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Integrated crop management, the basis for environment friendly crop protection of potatoes

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Abstract

Relatively large amounts of pesticides are needed to control diseases and pests in modern, intensive potato production. Integrated crop management offers a way of reducing the need for pesticides. It aims to reduce costs and improve the quality of the product and of the production methods, while maintaining soil fertility and the quality of the environment. The components of integrated crop management are described. Prevention of diseases and pests has high priority. If diseases or pests are present, non-chemical control methods are preferred and chemical control is based on economic criteria and the monitoring of the soil and crops. The contribution of integrated crop management to the control of two important fungal diseases, late blight (*Phytophthora infestans*) and stem canker (*Rhizoctonia solani*) and of one pest, potato cyst nematode (*Globodera* spp..) is described. The prospects for further development of integrated crop protection are discussed.

Additional keywords: non-chemical control, *Rhizoctonia solani*, *Globodera* spp., antagonists

Introduction

Since World War II the productivity of agriculture in the temperate zones has increased considerably, due to increased inputs of fertilizer and to the use of pesticides. Yields have increased spectacularly as a result. Mechanization has become widespread, giving high productivity per worker, but it requires large fields and these are prone to soil erosion. Farmers have had to intensify their cropping plan in order to make a living, particularly in regions with relatively small farms. The emphasis has shifted to cash crops, such as potatoes, sugar beet and vegetables. In the Netherlands this intensification has resulted in high cropping frequencies of potatoes: once per three or four years for ware and seed potatoes and once per two years for starch potatoes. This high cropping frequency of potatoes has increased soil-borne diseases and pests, such as potato cyst nematode or pcn (*Globodera* spp.), black scurf (*Rhizoctonia solani*), verticillium wilt (*Verticillium* spp.), etc., and therefore farmers are using increasing amounts of pesticides to control them.

It was Rachel Carson who, in 1962 in her book 'Silent Spring', drew the attention of the world to the disadvantages of pesticides and their dangers to the environment. That book has gradually improved awareness about the effect of certain pesticides on nature and has also stimulated research on alternatives to pesticide use, at first mainly in the field of insect control. However, it was not until the seventies that agricultural research organizations began to show broader interest in alternative plant protection systems, and during the last decade this trend has received increasing public support. This public concern has two reasons: enhanced concern about the environment and increasing interest in healthy food.

In the Netherlands this led to the establishment in 1979 of a research project on alternative arable farming systems, including integrated farming: the OBS experimental farm at Nagele.

Of the various approaches to reduce or to abandon the use of pesticides in agriculture, such as 'biological dynamic' farming, organic farming and integrated farming, the latter appears to have the greatest potential for large-scale application, given the increasing demand for food in the world.

Integrated farming

The definition of integrated farming strategies formulated by the working group on 'Integrated Arable Farming Systems' of the International Organization of Biological Control (IOBC) can be summarized as: 'Farming systems which aim for cost reduction and improvement of quality of products and production methods and at the same time maintain soil fertility and the quality of the environment (Vereijken and Royle, 1989). Integrated farming systems are based on a sound crop rotation, resistant cultivars and the use of non-chemical control methods whenever possible. This is done to maximize disease and pest prevention and to minimize the use of chemicals. If pesticides are required, the least poisonous and the least persistent will be chosen.

Organic fertilizers rather than artificial ones are used, in order to minimize energy consumption and the use of scarce raw materials and also to improve soil fertility. Optimal use of manure and fertilizer should minimize the losses of nutrients to the environment.

Integrated potato production

Potatoes are a demanding crop as far as the need for pesticides is concerned. For example, many fungicide applications are needed to control late blight (*Phytophthora infestans*). In some countries, including the Netherlands, soil disinfection with nematicides to control potato cyst nematodes is widespread, demanding large amounts of active ingredients per unit of area.

The potato is not very efficient in its nitrogen use and consequently there is a relatively large risk of nitrate being lost to groundwater and surface water. Thus in environmental terms the potato is not a very clean crop.

In 1984 Schöber and Keller pleaded for low input potato production with the emphasis on the production of healthy food and maintenance of soil fertility. Vereijken and Van Loon (1991) have further elaborated a strategy for integrated potato production. The objectives of integrated potato production can be achieved by the following methods.

Crop rotation. It has been found that when cropped once every six years potatoes yield 7% less than a first cropping with potatoes, and when grown once every three years this reduction can be as much as 20%. Potato cyst nematodes were not involved in this research (Hoekstra, 1989). Soil-borne diseases such as *Verticillium dahliae*, *R. solani* and *Streptomyces* spp. appeared to be the main organisms responsible for the decline in yields (Bollen et al., 1989). However, the maximum frequency of potatoes in a rotation appears to depend on the likelihood of preventing an infestation with potato cyst nematodes.

Soil cultivation. In integrated farming, soil cultivation should be directed to improving soil structure and controlling weeds, while using the minimum of energy (Specht, 1985).

Minimum tillage systems are interesting because they require very little energy . However, on a clay soil with no tillage prior to cereals and sugar beet and only rotovating (7 cm) before potatoes, Lumkes and Ouwerkerk (1980) found the net yield of potatoes was 8% less than that of a normal tillage system. This indicates that cultivations which restore soil structure are necessary for the preservation of soil fertility.

Nevertheless the number of operations should be reduced as much as possible. This is also important in order to avoid soil compaction which may strongly depress potato yields (Van Loon and Bouma, 1978). Soil compaction can further be limited by using low-pressure tires on tractors and by not cultivating soils that are too wet. On slaking soils, soil texture should not be made too fine – a risk when power driven implements are used – to avoid oxygen deficiency in the soil (Ridder et al., 1988).

Fertilization. In integrated farming the amounts of N, P and K applied should be adjusted to meet needs revealed by soil or tissue analysis. It is better to use organic manure rather than artificial fertilizer, provided that the losses of NO_3 and NH_3 to the environment can be minimized. The advantages of organic manure are: its relative cheapness, its beneficial effect on soil structure, its stimulating effect on soil fauna, and the extra yield increase that cannot be reached by artificial fertilizer. Organic manure is best applied in spring when the leaching of nitrate is minimal. Farmers can get onto sandy soils at that time of the year, but on the wetter clay soils this is more difficult. A disadvantage of organic manure is that it does not allow precise fertilization with N, since the proportion of the organically bound N that mineralizes during the growing season cannot be predicted. This may lead to shortage or excess of N in the crop. This problem can partly be overcome by a split application of N, provided the second application is based on the nitrogen status of the plant or the soil. Petiole nitrate content has proved to be a useful indicator of the crop nitrogen status (Van Loon and Houwing, 1989). Regular soil analysis of mineral N during the growing season may lead to a comparable result (Doll et al., 1971). The present nitrogen recommendations for potatoes in the Netherlands result in too much nitrate in the surface water in the autumn and winter after the potatoes have been grown. This is because of the inefficient use the crop makes of the available N. Only 35–40% of applied fertilizer N is recovered by the potato tubers (Neeteson, 1989). The remainder may leach out during winter, unless a green manure crop is sown after harvest, to fix part of the nitrate. On light soils such a catch crop may also protect the soil against wind or water erosion.

If current nitrogen recommendations for an optimum tuber yield are cut by about 15%, the nitrate content of surface and drinking water will not exceed the admissible level of 50 ppm. Such a reduction of the nitrogen rate will reduce the net returns of the potato crop by only 2% (Neeteson, 1989).

An additional advantage of such a reduction is that a number of quality characteristics of ware potatoes can be improved (Van Loon, 1989) and that crops develop less foliage which may reduce their susceptibility to late blight. A moderate application of nitrogen in seed potatoes will enhance maturity-resistance to virus diseases (Beemster, 1987).

Resistant cultivars. One of the most promising ways of reducing pesticide use is to plant cultivars that are resistant to certain diseases, particularly to late blight (*P. infestans*) and other fungal diseases such as *R. solani* and *Fusarium* spp. But resistance to virus diseases and to pests like the potato cyst nematode is also important. Partial (horizontal) resistance is preferable to avoid the development of new pathotypes.

Mechanical weed control. Weeds in potatoes not only result in lower yields, but also reduce quality. During harvesting they may cause extra tuber damage and harvest losses. Effective weed control is therefore important. Part of integrated weed control is a crop rotation in which perennial weeds can be controlled effectively. Cereals are suitable for this purpose. If pre-sprouted seed is used the crop develops rapidly and suppresses weeds. If, in addition, on loamy soils final ridging is postponed until just after crop emergence, weeds are often sufficiently controlled (Vereijken and Van Loon, 1991). If these measures do not control the weeds then a mechanical weeding, followed by a second ridging operation can be considered or as a last resort an under-foliage herbicide treatment. Mechanical weed control on sandy soils often consists of repeated harrowing or mechanical weeding, followed by ridging up. However, this may lead to root damage and loss of moisture, resulting in yield losses in dry weather.

Mechanical haulm destruction. Haulm destruction is often necessary to avoid virus infection of seed potatoes or harvest damage in ware and starch potatoes. Various mechanical alternatives to chemical haulm destruction are available, providing the soil is not too wet for their application. Under favorable soil conditions haulm can be pulled. A combined mechanical (haulm cutting) and chemical treatment can reduce the amount of chemical required by 50–70%. Green-crop harvesting may also be feasible under certain conditions. This system combines haulm pulling or haulm cutting in a green crop with lifting and recovering of the tubers.

The haulms of ware and starch potatoes may be cut, providing the soil is not too wet and the crop is not infected by late blight. Haulms are easier to destroy if the crop has not received large amounts of nitrogen fertilizer (Van Loon and Houwing, 1991).

Control of volunteer potato plants. Volunteer potato plants in crops following potatoes pose a phytosanitary threat. They may enhance multiplication of the potato cyst nematode and they may provide a source of inoculum of *P. infestans* for neighboring potato fields. Virus-infected volunteer potato plants present in a field next to a seed potato crop are also a potential danger. Control of volunteers is difficult. Several measures, including prevention of harvest losses, soil cultivation with a fixed tine cultivator instead of ploughing after a potato crop and application of the herbicide glyphosate to individual plants may achieve successful control.

Integrated potato production is more than the individual husbandry methods mentioned above. It is the interaction of two or more measures that may be particularly beneficial.

Integrated control of diseases and pests

One definition of 'integrated control' is the one presented by FAO (Anonymous, 1967): 'A pest management or integrated control system, that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest population levels below those causing economic injury'.

I would like to add to this definition: 'and in which the use of environment unfriendly control methods is limited as much as possible'.

Control of diseases and pests is only necessary if potentially harmful population levels are reached. An integrated control system therefore uses damage thresholds, if available.

This requires regular crop monitoring and analysis of soils, and a thorough knowledge of the population dynamics of pests and of the ecology and epidemiology of diseases. It also includes determination of infection potential of the pathogens in the soil. This notion characterizes the pathogenic activity of a certain amount of soil and integrates three aspects: inoculum density, infection capacity of the inoculum and the effect of the environment on the inoculum (Tivoli et al., 1983).

Automated management systems could also be an important aid in integrated control of diseases and pests. Such a system is currently being developed in the Netherlands for potato cyst nematode, in a joint research program involving several research institutions. The measures forming part of integrated control are: prevention (crop rotation, resistant cultivars, hygienic measures, healthy seed, fertilization, planting and harvesting dates), biological control methods and as a last resort pesticides.

Integrated control of *Phytophthora infestans*, *Rhizoctonia solani* and *Globodera* spp.

Late blight (Phytophthora infestans). Late blight can be considered as the most damaging foliar disease of potato in the world. Since the level of resistance is relatively low, even in the most resistant cultivars available, its control requires large amounts of pesticides. In the Netherlands susceptible cultivars have to be sprayed with a fungicide at least 10–15 times in a growing season. Since this disease is dealt with by Schöber elsewhere in this volume (Schöber, 1992) I will not discuss it extensively here. Given that cultivars possess only limited horizontal resistance, the integrated control of late blight currently depends mainly on preventive cultural practices, an adequate blight forecasting system and chemical control (Van Loon and Vos, 1989). However, it is doubtful that fungicide applications can be appreciably reduced, given the cultivars presently available. But the dose of fungicide currently applied to the most resistant cultivars could safely be reduced (Fry, 1977). Useful cultural practices include: hygienic measures, such as timely removal of potato waste, the use of healthy seed, a moderate nitrogen application, prevention of harvest losses and control of volunteer potato plants.

Stem canker (Rhizoctonia solani). Potato plants infected by stem canker can be found almost everywhere potatoes are grown. This fungus, which is soil-borne as well as tuber-borne, can cause several types of damage to potato plants. Young, emerging stems and stolons may rot away, plants show reduced vigor and sometimes wilt. The tubers may be covered by sclerotia. Integrated control of *R. solani* includes preventive measures such as a crop rotation with a maximum frequency of potatoes of 1 : 4–5 (Scholte, 1987) and cultural practices, e.g., the use of clean seed, shallow planting in a relatively warm soil and final ridging no earlier than around emergence. Because of the need for clean seed, the control of stem canker in a seed potato crop is not only directed to avoiding plant damage but also to preventing sclerotia from forming on the tubers. Biological control of black scurf, whether or not in combination with low doses of pesticides, appears to be feasible. As early as in 1939, Cordon and Haenseler reported that a bacterium, *Bacillus simplex*, could inhibit growth and kill *R. solani*. Van den Boogert and Jager (1984) found that inoculation of seed tubers with respectively *Verticillium biguttatum*, *Gliocladium roseum*, *Trichoderma hamatum* and *Hormiactus fimicola* reduced *R. solani* infestation of potato plants. *V. biguttatum* appeared to be the most promising antagonist under farming conditions. Inoculation of the sprouts of seed tubers with *V. biguttatum* also reduced formation of sclerotia on new tubers, particularly in sandy loam and clay loam soils (Jager and Velvis, 1985). However, this reduction was not sufficient to avoid considerable rejects after grading, because too many tubers were heavily infested with sclerotia. Most of the sclerotia of *R. solani* develop on tubers in the period between haulm destruction and harvesting. Bouman et al. (1983) found that there were fewer sclerotia on tubers after haulm pulling than after chemical haulm destruction. Inoculating sprouted tubers with spores of *V. biguttatum* combined with a soil application of 25% (marine loam) or 25–50% (acid sand) of the recommended rate of a fungicide gave about the same level of tuber infestation with sclerotia as chemical control at the recommended rate (Jager et al., 1991). A new harvest system, green-crop harvesting appears to fit in very well in integrated farming and integrated disease control. When tubers had been completely separated from other plant parts there was no increase in black scurf sclerotia on the tubers. But if plant parts were covered together with the potatoes and the tubers were sprayed with spores of *V. biguttatum*, before being re-covered with soil, the antagonist showed no effect on the incidence of sclerotia, but all sclerotia were killed by the mycoparasite (Mulder et al., 1990).

V. biguttatum was also found to be able to kill the sclerotia of black scurf during storage, providing the temperature was kept at 15–20 °C for a period of 6–8 weeks and the relative humidity in the store was not less than 99% (Jager and Velvis, 1988). If seed carrying sclerotia has to be used in ware and starch potato production, thresholds of control should be used to determine whether or not a chemical disinfection of tubers is necessary (Vereijken and Van Loon, 1991).

Potato cyst nematode (Globodera spp.). Potato cyst nematodes (*Globodera rostochiensis* and *G. pallida*) can be a serious problem in regions with an intensive potato production. Populations of these nematodes may reach such high levels that potato production becomes uneconomic. Integrated control of potato cyst nematodes (pcn) uses one or more of the following devices: a wide crop rotation, hygienic measures such as control of volunteer potato plants and prevention of wind erosion, the use of resistant and tolerant cultivars, intensive sampling methods, biological control methods and chemical control. Whether harmful populations of pcn develop depends greatly on the frequency of potato production. Although there is no consensus in the literature, most authors consider the frequency must not be less than once every four years, to avoid problems (Daniel and Smolik, 1974; Roth et al., 1981; Keller, 1989). However, a wide crop rotation is not always possible for economic reasons. This is the case on many relatively small arable farms in the Netherlands. Since volunteer potato plants neutralize the natural decline of a cyst nematode population in years when no potatoes are grown, control is essential to maximize the effect of crop rotation. Other valuable hygienic measures are: use of pcn-free seed and prevention of wind erosion by, e.g., green manure crops that cover the soil during autumn and winter and so prevent cysts dispersing to other fields. *G. rostochiensis* can be adequately controlled by available resistant cultivars, but resistance to *G. pallida* is polygenic and therefore less effective. Moreover, the number of cultivars with partial resistance to a number of populations of *G. pallida* is still very limited.

A problem of resistant cultivars is that the resistance of a cultivar may already be ineffective after 3–5 generations (Van der Wal, 1987). For an effective control of pcn with help of resistant cultivars one needs to know which species and which pathotype are involved. Nowadays, cysts from infested fields can be checked quickly for species, e.g., by an ELISA test (Schots et al., 1989). This test should be followed by a 'cultivar' test in which a group of cultivars with resistance to one or more pathotypes are grown in containers of infested soil, in order to find the cultivar that most discourages pcn from multiplying (Mulder et al., 1987). At present both tests are commercially available to farmers in the Netherlands. Cultivars that tolerate pcn can be grown on fields with relatively large populations of this nematode. To avoid further rapid increase of population levels, such cultivars should also be partially resistant.

Two biological control methods fit in a strategy for integrated control of pcn: the cultivation of catch crops and the use of antagonists. Potatoes can be used as catch crop for pcn by killing the plants as soon as the cysts have hatched. On dead potato roots, the cycle of pcn is interrupted and the level of infestation will have declined. At present a practical method of doing this is being developed in the Netherlands (Molendijk, personal communication). In the Netherlands and the UK (Atkinson et al., 1987), researchers are also attempting to synthesize the root exudates that stimulate cyst nematodes to hatch, and to use this product in nematode control. De Haan and Thijssen (1990) have shown that antagonistic fungi such as *Cilindrocarpon destructans, Fusarium oxysporum* and particularly *Plectosphanella cucumerina* are able to reduce the multiplication of pcn in natural soil. However, it is unlikely that these biological control methods will be as effective, in the short term, as a resistant cultivar (Van der Wal and Haverkort, 1989).

If population levels of pcn are above the damage threshold for tolerant, resistant cultivars, chemical soil disinfection can be considered. Recent research findings in the Netherlands enable nematicides to be used very efficiently. Schomaker and Been (1989) found that pcn are not normally uniformly distributed in a field, but occur in patches. By analyzing relatively large amounts of soil (ca 15 l ha^{-1}) they are able to detect infested patches with no more than 50 cysts kg^{-1} of soil in the center, with 95% probability. A recently introduced soil sampling machine is speeding up soil sampling considerably. Instead of treating the whole field, soil disinfection can now be restricted to the infested patches and their immediate surroundings, which allows the amount of nematicides to be reduced by about 80%.

Prospects for integrated potato production

In order to meet one of the important requirements of integrated farming, protection of the environment, pesticide use must be cut drastically. That this is potentially possible in arable farming is shown by the results obtained on the OBS experimental farm at Nagele, the Netherlands. Here the amount of active ingredient of herbicides, fungicides and insecticides used in an integrated farming system has been reduced to 35% of that used in conventional farming (Wijnands, 1990). Further significant reductions in the first place will require cultivars with increased resistance to the main diseases and pests and/or effective biological control methods.

Breeding of resistant cultivars. Modern conventional breeding methods, such as breeding at diploid level, may speed up the development of new cultivars (Concilio et al., 1990). In recent years molecular–biological techniques have been introduced in breeding. Recombinant DNA technology allows the breeder to incorporate a certain crop characteristic in an existing cultivar. This technology has already produced some modified existing cultivars, e.g., resistance to PVX and PVY in cultivars Bintje and Russet Burbank and to potato tuber moth in cv. Bintje. However, the introduction of fungus and nematode resistance through genetic engineering is much further away (Dellaert et al., 1989). At present, much work is being done in various countries on identifying the genes coding for interesting agricultural properties: RFLP-mapping. Such RFLP-maps are also very useful in conventional breeding programs, since they enable the desired individual plants to be spotted at an early stage (Concilio et al., 1990).

Taking into account the lack of knowledge about environmental and toxicological aspects of transgenic plants, it appears unlikely that many usable resistant cultivars produced with these new technologies will be available to the farmer before the year 2000.

Biological control. Biological control requires agents that are active under a wide range of conditions, e.g., soil type, pH, temperature, humidity. They should preferably be formulated for long survival in the soil and they should be easy for the farmer (Powell, 1991). These agents should not be toxic for man or the environment and so must be tested thoroughly. Most biological control agents are very specific. This means that they are expensive to develop commercially.

Moreover, the commercial success is doubtful as long as cheaper chemical alternatives are available. Therefore government subsidies appear to be necessary if they are to be introduced rapidly. The consequence of the negative factors mentioned above seems to be that there is no reason for great optimism about an important role of biological control in potato production in the near future.

In spite of more resistant cultivars and introduction of biological control in integrated potato production, pesticides will still be required in the next two decades to ensure economically sound potato production. Provided these pesticides are sufficiently environment friendly this can be tolerated.

Apart from further research to improve breeding techniques and biological control, more knowledge is required on the ecology and epidemiology of the main potato diseases and on the population dynamics of important pests. Only with this information can reliable disease forecasting and disease and pest management systems be developed. These are vital in the optimization of integrated disease and pest control.

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