is borne by the grower - varieties of lettuce resistant to root aphid cost no more than susceptible varieties. In addition, the growing of the resistant lettuce varieties has no known effect on natural enemies of the root aphid or on wildlife, while insecticides may adversely affect predators, parasites and wildlife, as well as present a potential hazard to the operator. Another advantage of using resistant varieties is the freedom from concern over the presence of insecticide residues in the marketed crop; this can be a special problem with short season crops, for example lettuce.

The growing of raspberry varieties resistant to the raspberry aphid (*Amphorophora idaei*) provides growers with an ideal method of crop protection because the varieties are resistant to not only the pest but also to the virus it transmits. The varieties are an attractive proposition to organic and low input growers and they offer the principal method of managing the pest and disease (Keep *et al.*, 1980). Four races of

A. idaei are known to exist but a range of varieties which possess resistance to all of them is available. Breeding crop varieties for resistance to virus vectors is now an important objective of many research institutes and seed companies, even in cases where the vector itself causes little damage (Jones,1987). This is because resistant varieties provide one of the most satisfactory methods of combatting those viruses borne by vectors which are inadequately controlled with chemicals.

The use of resistant varieties is particularly advantageous where a low-value crop is being grown and where chemical control may not be justified. In certain cases, the fact that the use of insecticides is uneconomical has provided the impetus to develop resistant varieties. A very good example of this is in the control of the hessian fly (*Mayetiola destructor*) which, for many years, threatened wheat production in north America, causing in excess of $100 million damage each year (Luginbill, 1969). Because it was prohibitively expensive to control this pest with insecticides, a concerted effort was made to breed resistant varieties of wheat (Painter, 1951). This research programme was highly successful and, in 1980, Everson & Gallun reported that 42 different varieties of wheat resisting the various races of *M. destructor* were grown annually in more than 30 states and provinces in north America. This pest and the wheat stem sawfly (*Cephus cinctus*), the other important pest of wheat in America, are controlled solely by resistant crop varieties (Everson & Gallun, 1980). Perhaps the present increase in organic and low input agriculture will provide the necessary impetus to persuade government and industry to invest more heavily in the breeding of resistant varieties of crops.

RESISTANT VARIETIES AS A SUPPLEMENT TO OTHER METHODS OF CROP PROTECTION

It is unusual to discover immunity to a pest in crop varieties or closely-related plant species but examples were mentioned above. More often, partial levels of resistance are discovered and these effect reduced damage and/or reduced numbers of the pest. We are discovering more and more examples of partial resistance as we unravel the complex relationships between plants, pests and the environment. We are also discovering many more ways of utilising this partial resistance in pest management. This is encouraging for organic and low input farmers because the partial resistance may lead to reduced chemical and labour inputs.

Two of my Institute's research projects and some research from Germany provide excellent examples of the contribution of host plant resistance to integrated programmes of pest control. In the protection of carrots against the carrot fly, partial levels of resistance have been shown to complement cultural and chemical methods of reducing crop damage. As mentioned above, the resistance to carrot fly discovered in certain commercially-acceptable carrot varieties provides a 50% reduction in damage to carrot roots and a 50% reduction in the numbers of carrot flies remaining at the end of the season compared with certain susceptible varieties (Ellis *et al.*, 1984). Although this level of resistance is insufficient when used alone, the marketed portion of the crop being damaged by the pest and very high levels of control being demanded by the industry, we have demonstrated that the partial levels of resistance complement the effects of insecticides against carrot fly. In experiments over two seasons at two sites, only one third of the dose of a soil-applied insecticide was required to provide adequate control of carrot fly on cv.

'Sytan', a partially resistant cultivar, compared with the dose on cv. 'Danvers Half Long 126', a cultivar highly susceptible to carrot fly (Thompson *et al.*, 1980). Several other commercially-acceptable varieties of carrots which possess this partial resistance have since been identified (Ellis *et al.*, 1987; 1990).

In further experiments, cvs 'Sytan' and 'Danvers Half Long 126' were grown to investigate the influence of different times of sowing and harvesting the crop on carrot fly attack. From the results of this work, illustrated in Fig 1, it can be seen that there were significant effects of variety and of dates of sowing and harvesting. Cv. 'Sytan' was consistently less damaged than cv. 'Danvers Half Long 126', except on two occasions when carrot fly attack was in its initial stages and, consequently, slight. The difference between the varieties is shown by the fact that the level of damage recorded on cv. 'Danvers' in September from the May sowing was not reached on cv. 'Sytan' until February of the following year - a 5-month delay in the build up of damage. On both varieties there was an increase in damage as the season progressed but, by referring to the numbers of carrot flies caught on monitoring traps, it was possible to select sowing and harvest dates which would lead to minimum levels of attack. Thus, nine combinations of sowing and harvest dates provided more than 75% marketable roots of cv. 'Sytan' compared with only three combinations of dates for cv. 'Danvers'. This work illustrates the potential of partial plant resistance to complement cultural and chemical control of carrot fly, a pest which, according to a report on organic farming in Germany, is very difficult to control without resort to chemicals (Anon., 1986). Other measures which would help the organic and low input grower to cope with carrot fly include the rotation of crops, certain types of synthetic crop covers (plastic sheets or fibrous mesh) and the harvest and storage of crops before damage by second generation carrot fly builds up in the autumn; these contributions to an integrated programme for carrot fly control have been discussed recently (Ellis & Hardman, 1988).

The damson-hop aphid (*Phorodon humuli*) is a serious pests of hops and, like the carrot fly, it is presently controlled by frequent sprays of insecticides. However, problems with the use of insecticides have focussed attention on alternative control measures for this pest. In the hop garden, the aphid colonises the crop before natural enemies exert any control of the pest. However, the initial build up of the aphid populations can be reduced by using soil-applied insecticide treatments and, during the period for which the insecticide treatments are effective, the numbers of predators increase. Frequently, anthocorid bugs, chrysopids and other predators will then regulate aphids to non-damaging population densities throughout the rest of the season. The discovery of partial resistance to the pest in six hop accessions amongst a total of 500 tested offers some prospects of combining reduced doses of insecticide with plant resistance and enhanced predator activity in an integrated approach to the problem (Darby & Cambell, 1988).

The combination of natural enemies, partial plant resistance and reduced doses of insecticides offers an integrated approach to low input protection of *Vicia faba* beans from attacks by the black bean aphid (*Aphis fabae*). In experiments in Germany, the use of the partially resistant variety 'Bolero' reduced aphid damage by 60% compared with damage on the susceptible variety cv. 'Diana'. The efficiency of two aphid predators, *Chrysopa carnea* and *Coccinella septempunctata*, and of two juvenile hormones was significantly greater on the resistant than on the susceptible variety (Poehling *et al.*, 1990).

There does not appear to be any shortage of examples demonstrating the potential of partial plant resistance to make a significant contribution to integrated programmes of pest control. It is also interesting to report that sources of partial resistance appear to have been discovered wherever they have been sought. It appears that the plentiful supply of relatively cheap and effective insecticides in the last 40 years has been one of the major constraints to the identification, development and exploitation of plant resistance to pests.

PROBLEMS AND PROSPECTS

All methods of protecting crops against insect pests have their drawbacks and problems as well as their advantages; the use of resistant varieties is no exception to this rule. However, none of these appears to be insurmountable and most of the problems are less difficult to overcome than some of those associated with the widespread use of insecticides.

There is a risk in the introduction or augmentation of natural toxicants in new crop varieties; this may be a problem especially when wild species of plants are used in breeding programmes. Many of the poisonous compounds in plants are believed to be present as part of the plants' natural defence system. A good example is the occurrence of glucosinolates in cruciferous crops; these can cause goitre in humans and haemolytic anaemia in cattle. Consequently, an integral part of research programmes to breed new fodder varieties of brassicas has been to select for low levels of glucosinolates. An interesting example of breeding plants containing toxicants concerns the potato cv. 'Lenape' which contained certain poisonous glycoalkaloids. Fortunately this problem was discovered before the variety had been distributed widely. In certain cases, new varieties need to be analysed for potential toxicants. However, in most cases, genes for resistance to pests and diseases are obtained from species closely related to the crop plant and therefore pose no problem from the edibility point of view. Genetic engineers who transfer genes from distantly-related or even unrelated plant species will also need to check the edibility of transformed material.

The incorporation of genes for resistance into a new variety may carry with it some sacrifice in yield (the 'yield penalty') which may be a particular drawback in organic or low input agriculture where there is a deliberate attempt to reduce fertilizer application and where other practices also tend to reduce yields. Under conventional systems of agriculture, additional fertilizer may be used to boost the yields of resistant varieties.

Plant breeders have to contend with a wide range of breeding objectives, resistance to pests being one (currently quite insignificant) factor. Ideally, crop varieties should possess resistance to all pests, diseases and disorders as well as satisfying other market demands. When using a new variety bred to resist one particular pest, growers may wonder how to cope with the other insects or mites attacking the crop. This is a real problem with the organic growing of crops but is less of a problem when the use of insecticides is permitted. It is analogous to the biological control situation where predators and parasites may be available for certain pests in the glasshouse but, for several other pests, only chemical methods are available. In the glasshouse, growers need to be highly selective over the choice of insecticides in order that the chemical treatments do not kill the natural enemies. This is less of a problem with resistant plants where the use of an insecticide rarely interferes with the expression of resistance. To overcome problems of specificity, breeding programmes are aiming increasingly to incorporate resistance to a wide range of pests. Sweet potato breeding is a very good example of what can be achieved; in this crop, new varieties have been developed with resistance to nine insects, certain root-knot nematodes and several diseases (Jones *et al.*, 1985). At Wellesbourne, our lettuce programme aims to incorporate in new varieties resistance to downy mildew, beet western yellows virus and four aphid pests.

The development of new races or biotypes of pests has been a major problem with insecticides and has severely restricted their useful life as effective crop protection materials. In the same way as new races arise to overcome the effects of insecticides, so a new race can arise which overcomes a resistant variety. However, there are numerous cases of resistance in plants remaining durable after many years, in some cases more than 100 years. The main reason for the relative rarity of insect biotypes developing to counter previously resistant plants is the fact that the relationships between pests and plants are often very complex, several mechanisms being involved. In the case of insects, the relationships may involve antixenosis (the display of preference or non-preference) and antibiosis (the display of factors which adversely affect insect development and reproduction). There is less chance of new biotypes of the pest developing as the numbers of factors operating against the insect increase. Gallun (1972) noted that biotypes of insects seldom arise in response to antixenosis and, when faced with a non-preferred plant, they leave and seek an alternative host.

Another drawback to the exploitation of plant resistance is that it takes a long time to produce new varieties. Many different techniques are being employed to overcome this problem, such as fast-breeding plants (Williams & Hill, 1986), genetic engineering to transfer resistance genes from wild or related species and the use of biochemical markers to enable resistant plants to be identified rapidly. Genetic engineering of crops offers a promising new tool in the development of insect resistant varieties. The technique has particular advantages over conventional plant breeding approaches. For example, it has the potential to speed up the release of resistant varieties, the desired gene(s) can be transferred without the incorporation of undesirable characters and the technique offers the chance of transferring genes across species barriers. The most limiting factor to progress in this field is the failure to identify useful genes and progress may be complicated if resistance is governed by many genes; many cases of insect resistance appear to be inherited polygenically. However, notable successes have been achieved in transferring *Bacillus thuringiensis* endotoxin genes (Vaeck *et al.*, 1987) and the cowpea protease inhibitor gene (Hilder *et al.*, 1987; Gatehouse & Hilder, 1988).

In conclusion, I believe that resistant varieties offer a very satisfactory basis for the protection of crops against insect pests; the examples presented in this paper illustrate how they can provide a cheap, long-lasting, and environmentally acceptable technique which is particularly suited to organic and low input agriculture.

REFERENCES

Anon. (1986) Ministry men look at European Organic Production. In: *The Soil Association Quarterly Review, June 1986*, pp. 16-17.

Darby, P.; Campbell, C.A.M. (1988) Resistance to *Phorodon humuli* in hops. In: *Integrated pest and disease control in hops, East Malling, England, 25-27 August 1987. IOBC-WPRS Bulletin*, **XI/5**, 56-63.

Dunn, J.A.; Kempton, D.P.H. (1974) Lettuce root aphid control by means of plant resistance. *Plant Pathology*, **23**, 76-80.

Ellis, P.R.; Freeman, G.H.; Hardman, J.A. (1984). Differences in the relative resistance of two carrot cultivars to carrot fly attack over five seasons. *Annals of Applied Biology*, **105**, 557-564.

Ellis, P.R.; Hardman, J.A. (1988) Non-insecticide contributions to an integrated programme for the protection of carrots against carrot fly. In: *Working Group "Integrated Control in Field Vegetable Crops", Tune (Denmark), 21-23 September 1987. IOBC/WPRS Bulletin*, **XI/I**, 33-39.

Ellis, P.R.; Hardman, J.A.; Dowker, B.D. (1987) Screening of carrot cultivars and breeding lines for their susceptibility to carrot fly at Wellesbourne in 1983. *Tests of Agrochemcals and Cultivars (Annals of Applied Biology* **110** *Supplement)*, No. **8**, pp. 136-137.

Ellis, P.R.; Hardman, J.A.; Thompson, A.R. (1990) Integrated control of carrot fly based on carrot resistance to the pest. *Sandoz Carrot Guardian* No. **6**, pp. 1-2.

Emden, H.F. van (1987) Cultural Methods: The Plant. In: *Integrated Pest Management*, A.J. Burn, T.H. Coaker and P.C. Jepson (Eds), London: Academic Press, pp. 27-68.

Everson, E.H.; Gallun, R.L. (1980) Breeding approaches in wheat. In: *Breeding Plants Resistant to Insects*, F.G. Maxwell and P.R. Jennings (Eds), New York: John Wiley & Sons, pp. 513-533.

Gallun, R.L. (1972). Genetic interrelationships between host plants and insects. *Journal of Environmental Quality*, 1, 259-265.

Gatehouse, A.M.R.; Hilder, V.A. (1988) Introduction of genes conferring insect resistance. In: *Proceedings of the Brighton Crop Protection Conference - Pests and Diseases - 1988*, Vol. **3**, 1245-1254.

Hilder, V.A.; Gatehouse, A.M.R.; Sheerman, S.E.; Barker, R.F.; Boulter, D. (1987) A novel mechanism of insect resistance engineered into tobacco. *Nature*, **330**, 160-163.

Jones, A.T. (1987) Control of virus infection in crop plants through vector resistance: a review of achievements, prospects and problems. *Annals of Applied Biology*, **111**, 745-772.

Jones, A.; Dukes, P.D.; Schalk, J.M.; Hamilton, M.G.; Mullen, M.A.; Baumgardner, R.A.; Paterson, D.R.; Boswell, T.E. (1985) 'Regal' Sweet Potato. *HortScience*, **20**, 781-782.

Keep, E.; Parker, J.H.; Knight, V.H. (1980) Recent progress in raspberry breeding at East Malling. *Acta Horticulturae*, **112**, 117-125.

Luginbill, P. (1969) Developing resistant plants - the ideal method of controlling insects. *United States Department of Agriculture Production Research Report*, **111**, 14pp.

Painter, R.H. (1951) *Insect Resistance in Crop Plants*, New York: Macmillan, 520pp.

Poehling, H.M.; Tenhumnberg, B.; Yakti, R.; Prüter, C. (1990) Some further studies of the *Vicia faba* variety 'Bolero' showing partial resistance to *Aphis fabae*. *IOBC/WPRS Bulletin* (in press).

Russell, G.E. (1978) *Plant Breeding for Pest and Disease Resistance*, London: Butterworths, 485pp.

Thompson, A.R.; Ellis, P.R.; Percival, A.L.; Hardman, J.A. (1980) Integrated control using insecticides with carrot cultivars of differing susceptibilities. *Report of the National Vegetable Research Station for 1979*, p. 30.

Vaeck, M.; Reynaerts, A.; Höfte, H.; Jansens, S.; De Beuckeleer, M.; Dean, C.; Zabeau, M.; Van Montagu, M.; Leemans, J. (1987) Transgenic plants protected from insect attack. *Nature*, **328**, 33-37.

Williams, P.H.; Hill, C.B. (1986) Rapid cycling populations of *Brassica*. *Science*, **232**, 1385-1389.

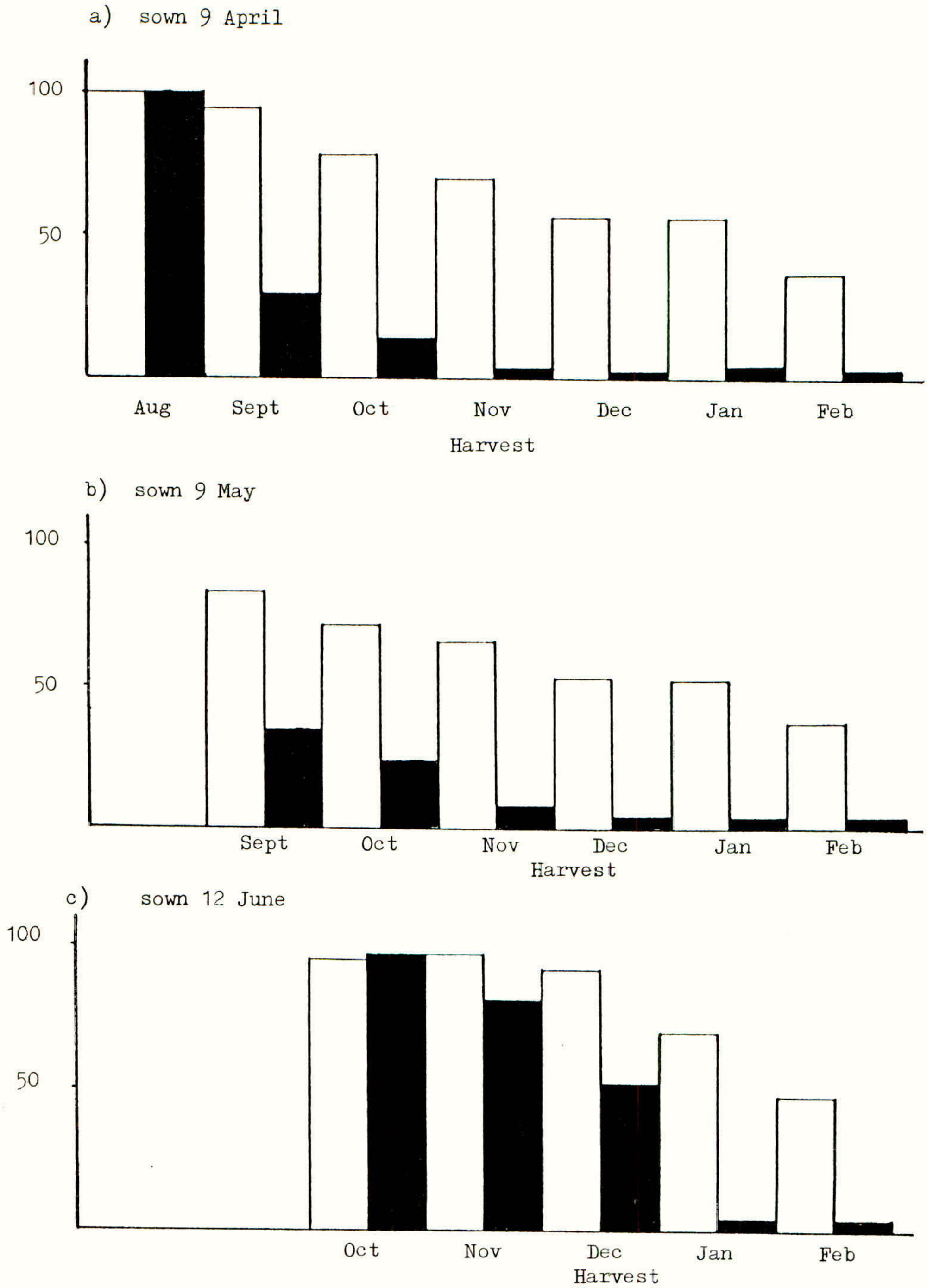


Fig. 1. The % marketable roots of two carrot cultivars, cv. Sytan (□, partially resistant) and cv. Danvers Half Long 126 (■, susceptible) tested against carrot fly at Wellesbourne in 1984-85.

4.
Disease Control

Chairman: DR R. PREW

INTRA-CROP DIVERSIFICATION: DISEASE, YIELD AND QUALITY

M. S. WOLFE

Institute of Plant Sciences, Swiss Federal Institute of Technology, CH-8092 Zürich, Switzerland

ABSTRACT

Extensive investigations with mixtures of varieties among cereal species have confirmed the effectiveness of mixtures in restraining development of a wide range of foliar diseases. These effects are often associated with yield increases in the mixtures relative to the components grown alone. Most importantly, the disease restraint and yield increases in mixtures tend to be stable over different environments when compared with the performance of the individual components. These advantages can be exploited to reduce fungicide inputs in low-input agricultural systems.
Extending these principles to the exploitation of species mixtures, or of variety mixtures combined with species mixtures, may provide a greater potential for the additional reduction of inputs of insecticides, herbicides and fertiliser.

INTRODUCTION

During the last half century, a major factor in the intensification of agriculture has been the development of pesticides. These additives have facilitated extraordinary increases in yield and have become essential to the production of some quality crops. However, disadvantages of this development are now perceived including:
- the direct cost of pesticides and the unpredictability of their cost:benefit ratio
- the tendency of pesticides to select for noxious organisms resistant to their effects, and to control beneficial organisms, particularly among arthropods, to an extent that may nullify control of the pests.

The sum of the disadvantages causes public concern to the extent that some Governments (e.g. Denmark and Sweden) now impose restrictions on pesticide use. Concomitantly this has led to an upsurge of interest in organic production and other forms of low-input, sustainable agriculture (LISA).

Unfortunately, a major method for reducing pesticide use, by maximising crop diversity through the use of long-term rotations on small fields, is not possible, because of the high demand for a small number of staple crops. Additional options are needed, therefore, to ensure control of diseases and insect and weed infestations if we are to reduce, reliably, dependence on pesticides. To a considerable extent, these will depend on breeding for resistance to pests. In breeding, however, it is difficult to combine adequate control of all major pests into a single variety. Moreover, the breeder has no control over the subsequent use of a new resistant variety in agriculture. One option, given varieties or species of crop plants that vary in resistance, is the use of mixtures of varieties or species to provide within-crop diversity of resistance; such mixtures restrict the rate of pathogen increase.

VARIETY MIXTURES: THE CURRENT SITUATION

Disease control

Evidence for the restriction of powdery mildew development in mixtures of barley or wheat varieties is extensive (e.g. Chin & Wolfe, 1984; Gacek, 1986; Hengstmann, 1987; Gieffers & Hesselbach, 1988a,c; Kolster *et al.*, 1989; Stuke & Fehrmann, 1988; Wolfe, 1990). The degree of control is negatively correlated with the potential susceptibility of the mixture. Thus, mixtures of more resistant components restrict the disease relatively more than those of more susceptible components (Buiel *et al.*, 1989; Kolster *et al.*, 1989). As a corollary, disease restriction is greater in years of lower potential infection. For example, in a long-term experiment on four spring barley varieties and the four three-component mixtures that can be made from them (Wolfe, 1990), mixtures restricted disease by 38% on average in four years of severe mildew infection but by 57% in four years with relatively light infection. Presumably, where more inoculum occurs, a greater absolute number of spores can spread from one susceptible plant to the next, thus increasing the infection rate closer to the maximum that occurs in pure stands.

Evidence for the restriction of yellow rust (*Puccinia striiformis*) and leaf rust (*P. recondita, P. hordei*) is also considerable (e.g. Hartleb *et al.*, 1986; Vallavieille-Pope *et al.*, 1988; Wolfe & Dubin, unpublished; Harjit & Rao, 1988; Malik *et al.*, 1988). Again, disease restriction is negatively associated with potential susceptibility.

Among the splash-dispersed diseases, *Septoria* infections appear to be reduced more often than not in mixtures (Jeger *et al.*, 1981; Karjalainen, 1986; Fried, 1986; Gieffers & Hesselbach, 1988c). This is probably also true for *Rhynchosporium* in barley (e.g. Gieffers & Hesselbach, 1988a,b; Wolfe & Minchin, unpublished, but see Aufhammer & Stützel, 1986). Further data are needed for pathogens such as *Pyrenophora* spp. and *Rhizoctonia cerealis*.

Mixtures are unlikely to affect the development of soil-borne diseases: infection in a mixture should be the average of the infection in the pure stand components. However, there is some evidence that mixtures can reduce infection with eyespot (*Pseudocercosporella herpotrichoides*) (Gieffers & Hesselbach, 1988a) at least in spring-sown mixtures. It may be that spread of the pathogen in spring crops is more dependent on the splash phase than in autumn-sown crops.

Since crops are often infected with a complex of diseases it is necessary to ensure that, as far as possible, a mixture is composed to restrict all of the major diseases. This is simpler than attempting to combine resistance to all diseases into a single host genotype. For example, in a winter wheat mixture used by de Vallavieille-Pope (unpublished) and in a spring wheat mixture used by Wolfe & Dubin (unpublished), one component was susceptible to yellow rust and resistant to leaf rust, while a second component had the reverse response; the third component in each mixture was resistant to both rusts. These combinations of components ensured control of both rust diseases.

An example of the effect of appropriate wheat mixtures on the disease complex can be summarised from recent data of de Vallavieille-Pope (personal communication; Table 1). The majority of '+' effects (more resistant to disease than the pure components) were statistically significant (P <5%), including one of the eyespot comparisons. The different numbers of comparisons in each column indicate the availability of disease comparisons in the trial series.

TABLE 1. Distribution of disease response in three-component mixtures of wheat varieties relative to the mean of the components.

Yellow rust		Leaf rust		Septoria		Eyespot		Green flag leaf	
+	-	+	-	+	-	+	-	+	-
8	3	17	1	18	6	2	2	22	2

Note: +, mixture is more resistant (or more green), -, less so, than the mean of the components.

Gieffers & Hesselbach (1988a,b,c) also advocated a measure of remaining green leaf to indicate the effect of the disease complex on mixtures and pure stands in their trials. While this may provide a more realistic impression of the effect of mixtures on the disease complex, compared with pure stands, the parameter is difficult to assess because observations tend to reflect the proportion of green leaf rather than the absolute amount or its quality.

Effects on yield

The most important aspect of yield in appropriately composed mixtures is their ability to buffer the crop against various stresses, giving improved yield stability relative to the components grown as pure stands (Wolfe, 1985, 1990). Unfortunately, much of the published data on mixtures is from trials in which there are few comparisons of particular mixtures and their components over many environments. Where extensive comparisons have been made, the benefit of yield stability becomes obvious. For example, Jorgensen (1989 and personal communication) reviewed 200 trials of barley mixtures over 10 years in Denmark and concluded that mixtures gave an overall yield benefit of about 4% relative to their components grown as pure stands, with the further advantages that these higher values were both stable and close to the yield of the best pure varieties. A similar conclusion was reached by Wolfe (1988) for more than 150 trial comparisons with cereals in the UK.

Two examples of the advantage of mixtures across different environments are combined in Table 2. The Table provides final yield data (t/ha) for the series of trials conducted for 8 years at Cambridge with four spring barley varieties and the four three-component mixtures that can be composed from them (Wolfe, 1990), and for trials in Germany with a three-component winter wheat mixture conducted over five sites in two years, also totalling eight trials (data derived from Gieffers & Hesselbach, 1988c). The overall advantages of the mixtures compared with the pure stands are statistically significant.

TABLE 2. Yields (t/ha) averaged over eight trials, of spring barley and winter wheat mixtures, compared with their components.

	Mixture				
	C-G-T	C-E-G	E-G-T	C-E-T	A-O-R
component i	4.33	4.33	4.33	4.94	6.47
ii	4.94	5.22	4.94	5.22	6.71
iii	5.22	5.29	5.29	5.29	6.87
mixture	5.27	5.35	5.48	5.63	7.04
mixture as % of mean	109	108	113	109	105

variety code: barley - C, Claret, E, Egmont, G, Goldmarker, T, Triumph
wheat - A, Kanzler, O, Okapi, R, Kraka

In any one trial, the mixtures were not necessarily higher yielding than all of the components. However, the highest yielding component varied among trials, so that, on average, the greater stability of the mixtures meant that each outyielded all of its components.

Some authors have been unable to find consistent beneficial effects of mixtures on disease or yield. One reason may be inter-plot interference in field trials (Wolfe, 1985). For example, Kolster *et al.* (1989), using square plots each surrounded by guard areas of a different species, showed clearly the effect of multilines of barley in controlling powdery mildew even though individual lines differed by only single genes. On the other hand, Priestley *et al.* (1988), obtained smaller effects with mixtures of varieties, even though they differed more in their resistance genotypes, probably because there were no guard areas in most of the trials. Moreover, the plots were long and narrow; such plots are less well able to buffer against inter-plot interference than are square plots.

Gieffers & Hesselbach (1988a) and others noted that performance of mixtures improved with increase in plot size; presumably this was also due to the greater buffering effect of the plot against exogenous inoculum. Beyond a certain limit of size, however, there must be a negative effect, through increased opportunity for selection of a pathogen race adapted to the mixture. This is a current concern in the use of single fields of the order of 100 ha for cultivation of single barley mixtures in eastern Germany.

Even among trials where foliar disease is not an important determinant of yield, the stabilising effect of mixtures is evident. From preliminary results from an ODA/CIMMYT trial (Wolfe, 1988; Wolfe & Dubin, in preparation) with three wheat varieties and their mixture grown over two years at different sites in south Asia, disease was generally unimportant and the mixture gave only a marginal yield increase over the mean of the components. However, the deviation from the mean yield of the components was considerably less for the mixture than for any of the three varieties grown alone.

The general conclusion is that, in the absence of serious disease, an appropriately constructed variety mixture will provide the benefit of yield stability. Where disease is serious, then mixtures will again provide yield stability, but at a higher level of yield than that of their components grown alone because of a reduction in overall disease levels. This does not take account of the potential that may exist for selection of direct complementation or resistance to other stresses among mixture components.

Durability of disease control

Jeger *et al.* (1981) pointed out that mixtures of varieties varying in degree of disease resistance (or susceptibility) support less infection of unspecialised pathogens than expected from the mean of their components grown alone. In other words, the resistance of such mixtures can be regarded as durable since novel specialisation of such pathogens is not expected.

From this observation, it may be argued that even if specialised pathogens become adapted to mixtures, it is likely that there will be residual differences in resistance (or susceptibility) among the components and that the mixtures will support less disease than the mean of the components grown alone. Thus mixtures are likely to have residual durable resistance against all pathogens, whether or not the latter show host specialisation.

However, against specialised pathogens, the resistance of individual components against different fractions of the pathogen population is usually exploited, which raises the question of the durability of the observed effects on disease restraint. Critical answers are difficult to obtain, partly because information from small plot trials is unreliable as an indicator for the likely course of events in large-scale exploitation of mixtures. This is because, in such trials, the starting inoculum for the epidemic generally comes from surrounding crops of pure varieties, not affected by the production of mixed varieties.

From the long-term trials with four spring barley varieties and their four three-component mixtures, Wolfe (1990) observed that over this period, the English population of the mildew pathogen changed from a high frequency of simple races (e.g. races able to overcome only one of the varieties in each mixture) to a high frequency of complex races. This was due to a rapid increase in cultivation of new pure varieties, each of which had several resistance genes combined and which thus caused direct selection and increase of the complex races. This led to increased infection by powdery mildew of the commonly grown pure varieties. During these changes, the mixtures tended to become less effective in controlling the disease, but their yield advantage did not change. The increase in infection of the mixtures may have been due, in part, to the generally higher infection levels (see above). In addition, it may have been due to the higher frequency of complex races, able to attack more than one component of each mixture. It is important to stress, however, that mixtures are unlikely to select for complex races as rapidly as do pure varieties with combined resistances.

Currently in Europe, the best opportunity to determine the effect of the large-scale use of variety mixtures on the pathogen population is in eastern Germany, where the spring barley crop is grown almost entirely as variety mixtures. Preliminary indications suggest that, so far, there has been little effect of the mixtures in selecting complex races. Indeed, data from Gabler (personal communication) suggest that pathogen populations on mixtures may be simpler than those on pure stand controls. On the other hand, McDonald et al. (1989), investigating the response of the *Rhynchosporium secalis* population to different composite cross populations of barley, found that the complexity of host and pathogen populations were correlated in terms of, respectively, resistance and pathogenicity genes. However, they too found no evidence for the selection of "super" races.

Recent investigations by Hovmoller & Ostergaard (1990) and Mundt & Brophy (1988), suggest that the underlying cause of selection of new genotypes in the pathogen population may be the overall frequency of resistance genes in the host population rather than the form of their dispersion. If so, this would not negate the value of mixtures but rather underline the need for maintenance and increase in diversity of resistance in the host population.

A different approach to durability is implicit in the successful use of multilines of wheat for control of rust diseases in northern India (Gill *et al.*, 1979; Gill, Nanda personal communication). The main area of multiline cultivation is in Himachal Pradesh in the hilly areas north of the major wheat-growing areas in the plains. Normally, the rust pathogens oversummer in the hill areas and spread southwards during the cooler wheat-growing season. However, the multilines help to minimise rust epidemics in the hill areas so that little inoculum is available to initiate rust epidemics in the plains. Furthermore, there is a different distribution of resistance genes in the plains so that any rust that does develop is unlikely to be well-adapted for infection of the multilines in the hills. This epidemiological cycle may well help to explain the apparent long-term durability of both multilines and pure varieties grown in northern India.

Large-scale use of variety mixtures

The use of multilines in India is an important example of the large-scale use of within-crop diversity in modern agriculture. However, the most ambitious project currently is the use of barley mixtures in eastern Germany, principally for the control of powdery mildew. For the last two years approximately 350,000 hectares have been cultivated in this way, representing virtually the whole of the spring crop, almost all of which is used for malting. As a result, fungicide use has been reduced whilst maintaining normal yields; this is very different from the early 1980's when fungicide use was increasing and pure crops were severely affected by mildew. However, there is now some threat to the project following the moves towards German unification since there may now be an attempt again to increase the use of fungicides for mildew control, with a return to intensive agriculture.

Simultaneously, in other parts of western Europe, particularly in Denmark and Sweden, there is governmental action to reduce inputs, including pesticides, which has stimulated further interest in the larger scale use of variety mixtures.

One perceived difficulty that has held back development of the use of mixtures is that of quality. This has been circumvented in eastern Germany and parts of the United States by re-defining the quality criteria from a basis of "pure variety" to that of "acceptably uniform quality for processing". It seems that wheat mixtures and multilines are now used on a considerable scale in the USA, largely through farmer initiative (Marshall, personal communication).

Mixtures are used extensively in parts of the developing world, largely by chance, because of the lack of adequate seed production facilities. Where such mixtures are composed of modern varieties carrying different but effective resistance genes, they may be providing useful, hidden benefits for the growers. The benefits could be greater, however, if the mixing was more controlled.

VARIETY MIXTURES: FUTURE PROSPECTS

There seems no doubt that variety mixtures can play a significant role in restricting plant diseases and stabilising yield, which may be particularly important for low-input systems. However, in the past, the value of mixed crops has often been more readily accepted by the farming community than by those who serve it. The reasons for this attitude is that the benefits of mixtures lie principally with the farmer; there is no extra profit for the seed producer, and a reduction in profit for the fungicide manufacturer. In recent years, a new factor has emerged, namely, public concern over pesticide usage. It remains to be seen whether or not this factor will be significant in changing the balance of attitudes more in favour of the use of mixtures.

In the meantime, there are still questions to be answered. For example, Chin & Wolfe (1984) and Martinelli (personal communication) have shown that induced resistance in mixtures, caused by spores from plants of one variety failing to infect nearby plants of a different variety, can play an important role in restricting the susceptibility of the components. The question now is how far this phenomenon can be exploited, for example, by screening potential mixture components for the extent to which their resistance may be induced. A second question relates to the tendency to compare directly the relative values of mixtures and fungicides for disease control. It is possible that broad spectrum fungicides control beneficial fungi that compete with or that are antagonistic to pathogenic fungi. If so, then disease control only by mixing host components may have a greater long-term advantage. Analogous effects of insecticides are well-known in relation to control of harmful and beneficial insects.

In addition to control of diseases it is clear that, from the principles involved, there is potential in variety mixtures for the reduction of the effects of other stresses on crop plants, such as abiotic stress, and insect and weed infestation.

Despite much experimentation, the potential for positive growth interactions among mixture components has not been resolved. For example, Qualset (1981) underlined the value of differences in maturity of mixture components in providing yield advantages for mixtures in the absence of disease. Such observations lead to the question of the value of deliberate breeding for mixture performance. Selection for direct interaction of components together with buffering against a range of stresses could provide an important objective for low input agricultural systems (see also Prakash *et al.*, 1987).

A particularly important aspect of component interaction is the quality of the crop product. Generally, the quality of the mixture product is regarded as a problem, limiting the uptake of mixtures by growers. However, there is sufficient evidence to indicate that mixture components could be selected for complementation for a range of positive quality characteristics that would otherwise be difficult to combine in a single plant genotype.

The majority of investigations on disease restriction in variety mixtures have been concerned with cereal species, but there is no doubt that this approach should be extended. For example, in oilseed rape (Leon &

Diepenbrock, 1987), common bean (Panse *et al.*, 1989) and other crops, there is evidence that variety mixtures can provide stability at a high level of yield. Experiments in these species have been largely agronomic, but control of disease or other stresses should be feasible in the same way as with cereals, which could again be valuable in reducing inputs.

SPECIES MIXTURES

Species mixtures provide the basis for many low-input agricultural systems; indeed, it is only in recent years that they have lost popularity in Europe through intensification of agriculture. Potentially, they can provide even more effective buffering against stress than can variety mixtures, simply because their components differ more in their environmental requirements (e.g. Aufhammer *et al.*, 1989). Thus, restriction of insect pests and improved weed competition are more evident for species mixtures than for variety mixtures. Concerning disease restriction, there is a further potential bonus in the likely permanence of such effects; it is highly improbable, for example, that extensive use of barley-oat mixtures would lead to selection of races of the mildew pathogen able to attack both species.

However, the large differences among species components may also alter the micro-climate in favour of some pathogens. For example, Tränkner & Weltzien (1989) found that in wheat-rye mixtures, *Rhynchosporium secalis* was reduced in the rye because of the improved air flow around the upper parts of the rye tillers but *Septoria* infection was increased on the wheat component because of interaction with rye pollen on the wheat leaves and the increased humidity at lower levels in the crop canopy. In a similar way, in wheat-bean mixtures, we noted a tendency to increased mildew infection in the wheat host probably because individual wheat plants had more available nitrogen than plants in a pure stand (Wolfe & Minchin, 1987).

Despite these negative tendencies, experimental evidence suggests that species mixtures often produce more than equivalent areas of their components grown alone. Barley-oat mixtures are particularly reliable in this respect although it is necessary to predict the proportions needed of each component (Wolfe & Minchin, 1987). From the data of Villich-Meller & Weltzien (1989), it is also clear that specific mixing ability can be important: in their experiments, the oat variety Alfred produced only small yield advantages when mixed with barley, whereas Erbgraf was consistently better.

In addition to mixtures of cereal species, we, and many others, have found that mixtures of cereals and legumes, e.g. barley-peas and wheat-beans, spring or autumn-sown (see also Bulson, this Symposium), can be highly productive (Wolfe & Minchin, 1987). However, considerable research is still needed on disease development in such mixtures to avoid negative effects. One obvious method is to use appropriate variety mixtures within each species; this approach can be highly effective, for example, in barley-oat mixtures (Wolfe & Minchin, 1987).

In summary, crop safety can be improved by mixing appropriate varieties and species partly to restrict the development of pathogens, pests and weeds, and partly to obtain the insurance provided by greater diversity of plant genotypes in the cropping system. Furthermore, imaginative consideration of the range of possibilities of species and variety mixtures, and their integration, could provide new scope for improving rotations and increasing productivity in low-input systems. In particular, the possibility exists not only for reducing or eliminating fungicide inputs for disease control, but also for reducing, or eliminating, the use of insecticides, herbicides and artificial fertilisers.

REFERENCES

Aufhammer, W.; Stützel, H. (1986) Einflüsse von Sortenmischungen bei Wintergerste auf den Befall mit Blattkrankheiten. *Journal of Plant Diseases and Protection,* **93**, 515-527.

Aufhammer, W.; Kempf, H.; Kübler, E.; Stützel, H. (1989) Effekte der Sorten- (Weizen) und der Arten- (Weizen-Roggen) Mischung auf die Ertragsleistung krankheitsfreier Bestände. *Journal of Agronomy and Crop Science,* **163**, 319-329.

Buiel, A.A.M.; Verhaar, M.A.; Van den Bosch, F.; Hoogkamer, W.; Zadoks, J.C. (1989) Effects of cultivar mixtures on the wave velocity of expanding stripe rust foci in winter wheat. *Netherlands Journal of Agricultural Science,* **37**, 75-78.

Chin, K.M.; Wolfe, M.S. (1984) The spread of *Erysiphe graminis* f. sp. *hordei* in mixtures of barley varieties. *Plant Pathology,* **33**, 89-100.

Fried, P.M. (1986) Erfahrungen mit Sortenmischungen in Getreide im Ausland und Ergebnisse der Mischungsversuche mit den Winterweizensorten Arina, Eiger, Sardona und Zenta in der Schweiz, 1982-1985. *Eidg. Forschungsanstalt Zürich-Reckenholz.*

Gacek, E. (1986) The use of cultivar mixtures for the control of barley mildew. *Roczniki Nauk Rolniczych, Ser E,* **16**, 95-103.

Gieffers, W.; Hesselbach, J. (1988a) Krankheitsbefall und Ertrag verschiedener Getreidesorten im Rein- und Mischanbau. I. Sommergerste (*Hordeum vulgare* L.). *Journal of Plant Diseases and Protection,* **95**, 46-62.

Gieffers, W.; Hesselbach, J. (1988b) Krankheitsbefall und Ertrag verschiedener Getreidesorten im Rein- und Mischanbau. II. Wintergerste (*Hordeum vulgare* L.). *Journal of Plant Diseases and Protection,* **95**, 63-69.

Gieffers, W.; Hesselbach, J. (1988c) Krankheitsbefall und Ertrag verschiedener Getreidesorten im Rein- und Mischanbau. III. Winterweizen (*Triticum aestivum* L.). *Journal of Plant Diseases and Protection,* **95**, 182-192.

Gill, K.S.; Nanda, G.S.; Singh, G.; Aujla, S.S. (1979) Multilines in wheat - a review. *Indian Journal of Genetics and Plant Breeding,* **39**, 30-37.

Harjit, S.; Rao, M.V. (1988) Association of disease restriction in wheat mixtures with severity of leaf rust (*Puccinia recondita* f. sp. *tritici*). *Cereal Research Communications,* **16**, 5-9.

Hartleb, H.; Kopahnke, D; Meyer, U. (1986) Der Effekt polyresistenter Sortenmischungen der Sommergerste auf den Befall mit Zwergrost (*Puccinia hordei* Otta). *Archiv für Pflanzenpathologie und Pflanzenschutz,* **22**, 427-429.

Hengstmann, U. (1987) Der Einsatz von Sortenmischungen zur Reduzierung des Krankheitsbefalls und zur Ertragsstabilität bei Sommergerste. *Journal of Agronomy and Crop Science,* **159**, 41-50.

Hovmoller, M.S.; Ostergaard, H. (1990) Gametic disequilibria between virulence genes in Danish barley powdery mildew populations in relation to selection and recombination. *Plant Pathology* (in press).

Jeger, M.J.; Jones, D.G.; Griffiths, E. (1981) Disease progress of non-specialised fungal pathogens in intra-specific mixed stands of cereal cultivars. II. Field experiments. *Annals of Applied Biology,* **98**, 199-210.

Jorgensen, J.H. (1989) Resistenter bygsorte, sortsblandinger og/eller fungicider? *6 Danske Plantevaernskonference. Sygdomme og skadedyr 1989*, 159-

171.
Karjalainen, R. (1986) Spring wheat mixtures in northern crop production: ability of mixtures to buffer disease development and yield loss caused by *Septoria nodorum*. *Journal of Agricultural Science, Finland,* **58**, 33-42.
Kolster, P.; Munk, L.; Stolen, O. (1989) Disease severity and grain yield in barley multilines with resistance to powdery mildew. *Crop Science,* **29**, 1459-1463.
Leon, J.; Diepenbrock, W. (1987) Yielding ability of pure stands and equal proportion blends of rapeseed (*Brassica napus* L.) with double-low quality. *Journal of Agronomy and Crop Science,* **159**, 82-89.
Malik, B.S.; Rao, M.V.; Yedev, S.P. (1988) Leaf rust infection in homo- and heterogeneous populations of bread wheat. *Plant Breeding,* **100**, 104-111.
McDonald, B.A.; McDermott, J.M.; Allard, R.W.; Webster, R.K. (1989) Coevolution of host and pathogen populations in the *Hordeum vulgare - Rhynchosporium secalis* pathosystem. *Proceedings of the National Academy of Sciences, USA,* **86**, 3924-3927.
Mundt, C.C.; Brophy, L.S. (1988) Influence of number of host genotype units on the effectiveness of host mixtures for disease control: a modeling approach. *Phytopathology,* **78**, 1087-1094.
Panse, A.; Davis, J.H.C.; Fischbeck, G. (1989) Compensation-induced yield gains in mixtures of common bean (*Phaseolus vulgaris* L.) *Journal of Agronomy and Crop Science,* **162**, 347-353.
Prakash, K.S.; Gautam, P.L.; Rao, B.P. (1987) Studies on inter-genotypic competition in a wheat multiline using alternative row designs. *Plant Breeding,* **98**, 323-329.
Priestley, R.H.; Bayles, R.A.; Parry, E. (1988) Effect of mixing cereal varieties on yield and disease development. *Plant Varieties and Seeds,* **1**, 53-62.
Qualset, C.O. (1981) Barley mixtures: the continuing search for high-performing combinations. *Barley Genetics IV. International Barley Genetics Symposium, Edinburgh,* 1981, 130-137.
Stuke, F.; Fehrmann, H. (1988) Plant pathological aspects in wheat cultivar mixtures. *Journal of Plant Diseases and Protection,* **95**, 531-543.
Tränkner, A.; Weltzien, H.C. (1989) Untersuchungen an Artenmischungen von Winterweizen und Winterroggen. I. Die Entwicklung von Blattkrankheiten in Freilandversuchen ohne Pflanzenschutzbehandlung. *Journal of Plant Diseases and Protection,* **96**, 11-18.
Vallavieille-Pope, C.; Goyeau, H.; Lucas-Chauvelon, J. (1988) Mixtures of wheat cultivars with adult plant resistance to *Puccinia striiformis*. *Proceedings 7th European and Mediterranean Cereal Rusts Conference, Vienna,* 181-183.
Villich-Meller, V.; Weltzien, H.C. (1989) Artenmischungen von Sommergerste und Hafer: Einfluss auf den Blattbefall pilzlicher Schaderreger und auf die Ertragsfähigkeit. *Journal of Plant Diseases and Protection,* **96**, 1-10.
Wolfe, M.S. (1985) The current status and prospects of multiline cultivars and variety mixtures for disease resistance. *Annual Review of Phytopathology,* **23**, 251-273.
Wolfe, M.S.; Minchin, P.N. (1987) *Annual Report of the Plant Breeding Institute 1986,* p. 99.
Wolfe, M.S. (1988) The use of variety mixtures to control disease and stabilize yield. *CIMMYT 1988. Breeding Strategies for Resistance to the Rusts of Wheat,* 91-100.
Wolfe, M.S. (1990) Recent developments in using variety mixtures to control powdery mildew of barley. *2nd Workshop: Integrated Control of Cereal Mildews, Riso, Denmark* (in press).

THE USE OF COMPOSTED MATERIALS FOR LEAF DISEASE SUPPRESSION IN FIELD CROPS

H. C. WELTZIEN

Institut für Pflanzenkrankheiten, University of Bonn, W.-Germany

ABSTRACT

The effects of compost application on leaf diseases was studied. Soil amendments increased the resistance of barley and wheat against Erysiphe graminis and of cucumbers against Sphaerotheca fuliginea. Watery extracts of composts were effective against Phytophthora infestans tomatoes and potatoes and Botrytis cinerea on phaseolus beans and strawberries. Amendments of the extracts with selected microorganisms increased and stabilized their efficiency. In field experiments some treatments equalled the efficiency of registered fungicides.

INTRODUCTION

Crop production with reduced or no use of chemical pesticides is threatened by unpredictable losses due to diseases and pests. While considerable progress has been made in biological pest management and control, biological plant disease management is still poorly developed. Philipp (1988) has summarized the methods developed so far, but only a few are applied in field crop protection. The work by Kuc` (1982) and Schönbeck et al. (1982), using induced resistance mechanisms, has indicated new potentials. Considering the high microbial activity of composts based on plant residues and animal manure, we have tried their capacity for plant disease suppression. Older reports (Howard, 1948; Seifert, 1971) have claimed plant health promoting effects of compost, but lack experimental evidence. Hoitink (1980) has repeatedly shown seedling and root disease suppression using bark composts of various composition. Other reports from Lumsden et al. (1986) and Hadar and Mandelbaum (1986) offered further proof with field crops such as lettuce and cucumber seedlings. The general literature on compost production and use has been competently reviewed by Gottschall (1988). No experimental evidence was offered so far that compost application can suppress leaf diseases, before we started our experimental program in 1985.

METHODS AND RESULTS

Soil application

We tested the hypothesis, that soil amendments with composts may increase plant resistance for leaf diseases (Budde und Weltzien, 1988). The compost used was based on horse manure and straw bedding with about 15 % amendment of mature horse manure compost to accellerate the decomposition process. It had been left outdoors for at least 6 months in shaped piles of about 1,5 m height and lengths between 8 and 15 m. It was mixed with ordinary field soil at varying relations, v/v. 9 cm pots were planted with winter barley (cv. Gerbel). After the primary leaves were fully developed, plants were inoculated with conidia of Erysiphe graminis f. sp. hordei and left for disease development in controlled environment chambers at 22°C and 16 h light. After 5 days the numbers of pustules/primary leaf were counted. In other series, primary leaves were cut, placed on benzimidazole-agar (Budde und Weltzien, 1988a) and inoculated, incubated and evaluated as described. Results are summarized in table 1. There was a clear negative correlation between the amount of compost in the substrate and the disease severity on primary leaves.

TABLE 1. Erysiphe graminis suppression on primary leaves of winter barley (cv. Gerbel) by soil amendments with horse manure compost.

Soil:compost relation v/v	1:0	5:1	2:1	1:1	1:2	1:5	0:1	Correl. Coeffic.
Number of pustules/ primary leaf	39,1	27,9	26,4	21,6	17,9	8,8	6,5	-0,98

Preliminary studies with Sphaerotheca fuliginea on cucumber under greenhouse conditions (Samerski, 1989) yielded similar results (Table 2). Again increasing amounts of composts in the substrate reduced powdery mildew development significantly under controlled conditions.

TABLE 2. Suppression of powdery mildew (Sphaerotheca fuliginea) on primary leaves of cucumber (Cucumis sativus cv. Vorgebirgstraube) by soil amendment with horse manure compost; 10 days after inoculation.

Soil:compost relation v/v	1:0	1:1	1:2	1:3
% leaf area colonized	100 a	76 b	69 b	59 c

Leaf application

We tested the hypothesis, that watery extracts of composts may contain active microorganisms and/or substances, capable to suppress leaf disease development in various host-pathogen systems. The extracts were obtained by mixing composts with water in relation between 1:3 and 1:10. They were left for extraction and fermentation at ambient temperatures for periods between 1 and 28 days, called "extraction time". Application with ordinary spraying equipment was usually prophylactic. The time between application and inoculation was called "induction time". Extraction container sizes varied between 1 and 5000 l. Experiments were performed under laboratory, greenhouse and field conditions. No artificial inoculation was used in field experiments.

Potato and Tomato - Phytophthora infestans

Our studies were based on detached leaf tests and field experiments (Ketterer, 1990). Table 3 summarizes some of our results with detached tomato leaves.

TABLE 3. Effects of compost extract sprays on _Phytophthora infestans_ infection of tomato leaves.
Extraction time 14 days, induction time 9 days.

Treatment	extract characteristics	% leaf area diseased
	check, tap water	70,5 a
1	horse manure, used fresh	11,5 c
	horse manure, stored 7 days	14,6 c
	horse manure, stored 14 days	39,0 b
	check, tap water	74,5 a
2	horse manure compost:water 1: 3	13,4 c
	horse manure compost:water 1:10	12,7 c
	horse manure compost:water 1:50	48,5 b
	check, tap water	80,0 a
3	horse manure	11,6 c
	hog manure	20,0 b
	goat manure	11,3 c

Disease suppression was highly significant against the check. Storage of the extract beyond 7 days reduced the efficiency. Compost/water relations for extraction between 1:3 and 1:10 caused no loss of activity, but at 1:50 the loss was apparent. Different composts were equally effective as horse manure compost.

If Phytophthora sporangia were exposed to extracts between 1 and 4 hours, the zoospore release rate was reduced but not inhibited (Table 4). It seems that most of the disease suppression is due to direct inhibition of zoospore release, but some other effects may be involved and need further studies.

TABLE 4. % of empty _Phytophthora_ _infestans_ sporangia (release rate) after exposure to compost extracts.

Exposure time	Origin of extract		Check
	Horse manure	Cattle manure	H_2O
1 hr	8,7 b	5,5 b	66,0 a
2 hrs	20,6 b	17,3 b	77,0 a
3 hrs	32,5 b	29,3 b	82,0 a
4 hrs	31,3 b	33,0 b	87,3 a

We have also sterilized the extracts by heat or filtration and lost the activity almost completely (table 5). Active microorganisms, mostly bacteria, were isolated from the extracts. If added to the original extract, the activity was significantly enhanced. The results indicate the importance of microbially active extracts for good results.

Field experiments with potatoes confirmed the results obtained on tomato leaves. Table 6 summarizes some of the 1987 and 1988 field data. Experiments were performed in the vicinity of Bonn. They were located on the university experimental farm for organic farming "Wiesengut" and on a conventional farmer's field. Plot sizes varied between 25 and 75 m^2 . The fields were left for spontaneous infection.

TABLE 5. Effects of sterilization of the extracts, selected microorganisms from the extracts and microbially amended extracts on Phytophthora infestans infection of tomato leaves.

Treatment	% leaves diseased
check, tap water	69,5 a
compost extract	11,0 b
compost extract, sterilized	66,8 a
microorganisms from compost extract	8,5 bc
microbially amended extract	2,2 c

TABLE 6. Control of Phytophthora infestans in potatoes (organic farm: cv. Hansa; Conventional farm: cv. Sieglinde) in 1987 and 1988 by regular and microbially amended compost extracts.
Date 1: Org. farm: 31.7.87; 12.8.88. Conv. farm: 6.8.87; 19.7.88.
Date 2: Org. farm: 21.8.87; 30.8.88. Conv. farm: 21.8.87.

Treatment and location	% leaf area diseased date 1	date 2	Yield dt/ha
Organic farm 1987			
compost extract	30,8 b	90,0 a	222 a
compost extract + microorg.	4,8 c	16,6 b	434 b
check	45,0 a	92,2 a	211 a
Organic farm 1988			
compost extract	29,0 b	62,0 a	227 a
compost extract + microorg.	5,0 c	16,0 b	413 b
check	36,0 a	65,0 a	230 a
Conventional farm 1987			
compost extract + microorg.	4,0 c	11,3 a	335,5 c
Ciluan R	8,7 b	17,5 b	285,5 b
Ridomil MZ R	3,7 c	7,5 c	341,0 c
check	70,0 a	96,3 a	250,0 a
Conventional farm 1988			
compost extract + microorg. (6 applications)	12,5 c	-	
compost extract + microorg. (4 applications)	27,5 b	-	
Ridomil MZ R / Brestan 60 R	8,8 c	-	
check	78,8 a	-	

It is evident, that Phytophthora infestans was efficiently controlled outdoors under heavy infection pressure, if compost extracts amended with microorganisms were applied. After weekly application the disease rates equalled those after treatments with Brestan 60R and Ridomil MZR · Yields were increased up to 34 % in the conventional farming system where an early maturing cultivar was used, and up to 106 % on the organic farm with a late maturing cultivar.

Phaseolus beans and strawberries - Botrytis cinerea.

Wood (1951) already showed the high susceptibility of Botrytis cinerea to antagonistic microorganisms. We have therefore tested these host-parasite systems as a possible target for compost extract application (Stindt und Weltzien, 1988). In detached leaf tests with Phaseolus vulgaris, cattle manure compost extracts were equally effective as the fungicides Euparen[R] and Sumisclex[R] (table 7). The extracts even had a significant curative effect if applied 36 h after inoculation with Botrytis, which became apparent after 7 days. Bacteria isolated from the extract and tested as pure cultures equalled the compost extract in some cases.

TABLE 7. Size of lesions in mm^2 of primary leaves of phaseolus beans when Botrytis infection spots were treated 36 h after inoculation.

Time of measurement	check H_2O	Euparen	Sumisclex	Comp. Extr.	Bact. 1	Bact. 2	Bact. 3
3 days after treatment	130	50	80	51	65	52	68
7 days after treatment	375	80	185	80	85	102	85

In view of these results we ran field experiments to control strawberry grey mold (Botrytis cinerea), one of the most devastating fruit rots of strawberries (Stindt und Weltzien, 1988a). Compost extract was used and applied in weekly intervals from early flowering up to 10 days before the first picking. Some results are summarized in table 8. Control efficiencies as compared to the check of 60-80 % were frequently achieved and proved to be highly significant. Depending on the absulute value of the disease incidence in the checks, yield data were significantly decreased.

TABLE 8. Control efficiency in % of check of various treatments against strawberry grey mold (Botrytis cinerea) on fruits of cv. Corona 1987, 1988.

Year of experiment	Treatment: cattle compost extraction time 7 days	Treatment: horse compost extraction time 3 months	Yield increase %
1987	-	53	40
1988	42	-	17

CONCLUSIONS

Considerable advances have been made towards biological control of leaf diseases by using microbially highly active extracts from composted materials. The extract activity was largely based on the presence of living microorganisms. Significant and regular results were obtained on detached leaves, greenhouse plants and under field conditions through three successive years. The efficiency of the extracts can be increased and stabilized by addition of active microorganisms, isolated from the extracts and multiplied in pure culture. The development of a new element for biological plant protection systems in conventional and organic agriculture seems possible.

REFERENCES

Budde, K.; Weltzien, H.C. (1988) Phytosanitäre Wirkungen von Kompostextrakten und Substraten im Wirt-Erreger-System Gerste-Echter Mehltau (Erysiphe graminis DC f. sp. hordei MARCHAL). Med. Fac. Landbouww. Rijksuniv. Gent, 53, 363-371.

Budde, K.; Weltzien, H.C. (1988a) Untersuchungen zur Wirkung von Kompostextrakten und Kompostsubstraten im Pathosystem Getreide - Echter Mehltau (Erysiphe graminis). Mitt. BBA Berlin-Dahlem 245, 366.

Gottschall, R. (1988) Kompostierung. Verl. C.F. Müller, Karlsruhe, 3. Aufl.

Hadar, Y.; Mandelbaum, R. (1986) Suppression of Pythium aphanidermatum damping-off in container media containing composted liquorice roots. Crop protection 5, 88-92.

Hoitink, H.A.J. (1980) Composted bark, a lightweight growth medium with fungicidal properties. Plant Disease 64, 144-147.

Howard, A. (1948) Mein landwirtschaftliches Testament. Frankfurt, Siebeneicherverlag.

Ketterer, N. (1990) Untersuchungen zur Wirkung von Kompost-Extrakten auf den Blattbefall der Kartoffel und Tomate durch Phytophthora infestans sowie auf den Befall der Weinrebe durch Plasmopara viticola, Pseudopeziza tracheiphila und Uncinula necator. Dissertation, Bonn.

Kuc', J. (1982) The immunization of cucurbits against fungal, bacterial and viral disease. In: Plant Infection. The Physiological and Biochemical Basis. Ed. by Y. Asada, W.R. Bushnell, S. Ouchi & C.P. Vance, Jpn. Sci. Sco. Press Tokyo & Springer Berlin, Hamburg.

Lumsden, R.D.. Millner, P.D.; Lewis, J.A. (1986) Suppression of lettuce drop caused by Sclerotinia minor with composted sewage sludge. Plant Disease 70, 197-201.

Philipp, W.D. (1988) Biologische Bekämpfung von Pflanzenkrankheiten. Ulmer Verlag, Suttgart.

Samerski, C. (1989) Untersuchungen zu Wirkung und Wirkungsmechanismen von Kompostextrakten im Pathosystem Gurke (Cucumis sativus L.) - echter Gurkenmehltau (Sphaerotheca fuliginea (Schlechtendahl ex Fr.) Pollacci). Dissertation, Bonn.

Schönbeck, F.; Dehne, H.W.; Balder, G. (1982) Zur Wirksamkeit induzierter Resistenz unter praktischen Anbaubedingungen (Echter Mehltau an Reben, Gurken und Weizen). Ztschr. PflKrankh. PflSchutz 89, 177-184.

Seifert, A. (1971) Gärtnern - Ackern - ohne Gift. Bidersteinverlag München, Ausgabe 1982.

Stindt, A.; Weltzien, H.C. (1988) Wirkung von wässrigen, mikrobiologisch aktiven Kompostextrakten auf Botrytis cinerea und Erklärungen zum Wirkungsmechanismus. Mitt. BBA Berlin-Dahlem, 245, 368.

Stindt, A.; Weltzien, H.C. (1988a) Der Einsatz von Kompostextrakten zur Bekämpfung von Botrytis cinerea an Erdbeeren - Ergebnisse des Versuchsjahres 1987. Ges. Pflanzen 40, 451-454.

Wood, R. (1951) The control of diseases on lettuce by the use of antagonistic organisms. 1. The control of Botrytis cinerea Pers. Ann. Appl. Biol. 38, 203-216.

DISEASE CONTROL IN CEREALS GROWN TO CONSERVATION GRADE AND UKROFS STANDARDS

D.J. YARHAM, F.A. CULSHAW and C.E. SANSFORD

Plant Pathology Department, A.D.A.S., Block C, Government Buildings, Brooklands Avenue, Cambridge CB2 2DR.

ABSTRACT

Organic farming practices, particularly the emphasis on sound rotation and the comparatively low rates of nitrogen used, will reduce the susceptibility of organic crops to the depredations of many plant pathogens. They will not, however, wholly obviate the risks of disease losses. The use of resistant cultivars, of appropriate husbandry practices and, where necessary, of permitted fungicidal materials allow for the development of an integrated disease control strategy for cereals grown to UKROFS and Conservation Grade standards.

INTRODUCTION

"Organic Agriculture" has been defined as a system which "coexists with (rather than dominates) natural systems, sustains and builds soil fertility, minimises damage to the environment, and minimises the use of non-renewable resources". Its basic characteristics are sound rotations, the extensive and rational use of manure and vegetable wastes, the use of appropriate cultivation techniques, the avoidance of fertilisers in the form of soluble mineral salts and the prohibition of synthetic pesticides (Anon. 1987). Fungicides permitted by the United Kingdom Register of Organic Food Standards (UKROFS) include natural products such as Bordeaux mixture (for potato blight), sulphur, sodium silicate, sodium bicarbonate, homeopathic and biodynamic preparations.

"Conservation Grade" production differs from "organic" agriculture in that the use of selected artificial fertilisers and of a few carefully selected non-residual synthetic pesticides is permitted (Anon., 1989).

The standards laid down by UKROFS require that before produce can be marketed as "organic" the land on which it is grown must have undergone a two year "conversion period" during which no prohibited inputs will have been used. No such conversion period is necessary for the production of "Conservation Grade" produce.

THE DISEASE SUSCEPTIBILITY OF ORGANICALLY GROWN CROPS

Studies such as those carried out at the Royal Agricultural College, Cirencester (Samuel, Guest & Davies, 1990) seem to endorse the anecdotal evidence of many organic growers that disease levels in their crops tend to be lower than those in conventional crops. That this is so may be due to a number of factors:-

i) Organic farmers will normally practice a rotation which will reduce the risks of such diseases as take-all (Gaeumannomyces graminis) and eyespot (Pseudocercosporella herpotrichoides).

ii) Compared with their conventionally farming neighbours, organic farmers will be using lower inputs of the nitrogen - the liberal application of which increases susceptibility to most, if not all, cereal leaf diseases (Jenkyn & Finney, 1981).

iii) The incorporation of organic manures and green crop residues will modify the soil micro-flora and could favour organisms which are antagonistic to, or competitors of, soil-borne fungal pathogens. Organic amendments can, moreover, directly affect the physiology and nutrition of crop plants (Albuzio et al., 1986) and may in this way influence their susceptibility to disease. These effects, which are, extremely complex, are by no means fully understood and appear sometimes to be contradictory. For example, green manuring has sometimes been claimed to reduce (Shipton, 1981) and sometimes to increase (Huber, 1981) the severity of take-all.

Linderman (1989) noted that the decomposition products or organic amendments could either decrease or enhance disease depending on the microbial circumstances. He commented that "the addition of humic substances to soils can induce a variety of plant physiological and microbial responses, but in such an unpredictable fashion as to make their use as a cultural practice unreliable".

Linderman's reservations notwithstanding, there seems no reason to discount the organic growers' claims that their crops are less susceptible to disease than are conventionally grown crops. Organic crops are not, however, immune to pathogen attack and attention still needs to be given to disease control practices at every stage of the crop production process.

DISEASE CONTROL MEASURES FOR ORGANIC CEREALS

Rotation

The cropping sequence followed by a light-land farmer in west Norfolk provides a good example of a sound organic rotation: years 1 and 2 - grass/clover ley cut for ensiling, year 3 - spring-sown milling wheat, year 4 - carrots or parsnips, year 5 - spring-sown malting barley.

If required, a second spring wheat crop could be introduced without too much risk after the two year ley as the antagonistic fungus Phialophora graminicola (which builds up on the grass) can usually be relied on to suppress the development of G. graminis in the subsequent wheat crops (Wong, 1981). If for any reason it was decided to take two cereal crops after the vegetable break then it would be safer to take oats (which are immune to the common strain of G. graminis) as the second of these.

More problems would arise if the farmer wished to increase the yield potential of his spring wheat by sowing it in late autumn. Autumn sown spring wheat is very susceptible to eyespot and both the second wheat after the ley and the wheat after the vegetable break would be at risk (infected debris ploughed under before the carrots would be ploughed up again after them). (Even after the two year break the risk of eyespot is not completely eliminated as ley grasses can carry P. herpotrichoides).

Choice of variety

The NIAB has suggested that the winter cultivars Mercia and Pastiche, and the spring cultivars Axona and Canon would be particularly suitable for the organic production of milling wheat. They yield well in the absence of fungicides, stand well in the absence of growth regulators and are long enough in the straw to compete well against weeds (Anon., 1990).

The principles of varietal selection for organic cereal production may be further illustrated by reference to malting barley (though in this instance, of course, the final decision will depend on the requirements of the maltster). The winter cultivar Puffin and the spring cultivar Alexis combine good disease resistance, and high yield in the absence of fungicide, with the good standing ability (score 8) necessary if no growth regulants are to be used and a reasonable length of straw (score 7) to help suppress weeds.

It is best not to grow autumn-sown and spring crops in close proximity. If, however, this is unavoidable, a combination Puffin and Alexis (which have different genes for mildew resistance) would be preferable to, say, Puffin and Blenheim. The latter two varieties are susceptible to the same strain of mildew (Erysiphe graminis) which could readily spread to the Blenheim from its overwintering source in the Puffin.

The use of varietal blends to reduce disease risks has been shown to work particularly well against mildew in spring barley (Wolfe, Barrett & Jenkins, 1981). The cultivars Triumph, Prisma and Alexis, for example, have different genes for mildew resistance and if these three were grown in a blend mildew levels would be lower than the average of the levels in the 3 cultivars grown separately. In the absence of a mildew strain virulent on cv Alexis, however, they would not be so low as in the latter variety grown on its own - and in any case the produce of a blend is less likely to be acceptable to the maltsters.

Seed selection

Organic farmers are, of course, precluded from using synthetic fungicidal seed treatments. Seed for organic crops may, however, be taken from crops which were themselves grown from treated seed and this has to be accepted as the most effective way of avoiding such diseases as wheat bunt (Tilletia caries) and barley leaf stripe (Pyrenophora graminea) on barley on an organic farm. Recent experience in conventional agriculture has shown how quickly a disease such as bunt can build up in untreated seed stocks of some modern cultivars (though cv. Maris Widgeon has been grown on some organic farms for many years without seed treatment).

If home-saved seed is to be used it should be saved from a crop grown specifically for the purpose and very carefully monitored to ensure that it is free of seed-borne diseases. If any crop on the farm is found to be infected with bunt or covered smut it should be harvested after the crop intended for seed. Note that (so long as they remain dry) bunt spores can persist on contaminated machinery from one season to the next.

The use of seed treatment on the parent stock will usually provide a satisfactory control of diseases such as bunt which are invariably seed-borne. It will not, however, prevent the daughter seed becoming infected by pathogens such as the Fusarium spp. which can occasionally cause serious problems of seedling blight in organic crops (Richards, 1990). Since losses are most likely to be severe when soil temperatures are low, one would advise against the very late sowing of winter cereals and the very early sowing of spring varieties.

Disease levels in home-saved seed stocks can be checked by sending a sample to the official Seed Testing Station, Huntingdon Road, Cambridge.

Cultivation and seedbed preparation

There should be no need to remind organic farmers of the need for careful soil management. Good drainage and the maintenance of good soil structure help to produce vigorous root systems which reduce the effects of root rotting diseases such as take-all. If second wheats are grown care should be taken to produce a good firm seedbed as this checks the spread of the take-all fungus over the root surface.

Sowing date

Autumn sown spring wheat and winter wheat sown in September or very early October are at greatest risk from eyespot. Even after a two year break severe infection may occur in crops sown in early- to mid-September. Early sowing can also increase the severity of a number of other cereal diseases including take-all, barley yellow dwarf (BYDV), net blotch, septoria and yellow rust. The risk of autumn infection by diseases such as yellow rust is increased by the presence of infected volunteers in nearby unploughed stubbles.

It is advised that organic cereal crops should not be sown before October, preferably not before mid-October. This will reduce the risks both of fungal diseases and of BYDV. If the cereal follows a ley this should be ploughed-in in late August or early September to reduce the risks of viruliferous aphids surviving on the ploughed-in grasses and infecting the roots of the following cereal. Ploughing-in the ley at this time will also reduce the risks of frit fly attack - but beware of ploughing any earlier than late August as this could increase the risks of wheat bulb fly. Delaying the sowing date until November increases the risks of fusarium seedling blight should the farmer be unfortunate enough to have a badly contaminated seed sample.

Weed control practices

Weed control is amongst the most difficult of the problems faced by organic farmers. Poor control not only reduces yields directly but can also exacerbate certain diseases. Failure to control rhizomatous grass weeds such as couch will allow the take-all fungus to be carried through a break crop. Dense weed growth can provide a microclimate at the stem base particularly conducive to eyespot infection. The early season build up of

Claviceps purpurea on meadow foxtail and black grass can lead to high levels of ergot in wheat crops infested with these weeds.

Fertiliser practices

While the relatively low rates of nitrogen used by organic growers will reduce crop susceptibility to most foliar diseases they can increase the damage done by take-all. Deficiencies of other plant nutrients can also exacerbate diseases. Of relevance to organic growers are the comments of Jenkyn and Bainbridge (1978) who, citing work carried out by G.T. Spinks, M.D. Glynne and C.E. Yarwood, state that "crops grown in soil to which dung has frequently been applied may have relatively little mildew. This may be because the dung supplies many of the elements known to increase resistance, but the slow release of nitrogen to plants may also be a factor in retarding mildew development. Dung will also increase the available water content of most soils and this in turn might affect resistance".

In the southwest of England, delaying the main nitrogen dressing from mid-March to mid-April has been shown to delay early-season disease development in winter barley (Jordan, Stinchcombe & Hutcheon, 1989) and can reduce the severity of wheat mildew, Septoria tritici and eyespot (Jordan, Hunter & Fielding, 1988). However, ADAS trials have failed to show a similar effect on barley in the east of the country (M. Foley, ADAS, Cambridge, pers. comm.).

Use of permitted disease control agents

The development of safe and effective biological agents for the control of crop diseases would be of great benefit to organic growers but, as yet, progress in this field is very slow. One agent, based on Streptomyces griseoviridis, has been developed in Finland (Lahdenpera, Simon & Uoti, 1990). It is claimed to control a number of crop diseases including Fusarium seedling blight in cereals. There have also been suggestions that its use as a seed treatment can induce resistance to mildew. The agent is being commercially developed (as 'Mycostop') in a number of countries but it is yet not cleared for use (neither has it been tested) in the UK.

At the moment, the most effective fungicide permitted for use on organic cereals is sulphur. ADAS Plant Pathologists have investigated the use of this material in a series of trials on cereals grown to Conservation Grade or UKFOFS standards.

1986 trials

Two trials were carried out on the same Norfolk farm on wheat sown mid/late October on clay loam soil. One of the trials was on cv. Flanders grown to Conservation Grade standards, the other on conventionally grown cv. Galahad. Treatments included:-

1. Sulphur (as "Thiovit", 80% wp, @ 10 kg/ha) applied at GS 31 (7 May), GS 45 (12 Jun), GS 59 (24 Jun) and GS 71 (15 Jul).

At GS 31 the sulphur was applied with seaweed extract (as "Marinure" @ 10 l/ha). At GS 45, 59 and 71 it was applied with the sticker poly-l-p-menthene (as "Nufilm P" @ 0.18 l/ha).

2. Cupric hydroxide (as "Wetcol 3", 3% liquid @ 67 l/ha) at GS 31, GS 45, GS 59 and GS 71.

3. Sulphur and cupric hydroxide at GS 31, GS 45, GS 59 and GS 71.

4. A mixture of sodium metabisulphate (as "Brimstone Plus A" @ 0.5 kg/ha) and sodium proprionate + potassium sorbate (as "Brimstone Plus B" @ 2.5 l/ha) applied at GS 31, GS 45 and GS 59 (this fungicide is permitted on Conservation Grade but not on Organic crops).

5. Prochloraz plus carbendazim (as Sportak Alpha @ 1.5 l/ha) at GS 31, triadimefon plus captafol (as Bayleton CF @ 2 kg/ha) and fenpropimorph (as Corbel @ 1 l/ha) at GS 39, and propiconazole (as Tilt @ 1 l/ha) plus carbendazim (as Bavistin @ 0.5 l/ha) at GS 59 (conventional crop only).

The results of the trials are presented in Table 1.

TABLE 1. Effects of fungicide programmes on disease incidence and yield of conservation grade and conventionally grown wheat - 1986

	27 June % mildew (NIAB whole plot assessment)	14 July (% leaf affected) Mildew	GLA	Yield t/ha	TGW g	Sp Wt kg/ha
<u>Conservation grade</u>		lf 2	lf 2			
Control	16.3	7.9	72.5	6.36	45.2	77.0
Sulphur	5.3	6.8	79.4	7.09	47.3	78.0
Copper	5.5	3.7	84.3	6.26	45.1	77.8
Sulphur + copper	4.0	4.9	83.7	6.58	46.8	78.0
Brimstone	13.8	6.4	73.6	6.39	44.4	76.8
SED (27 df)	2.4	1.3	4.3	0.13	0.9	0.3
CV%	34.5	34.7	7.8	3.0	2.8	0.7
<u>Conventional crop</u>		lf 3	lf 3			
Control	0	0	48.8	7.41	46.8	75.2
Sulphur	0	0	68.1	7.43	47.5	76.2
Copper	0	0	62.8	7.06	46.4	75.6
Copper + sulphur	0	0	69.3	7.46	47.2	76.1
Brimstone	0	0	33.3	7.21	46.6	75.6
SpA/BCF+Cor/T+Bay	0	0	79.4	7.69	48.8	76.1
SED (33 df)			8.6	0.20	0.3	0.2
CV%			21.7	3.9	0.7	0.5

The sulphur programme reduced mildew levels and increased yield in the Conservation Grade crop of Flanders. However, it failed to produce a response in the more mildew resistant cv Galahad grown in a field where inoculum levels would have been kept low by the spraying of the surrounding crop and in which the disease never developed on the upper leaves.

Cupric hydroxide gave good control of mildew but scorched the flag leaf (even though it prolonged the lives of leaves 2 and 3) and failed to increase yield.

1987 trials

One trial was carried out on a Conservation Grade crop of mid-October sown cv. Flanders on the same farm as the previous year's study. Various sulphur (Thiovit) and copper (Wetcol 3) programmes were compared. Again the copper was phytotoxic and significantly reduced yield. The results of the sulphur programmes are presented in Table 2.

TABLE 2. Effects of fungicide programmes on disease incidence and yield of conservation grade wheat - 1987 (Cook & Culshaw, 1989).

GS31	GS32/3	GS37	GS45	GS59	GS65	Lf diseases S. trit (1f 2)	GS 75 GLA (1f 2)	Yield	TGW	Sp Wt
-	-	-	-	-	-	5.3	37.1	5.66	39.4	70.7
+	-	-	-	-	-	3.9	59.7	5.81	38.6	70.4
+	+	-	-	-	-	3.2	48.5	5.83	39.8	70.6
+	+	+	-	-	-	5.7	63.8	5.93	40.8	71.1
+	+	+	+	-	-	2.1	84.2	6.06	41.3	71.2
+	+	+	+	+	-	1.6	85.4	6.18	42.8	71.2
+	+	+	+	+	+	2.2	82.2	6.46	42.4	73.1
-	-	-	-	+	-	4.3	60.9	5.88	40.2	70.9
+	-	-	-	+	-	4.6	66.1	6.02	40.0	70.7
SED (33 df)						1.2	6.6	0.16	0.8	
CV %						45.1	15.5	4.0	3.0	

Mildew did not develop in this trial but significant reductions in the levels of *Septoria tritici* and significant increases in yield and quality were obtained when the sulphur programme was extended to provide protection in the later stages of growth.

1988 and 1989 trials

In 1988 a trial was carried out on a crop of cv. Avalon (sown 1 October) grown to Organic Farmers and Growers (OFG) standards on sandy loam in Suffolk. In 1989 trials were carried out on two crops grown to OFG standards: cv. Mercia on silty loam in S Yorkshire and spring sown cv. Tonic on sandy loam in Essex. The main treatments applied in the trials are given in Table 3.

TABLE 3. Treatments applied in ADAS organic wheat trials in 1988 & 1989.

Suffolk 1988	5 May	17 May	6 Jun	15 Jun	20 Jun	5 Jul
Yorks 1989	18 Apr	2 May	16 May	30 May	14 Jun	27 Jun
Essex 1989	15 May	30 May	12 Jun	10 Jul	10 Jul	24 Jul
Untreated	-	-	-	-	-	-
Thiovit	+	+	+	+	+	+
"	-	+	+	+	+	+
"	-	-	+	+	+	+
"	-	-	-	+	+	+
"	-	-	-	-	+	+
"	-	-	-	-	-	+

Control yields in the 3 trials were:-

1988 Suffolk: 3.27 t/ha; 1989 Yorks 5.52 t/ha, Essex 2.85 t/ha.

At none of the three sites were any significant treatment effects on yield or quality of grain recorded.

In all three trials foliar disease levels were low and treatment effects slight. In the 1988 trial the 6 spray programme of sulphur significantly increased green leaf area of the flag leaf at GS 75 and there was again evidence of the sulphur programmes reducing the incidence of S. tritici. In the spring wheat trial in Essex (1989) sulphur applied in May or early June reduced the incidence of mildew on the lower leaf sheaths and delayed the senescence of the lower leaves.

The results of these trials suggest that fungicides are more likely to be cost effective on Conservation Grade than on truly organic crops. On Conservation Grade crops a case can be made for the use of a sulphur programme for the prophylactic control of mildew and septoria. It is particularly important to protect the upper leaves from disease during the period from flag leaf emergence until the grain filling period.

CONCLUSIONS

While organic crops are likely to be less susceptible to diseases than conventionally grown crops, they are not immune to pathogen attack. Sound husbandry practices and the use of disease resistant cultivars must form the basis of any disease control strategy but the use of sulphur sprays may be integrated into such a strategy. Sulphur should be applied either as a routine programme (as would be allowable for Conservation Grade crops) or at the first sign of disease in crops grown to the more exacting Organic standards.

REFERENCES

Albuzio A.; Ferrari G.; Nardi S. (1986) Effects of humic substances on nitrate uptake and assimilation in barley seedlings. Canadian Journal of Soil Science 66 731-736.

Anon. (1987) The Soil Association Symbol Scheme, Standards for Organic Agriculture, Bristol: The Soil Association, p. 5.

Anon. (1989) Conservation Grade Standards, The Guild of Conservation Food Producers, p. 2:1.

Anon. (1990) Farmers leaflet No 8: Recommended varieties of Cereals, Cambridge: National Institute of Agricultural Botany, 36 pages.

Cook, R.J.; Culshaw, F.A. (1989) Effects of fungicide on winter wheat grown to organic standards. Tests of Agrochemicals and Cultivars 10, Annals of Applied Biology 114 (Supplement) 72-73.

Huber, D.M. (1981) The role of nutrients and chemicals. In: Biology and Control of Take-all, M.J.C. Asher & P.J. Shipton (Eds.), London: Academic Press, pp. 317-342.

Jenkyn, J.F.; Bainbridge, A. (1978) Biology and pathology of cereal powdery mildews. In The Powdery Mildews, D.M. Spencer (Ed.), London: Academic Press, pp. 284-322.

Jenkyn, J.F.; Finney M.E. (1981) Fungicides, fertilisers and sowing date. In: Strategies for the control of cereal disease, J.F. Jenkyn & R.T. Plumb (Eds.), Oxford: Blackwell Scientific Publications, pp. 179-188.

Jordan, V.L.W.; Hunter, T.; Fielding, E.C. (1988). Interactions of fungicides with nitrogen and plant growth regulators for cost effective control of wheat diseases. Proceedings Brighton Crop Protection Conference - Pests and Diseases, Thornton Heath: BCPC, pp. 873-880.

Jordan, V.L.W.; Stinchcombe, G.R.; Hutcheon, J.A. (1989) Fungicide and nitrogen applications in relation to the improvement of disease control and yield in winter barley. Plant Pathology 38 26-34.

Lahdenpera M.L.; Simon E.; Uoti J. (1990) 'Mycostop' - a novel biofungicide based on streptomyces bacteria. Biotic Interactions and Soil-borne Diseases, Proceedings of the First Conference of the European Foundation for Plant Pathology, Wageningen, 26 Feb - 2 Mar 1990 (in press).

Linderman, R.G. (1989) Organic amendments and soil-borne diseases. Canadian Journal of Plant Pathology 11 180-183.

Richards M.C. (1990) Crop protection constraints and choice of variety for organic cereals. Crop Protection in Northern Britain 1990, Proceedings of a Conference held at Dundee University, 20-22 March 1990, pp. 159-164.

Samuel, A.; Guest, J.; Davies, W.P.; (1990) Disease development in organic wheats, Proc. BCPC Symposium on Crop Protection in Organic and Low Input Agriculture (these proceedings).

Shipton, P.J. (1981) Saprophytic survival between susceptible crops. In: Biology and Control of Take-all, M.J.C. Asher & P.J. Shipton (Eds.), London: Academic Press, pp. 317-342.

Wolfe M.S.; Barrett J.A.; Jenkins, J.E.E. (1981) The use of cultivar mixtures for disease control. In: Strategies for the control of cereal disease, J.F. Jenkyn & R.T. Plumb (Eds.), Oxford: Blackwell Scientific Publications, pp. 73-80.

Wong, P.T.W. (1981) Biological control by cross protection. In: Biology and Control of Take-all, M.J.C. Asher & P.J. Shipton (Eds.), London: Academic Press, pp. 417-433.

CONTROL OF DISEASES IN FIELD VEGETABLES USING RESISTANT CULTIVARS AND THEIR INTEGRATION WITH BIOLOGICAL AND CHEMICAL METHODS

R.E. BEALE, J.B. SWEET

Plant Pathology Department, National Institute of Agricultural Botany, Huntingdon Road, Cambridge, CB3 0LE, U.K.

ABSTRACT

Resistance of field vegetable cultivars to several economically important diseases was investigated. Commercial cultivars were screened using naturally infected field trials grown using organic and conventional techniques. Resistance of cultivars of Brussels sprouts to powdery mildew, white blister, light leaf spot and ringspot were examined in detail. Studies examining levels of resistance to foliar diseases in other vegetable brassicas examined the resistance of winter white cabbage to ringspot and of Chinese cabbage to powdery mildew and alternaria leaf spot.

The integration of cultivar resistance with chemical or biological methods of control was studied for the control of soil borne diseases of carrots. A metalaxyl plus thiram fungicide was integrated with cultivars for the control of cavity spot. Preliminary screening with biological control agents has indicated potential for integration with low level cultivar resistance to violet root rot disease.

INTRODUCTION

Methods of controlling diseases of vegetables include methods of avoidance such as, rotation, use of clean seed and destruction of alternative hosts, direct control with fungicides, control using resistant cultivars and biological methods of control. The cheapest and most effective method of controlling diseases of vegetables is the use of resistant cultivars (Russell, 1978). Provided that the inherited resistance is not linked with undesirable characters such as inferior quality or yield, it is as cheap for a farmer to grow a resistant cultivar as one which is susceptible.

Studies at the National Institute of Agricultural Botany (NIAB) have investigated the resistance of vegetable cultivars to many economically important diseases. Although the majority of this work has evaluated resistance in conventionally grown cultivars, the importance of organic and low input systems has been recognised. Specific information has been produced for organic growers (Anon., 1989) and low input systems have also been examined (Sweet et al., 1989).

The importance of this work has been emphasised by the recent tightening of regulations on the use of pesticides and on their residues in food stuffs and by increasing public concern over the use of pesticides in horticulture and their fate in the environment. Concern has been focused on resistance to diseases that reduce marketable yield of vegetable crops through their cosmetic affect on produce. This paper reviews work at the NIAB on the control of a number of such diseases.

CULTIVAL RESISTANCE

Brussels sprouts

Losses in marketability of this crop frequently occur through infections of buds with Erysiphe cruciferarum (powdery mildew), Mycosphaerella brassicicola (ringspot), Albugo candida (white blister) and Pyrenopeziza brassicae (light leaf spot). The resistance of cultivars to these diseases was assessed in replicated field trials at sites in Devon, Warwickshire, Cambridgeshire, Lincolnshire, Yorkshire, Lancashire, Bedfordshire and Hampshire. These trials were of three types; (i) conventionally grown with the use of fungicides (Holland, 1985), (ii) disease observation plots lacking fungicides and (iii) organically grown trials (Henry Doubleday Research Association trial ground, Coventry). Assessments of natural infections on leaves and buds were made using standard keys (Anon., 1985) and means of percentage infection were compared using a fitted constant analysis (Silvey, 1978).

Data collected since 1978 are summarised in Table 1 for cultivars selected for organic production systems (Anon., 1989). Cultivars are listed in maturity order with fitted constant adjusted means of percentage infection. High levels of resistance to powdery mildew were identified in a number of cultivars including Cor, Rampart and Sheriff. The cultivars Cor and Lunet were among those showing good resistance to ringspot. Lunet and Lauris were among those showing resistance to white blister and Cavalier and Orkney among those showing resistance to light leaf spot.

Winter white cabbage

Diseases occurring both in the field and in store result in economic losses through rejection, down grading and increased trimming and sorting costs. The pathogens responsible are similar to those affecting Brussels sprouts but with Alternaria spp. Peronspora parasitica and turnip mosaic virus (TuMV) also being important.

Disease resistance data have been collected from replicated trials (Holland, 1985) in Cambrigeshire, Lincolnshire, Hampshire, Yorkshire, Lancashire and Norfolk since 1987 (including a farm with Soil Association Symbol). Significant differences in resistance to TuMV (Anon., 1990) and ringspot (Table 2) have been found. Results have also indicated differences in the susceptibility of cultivars to powdery mildew and light leaf spot but further work is needed before information can be published.

Chinese cabbage

Infections by E. cruciferarum and Alternaria spp. regularly result in reductions in marketable yields of this crop. Replicated field trials grown on the NIAB trial ground in Cambridge between 1985 and 1987 and on the Henry Doubleday Research Association trial ground at Coventry in 1988 have examined the resistance of cultivars to natural infections of these diseases. Chiko, Green Rocket and Kingdom 65, have shown a high degree of susceptibility to powdery mildew whereas Tiptop has been among those showing good resistance to this disease. Signficant differences in resistance to Alternaria have also been found (Table 3).

INTEGRATION OF CULTIVAR RESISTANCE AND CHEMICAL OR BIOLOGICAL CONTROL

Studies have examined the control of soil-borne diseases of carrots, in particular cavity spot (*Pythium* spp.) and violet root rot (*Helicobasidium brebissonii*).

Control of cavity spot may be achieved through the use of resistant cultivars (Sweet *et al.*, 1986) or through the use of fungicides (Gladders & Crompton, 1984). However, because cultivars at best only possess moderate resistance, the integration of both methods of control is usually advocated. Examinations of the roles of these two methods have investigated the use of lower fungicide inputs (Sweet *et al.*, 1989). Data from these trials not only demonstrated the benefit of growing resistant cultivars such as Redca but also found that the loss in marketable roots through cavity spot disease was not significantly greater when a half rate fungicide input was used compared with a full rate (Table 4).

While significant differences in the levels of violet root rot infection on different cultivars have been identified (Beale *et al.*, 1989), the levels of resistance are unlikely to offer satisfactory control in their own right. However, recent investigations have identified a number of organisms which suppress *H. brebissonii in vitro* (Beale *et al.*, 1989) and their potential for integration with low level cultivar resistance is being investigated.

DISCUSSION

These studies have shown that resistant cultivars are beneficial in significantly reducing losses caused by blemishing diseases in a number of vegetable brassica crops. Screening of these cultivars under organic and low input systems has shown that they also offer significant control of diseases under these conditions, and several of them have been selected for organic production systems (Anon., 1989).

Results from studies on soil-borne diseases of carrots show that, in certain cases (Camden and Redca, 150 d harvest), cultivar resistance can be equally effective at reducing unmarketable roots as fungicide, and likely to be of significant benefit to organic producers. Although studies of reduced fungicide inputs are at an early stage, it is hoped that they will offer future economical and environmental benefits in conventional production systems.

REFERENCES

Anon.(1985) *Disease Assessment Manual for Crop Variety Trials*. Cambridge, National Institute of Agricultural Botany.

Anon.(1989) *Vegetable Varieties for Organic Growers*. Cambridge, National Institute of Agricultural Botany.

Anon.(1990) Recommended varieties of cabbages. *Vegetable Growers Leaflet No.2*.Cambridge, National Institute of Agricultural Botany.

Beale, R.E.; Hamilton, W.A.; Sweet, J.B. (1989) Studies on the control of violet root rot of carrots using cultivar resistance and antagonistic microorganisms. *Aspects of Applied Biology*, *22*, 279-287.

Gladders, P.; Crompton, J.G. (1984) Comparison of fungicides for control of cavity spot in carrots. Tests of Agrochemicals and Cultivars 5, Annals of Applied Biology, 104 (supplement), 36-37.
Holland, R.W.K. (1985) Techniques used in vegetable variety performance trials. I. Brassica crops. Journal of the National Institute of Agricultural Botany, 17, 117-128.
Russell, G.E. (1978) Plant Breeding for Pest and Disease Resistance. London, Butterworths.
Sweet, J.B.; Beale, R.E.; Wright, I.R. (1989) Cavity spot disease in six carrot cultivars treated with a metalaxyl and thiram fungicide. Tests of Agrochemicals and Cultivars 10, Annals of Applied Biology, 114 (supplement), 38-39.
Sweet, J.B.; Lake, S.E.; Wright, J.R.; Priestley, R.H. (1986) Resistance of carrot varieties to cavity spot disease. Aspects of Applied Biology, 12, 235-245.
Silvey, V. (1978) Methods of analysing NIAB variety trial data over many sites and several seasons. Journal of the National Institute of Agricultural Botany, 14, 385-400.

TABLE 1. Levels of infection of Brussels sprout cultivars with four fungal diseases in field trials between 1978 and 1988. Cultivars are those selected by NIAB for organic systems (Anon., 1989).

Cultivar	Mean percentage infection*			
	Powdery mildew	Ringspot	White blister	Light leaf spot
Oliver	3.11	11.04	2.88	5.67
Adeline	14.62	3.29	5.60	12.73
Mallard	2.88	6.09	1.19	4.13
Cavalier	5.98	9.27	4.24	1.20
Richard	3.54	10.19	2.56	1.77
Cor	1.12	2.18	2.33	3.39
Porter	1.61	5.99	3.02	5.58
Lunet	3.99	2.02	0.93	2.49
Rampart	1.06	4.56	2.34	4.81
Lauris	11.77	10.11	1.04	1.59
Orkney	1.51	6.41	3.05	0.00
Gabion	1.13	1.94	2.89	2.37
Odette	1.36	6.31	-	2.33
Troika	2.49	6.37	2.19	2.10
Sheriff	0.85	6.35	1.52	1.28
Rasmunda	3.77	9.75	2.99	5.57
Stephen	1.84	9.30	2.31	2.93
LSD (P=0.05)	2.251	3.664	3.004	3.668

* Adjusted means from fitted constant analysis.

TABLE 2. Levels of *Mycosphaerella brassicicola* infections of winter white cabbage cultivars

Cultivar	% leaf area infected*			Overall Mean
	Efford 1987	Efford 1988	Kirton 1988	
≠Bison	1.4	1.3	2.3	1.67
≠Horizon	4.5	1.8	2.3	2.87
Fidelio	3.3	4.5	2.5	3.43
≠Marathon	3.4	5.2	2.3	3.63
Prevalent	2.0	4.9	6.3	4.40
Slawdena	3.0	4.1	7.5	4.87
Polinius	2.8	18.7	5.5	9.00
LSD (P=0.05)	1.80	7.62	1.40	

* Means from four replicates
≠Cvs. selected for organic production (Anon., 1989)

TABLE 3. Levels of *Alternaria* infections of Chinese cabbage cultivars in field trials at NIAB and the Henry Doubleday Research Association (HDRA).

Cultivar	% leaf area infected*				Overall Mean
	NIAB 1985	NIAB 1986	NIAB 1987	HDRA 1988	
Chiko	0.6	4.7	3.0	1.3	2.4
Granado	2.0	9.3	5.5	-	5.6
Green Rocket	1.5	6.0	2.8	-	3.4
Hopkin	-	6.0	5.5	4.0	5.2
Jade Pagoda	1.0	8.0	5.5	-	4.8
Kasumi	1.1	6.0	4.8	4.7	4.2
Kinap	3.5	6.2	6.5	-	5.4
Kingdom 65	2.5	5.7	4.5	-	4.2
Nerva	-	8.7	5.0	8.7	7.5
Nestor	-	10.3	4.3	4.3	6.3
Okido	-	3.7	4.5	3.3	3.8
Spring A1	2.1	15.2	8.0	-	8.4
Tako	0.8	9.7	4.5	4.3	4.8
Tip Top	1.0	9.3	6.5	4.3	5.3
LSD (P=0.05):	NS	3.61	1.31	2.11	

*Each figure is the mean from 2 (1985 & 1987) or 3 replicates.
-, Cultivar not included in trial.

TABLE 4. Results of trials evaluating the integration of six carrot cultivars with a metalaxyl plus thiram fungicide for the control of cavity spot.

Fungicide ≠ application rate	% roots unmarketable through cavity spot*					
	NANDOR	TINO	CAMDEN	AK-VITA LONGA	REDCA	CRC-SUPREME
Harvested at 150d						
Full	1.0	2.3	4.0	1.7	1.7	1.0
Half	3.3	4.7	3.0	4.0	2.3	5.7
Zero	16.3	27.0	7.7	16.0	11.3	27.3
	LSD (P = 0.05) = 10.86					
Harvested at 240d						
Full	3.8	6.2	7.8	2.2	3.5	11.5
Half	4.0	9.0	3.8	3.5	2.0	12.2
Zero	18.2	34.0	16.2	19.2	23.7	44.3
	LSD (P = 0.05) = 10.13					

* Each figure is the mean from two three replicate trials at different sites (on a 1-9 scale where 1 = very susceptible and 9 = very resistant Nandor = 4, Tino = 2, Camden = 4, AK-Vita Longa = 2, Redca = 5 and CRC-Supreme = 1).

≠ Full rate = 12 l/ha 'Favour 600 FW' (100g/l metalaxyl; 500g/l thiram) in 1000 l/ha water; half rate = 6 l/ha 'Favour 600 FW';

5.
Systems Management

Chairman: MR L. WOODWARD

FARMING SYSTEMS RESEARCH IN THE NETHERLANDS: PERSPECTIVES FOR INTEGRATED ARABLE AND ORGANIC MIXED SYSTEMS

F.G. WIJNANDS

PAGV, Research Station for Arable Farming and Field Production of Vegetables, P.O. Box 430, 8200 AK Lelystad, the Netherlands

ABSTRACT

Worldwide agriculture is facing a crisis. Many alternatives have been suggested. Farming strategies for integrated arable and organic systems are presented here. Based on 10-years experience on the Nagele experimental farm in the Netherlands, strategies for the major system factors are highlighted. On this farm these two alternative farming systems are being developed and compared with a conventional system. On the basis of the results, that are discussed here, integrated arable systems are being introduced in practice in the Netherlands. Perspectives of organic farming are briefly discussed.

INTRODUCTION

Agriculture is facing a worldwide crisis. This cricis concerns a complex of problems on economic, technical and environmental levels. Intensification of production has led to surplusses which European tax-payers and the trading partners are no longer willing to finance, this prices are under pressure. Production costs are steadily increasing, since conventional production techniques are heavily dependent on high inputs of agrochemicals. However, there are doubts as to the efficacy and success achieved in the control of pests, diseases and weeds. The intensive use of chemicals has also led to increasing problems of pollution and a general decline in the quality of the environment. Society is now forcing agriculture to take account of the demand for a sustainable and high quality management of our biotic and abiotic surroundings. Consequently there is a urgent need to adapt production techniques to meet this demand.
So, worldwide researchers and farmers are searching for alternative production systems.

So much is clear that conventional agriculture must adopt wider objectives. Currently it is totally oriented towards the market and involves the production of plant and animal commodities aimed al realising maximum profit within a minimally regulated, protected or subsidised system. However two major conflicts of objectives arise: firstly between income/profit and employment; secondly between income/profit and nature/environment. The main cause of these conflicts is the one-sided technology aiming at maximal production.

The opposite approach could be termed the eco-system oriented vision (after Vereijken, in prep.), where agriculture involves the management of the agro-ecosystem aimed at the provision of sufficient food through a sustainable production system based on feelings of respect and responsibility for the biosphere, which in its most radical form would preclude the use of agrochemicals. This may imply an extra contribution to employment, environment, landscape/nature and health/well-being. At the same time it could raise conflicts with food supply and income/profit. This last objective should be satisfied through the provision of sufficient prices for farm products.

Of course, both visions have their strong and weak points. So, it seems logical to try to develop intermediate systems with integrated objectives and methods (Vereijken et al., 1986).

Since 1981 a working group of the International Organization of Biological Control (IOBC) is trying to develop such integrated arable farming systems. This was inspired by the aims and methods of integrated pest management (IPM) (Vereijken, 1989a). The two oldest projects are the Lautenbach experimental farm near Stuttgart, West Germany (El Titi, 1989) and the Nagele Experimental farm in the Netherlands. Full details of the design and implementation of the work at the Nagele Experimental farm are presented in Vereijken (1989b). The aim of the work (established in 1979) is the development and comparison of alternative farming systems (integrated arable and organic (BD) mixed) with a conventional arable system.

FARMING STRATEGIES AND FARMING SYSTEMS RESEARCH

An overall strategy for integrated farming systems could be a multiple goal approach including the following (Vereijken and Royle, 1989)
1. A shift in emphasis from greater production to cost reduction and improvement of quality of both products and production methods, through substituting expensive and potentially inputs (particularly fertilizers and pesticides) by both agricultural an ecological knowledge, labour and non-chemical husbandry techniques.
2. Encouragement and conservation of flora and fauna in and around fields to stabilise the agro-ecosystem as a major preventive measure against outbreaks of pests, weeds and diseases.

As the main social effects of this integrated farming strategy it can be expected:
a. less pressure on income/profit and employment of the farmers at increasing cost of production means and decreasing prices of products caused by a more market-oriented policy;
b. less pollution of the environment, so more safety for public health and nature/landscape.

The succes of this strategy is still a question, since integrated systems do not exist yet in practice. However, from the results of the Nagele experiment, it can be expected to alleviate the environmental problems. Whether it can also help to maintain employment is rather doubtful.

An overall strategy for ecosystem-oriented farming would be the most radical approach of these integrated objectives, the complete substitution of chemical pesticides and fertilizers. The implications of this have already been discussed.

On the basis of these overall strategies, farming systems were developed at the Nagele experimental farm, on a semi-practical scale, synthesizing knowledge from diverse disciplines. A general design for this 'farming systems research' is described by Vereijken (1986). Whilst the precise methodology is presented in Vereijken (in prep.) the experience of the past 10 years has enabled the formulation of general strategies for rotation-design crop protection and fertilization. Each of these will be examined in more detail below.

CROP ROTATION

The EC guaranteed prices for certain products has led to crop rotations including relatively few different crops. It would appear that this has provoked problems of soil structure and/or diseases and pests. These problems are being countered with a range of physical and chemical means. The current cropping-plans are based on a balance between the costs of counteracts and the profits of intensification.

From an integrated point of view, crop rotation has totally different objectives:
- to maintain the soil fertility and to ensure the quantity and quality of the produce;
- to minimize the need for pesticides for the benefit of nature and environment and the quality of the produce;
- to realize in this way an acceptable economic result.

An optimal integrated crop rotation can be designed on the basis of the following guidelines:
- limit the intensity of cropping of a certain crop to such an extend that soil borne pests and pathogens do not become economically damaging leading to the need for chemical control;
- balance negative and positive effects of crops on physical-chemical soil properties by the choice of crops and cropping sequence;
- design the crop rotation in such a way that negative influences are avoided and positive influences are used (structure, N-delivery (reserves), pest, diseases and weeds).

Gross margins of crops only give an indication of the value of that crop. The real value of a crop for the system as a whole depends on the impact that crop has on the level of performance of other crops and on the management of the whole farm. Thus the gross margin of the whole crop rotation should be considered as a more relevant economic criterion.

For an organic system the strategy is based on similar guidelines. However there is one major difference: In a mixed farm grassland and arable land should be alternated to the benefit of both. The mixed character offers excellent opportunities for a diversified and sound rotation; pastures with grass and clover supress weeds, restore the soil structure and increase de organic matter and nitrogen content of the soil.

FERTILIZATION

Many problems in conventional agriculture are related to fertilization management. Overdosing minerals is one of the biggest problems, in many cases caused by an injudicious use of organic manure in combination with mineral fertilizers. Too high levels of availabe nitrogen may lead to a higher disease and pest pressure (Daamen et al., 1989), increased risks of lodging and potentially polluting losses to the environment. In addition they may reduces the quality of the produce (onions, potatoes, sugarbeet). Organic manure should only be used when directly after application it is mixed with and covered by soil and followed by a (green manure) crop to avoid volatilization of ammonia. The amount applied should be appropriate to the potential nitrogen uptake of crops, crop residues or green manure crops, otherwise the nitrogen may be lost by volatilization or leaching. These unwanted emissions are damaging the value of ecosystems or endangering the quality of drinking water.

The objectives of an integrated fertilization strategy are both economic and ecological: An acceptable profit and a minimum of unwanted emissions. These objectives may be achieved by considering the following guidelines.

- Maintain soil fertility at a level appropriate for economic returns. This implies that it should not be too low for adequate yields and not too high for producing high quality produce based on healthy crops with a minimum need for chemical control.
- Dosing and application of minerals aimed at maximum uptake by the crops and minimum emissions.
- The use of organic manure, substituting mineral fertilizers, is advocated. It wil contribute towards:
  - more equilibrium on the national NPK balances and thus lead to less pressure on nature and environment;
  - maintenance and improvement of soil fertily in terms of physical (structure), chemical (nutritional) and biological (dissease resistance) attributes;
  - cost savings and yield increases;
  - maintenance of finite resources mainly energy.

For the Dutch situation the highest priority is given to the optimal use of organic manure. The input and output of P and K should be in balance. For N, the losses should be as low as possible. At the farm level leaching of N should be minimized by supporting cultural practices such as the use of cropping green manure crops and returning the straw to the system.

Again, basically the strategy is the same in an organic farm. However in a mixed farm N-fixation is the main source of nitrogen in the farm cycle. Every step from N-fixation over the level of protein consumption and conversion by livestock, manure production and storage up to application and dosing of manure should be optimized to minimize emissions as possible. Through manure-application P and K can be effectively redistributed within the farm. Because products are sold off the farm, soil reserves will deplete gradually (Vereijken, 1986b). This can be compensated by purchasing straw and/or fodder.

CROP PROTECTION

Intensification of crop rotations and production techniques has increased the pressure of pests, diseases and weeds whilst the increased levels of fertilization and the use of high yielding, but often susceptible cultivars has encouraged this even more. The complex of pest, diseases and weeds is currently almost only controlled by chemical means. However in spite of the large quantities of inputs used, the level of control is often not satifactorily because the cropping techniques tend to stimulate the occurence of damaging organisms more then it limits them. Input costs have increased and since the prices of produce are declining, these increasing costs are a threat to the returns of the conventional farming system. Furthermore the excessive use of pesticides created environmental problems, particularly with respect to drinking water quality.

The logical solution to these problems seems to be to broaden the concept of crop protection in its objectives as well as its techniques. Integrated crop protection aims at minimum costs, acceptable level of control and minimum use of chemicals. The strategies for weed disease and pest control are described in table 1 and 2 (Vereijken, 1989a).

TABLE 1. Integrated control techniques for pests and diseases, in order of preference.

(1)	Biological
	Proper crop rotation to avoid soil-borne pests, especially nematodes
	Resistant cultivars
	Nitrogen fertilization under the current advice to enhance crop resistance against aphids and moulds
	Enhancement of benificial organisms (parasitic and predatory insects, antagonistic fungi) by organic manure, minimum tillage and selective chemical control
	Introduction of (mass-reared) biological control agents
(2)	Chemical
	Monitoring harmful species to develop control thresholds
	Choice of pesticide based on efficacy, selectivity, toxicity for man and animal, persistence, mobility[1], price
	Seed dressing and row application instead of area-wide treatment

[1]With respect to toxicity, persistence and mobility of the chemicals a 'black' list has to be respected.

TABLE 2. Integrated control techniques for weeds, in order of preference.

(1)	Biological
	Cultivars with rapid soil covering and abundant leaf development
	Similar green manure cultivars to suppress weeds in the stubbles
	Late sowing to combine seed bed preparation with weed control
(2)	Physical
	Harrowing, hoeing, tilling and weeding, in combination with apporpriate drilling techniques
	Weed flamers (pre-emergence or pre-harvest)
(3)	Chemical
	Choice of pesticide based on efficacy against the weeds present, toxicity for man and animal, persistence, mobility[1], price
	Row application against annual weeds
	Treatment of spots or single plants (perennial weeds) with special equipment

[1]With respect to toxicity, persistence and mobility of the chemicals a 'black' list has to respected.

Absolute priority should be given to the substitution of pesticides that are susceptible to leaching. Through the combination of high mobility and persistence, this group of pesticides potentially endangers every part of the environment and includes most of the pesticides used to treat the soils. Because this indirect control method often needs high doses of active ingredients, they should be substituted by seed treatments, resistent cultivars, mechanical weed control etc. To summarize it integrated crop protection implies a maximum of prevention and a minimum use of chemicals. Crop protection in organic agriculture totally relies on biological and physical methods. So prevention has absolute priority starting of with a sound and diverse crop rotation.

RESULTS OF THE NAGELE - EXPERIMENTAL FARM

The design of this research farm has extensively been described elsewhere (Vereijken, 1989). Here only the rotations are given (table 3).

TABLE 3. Crop rotations of the farming systems at Nagele.

conventional/integrated		organic (BD)	
1.	$^1/_2$ seed potato, $^1/_2$ ware potato	1.	ware potato
2.	$^1/_4$ sowed onions, $^1/_4$ carrots	2.	winter wheat
	$^1/_2$ dry peas	3.	carrot
3.	sugar beet	4/5/6.	pasture (ryegrass/clover)
4.	winter wheat	7.	sowed onions
		8.	winter wheat
		9/10/11.	pasture (ryegrass/clover)

Economics and the environment represent the two main criteria for the social acceptibility of the three production systems. The inputs of fertilizers and pesticides were important indicators of the environmental impact. The economic viability was indicated especially by net surplus and labor returns. Because of considerable changes in the management of the systems since 1984, only the latest results are presented (1985-1988).

TABLE 4. Average farm economic results of the conventional, integrated and organic farming systems, 1985-1988.

	Economic Results (Dutch guilders/hectare) Conventional	Integrated	Organic
1. Returns from marketable crops	6,490	6,110	12,090
2. Returns from grassland and fodder crops	-	-	9,170
3. Total returns	6,490	6,110	10,630
4. Labor cost*	2,190	2,190	5,790
5. Contract work	1,230	1,200	1,290
6. Equipment and machinery	1,670	1,760	2,490
7. Total operation cost (4 to 6)	5 090	5,150	9,570
8. Land and buildings	1,390	1,390	2,640
9. Cattle and fodder	-	-	1,920
10. Fertilizers	450	300	-
11. Seeds	670	780	440
12. Pesticides	700	260	-
13. Other cost	590	610	880
14. Total cost (7 to 13)	8,890	8,490	15,450
15. Net surplus (3 minus 14)	- 2,400	- 2,380	- 4,820
16. Labor returns (15 plus 4)	- 210	- 190	970
Technical and economic data			
17. Marketable crops (ha)	17	17	10.7
18. Grassland + fodder crops (ha)	-	-	11.4
19. Livestock units	-	-	21.8
20. Number of labor units	0.7	0.7	1.7
21. Standard holding units (SHU) per ha	6.1	6.1	5.7
22. SHU per labor unit	154	156	69

* 27 guilders/hour was the normal gross reward for the farmers own labor in Dutch agriculture during 1985-1987.

Total returns of the organic farm appear to be considerably higher, because of the high premiums on standard product prices (table 4).
Marketable organic crops clearly have higher returns than grassland and fodder crops. However, the total production cost was much higher than on the conventional and integrated arable farms, especially in labor, buildings, and cattle/fodder, which renders by far the lowest net surplus.
Inspite of this, returns on labor on the organic farm were highest, although insufficient compared to other professional groups. The integrated farm fell short of the conventional farm in total returns because of less physical yields. However, the integrated farm gave considerable savings of expenses in fertilizers and pesticides. As a result, the integrated farm achieved an almost equal net revenue. The three farms were hardly different in intensity of soil use (standard holding units per hectare). Labor productivity of the organic farm, however, was less than half of those of the two other farms (standard holding units per labor unit).

TABLE 5. NPK-balances (kg/ha year) and nitrate-nitrogen content of the drainagewater (mg NO_3-N/l) in the systems, averaged for 1986-1988.

	conventional			integrated			organic		
	N	P	K	N	P	K	N	P	K
Inputs									
fertilizers	135	15	145	55	-	5-	-	-	-
manure	80	40	65	100	35	65	-	-	-
biol. N. fixation	35	-	-	35	-	-	100	-	-
concentrates	-	-	-	-	-	-	50	8	50
straw	-	-	-	-	-	-	20	3	15
deposition	45	1	5	45	1	5	45	1	5
total input	295	56	215	235	36	120	215	12	70
Outputs									
plant products	165	30	135	150	25	130	35	7	40
animal products	-	-	-	-	-	-	25	5	5
total output	165	30	135	150	25	130	60	12	45
input - output*	130	26	80	85	11	-10	155	-	25
NO_3-N drainagewater	10			8			3		

*N-emissions = NH_3-volatilization + NO_3-denitrification + NO_3-leaching.
N-leaching (kg/ha) = precipitation surplus (1 m^2) x N-content drainage water (mg/l) x 10^{-2}.
K-emissions = K-leaching ±20 kg/ha/year at Nagele.
P-emissions <1 kg/ha/year at Nagele.

On the organic farm, inputs of NPK were by far the lowest (table 5). On the integrated farm, inputs of NPK were considerably lower than on the conventional farm and an important shift has taken place from mineral to organic fertilization. Only the organic farm had a satisfactory balance between inputs and outputs of P and K. All three systems could meet the standards of the Dutch Ministry of Environment for shallow waters (10 milligrams of nitrate-N per liter). But the drainwater of the organic farm was so clean that it could also reach the European Economic Community guidelines for the maximum admissable nitrate content of drinking water (5.6 milligrams of nitrate-N per liter = 25 milligrams of nitrate per liter).

TABLE 6. Chemical control in the conventional and integrated systems 1986-1988.

	Average number of treatments per field		Input of active ingredients (kg/ha)	
	Conventional	Integrated	Conventional	Integrated
Herbicides	3.5	1.9	4.2	1.4
Fungicides	3.8	1.6	5.6	2.2
Insecticides	1.3	0.7	0.5	0.2
Growth regulators	0.3	0.1	0.3	0.1
Subtotal	8.9	4.3	10.6	3.9
Nematicides*	0.3	0.0	42.3	0.0
Total	9.2	4.3	52.9	3.9

*Soil fumigation against potato cyst eelworms.

On the conventional farm, 8.5 pesticide treatments per field were applied; only 3.6 were applied per field on the integrated farm (table 6). If the use of chemical means per year are expressed in kilograms per hectare active ingredient, differences are still greater, that is, 10.4 versus 4.6 and even 53.1 versus 4.6 if routine fumigation of the soil against potato cyst eelworm on the conventional farm is included. When soil fumigation was introduced on the conventional reference farm, as most farmers did at the time, it was decided to grow eelworm-resistant potato varieties on the integrated farm.

INTRODUCTION OF INTEGRATED ARABLE FARMING INTO PRACTICE

From the experimental results it can be concluded that drastic reductions in the use of fertilizers and pesticides by means of integrated farm management are not only attractive from an environmental point of view. The resulting cost reductions offer sufficient compensation for lower yields so that the net profit may be equivalent to that achieved in a conventional system. Moreover, when costs are increasing and especially prices of agricultural products decrease putting profits under pressure, it becomes attractive to convert to integrated management.

These results initiated two new experiments. In the South-East (since '89) and North-East (since '86) of the Netherlands integrated farming systems are being developed for the specific regional conditions. The environmental problems are forcing governments to restrict the use of pesticides and fertilizers. To stimulate the necessary adaptations in farming practices, the Dutch government decided to introduce stepwise integrated farming into practice. The first step is the testing of the prototype-system developed at Nagele by a group of experienced commercial arable farmers. This is necessary to attain technically and economically feasible farming scenarios. It is expected that this will also lead to the development and improvement of the current integrated cropping programs, promoted by the wide variety of attitudes and skill of farmers, the nature and size of their holdings, soil types, crop rotations and other factors.

In five regions of the Netherlands, a group of about eight farmers will convert to integrated farming, over the next four years. This will be supported intensively by research and extension workers. In every region a specialist has been appointed to guide these farms and promote integrated farming. These extension workers have been made familiar with integrated cropping techniques through a special course for this purpose, financed by EC. We expect that after the project-period of four years enough regional-specific insights will be gamed to enable the introduction of integrated arable farming on a large scale.

PERSPECTIVES ON ORGANIC FARMING

The net output of the organic farm increased steadily since 1985. This was due to the replacement of fodder crops by higher profitable root-crops and vegetables. On the other hand the milk production was raised to a higher level through supplementary purchase of concentrates and an improved management. It can be foreseen that within some years an acceptable income can be realised. However this is still based on the higher price levels that are obtained for the organic products compared to the conventional market. These are clearly necessary to make up for the higher investments in capital and labor. However, they appear to be too high a treshold for the majority of farmers and consumers up untill now. This does not mean that organic farming is doomed to play a marginal role. Several developments are occuring that offer new opportunities for the more radical approach of organic agriculture. In areas with sensitive ecological characteristics and also in water collecting areas organic farming may play an important role because of its minimum introduction of nutrients and its rejection of chemicasl pest controle measures. Therefore, organic farming in these areas deserves financial support from public funds. Finally, an increasing demand on the European market for organic products is occurring, inspired by growing concerns for mankind and the environment and for the well being of animals. Sooner or later this may lead to a breakthrough of organic farming into the conventional practices of farm production, trade, and consumption.

RESEARCH FOR FIELD PRODUCTION OF VEGETABLES

Initiated by questions of the organized farming community we started a preparatory study on the potential for integrated management of farming systems dominated by intensive production of field vegetables. Based on this desk-study experiments were set up and started in spring 1990. On four regional experimental farms, located in the heart of the main production areas, 4 systems are laid out with different crop rotations and intensity of land use. All systems are approached from an integrated point of view. One system has been set up to provide the opportunity for conversion to an organic system.

In the intensive vegetable sector the urge to adapt production techniques is considerable since the level of agrochemical use is much higher than in arable systems. However the allocated costs of agrochemicals are a fraction of the production value of the produce and since external quality is an absolute requirement for achieving acceptable prices, reduction in agrochemical input should only be contemplated provided the risk to the producer is not increased. It is a great challenge for the next decade to develop production methods for field vegetables which can meet the demands of the future.

ACKNOWLEDGEMENTS

The author would like to thank cordrally mr. C. Stopes. Elm Farm Research Centre, for corrections to the manuscript.

REFERENCES

El Titi, A. (1989). Research on integrated farming systems at Lautenbach. In: Current status of integrated arable farming systems research in Western Europe, P. Vereijken and Royle D.J. (eds), IOBC/WPRS Bulletin 1989/XII/5, Wageningen, pp. 21-36.

Daamen, R.A.; Wijnands, F.G.; van der Vliet, G. (1989). Epidemics of diseases and pests of winterwheat at different levels of agrochemical input. J. of Phytopathology, 125, 305-319.

Vereijken, P. (1986). Maintenance of soil fertility on the biodynamic farm in Nagele. In: The importance of biological agriculture in a world of diminishing resources, H. Vogtman; E. Boehncke and Fricke J. (eds), Witzenhausen: Verlagsgruppe Weiland, Happ, Burkhard, West Germany, pp. 23-30.

Verijken, P.; Edwards, C.; El Titi, A.; Fougeroux, A.; Way, M. (1986). Report of the studygroup "Management of farming systems for integrated control", IOBC/WPRS Bulletin 1986/IX/2, 70 pp.

Vereijken, P. (1989a). From integrated control to integrated farming, an experimental approach. Agriculture, Ecosystems and Environment, 26, 37-43.

Verijken, P. (1989b). Research on integrated arable farming and organic mixed farming in the Netherlands. In: Current status of integrated arable farming systems research in Western Europe, P. Vereijken and Royle, D.J. (eds), IOBC/WPRS Bulletin 1989/XII/5, Wageningen, pp. 41-50.

Verijken, P. (in prep.). Methodological aspects of farming systems research.

CEREAL VARIETIES FOR THE ORGANIC AND LOW INPUT GROWER

M. C. RICHARDS

The Scottish Agricultural College, Crop Production Advisory and Development Department, Bush Estate, Penicuik, Midlothian, EH26 0QE

V. HEPPEL

The Scottish Agricultural College, Crichton Royal Farm, Bankend Road, Dumfries, DG1 4SZ

ABSTRACT

Over the past forty years plant breeders have greatly increased the yield potential of cereal varieties. Other characters such as straw strength and malting quality have also been improved. Some modern high yielding varieties have good disease resistance and have performed well in trials on organic farms. The strategy for selecting varieties for organic and low input production is discussed.

INTRODUCTION

Organic farming is becoming established on some farms, and low input crop production could do the same.

Organic production is market led, some farmers who favour this type of production have developed successful integrated businesses supplying a strong market (Tolhurst 1987). The expansion of organic production looks set to continue.

Low input crop production has no single definition, there are a number of likely reasons for constraints on inputs. In some areas there are political reasons for reducing fertiliser input in order to comply with the EC drinking water directive; nitrate leaching has been identified as a problem in water catchment areas in East Anglia and the midlands (Farmers Weekly 1988). In West Germany levels of pesticides in aquifers has led to restrictions in the use of some pesticides. The same could happen in the UK. Integrated crop protection, as used in the Lautenbach project, may be the viable way to achieve these reductions in inputs (El-Titi 1989).

The approach might be to initially decide what chemicals are available and desirable to use. This takes into account any legal restrictions that are introduced, decisions based on cost, and decisions within an integrated system on grounds of safety of chemicals to beneficial organisms that are being encouraged. Carefully managed inputs of fertilisers and pesticides would be made to reduce leaching and damage to beneficial organisms. Machinery would be managed to reduce damage to beneficial organisms and minimise energy input. Rotations would reduce the requirement for fertilisers and pesticides. Modern plant varieties would be chosen to give high yield by making efficient use of inputs and reducing the need for pesticides.

Plant breeders have provided progressive improvement in varieties so that yields are possible today that were considered unattainable 10 years ago (Fiddian 1977). Between the years 1947 and 1983 national wheat yields increased by 167%; of this a 75% increase in yield between 1947 and 1983 is attributable to variety (Silvey 1986). There is evidence that this increased yield potential of modern varieties is available in organic situations (Stoeppler et al 1987). While much effort has been directed at yield, other characters such as straw strength and malt extract levels in barley have also been greatly improved. To qualify for addition to the UK National List one of the requirements is to meet minimum standards for disease resistance, but the standard is not high. Breeders objectives for disease resistance, however are often considerably above these standards.

This paper sets out to present some results of organic variety trials in Scotland and consider what parameters are involved in the selection of varieties for organic and low input systems.

SCOTTISH ORGANIC TRIALS WITH SPRING BARLEY AND OATS

The varieties grown in these trials were of varying competitiveness with weeds, straw length and disease resistance. A full range of varieties with potential for organic was not grown, but the results indicate the relative importance of these characters in the organic situation. There are further trials in 1990, with these additional sites a detailed analysis should be possible.

Methods

TABLE 1 Spring barley trial details

Location	Edinburgh	Annan	Edinburgh	Annan
Year	1988	1988	1989	1989
Organic standards	OF&G	SA (c)	OF&G	SA (c)
Preceeding crops	grass (o) grass (o) grass (o)	grass (n) grass (n) grass (n)	oats (o) swedes (o) grass (o)	grass (n) grass (n) grass (n)
Date sown	24 April	5 April	1 April	19 April
Seed rate	188 kg/ha	188 kg/ha	188 kg/ha	190 kg/ha
Harvest	26 Sept	27 Aug	7 Sept	22 August

Spring oat trial details

Location	Edinburgh	Edinburgh	Aberdeen	Edinburgh	Aberdeen
Year	1987	1988	1988	1989	1989
Organic standards	SA (c)	OF&G	SA	OF&G	SA
Preceeding crops	s barley (c) w wheat (n) potatoes (n)	grass (o) grass (o) grass (o)	grass (o) grass (o) oats (o)	oats (o) swedes (o) grass (o)	potatoes (o) s beans (o) swedes (o)
Date sown	17 April	24 April	28 April	1 April	21 April
Seed rate	225 kg/ha	225 kg/ha	500 viable seeds/m^2	188 kg/ha	225 kg/ha
Harvest	29 Sept	1 Nov	19 Sept	7 Sept	12 Sept

(Note: (o) = organic; (c) = conversion; (n) = conventional)

Trials were managed to Soil Association (SA) or Organic Farmers and Growers (OF&G) standards. Some trials were in conversion to organic; the Annan trials in 1988 and 1989 from a grass rotation that had received low fertiliser inputs and slurry but no pesticides, the 1987 spring oat trial at Edinburgh from arable. Trials were sown with plot size 2 x 22m, apart from spring oat trials at Aberdeen where plots were 2 x 10m. Trials were replicated either three or four times. Harvest was either by Class Compact or Deutz-Fahr M660 combine harvester. Other site details are given in table 1.

Where a variety was not present in every trial, the fitcon technique was used to adjust for differences between trials.

Results and discussion

TABLE 2. Spring barley; fitcon of 1988/89 crop and weed ground cover %, straw length, mildew infection and yield of grain at 85% dry matter.

	Year of introduction	Crop ground cover % Edinburgh GS 30-32	Crop ground cover % Edinburgh GS 60-70	Weed ground cover % Edinburgh GS 60-70	Straw length cm, all trials	Mildew % GS40-75	Mean yield of grain t/ha
Blenheim	1987	43.2	51.7	30.5	70	18.2	3.58
Tyne	1988	56.7	49.2	34.7	67	0	4.37
Nomad	1989	42.3	51.2	34.5	74	2.7	3.66
Camargue	1986	56.0	57.9	25.2	69	13.1	3.71
Prisma	1989	39.1	62.1	27.6	70	38.6	3.13
Malibu	-	50.8	67.1	29.2	74	0.8	4.78

(Note: - = not commercialised)

All were modern varieties that have given high yields in conventional trials, from these results it is possible to indentify factors limiting yield in organic trials. Mildew had a large effect, Malibu and Tyne that are mildew resistant performed relatively well, Prisma and Blenheim that are susceptible performed less well. Varietal susceptibility to mildew followed a similar pattern to that seen in conventional trials. The effect of earliness of crop ground cover and straw length was less pronounced although Malibu, a tall variety that achieved ground cover early and was mildew resistant, performed particularly well.

TABLE 3. Mean grain specific weight, thousand grain and nitrogen %

	Specific weight (kg/hl)	Thousand grain wt (g)	Nitrogen %
Blenheim	61.9	45.4	1.70
Tyne	63.7	42.5	1.61
Prisma	58.5	48.6	1.72
Malibu	64.9	49.3	1.61
Nomad	63.2	46.0	1.73
Camargue	62.1	44.4	1.70

In some years Rhynchosporium is a problem, it is important to consider the risk of disease occurring in the location where the crop is to be grown, this is discussed in more detail later.

Spring barley trials were on high yielding sites. Grain nitrogen was higher than might be expected, there is a possible relationship with disease, leading to lower specific weight grain with higher nitrogen. Nitrogen was at acceptable levels in the mildew resistant varieties Tyne and Malibu (table 3).

Spring oat trials were on both high and low fertility sites. Specific weight met the 50 kg/hl requirement for milling in 1987 but not in 1988 or 1989. In the high fertility site at Edinburgh in 1988 lodging and grain sprouting occurred, yield data from this site is omitted from the mean values given in the table, it illustrated the fact that oats should not be grown at the point of highest fertility in the rotation. Rotation design commonly recognises this in organic farming systems.

TABLE 5. Spring oats; fitcon of 1987-89 crop and weed ground cover %, straw length, mildew infection, BYDV infection and yield of grain at 85% dry matter.

	Crop ground cover % Edinburgh		Weed ground cover % GS 30-65 all trials	Straw length cm	Mildew % GS 60-70 Edinburgh 1987-89	BYDV % Edinburgh 1989	Mean yield of grain t/ha
	GS 24-30	GS 60-65					
Dula	35.2	71.0	27.3	101	24.3	65	4.11
Matra	33.4	68.2	28.4	92	26.7	70	3.86
Sang	39.3	-	18.3	98	34.7	70	3.47
Adamo	44.2	60.7	23.6	96	14	31.3	4.22
Ketty	40.5	-	19.5	94	6.2	38.8	4.27
Major	39.7	70.0	24.2	103	22.3	-	4.23
Keeper	49.0	60.7	25.6	102	0	-	4.01
Rollo	35.5	63.1	30.7	103	0	-	3.66
Commander	38.3	85.6	19.4	98	0	-	4.42

Varietal resistance to mildew followed a similar pattern to that seen in conventional trials. There were differences in earliness of ground cover and straw length, there was not a clear relationship with yield although Matra that was the shortest strawed variety and was slow to achieve ground cover performed less well than taller varieties. BYDV infection at the Edinburgh trial in 1989 varied between varieties, Adamo and Ketty that were less severely infected yielded particularly well in that trial. Rollo and Sang that gave lower mean yield have given similar lower mean yields in conventional trials in Scotland. Commander had a good combination of high crop ground cover, long straw and good mildew resistance.

INFORMATION FROM CONVENTIONAL TRIALS

There is a well established system for testing varieties in the UK (Patterson & Silvey 1980). Much of the information required for decision making on varieties for organic or low input is available. Much of the information that is published on disease has assumed less importance in recent years because of the availability of effective fungicides, but this information is of particular value for organic or low input.

The information, however, does not remove the need for actual data from trials grown organically or with low inputs. Both types of information are important. Currently conventional variety trials are grown with two replicates with no fungicide and two replicates with a full fungicide, and in winter wheat growth regulator, program. Fertiliser application is designed to show the full yield potential of high yielding varieties and is the same on all replicates. If in the future low input husbandry has clearly defined rules, it might be more appropriate to replace the untreated replicates with low input management. In addition to this there is a need for further trials grown under organic management.

Competitiveness with weeds

Those involved in variety testing will have noted large differences between some varieties in how early they achieve ground cover. This is a character that has not been routinely recorded in variety trials, so data is not generally available. Earliness of ground cover is not the only parameter affecting the ability of varieties to compete with weeds. Factors such as root morphology, competition for nutrients and allelopathy all have an effect (Hurd 1968, Zimdahl 1980). But differences in earliness of ground cover are quick to record and have an effect on competition with broad-leaved weeds (Donald 1961, Richards 1989). This is illustrated by data from a trial in the east of Scotland this year with five winter wheat varieties, no herbicide.

TABLE 6. The relationship between earliness of crop ground cover and weed infestation at Zadoks growth stage 24 and 39 in winter wheat, Ploughlands 1990.

	Earliness of ground cover 1-9 (crop)	Number per m^2 GS 24 *Fumaria officinalis*	*Stellaria media*	Ground cover % GS 39 *Fumaria officinalis*
Parade	5	114	11	62
Slejpner	7	78	18	37
Fortress	7	75	13	37
Mercia	8	92	17	20
Apollo	9	73	13	22
SED	0.56	14.7	1.53	6.27

As has been observed in other trials Parade was the slowest variety to achieve ground cover. Infestation of the dominant weed *Fumaria officinalis* was greater with Parade than other varieties. *Stellaria media* was slower to germinate than *F. officinalis*, populations of *S. media* were affected by competition from the crop and from *F. officinalis*.

Scottish trials are now routinely assessed for 'earliness of ground cover' and 'canopy density'. Canopy density may be particularly important in wet seasons when weed growth can continue into the summer. If this occurs the ability of the crop to shade weeds becomes important.

In Scotland there is no blackgrass, there are wild oats and barren brome in some areas, but broad-leaved weeds predominate. The results should be viewed in that context, they might be different in situations with severe grass weed infestation. There is some English data, however, that indicates variation in ability of varieties to compete with grass weeds. Moss (1985) identified differences in competitiveness of winter wheat and winter barley varieties with *Alopecurus myosuroides*, but he found that differences in crop competitiveness were not simply related to either crop height or tillering capacity.

Regional and seasonal variation in disease incidence

Information on disease incidence is published in the NIAB Recommended List, NIAB Bulletins and elsewhere (NIAB 1990, NIAB 1984-1989, King 1977). Data for mildew and Rhynchosporium infection in Scottish winter and spring barley trials is presented in table 7. The information can be used to match varietal disease resistance to disease risk in a particular region.

TABLE 7. Percentage of barley trials infected with greater than 10% disease GS 65-75.

	Mildew			Rhynchosporium		
Location Year	North Scotland	East Scotland	West Scotland	North Scotland	East Scotland	West Scotland
1981	5	0	7	0	0	0
1982	0	58	0	0	0	0
1983	46	0	0	50	0	25
1984	50	48	10	16	0	0
1985	42	34	65	0	0	10
1986	14	0	0	0	0	25
1987	62	58	0	7	0	0
1988	50	41	37	0	10	0
1989	20	39	32	0	0	0

The data in table 7 may be an underestimate because it refers to recordings made between GS 65-75 only, although this is a critical time when disease has a large effect on yield.

Because mildew is a problem in most years in Scotland resistance to mildew is most important in organic cereals. Varieties should not be below 6 for Rhynchosporium resistance particularly in the north or west so that in bad Rhynchosporium years severe crop loss is avoided.

In low input cereals mildew resistance is important, Rhynchosporium is less critical because in the occasional Rhynchosporium years fungicide can be used.

Cereal variety diversification

Risk of spread of infection by yellow rust or mildew can be reduced by growing varieties that have been shown by the UK Cereal Pathogen Virulence

Survey to offer a low risk of disease spead. Information on diversification is given in SAC and NIAB Recommended Lists (SAC 1990, NIAB 1990).

Other data from conventional trials

Untreated yield provides a useful guide to performance without use of fungicides or growth regulator. It should be borne in mind that for new varieties severity of disease in the trial years can have a large effect on untreated yield. A variety might be lucky and a disease to which it is susceptible does not occur. Atem has low untreated yield because it is an old variety, newer introductions have higher yield potential. Prisma has low untreated yield because it is susceptible to disease. Untreated trials are grown with full fertiliser input and do not represent low input.

TABLE 8. Example of data from Scottish conventional trials used to select spring barley varieties that have potential for organic or low input.

	Untreated yield as % controls	Mildew rating 1-9	Rhyncho-rating 1-9	Straw length cm	Straw strength 1-9	Malting quality	Year of intro-duction
Alexis	107	8	3	75	8	Good	1990
Atem	98	9	5	85	6	Inter.	1980
Blenheim	104	7	4	74	8	Good	1987
Camargue	103	8	5	72	9	Good	1986
Heritage	112	8	7	87	5	Inter.	in trial
Malibu	112	9	7	84	6	Poor	-
Nomad	110	7	4	75	8	Inter.	1990
Prisma	99	6	3	78	8	Good	1989
Sherpa	107	9	6	76	7	Good	1986
Shirley	110	9	3	84	5	Poor	in trial
Tyne	111	9	5	71	6	Inter.	1988

(Note: - = not commercialised)

Information on disease susceptibility, straw length and strength is highly relevant to organic and low input situations, as is resistance to pests such as cereal cyst nematode.

STRATEGY FOR CHOOSING A VARIETY

Quality as specified by the end user is currently one of the most important considerations when selecting a variety and often leads to substantial areas being grown of a variety that is in demand. Under organic or low input systems selection of a variety to suit local conditions is more important and will inevitably lead to a more diverse range of varieties being grown. A computer program has been developed to match varieties to specific situations (Richards et al 1989).

Organic

In light of experience with Scottish organic trials parameters for organic growing are as follows:

The variety should have high untreated yield potential and quality to suit the intended market. If fertility is high stiff straw is desirable, if the field is on high ground or in an exposed situation earliness of ripening and resistance to shedding are important. If a damaging disease occurs regularly in the locality then good resistance to that disease is essential, for other diseases that occur infrequently or are less damaging a resistance score of '6' or better should be the aim. Where weed levels are likely to be high it is desirable to choose a tall variety that achieves early ground cover. The variety should not lodge or brackle which can lead to harvesting problems.

Applying these criterea for malting barley in Scotland, in the east grow Sherpa, Tyne, Alexis or Atem that is becoming outclassed on yield. In the north or west Alexis is more at risk because of the greater incidence of Rhynchosporium. The new variety Heritage looks promising and is in organic trials this year, as is the feed variety Shirley.

Low input

Initially it must be decided what chemicals are available and desirable to use. This takes into account any legal restrictions that are introduced, decisions based on cost, and decisions within an integrated system on grounds of safety of chemicals to beneficial organisms that are being encouraged. It is then a case of studying which weeds, pests and diseases will be difficult to control with the chemicals that are available and choosing a high yielding variety with good resistance to these. If availability of plant growth regulators is restricted, stiffer straw is desirable in situations where fertility is high or variable. The usual considerations of earliness of ripening and resistance to grain loss to suit the site also apply.

ACKNOWLEDGEMENTS

The organic trials have been partly funded by support from plant breeders. We would like to thank our colleagues at Aberdeen for their trial results that are included in this paper, and the Scottish Agricultural Statistics Service for advice.

REFERENCES

Amos, D. (1988) Bsc Honours project. Edinburgh University, School of Agriculture.

Commissie voor de Samenstelling van de Rassenlijst voor Landbouwgewassen (1989). Beschrijvende Rassenlijst voor Landbouwgewassen.

Donald, C.M. (1961) Competitive plants, communal plants, and yield in wheat crops. Wheat Science. -Today Tomorrow. ed L.T. Evans & W.J. Peacock. Cambridge University Press. pp 203-222.

El-TiTi, A. (1989). Integrated control in the Lautenbach project. Lecture given as part of European Training in Integrated Crop Protection, Long Ashton Research Station, November 1989

Farmers Weekly (1988) Nitrates. Farmers Weekly 30 September 1988 63-70

Fiddian, W.E.H. (1977) Factors affecting cereal yields. Proceedings, British Crop Protection Conference, Brighton 3 755-761

Hurd, E.A. (1968) Growth of roots of seven varieties of spring wheat at high and low moisture levels. Agronomy Journal 60, 201-205.

King, J.E. (1977) The incidence and economic significance of diseases in cereals in England and Wales. Proceedings 1977 British Crop Protection Conference 677-687.

Moss, S.R. (1985) The influence of crop variety and seed rate on Alopecurus myosuroides competition in winter cereals. 1985 British Crop Protection Conference - Weeds 701-708

NIAB (1984-1989) Bulletins of Crop Varieties and Seeds 1984-1989. NIAB, Huntingdon Road, Cambridge

NIAB (1990) Recommended varieties of cereals 1990. NIAB, Huntingdon Road, Cambridge

Patterson, H.D. & Silvey, V. (1980) Statutory and Recommended List trials of crop varieties in the United Kingdom. The Journal of the Royal Statistical Society, Series A (General) 143, 219-252.

Richards, M C; Morgan, O W; Oskoui K E; McGregor M J (1989) CUE (Cultivar Expert), a computer program for crop variety selection. Plant Varieties and Seeds (1989) 2, 179-191

Richards, M C (1989) Crop competitiveness as an aid to weed control. Proceedings, British Crop Protection Conference, Brighton. In press.

Silvey, V. (1986) The contribution of new varieties to cereal yields in England and Wales between 1947 and 1983. J. natn. Inst. agric. Bot. (1986), 17, 155-168

Stoeppler, H; Koelsch, E; Vogtmann, H (1987) Suitability of Varieties of Winter Wheat in Ecological Agriculture Proceedings 6th International Scientific Conference of International Federation of Organic Agriculture Movements ed. Allen, P. and Van Dusen, D.G. Global perspectives of agro-ecology and sustainable agricultural systems. University of California, Santa Cruz p407-412

Tolhurst, I. (1987) Growing fruit and vegetables organically. National Agricultural Centre Conference 3 March 1987.

Wilson, B.J (1986) Yield responses of winter cereals to the control of broadleaved weeds. Proc. EWRS Symposium 1986, Economic Weed Control, 75-82.

Zimdahl, R L. (1980) Weed-Crop competition. A review 1980. IPPC, Oregon.

PRACTICAL CONSTRAINTS AND OPPORTUNITIES FOR IMPROVING CROP PROTECTION IN ORGANIC VEGETABLE PRODUCTION

L. PEACOCK*

Silwood Centre for Pest Management, Department of Biology, Imperial College at Silwood Park, Ascot, Berkshire, SL5 7PY

ABSTRACT

Fifty-five organic vegetable growers and a limited number of organic carrot growers were interviewed on their perceptions of crop protection problems in organic systems. Weeds, slugs or birds are considered the most serious problems, with specific insects and diseases, notably carrot fly (Psila rosae) and potato blight (Phytophthora infestans), seen as serious threats. The major crop protection method used by the growers is avoidance of pest attack, which includes stopping, or not even starting, to grow those crops most troubled by pests, rotations, timely planting and harvesting, transplanting and avoiding high pest areas on the farm. Organic carrot growers show a general lack of knowledge of the life cycle and habits of the carrot fly, and the methods for its control. While many of the crop protection methods used by organic growers are complex, labour intensive, unreliable and expensive, there are some opportunities for improvements. These require: research and development that is specifically targeted on non-chemical control methods and practices, developing control recommendations in a form that can be used by organic growers and/or their advisors, and a more active role in crop protection being taken by organic growers.

INTRODUCTION

An important element in directing research programmes towards practical improvements in crop protection is the need to address the problems of the growers themselves (Norton, 1976). A grower interview survey can provide information on growers' views of their crop protection problems and controls, as well as an appreciation of their objectives and constraints. This allows control options to be judged according to the criteria important to growers and enables likely future decisions to be predicted. Such surveys can also identify research and information gaps.

This paper summarises the major findings of two such surveys of British organic vegetable growers carried out to obtain this information (Peacock, 1990; Peacock and Norton, 1990). Based on these results, the constraints and opportunities for improving crop protection in organic vegetable production are discussed.

METHODS

A random sample of organic vegetable growers was chosen from a list of Soil Association (SA) symbol holders (Peacock and Norton, 1990).

Growers were chosen from the counties of Lincolnshire, Norfolk and Suffolk in the East, and Somerset, Devon, Dyfed and Herefordshire in the West. Fifty-five growers were interviewed in total, representing 18% of the 309 registered SA vegetable symbol holders in Britain in June, 1987.

A limited number of SA carrot symbol holders (not previously interviewed) were questioned, in 1989, on their perceptions and knowledge of a major pest - carrot fly (Psila

* current address: 31 The Glebe, Wrington, Avon BS18 7LX

rosae) - and the control methods they employ (Peacock, 1990).

RESULTS

More than 50% of the growers thought that deleterious insects, diseases, weeds, etc. caused more than 10% revenue loss. Fifty-six percent of growers thought the amount they lost was more than they could afford to lose.

The general survey confirmed that weeds, slugs or birds were considered the most serious problems. When asked - which is the worst weed species? - over 50% of growers nominated one of three weeds: chickweed (Stellaria media), couch grass (Elymus repens) or thistle (Cirsium spp.), chickweed being the most frequently mentioned.

Some specific insects and diseases, notably carrot fly and potato blight (Phytophthora infestans), were also seen as serious, albeit intermittent, threats. To determine which crops have most non-weed crop protection problems, growers were asked their opinion on the seriousness of specific non-weed problems of particular crops (Fig. 1). Lettuce was the crop thought to have most non-weed problems; by contrast, only a few growers thought that non-weed problems of onions and leeks were a problem.

Since organic growers are unable to use most pesticides, they have to deal with their insect, disease, weed, etc. problems in some other way. From the growers' responses, six categories of dealing with these problems can be distinguished:

1. Not grow the crop. Growers stop, or do not even start, growing crops most troubled by crop protection problems.

2. Isolate the crop. Those who start growing organic vegetables are not in areas of intensive vegetable production.

3. Produce healthy plants. Almost all growers think their major 'control method' is to produce healthy plants which are less attractive or more tolerant to attack.

4. Use preventive measures. Common preventive measures employed include: cultivations, use of resistant or traditional varieties, rotations, transplanting, avoid areas of the farm where serious problems, particularly weeds and wireworms, are known to be present, ploughing-in and re-planting the crop when it is attacked at an early stage, plastic or paper mulches and, when problems are too serious, moving the entire vegetable area to another part of the farm.

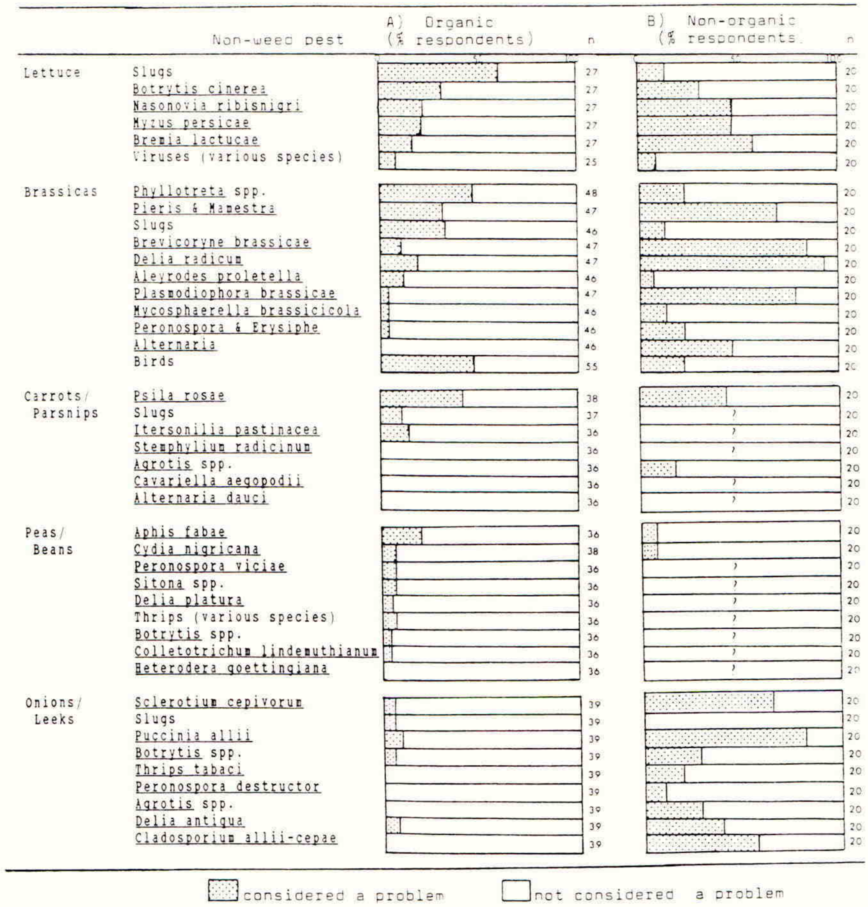
5. Use curative measures. Measures include sprays, such as derris, pyrethrum, bicarbonate of soda or garlic, as well as the biological control agent, Bacillus thuringiensis. The majority of growers say these methods are not very effective or economic.

6. Accept damage. Just over 40% of growers could afford greater than 10% crop loss due to pests, and did not consider damage to be too serious if slightly damaged. Acceptance of some damage was the suggested method of dealing with specific crop protection problems by certain growers.

In a second survey, five carrot growers were interviewed. While the results cannot be treated as representative of organic carrot growers in general, these case studies do give some indication of the issues involved. Growers are generally unaware of the life cycle and habits of the carrot fly. This information is essential for the correct implementation of cultural controls, which act by damage prevention. The majority of growers thought that carrot fly management

Fig. 1. Major non-weed pests by crop, as perceived by a) organic growers and b) non-organic growers (after Jusoh, 1984). n = number of respondents.

(From Peacock & Norton, 1990).



could be improved simply by providing this information. There also appears to be a general lack of knowledge and use of available cultural controls, either because growers do not know how to implement the controls correctly, or because they do not consider them feasible. The reasons given are: the controls are limited to small-scale production, are ineffective, time-consuming, constrained by weather, or in conflict with growers' objectives.

DISCUSSION

Pest problems, including insects, weeds, slugs and diseases, are perceived by the interviewed organic growers to be of economic importance. The survey confirmed that weeds, slugs or birds are considered the most serious problems, although specific insects and diseases, notably carrot fly and potato blight, are also seen as serious threats.

While there are many ways in which organic growers attempt to deal with their problems, avoidance is the main method, including: stopping, or not even starting, to grow those crops most troubled by problems, timely planting and harvesting, transplanting and avoiding high risk areas on the farm.

When making a decision on the use of control measures, growers consider the options available to them, the constraints to their use and the extent to which each option is likely to meet their own objectives (Norton, 1982). Most of the cultural means of control used by organic growers are complex, unreliable, expensive and have other major constraints (Peacock and Norton, 1990) (Table 1), as mentioned by the surveyed growers. For instance, many methods do not work well against exogenous or multi-crop pests, such as carrot fly, slugs and birds, while some features of organic agriculture, such as frequent cultivations and high organic matter, may actually encourage certain problems - especially weeds and slugs. This may account for these being the most serious crop protection problems, as perceived by the organic growers.

Indeed, when the results of the present study are compared with the findings of a previous survey of conventional growers carried out in the Thames Valley, UK by Jusoh (1984), differences are noticed between the perceptions of crop protection problems of both groups (Fig. 1). Conventional growers perceived insects (especially aphids, Pieris spp. and Delia radicum) and diseases (especially Plasmodiophora brassicae and fungal diseases of leeks and onions) to be their major problems. Although some weeds were mentioned by conventional growers as major problems in specific crops, they were perceived as less serious than other pest groups (Peacock and Norton, 1990). Differences in production and protection techniques, especially the use of pesticides by conventional growers, will undoubtedly account for much of this disparity.

The use of some control options may be limited for organic growers by characteristic features of organic vegetable growing, such as labour and capital constraints (Peacock and Norton, 1990) and small field sizes and holdings (Table 1). However, some general features of organic agriculture provide opportunities for the use of other options. For instance, intercropping and 'net' barriers over the crop are easier to implement on small, garden-sized holdings.

Another complication is that adoption of one practice can have both beneficial and detrimental effects. For example, intercropping gives better utilisation of the landspace, yet can impede mechanical cultivation and demands more labour but can also reduce potential yield (Peacock, 1990).

Finally, the choice and implementation of certain control options is constrained by a lack of information or, because crop protection is given a lower priority relative to other factors like marketing and soil-fertility-building. As a result, growers simply accept some pest damage or

Table 1 Major constraints to current measures used by organic growers in dealing with pests.

(From Peacock & Norton, 1990).

Measure to deal with pests	*Major constraint*
1. Stop growing crop & isolate farm	*-limited number of crops growers can stop growing.*
2. Preventive measures	
a)Rotations	*-spatial separation of specific crops from one year to the next is a problem for small holders:over 70% of growers interviewed have holdings of <20ha total area.* *-rotations not effective against all pests, particularly exogenous or multi-crop pests.*
b)Timely planting and harvesting dates	*-timing to avoid one pest can result in direct yield reduction and create problems with other pests, with unfavourable soil and climate conditions, and with labour shortages.*
c)Transplanting	*-little further potential for adoption as almost 100% of brassica, leek, onion and lettuce growers transplant these crops.*
d)Mulches	*-labour intensive, costly and may not be suitable for all crops and holdings.* *-not acceptable to some growers because plastics are not biodegradable.* *-certain pests, such as slugs and diseases, encouraged by altered microenvironment.*
3. Curative measures	*-often uneconomic or ineffective.* *-some "organic pesticides" unacceptable due to possible detrimental effects on the environment (Dudley, 1988).* *-Bacillus thuringiensis effective only against lepidopterous pests.*
4. Accept losses	*-feasible only if market premium remains.*

stop growing certain crops. If organic vegetable production does increase in the future, and if this results in a reduction in the price premium of 30-100% (Hill, 1986), the acceptance of losses as a means of crop protection will become less feasible.

RECOMMENDATIONS

In the shorter- or medium-term, the best way of achieving improvements in organic vegetable crop protection is likely to be found in reducing constraints. Growers may be constrained by a lack of technical knowledge and information on protection practices. Thus, there is a need to integrate relevant information on control practices and on the biological characteristics of the problem under consideration, and to develop recommendations in a form that can be more easily utilised by organic growers and/or their advisors. Organic growers wishing to reduce the crop loss caused by insect, disease, weed, slug, etc. problems must take a more active role in crop protection, instead of simply accepting the losses.

In the longer-term, new technologies and practices can be developed. However, much of the research to date, aimed at reducing excessive use of pesticides, has been based on the philosophy of integrated pest management, and the determination of economic thresholds (Perkins, 1982). This has influenced the approach taken and questions asked in research (Norton, 1987). Much of this research and development, since it still ultimately relies on the use of pesticides, is irrelevant or incompatible with the constraints and objectives of organic growers. If future research is to be targeted more at organic growers, the emphasis needs to be on developing and implementing totally non-pesticide control methods and practices. However, organic agriculture is not just conventional agriculture without chemicals. The interactions, objectives and constraints within this farming system, which differ from those of the conventional system, are factors which must be considered when developing research programs.

ACKNOWLEDGEMENTS

This work was carried out during a studentship sponsored by the Association of Commonwealth Universities. Thanks to all the organic growers who patiently answered the questions.

REFERENCES

Hill, C.E. (1986) The future for organically grown produce. Food From Britain, 51 pp.

Jusoh, M.D. (1984) Decision-making in the control of vegetable pests in the Thames Valley. Ph.D. thesis, University of London (unpublished), 225 pp.

Norton, G.A. (1976) Analysis of decision making in crop protection. Agro-ecosystems, 3, 27-44.

Norton, G.A. (1982) Crop protection decision making - an overview. Proceedings of the British Crop Protection Council symposium on Decision Making in the Practice of Crop Protection. pp. 3-11.

Norton, G.A. (1987) Pest management and world agriculture - policy, research and extension. Imperial College, University of London. Papers in Science, Technology and Public Policy, Number 13, 28 pp.

Peacock, L. (1990) Organic vegetable crop protection: an analysis of carrot fly (Psila rosae) (F.) management. Ph.D. thesis (unpublished), University of London, 239 pp.

Peacock, L. and Norton, G.A. (1990) A critical analysis of organic vegetable crop protection in the U.K. Agriculture, Ecosystems and Environment (to appear).

Perkins, J.H. (1982) Insects, experts and the insecticide crisis. The quest for new pest management. Plenum Press, New York, 304 pp.

ROTATIONAL DESIGN AND THE LIMITS OF ORGANIC SYSTEMS - THE STOCKLESS ORGANIC FARM?

S. MILLINGTON, C. STOPES, L. WOODWARD,

Elm Farm Research Centre, Hamstead Marshall, Newbury, Berks RG15 OHR

H. VOGTMANN

University of Kassel, Department of Alternative Agriculture, 3470 Witzenhausen, Germany

ABSTRACT

The successful performance of organic farming systems relies upon a viable crop rotation, defined as one which can maintain fertility and contribute to the control of weeds, pests and diseases. This paper considers the main components of the rotation; the sequence of crops and the balance of enterprises; and outlines the way in which this interacts with other husbandry and management practices to achieve sustainable production. The extent to which the constraints of rotations (designed to maintain fertility and control weeds, pests and diseases) may pose a limit to the agronomic or economic performance of organic systems is considered from the point of view of current knowledge and an interpretation of organic standards as applied in the UK. The viability of all-arable organic rotations, practised and under research in the UK, is discussed.

INTRODUCTION

The successful performance of organic farming systems relies upon a viable crop rotation, defined as one which can maintain fertility and contribute to the control of weeds, pests and diseases. To enable the farmer to meet consumer demand for certified organic produce, all aspects of the production system must meet the requirements stated in the standards of the Certifying Body (Soil Association, 1989; UKROFS, 1989). Many different rotations may be acceptable, depending upon the interpretation of these requirements, but typically the rotation should conform to the following guidelines (Soil Association, 1989):

1. balance fertility building and exploitative cropping;
2. include a leguminous crop;
3. include crops with differing rooting systems;
4. separate crops with similar pest and disease susceptibility;
5. vary weed susceptible with weed suppressing crops;
6. employ green manure crops (as catch crops or by

undersowing) to minimise bare ground overwinter;
7. maintain or increase soil organic matter levels.

The crop sequence (including species and variety choice) is the main component of a rotation and in part depends upon the balance of enterprises on the farm and will be constrained by the soil type and climatic conditions. In addition, the productive success of the chosen crop sequence depends upon and interacts with other husbandry and management practices employed by the farmer. Together, these will dictate the extent to which the objectives of maintenance of soil fertility and the control of weeds, pests and diseases is achieved in practice by organic farmers.

MAINTENANCE OF SOIL FERTILITY

This paper focusses upon the control of weeds, pests and diseases through the rotation. However, the maintenance of soil fertility, necessary to ensure healthy crop growth and optimal yields, may act as an important constraint to the design of rotations. Usually this has not been found to be the case for mixed ley farming systems but is particularly true for rotations which are predominantly arable based.

The guidelines outlined above are most easily followed within a mixed ley farming system. In such organic rotations, the grass/clover ley period is expected to accumulate sufficient nitrogen by fixation to support subsequent arable crops. The nitrogen accumulated is made available to the succeeding crops through the microbial decomposition of the plant matter following cultivation of the ley. In addition, the return of manure and slurry from grazing and housed stock allow the movement of nutrients (particularly phosphorous and potassium) around the farm. The significant feature of such rotations is that the fertility building phase (the grass/clover ley) is economically productive since it supports a viable livestock enterprise.

In the case of predominantly arable based organic rotations, the maintenance of fertility would depend upon the inclusion of a leguminous green manure managed with the objective of maximising the accumulation of nitrogen. Such systems are designed to operate with neither livestock, nor the use of imported livestock manures, consequently they are testing the limits for viable and productive rotations. Clearly the lack of financial return, coupled with the costs of establishment and management of the green manure reduce the economic viability of the whole rotation. However, in areas of the country where conventional arable farming systems currently predominate, the capital required to introduce a livestock enterprise will be considerable and thus mixed ley/arable organic rotations may not be appropriate. Questions of the agronomic and economic viability of genuinely stockless systems has prompted research directed at identifying the rotational constraints in this context. This is discussed in more detail below.

The development of 'stockless' rotations relying on the use of leguminous green manures for fertility building, is broadly in accord with the principles of current organic standards (Soil Association, 1989; UKROFS, 1989). An alternative approach to resolving the difficulty of maintenance of fertility in predominantly arable rotations is the use of animal manures brought onto the farm. In such 'organic-input' based farming systems, manures brought onto the farm (commonly from highly intensive animal production systems) are almost completely relied upon to supply and maintain soil fertility. Such rotations are commonly considered to be at variance with the principles which provide the basis for organic standards. In addition, the agronomic sustainability of these 'manure based' rotations from the point of view of weed, pest and disease control is uncertain.

CONTROL OF WEEDS, PESTS AND DISEASES

Within organic farming systems, the emphasis is on rotation design and management to avoid development of serious levels of weeds, pest and diseases, both within a single crop, and over time. The prohibition in organic standards of synthetic agro-chemical biocides of all types (herbicide, insecticide, fungicide etc) results in a total reliance upon the successful rotation coupled with other husbandry and management techniques.

Weed control through rotation design

Total weed eradication is not sought in organic systems, farmers aim to achieve a balance between the benefits of environmental diversity and the yield penalties imposed by high populations of weeds. Some non-crop plants are beneficial, for example by providing nutrients and shelter for natural predators of crop pests, or by acting as 'trap crops' for pests (Kloen & Altieri, 1990). Seed and pest-feeding birds will also be encouraged by weeds in the crop and particularly the crop margin and hedgerows (Muenscher, 1955; Hald, 1990).

Since there are no acceptable herbicides for organic farmers, optimum weed control strategies must be an integral part of rotation design and operation, and there are a number of weed control strategies available to the organic farmer which interact with the rotation.

Cultivations in the rotation

Mechanical weed control methods remove weeds in several ways: by burying weed seed below germination depth; by allowing or encouraging weed seed germination and killing the emerging seedlings prior to drilling the crop; or by removal from within the growing crop. The selection of an appropriate method will depend upon soil conditions as well as the growth habit, time of establishment and time of harvest of the crops in the rotation. There is considerable potential for the further development of specialised weed control equipment.

A range of cultivations may be used during incorporation of crop residues and seedbed preparation to maximise weed seed germination and kill. Thus, in the transition from the ley to the arable phase of a mixed rotation, cultivations for seed-bed preparation, for example involving the use of stale seed bed techniques, will limit the establishment of weeds prior to drilling. During the arable phase there will be opportunities for mechanical weed control depending on the crop. Hoe, harrow and brush type weeders of various designs are available for use within the crop, either between the rows or through the standing crop.

The potential for a specific method of mechanical or other weed control techniques in a crop may be an important part of the weed control strategy within the whole rotation. Crop choice can thus be important in allowing mechanical and other weed control methods, thus a row crop such as potatoes can allow weed control by ridging. The slow germination of carrots, permits the use of flame weeding techniques. Rotations may also be manipulated to allow for cultivations at strategic times for problem species on a particular farm. For instance weed control cultivations may take place during a fallow, with repeated cultivations during the period of maximum germination of a problem weed to deplete reserves of seeds and possibly storage roots.

Crop sequence and variety choice for weed control

A strict rotation has traditionally been considered to facilitate weed control. In the case of ley/arable rotations, the ley period permits the reduction of weed populations through competitive exclusion by more vigorous grass/clover species; through the direct removal of plants by grazing livestock or by cutting for silage, thus depleting plant reserves and preventing seeding; and to some extent by exhaustion of seeds in the soil seed bank. Weed pressure tends to increase during the arable phase of the rotation, thus the crop sequence must contribute to the weed control strategies as far as possible. The cultivation of crops which offer the opportunity for mechanical or other weed control methods has been considered above.

Different crop species compete with or suppress weed growth to a varying degree. Amongst cereals, it is commonly noted that oats and rye have a considerably higher competitive ability with weeds than wheat, and thus these species can usefully be included later in the arable crop sequence. Grain legumes have a relatively poor competitive ability. Winter cereals are generally better weed suppressants than spring cereals since the well-established plant can effectively compete with weeds in the spring. Winter cropping may also be favoured because there are fewer autumn germinating weed species. Spring crops may, however, offer opportunities for mechanical weed control in autumn and spring and the use of weed-competitive over-winter green manures. Thus both winter and spring crops can be useful in a rotation to gain control of autumn and spring germinating weeds.

In addition, certain crop varieties may be more effective at competing or suppressing weeds than others. This may be the consequence of different growth habits, for example early prostrate growth. Variety selection and assesment procedures (for example by the National Institute of Agricultural Botany) do not record such factors and it is therefore difficult for organic farmer to make rational variety choices on the basis of published information. Practical farm experience will, however, often indicate varieties most suited in terms of competitive ability against specific weed problems (Moss, 1985).

Crops may also be grown in combination, effectively leading to increased competition with weeds. The use of undersowing cereals as a technique for establishing the grass/clover ley at the end of the arable phase of the rotation may lead to a reduction in weed levels in the cereal (Williams, 1972; Hartl, 1989). The use of intercropping (growing two or more species which are both harvested) has been demonstrated to reduce weed populations (Bulson *et al*. 1990)

Allelopathic interactions between weeds and root exudates from the growing crop and crop residues can sometimes affect weed levels. Weeds may also have allelopathic effects on other weeds or crops (Anaya *et al*, 1988). Decomposing crop residues may depress weed levels, but may also potentially depress germination of the following cash crop (Patriquin *et al*, 1986; Barnes & Putnam, 1983; White *et al*, 1989), therefore appropriate management of residues should be taken into account when planning rotations. The topic of allelopathy is only now starting to receive serious research interest, and its exploitation could be of great benefit to organic producers in the future, facilitating more subtle manipulations of their rotations.

<u>Residue management</u>

The presence of viable weed seeds in crop residues and manures can lead to the spread of weed problems around the farm. Optimum management of residues is therefore important. Composting, if carried out properly, can make a contribution to weed control since the activity of aerobic thermophillic organisms responsible for composting lead to a substantial rise in temperature (up to 70^{o}C) which can inactivate weed seeds (Stopes *et al*, in press).

Pest and disease control in organic rotations

As with weed control, total eradication of pests and diseases is neither achievable, nor desirable. As noted by ADAS in their survey of a long-established organic enterprise at Rushall (ADAS, 1986), a range of crop diseases were present every season , but at low levels. Authors have reported a generally low susceptibility of organically grown crops to pest and diseases (Vine & Bateman, 1981). There are only a few pesticides and disease-control substances permitted within organic systems, in most cases these are not appropriate for use in field-scale arable crops. Thus the principle approach to pest and disease control is rotation design to avoid the build-up of P&D problems by a variety of methods (Cook, 1988). These include optimum soil fertility, appropriate crops and varieties, optimum pest/predator populations and the appropriate management of residues.

Optimum and balanced fertility

The observation that organic crops do not suffer to a large extent from pests and diseases may in part be due to the generally lower levels of sap nitrogen in the plant. The lower levels of readily available nitrogen in organically managed soils do not allow for luxury uptake. England (1986) and Spiertz (1980) have reported increases in diseases with increasing N levels in conventional crops, while El Titi (1988) noted a positive correlation between the amount of N applied and the incidence of pest attack in cereals. The mechanisms for such effects are not currently understood; research in this area would be valuable.

Crop sequence and variety choice

Diversification of crops in both space and time is a valuable tool for optimum pest and disease control (Altieri & Liebman 1986). Conventional continuous arable rotations have had to confront a range of pests and diseases which do not arise in organic systems to the same extent because organic rotations are designed to avoid factors which predispose towards damaging levels of pests and diseases. Successive crops of the same species are avoided, and crops with common pests and disease problems are not grown too close to each other in the rotation. For instance red clover and winter beans are both susceptible to Sclerotinia trifolium, so should ideally not be grown in proximity to each other in the rotation.

The choice of crop varieties resistant to diseases is a primary consideration for limiting pests and diseases. The efforts of breeding pest and disease resistance to crops in conventional systems give equivalent benefits to organic as to conventional farmers. This has been demonstrated by Stoeppler *et al* (1988), who demonstrated that modern high yielding, disease-resistant varieties of winter wheat outperformed their predecessors in organic systems as well as in the conventional settings for which they had been bred.

Cropping patterns such as undersowing can increase predatory insects and reduce cereal aphid populations (El Titi, 1986; Vickermann, 1978). Other forms of intercropping are often employed in organic horticultural systems to increase plant diversity and optimise predator populations, for instance the use of Phacelia tanacetifolia and Calendula species to attract syrphids (HDRA, 1988).

Green manures may harbour beneficial insects eg Melilotus alba (sweet white clover), Fagopyrum esculentum (buckwheat), vicia faba (field bean), Vigna ungiculata (cow pea) are attractive to a range of nectivorous predators (Bugg & Ellis, 1988). Some weeds provide nutrients and shelter for natural enemies of pests (Altieri & Whitcomb, 1979).

Optimising pest and predator populations

Appropriate crop rotations are generally considered to be an effective approach to reducing soil-borne pathogens. They are effective through a number of mechanisms including removal of host material, burial or dessication of pathogens, incorporation of crop residues or green manures with anti-pathogenic effects (Allison, 1973).

The requirement for a diverse environment for optimum pest and disease control leads also to a consideration of optimum field size to provide diversity of crop and crop margin habitat for beneficial organisms (Rabb *et al*, 1976). Better knowledge of the ecology of pest and predator organisms would aid rotation design, and there could be considerable potential for the management of rotations to optimise populations of pests and predators.

Residue management

Composting of manures and crop wastes (in the case of horticulture) leads to the death of disease organisms, as long as thorough heating of the entire compost heap is attained (Bollen, 1985). There is recent evidence that some composts may themselves have antipathogenic effects (Schuler *et al*, 1989).

WHAT ARE THE LIMITS OF ORGANIC SYSTEMS?

Rotations are the primary means of maintaining soil fertility and achieving weed, pest and disease control in organic systems. Most organic farmers manage rotations within the constraints outlined in this paper, thereby ensuring the sustainable operation of their farming systems. However, the importance of these rotational constraints is not known in all cases, consequently we are uncertain as to the extent to which organic rotations may be modified or extended. This is particularly true for predominantly arable and horticultural rotations where more intensive cropping occurs. In these situations there is limited opportunity for maintaining adequate nutrient supply by balancing fertility building through legumes with exploitative cropping. An alternative approach relies upon the import of animal manures to maintain soil fertility. However, such organic-input based systems may result in poor control of weeds, pests and diseases and furthermore they may not fully conform to the requirements of organic standards.

Research currently in progress is addressing some of these issues, with an investigation into the sustainability of organic rotations without livestock and which do not rely upon the import of animal manures. Elm Farm Research Centre has been operating eight different organic stockless rotations since 1987, three in a fully-replicated small field trial in Berkshire, and five in a large-scale unreplicated experiment in Kent. Each rotation relies on a one-year fertility building legume course, followed by a range of crops including winter and spring cereals, spring beans, potatoes, non-leguminous catch crops and legumes undersown for autumn and spring nitrogen fixation. In most cases, the fertility building course gives no financial return, unlike the ley in a mixed organic farming system which provides a return through the livestock enterprise. This results in the gross margins of some of the experimental rotations being unfavourable, although the potential for the production of forage legume seed during the fertility building course is being explored.

Nutrient budgets for most of these rotations appear unfavourable, but such an exercise does not necessarily reflect the potential availability of soil nutrients from mineralisation of organic matter or solubilisation from soil reserves by crop roots, residues or green manures. Results so far have revealed no deficiency problems, despite apparently low soil nutrient status in the Kent trial. Crop yields and quality have been acceptable. For the initial period of one rotation, no soil supplements are being used, although we consider that there may be considerable potential for the use of composts bulky organic wastes from non-animal sources.

In rotations without an extended ley period, the potential for weed control is reduced. Such rotations may therefore experience a build-up of weed populations over time, to levels at which yields are seriously affected. Results so far show no such increase. The rotations are necessarily shorter than ley/arable rotations, hence there is closer cropping of all species. Disease problems may be anticipated, but have not so far been experienced.

Other potential limits to the sustainable operations of such systems, including the possible impact on long-term soil fertility, soil structure and soil organisms, are under investigation. No deleterious effects have been recorded up to the present, indeed soil fertility appears to be improving on the Kent site.

ACKNOWLEDGEMENTS

The authors acknowledge with thanks the assistance given to this work by: G. Forde and G. Dinnage of Elm Farm Research Centre, and J. Sundt and G. Minister of Luddesdown Organic Farms Ltd.

REFERENCES

ADAS (1986) Monitoring of an organic farm, harvest year 1984/85. Internal report.

Allison, F.E. (1973) Soil organic matter and its role in crop production. Developments in Soi Science 3. Amsterdam: Elsevier Scientific Publishing, pp 378-398.

Altieri, M.A.; Liebman, M. (1986) Insect, weed and plant disease management in multiple cropping systems. In: *Multiple Cropping Systems*, C A Francis (Ed.), New York: Macmillan Publications, pp. 183-218.

Altieri, M.A.; Whitcomb, W.H. (1979) Manipulation of insect populations through seasonal disturbances of weed communities. *Protection Ecology* **1**, 185-202.

Anaya, A.L.; Gliessman, S.R.; Cruz-Ortega, R.; Rosado-May, F.; Nava-Rodriguez, V. (1988) Effects of allelopathic weeds used as cover crops on the floristic potential of soils. *Sixth International Scientific Conference of IFOAM, Santa Cruz*, 607-618.

Barnes, J.P.; Putnam, A.R. (1986) Evidence for allelopathy of residues and aqueous extracts of rye (Secale cereale). *Weed Science* **34**, 384-390.

Bollen, G.J. (1985) The fate of plant pathogens during composting of crop residues. In: *Composting of agricultural and other wastes*, J K R Gasser (Ed), London: Elsevier, pp. 282-290.

Bugg, R.L.; Ellis, R.T. (1988) Use of green manure crops to subsidise beneficial insects: a study in progress. *Sixth International Scientific Conference of IFOAM, Santa Cruz*, 553-557.

Bulson, H.A.J.; Snaydon, R.W.; Stopes, C.E. (1990) Intercropping autumn-sown field beans and wheat: effects on weeds under organic farming conditions. *BCPC Symposium: Crop Protection in Organic and Low Input Agriculture 1990.*

Cook, R.J. (1988) Biological control and holistic plant health care in agriculture. *American Journal of Alternative Agriculture* **3** (2,3), 51-62.

El Titi, (1986) Management of cereal pests and diseases in integrated farming systems. *1986 British Crop Protection Conference - Pests and Diseases,* 147-156.

El Titi, (1988) Influence of cultural factors and practices on integrated pest management systems in cereal crops. *1988 CEC/IOBC/EPPO Conference - Integrated crop protection, from principles to practical implementation*, 69-74.

England, R.A. (1986) Reducing the nitrogen input on arable farms. *Journal of Agricultural Economics* **37** (1), 13-24.

HDRA, (1988) Step by step organic gardening. Pest control without poisons. Henry Doubleday Research Association, Ryton-on-Dunsmore, 12pp.

Hald, A.B. (1990) Fuglefode i kornmarker - uschter og vilde planter. [Bird food sources in cereal fields - insects and wild plants.] Copenhagen, Denmark, Miljostyrelsen.

Hartl, W. (1989) Influence of undersown clovers on weeds and on the yield of winter wheat in organic farming. *Agriculture Ecosystems and Environment* **27**, 389-396.

Kloen, H.; Altieri, M.A. (1990) Effect of mustard (Brassica hirta) as a non-crop plant on competition and insect pests in broccoli (Brassica oleracea). *Crop Protection 9*, 90-96.

Kowalski, R.; Visser, P.E. (1983) Nitrogen in a crop-pest interaction: cereal aphids 1979. In: *Nitrogen as an ecological factor.* J A Lee, S McNeill, I H Ronson (Eds), Oxford: Blackwell, pp. 283-300.

Moss, S.R. (1985) The influence of crop variety and seed rate on Alopecurus myosuroides competition in winter cereals. **1985 British Crop Protection Conference - Weeds**, 701-708.

Muenscher, W.C. (1955) *Weeds* (Second edition), New York: MacMillan, 560pp.

Patriquin, D.G.; Hill, N.M.; Baines, D.; Bishop, M.; Allen, G. (1986) Observations on a mixed farm during the transition to biological farming. *Biological Agriculture and Horticulture* **4** (2), 69-154.

Rabb, R.L.; Stinner, R.E.; van den Bosch, R. (1976) Conservation and augmentation of natural enemies. In: *Theory and practice of biological control*, C B Huffacker and P S Messenger (Eds), New York: Academic Press, 233-253.

Schueler, C.; Biala, J.; Vogtmann, H. (1989) Anti-phytopathogenic properties of biogenic waste compost. *Agriculture Ecology and Environment* **27**, 477-482.

Soil Association (1989) Standards for Organic Agriculture. Bristol, Soil Association, 79pp

Spiertz, F. (1980) Grain production of wheat in relation to nitrogen, weather and diseases. In: *Association of Applied Biologists meeting 1979 - Opportunities for increasing crop yields,* R G Hurd, P V Biscoe and C Dennis (Eds), London: Pitman, 97-114.

Stoeppler, H.; Koelsch, E.; Vogtmann, H. (1988) Investigation into suitability of varieties of winter wheat in low external input systems in West Germany. **International Federation of Organic Agriculture Movements English Bulletin 6**, 12-18.

Stopes, C.; Woodward, L.; Forde, G.; Trenbath, B. (in press) Farm yard manure: Potential for farm-scale composting, preliminary trials. *Elm Farm Research Centre Research note 7 (in press).*

UKROFS (1989) UKROFS Standards for Organic Food Production. London, UK Register of Organic Food Standards, Food From Britain

Vickerman, G. (1978) The arthropod fauna of undersown grass and cereal fields. *Scientific proceedings of the Royal Dublin Society (A)* **6**, 273-283.

Vine, A.; Bateman, D. (1981) Organic farming systems in England and Wales: Practice, Performance and Implications. *University of Wales, Aberystwyth*, 210pp.

White, R.H.; Worsham, D.; Blum, U. (1989) Allelopathic potential of legume debris and aqueous extracts. *Weed Science* **34**, 384-390.

Williams, E.D. (1972) Growth of Agropyron repens seedlings in cereals and field beans. *Eleventh British Weed Conference*, 32-37.