AGRICULTURAL AND FOOD SCIENCE

Vol. 20(2011): 3–14.

Pests and diseases in a changing climate: a major challenge for Finnish crop production

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A longer growing season and higher accumulated effective temperature sum (ETS) will improve crop production potential in Finland. The production potential of new or at present underutilised crops (e.g. maize (*Zea mays* L.), oilseed rape (*Brassica napus* L.), lucerne (*Medicago sativa* L.)) will improve and it will be possible to grow more productive varieties of the currently grown crops (spring wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.)). Also cultivation of autumn sown crops could increase if winters become milder and shorter, promoting overwintering success. Climatic conditions may on the other hand become restrictive in many ways. For example, early season droughts could intensify because of higher temperatures and consequent higher evaporation rates. Current low winter temperatures and short growing season help restrict the development and spread of pests and pathogens, but this could change in the future. Longer growing seasons, warmer autumns and milder winters may initiate new problems with higher occurrences of weeds, pests and pathogens, including new types of viruses and virus vectors. Anoxia of overwintering crops caused by ice encasement, and physical damage caused by freezing and melting of water over the fields may also increase. In this study we identify the most likely changes in crop species and varieties in Finland and the pest and pathogen species that are most likely to create production problems as a result of climate change during this century.

Key-words: climate change, crop, overwintering, pathogen, pest, virus, vector, winter

Manuscript received January 2010

Introduction

Finland lies between latitudes 60º and 70ºN, but despite its northern location supports active agriculture on about 2.3 million hectares of arable land almost throughout the country, even beyond the Arctic Circle. This makes Finland the northernmost country in the world with successful agriculture. However, short, cool growing seasons, a low effective temperature sum (ETS, base temperature +5 ºC for crops commonly cultivated in Finland) and long, harsh winters with thick snow cover limit effective production of most crops (Mela 1996) and yields per unit area remain significantly lower than in Sweden and Denmark (FAO 2010). Moreover, frosts disrupt the growing season till mid June and from mid August (Mela 1996), affecting frost sensitive crops such as maize (*Zea mays* L.). Because of the limiting conditions, climate warming with higher ETS, a longer growing season and milder winters is expected to have beneficial effects on Finnish agriculture (Mela 1996), in contrast to more southern countries such as those around the Mediterranean that may face serious drought problems as a consequence of climate change (IPCC 2007b).

While crop production is generally expected to benefit from climate change in Finland (Peltonen-Sainio et al. 2009b), problems with weeds, pests and pathogens, including new types of viruses and virus vectors, are expected to increase (Tiilikkala et al. 2010). Extra investment in plant protection measures, as well as the possible yield losses caused by the higher pest and pathogen pressure in the future, could reduce the net profit that Finnish farmers are expected to gain as a consequence of beneficial changes in climate. This review focuses on both the prospects for agriculture and the problems that Finnish agriculture is already experiencing and will continue to experience in the future in a changed climate.

Climate change in the northern latitudes

The average annual global temperature has increased 0.76ºC during the past century (IPCC 2007a). During the most recent decades and especially in the 2000s the increase has accelerated, the period 1995–2006 being the warmest ever recorded (IPCC 2007a). In Fennoscandia, the growing season has become one to three weeks longer during 1890–1997, with the lengthening taking place both at the start and at the end of the growing season (Carter 1998). At the same time, the ETS has increased, though without affecting the growing season intensity (average temperature during growth season). In Fennoscandia in general, the lengthening has been most noticeable at the end of the growing season, but in Finland it has taken place more at the beginning (Carter 1998). On average, since the 1960s there has been a trend of the growing season starting 2.1 days earlier per decade in the east and north of Finland, and 2.8 days earlier per decade in the west, with the pace of the development accelerating since the 1980s (Kaukoranta and Hakala 2008).

The increase in annual temperatures has been predicted to continue, with a greater increase at higher than at lower latitudes (IPCC 2007a). Temperatures are also predicted to increase more in winter than in summer (IPCC 2007a). Thus, in winter the temperatures would increase (compared with the period 1961–1990 and depending on scenario) 1.2–5.0 ºC by the 30 year period centred on 2025, 2.0–7.8 ºC by the 30 year period centred on 2055 and 3.7–10.9 ºC by the 30 year period centred on 2085 (later, 2025, 2055 and 2085, respectively) (Jylhä et al. 2004). In summer the corresponding increase would be 0.6–1.6, 1.1–3.9 and 1.6–5.5 ºC by 2025, 2055 and 2085. In the spring and in the autumn the predicted changes in average temperatures would be intermediate between the winter and summer figures. Furthermore, with increasing temperatures the length of the growing season and the ETS accumulated during the growing season will continue to increase. In general the growing season is expected to become 39–47 days longer by 2085 in northern Europe, compared with a baseline period of 1961–1990, with a stronger effect at the end than at the start of the growing season (Fronzek and Carter 2007). In Jokioinen, in southern Finland (60º 49'N, 23º29'E), among one of the best crop production regions in Finland, the thermal growing season is expected to lengthen from 169 days at present (1971–2000) to 181 days in 2025, 196 days in 2055 and 219 days in 2085. The ETS will increase from about 1200 degree days (ºCd) at present to about 1370 ºCd in 2025, 1580 ºCd in 2055 and 1860 ºCd in 2085 (Peltonen-Sainio et al. 2009c). At the same time the beginning of the growing season would be 5, 9 and 22 days earlier and the end of growing season 6, 16 and 27 days later in 2025, 2055 and 2085 respectively than at present, according to the A2 scenario of the IPCC (Nakicenovic et al. 2000, Peltonen-Sainio et al. 2009c). Over the same time, extreme climatic events such as heat waves and heavy rains are predicted to increase (IPCC 2007a).

Climate change will lengthen the growing season and increase the ETS of the growing season markedly. However, when much of the increase in the growing season length will take place in the autumn, the plants that are dependent on radiation to produce biomass will benefit only partly from the warmer conditions. Also autumn rains could hamper field work to an even greater extent in the future than at present (Jylhä et al. 2004). Thus when crop production potential is evaluated on the basis of ETS and growing season length, adverse climatic conditions in the autumn have to be taken into account. However, while these conditions limit crop production, they do not necessarily limit pest and pathogen proliferation, which can continue in wet conditions and low light levels. In the spring, again, neither radiation levels nor temperatures, according to the present scenarios, will be limiting crop production starting from the beginning of April (Peltonen-Sainio et al. 2009c). Then, however, the remaining snow cover and excess field moisture could hamper field work (Carter 1998, Peltonen-Sainio et al. 2009b). On average, the period from 15 April to 30 September would most probably represent the technically feasible crop growing season in Finland in the future (Peltonen-Sainio et al. 2009b, 2009c), while pests and pathogens would most probably thrive over a longer period, at least for the period that the calculated growing season with an ETS above 5ºC might suggest (Carter et al. 1996).

A new era for northern crop production

According to Peltonen-Sainio et al. (2009b), the ETS of the technically feasible crop growth period would increase by about 160 ºCd by 2025, 320–340 ºCd by 2055 and by 550 ºCd by 2085, if emissions continue as described by the IPCC scenario A2 (Nakicenovic et al. 2000). This would mean, among other things, that new crops such as forage maize, lupin (*Lupinus angustifolius* L.) (Peltonen-Sainio et al. 2009b) and oilseed rape (*Brassica napus* L.) (Peltonen-Saino et al. 2009a), which demand high ETS to mature, and have up to now been cultivated on very limited areas in Finland, could be cultivated successfully on larger areas. Also some promising minor crops such as flax (*Linum usitatissimum* L.), buckwheat (*Fagopyrum esculentum* Mill.), faba bean (*Vicia faba* L.) and sunflower (*Helianthus annuus* L.) might be taken into more extensive cultivation (Peltonen-Sainio et al. 2009b). In addition to this, the longer growing season would mean that more productive varieties of the presently cultivated common crops, barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.) and wheat (*Triticum aestivum* L.) could be taken into use and the cultivated area of these crops would increase (Table 1).

Areas and importance of autumn sown cereals and perennials will increase

Autumn sown cereals

In the future cultivation of most spring sown crops will not be limited by ETS in Finland, even at the borders in Lapland. At the same time, however, drought problems are likely to get more serious during the spring and early summer despite the slight increase in precipitation expected with climate change (Jylhä et al. 2004, Peltonen-Sainio et al. 2011b). Therefore there will be increasing need for autumn sown crops in the southern and central parts of Finland. For overwintered crops with well established root systems, increased precipitation in

Table 1. Novel or minor spring sown crops currently grown (1971–2000, centred on 1985) or promising crops for Finland following climate change according to a 30 year period centred on 2025, 2055 and 2085 (adapted from Peltonen-Sainio et al. 2009b). ETS, effective temperature sum with threshold temperature 5 ºC, except for maize, 10 ºC. Buckwheat needs 10 ºC for emergence (Montonen and Kontturi 1997). Southern Finland (South), up to 62 ºN, central Finland (Central), up to 64 ºN, northern Finland (North), up to 66 ºN, Lapland, up to 68 ºN, north Lapland (Lapland N), up to 70 ºN. South+, coastal area at about 60 ºN.

Crop	ETS required	Suitable in 1985 up to	Suitable in 2025 up to	Suitable in 2055 up to	Suitable in 2085 up to
Spring barley *Hordeum vulgare* L.	890	North	North	Lapland	Lapland N
Spring oats *Avena sativa* L.	960	Central	North	Lapland	Lapland N
Spring wheat *Triticum aestivum* L.	990	Central	North	Lapland	Lapland N
Spring turnip rape *Brassica rapa* L.	1010	Central	North	Lapland	Lapland N
Spring oilseed rape *Brassica napus* L.	1090	South	Central	North	Lapland
Buckwheat *Fagopyrum esculentum* Mill.	900	North	Lapland	Lapland	Lapland N
Field pea *Pisum sativum* L.	930–980	Central-North	Lapland	Lapland	Lapland N
Faba bean *Vicia faba* L.	1060	South	Central	North	Lapland
Flax *Linum usitatissimum* L.	1040	Central	North	Lapland	Lapland N
Hemp *Cannabis sativa* L.	1150	South	Central	North	Lapland
Forage Maize *Zea mays* L.	700–850	Not suitable	South +	South	Central
Sunflower *Helianthus annuus* L.	1100	South	Central	North	Lapland N

the winter (Jylhä et al. 2004) would secure sufficient soil moisture for early growth in spring and early summer. Currently overwintering crops are sown only in the south of Finland. Increase in temperatures, especially during the winter, is expected to gradually improve conditions for autumn sown crops to overwinter, thus facilitating a change from spring sown to autumn sown crops (Peltonen-Sainio et al. 2009b). For example, winter wheat, which is currently restricted to southern Finland up to about 61 ºN, could be grown successfully up to 64 ºN in 2025, and by 2055 up to 66 ºN. Winter rye (*Secale cereale* L.) is currently grown almost throughout Finland, but the yield levels drop dramatically north of 64 ºN. By 2025 the area for winter rye cultivation could expand to include all Finland (Peltonen-Sainio et al. 2009b). Even though overwintering problems will not be overcome soon, despite increases in winter temperatures (Peltonen-Sainio et al. 2011a), the number of winter days (days with average temperatures below 0 ºC) will gradually decrease. There is likely to be fewer than 100 winter days in southern Finland by 2055, and, depending on the climate change scenario, fewer than 100 winter days up to 66 ºN (scenario A2) or up to 62 ºN (B1 scenario) by 2085 (Peltonen-Sainio et al. 2009b). By 2085, if climate warming occurs according to scenario A2 (Nakicenovic et al. 2000), southern Finland might have winter conditions that resemble those of today's Denmark (1961–1990, Tveito et al. 2001, Peltonen-Sainio et al. 2009b, 2009c). However, the overwintering problems will not all be solved by then, as frost periods with intermittent warm spells are still expected to occur in Finland up to the end of the 21st century even according to the relatively high IPCC emission scenario A2 (Jylhä et al. 2008). Such conditions could be especially damaging for autumn sown crops, as when temperatures fluctuate around zero, snow melts and ice forms on the fields. This will cause ice encasement problems, such as anoxia, ice scorch and heaving, and maybe even frost damage if there is no protecting snow cover despite temperatures being well below zero (Hömmö 1994, Bélanger et al. 2002, Jylhä et al. 2008). For sensitive varieties of overwintering crops warm spells in mid-winter might also lead to decreased cold hardiness and increased susceptibility to frost damage (Bélanger et al. 2002). Increased physiological activity too early in the spring could lead to loss of reserve carbohydrates through respiration. This could result in reduced resistance against pathogens and weakened growth early in the season, when reserve carbohydrates are required for growth and maintenance of the photosynthesising leaves (Hakala and Pahkala 2003). Long and warm autumns could also lead to reduced cold hardening (Bélanger et al. 2002) and too dense canopies that favour pathogens (Serenius et al. 2005).

Perennial grasses and forage legumes

In experiments with simulated future conditions in Jokioinen, Finland, meadow fescue (*Festuca pratensis* L.) produced significantly higher yield when the growing season started earlier and finished later in a simulated warmer climate in the greenhouse (Hakala and Mela 1996). Furthermore, elevation of CO_2 levels had a more marked effect on yield under the warmer conditions with a prolonged growing season (Hakala and Mela 1996). In addition to the lengthening of the growing season, overwintering conditions for perennial grasses and legumes could become better with climate change, when the snow cover during the winter thins and stays for a shorter period (Jylhä et al. 2008). Under the present climatic conditions, deep and long lasting snow cover often favours low temperature fungi that damage the canopy and reduce the yield of crops in the following growing season (Ylimäki 1969, Nissinen 1996, Yli-Mattila et al. 2010). On the other hand, without snow cover, perennial grasses and legumes can face the same problems as autumn sown cereals; ice encasement, ice scorch and heaving injury (Hömmö 1994), often followed by disease attacks (Ylimäki 1967). It is possible that before mild winters typical of regions such as Denmark and southern Sweden have reached Finland, cultivation of grasses and legumes may face new and severe problems due to unstable autumn and winter conditions.

The importance of perennial legumes in forage leys and as bioenergy crops is currently increasing and will probably continue to grow. Legumes fix atmospheric nitrogen and reduce the need for chemical nitrogen fertilisation, thereby helping to reduce greenhouse gas emissions that would otherwise result from the manufacture of the fertiliser. In addition, forage production and especially the production of perennial bioenergy crops, requires sustainable and cheap production technology because of the low price of the product. Leguminous crops could add nitrogen to the system in an efficient and economical way.

The most common perennial legume forage grown in Finland is red clover (*Trifolium pratense* L.) (Evira 2009). Some alsike clover (*Trifolium hybridum* L.) is also grown and some white clover (*Trifolium repens* L.) is a component of pastures (Evira 2009). According to Halling et al. (2004), both annual accumulation of degree days, especially during the regrowth period, and average daily temperatures during the growth period, are generally positively correlated with both red clover and white clover yield. This suggests that in the future longer and warmer growing seasons in Finland will promote clover yields. In northern European areas south of Finland, lucerne (*Medicago sativa* L.) is an important forage legume. It produces high yields and is very persistent in a ley (Halling et al. 2004). If growing conditions improve, lucerne might become a major forage crop also in Finland, but red clover will probably remain in cultivation because of its stable and nutritionally superior yield (Bertilsson and Murphy 2003, Dewhurst et al. 2003).

Pest and pathogen problems in a changed climate with warmer and milder winters and autumns and with new crop forms and species

The classic disease triangle emphasises that virulent pathogens cannot induce disease on a highly susceptible host if weather conditions are not favourable. In addition, the environment can influence host-pathogen interactions through growth and susceptibility of the host plant and reproduction, dispersal, survival, and activity of the pathogen. The impacts of environmental change on plant diseases can be positive, negative or neutral and the effects are highly localised (Ghini et al. 2008). Carter et al. (1996) showed that in the future pests and pathogens will exploit the longer growing season and milder winters at least as efficiently as the crops. Pests and pathogens are not as dependent on radiation as crops, thus their growth could exploit a much longer period of the year than the effective growing season for plants at average daily temperatures above 5 ºC. With longer growing seasons and higher temperatures, development of pests is faster and the annual generations of multivoltine species could increase (Bale et al. 2002). With a longer growing season plant pathogens will thrive. For example, studies based on simulation models indicate that an increase of 1°C in mean temperature in southern Finland extends the period when potato late blight (*Phytophthora infestans* (Mont.) de Bary) control is necessary by 10 – 20 days, which means 1 – 2 more fungicide applications per season (Kaukoranta 1996). The need for plant protection measures for potato late blight control has already increased following climate change, and the epidemiology of the pathogen has also changed substantially (Hannukkala et al. 2007). As new crops are taken into active cultivation, their pests and diseases will gradually enter Finland.

Climate change will also affect the winter survival of overwintering plants such as grasses and autumn sown cereals. For example, red clover currently becomes less persistent the further north and east (continental) it is grown (Halling et al. 2004). The extent of this could be determined by the thickness and persistence of snow cover, which increase towards the north and inland (east). The pathogens that infect red clover, clover rot (*Sclerotinia trifoliorum* Erikss.) and root rot (several *Fusarium*-species) thrive best under thick snow cover, and especially when snow cover stays for a long period (Ylimäki 1967, 1969, Willets and Wong 1980, Yli-Mattila et al. 2010). With milder winters and thinning of the snow cover red clover, as well as other perennial grasses and legumes, might survive better in Finnish leys, which will prolong the profitable period of yield production and thus reduce the cultivation costs.

Examples of possible increased plant disease risks

The shift towards autumn sown cereals will change the prevailing pathogen spectrum and increase the need for plant disease control during autumn. Eyespot (*Oculimacula yallundae* (Wallwork & Spooner) Crous & W. Gams and *Oculimacula acuformis* (Boerema, R. Pieters & Hamers) Crous & W. Gams, anamorf *Pseudocercosporella herpothrichoides* (Fron) Deighton) is a severe disease of winter wheat (Fitt et al. 1988), rye and perennial grasses (Cunningham 1981) in temperate regions, causing up to 50% yield losses (Fitt et al. 1988). In Finland this disease was frequently found in spring wheat throughout the country in 1946 – 1953 (Hårdh 1953). Eyespot was commonly found in some years in the 1960s, but was practically absent in 1975 – 1978 (Mäkelä and Parikka 1980). In surveys carried out in the late 1980s and early 1990s eyespot was rare and it is not currently regarded as an important cereal disease in Finland (Hannukkala unpublished). Eyespot has, however, great potential to become a major stem base disease in a changed climate, as it already is in Denmark (Sindberg et al. 1994) and other countries with moist autumns (Fitt et al. 1988). The anamorphic spores of the pathogen infect hosts in the moist autumn conditions when the temperature is 8 – 21 °C. The apothecia of the fungus are produced on the bases and culms in straw stubble two months after harvest and mature ascospores spread during winter and early spring in the British climate (Dyer et al. 1994). Ascospores represent important source of infectious inoculum as well as a source of genetic variation for build up of fungicide resistance (Daniels et al. 1995). Predictions for future autumn conditions in Finland suggest that eyespot may have improved possibilities for proliferation in Finland.

Changing climate will also favour powdery mildew (*Blumeria graminis* (DC.) Speer) infections of winter wheat and barley (Gregory et al. 2009). The dynamics of barley powdery mildew epidemics will change, particularly when autumn sown barley is incorporated into production. Currently barley powdery mildew cannot overwinter in Finland as suitable hosts do not exist. In Denmark and southern Sweden, where winter barley is grown, powdery mildew is one of the most serious diseases (Bousset et al. 2002). Chemical control is frequently needed and rapid development of new races of both wheat and barley mildews will challenge resistance breeders in the future (Limpert et. al 1999). Also rusts, especially brown rust (*Puccinia recondita* Dietel & Holw), could become an increasing problem. Winter cereals can be attacked already in autumn, which can have detrimental effects for overwintering of crops (Serenius et al. 2005). Climate warming can also have indirect effects by changing rust and powdery mildew resistance gene expression. Genes active against diseases at low (10 °C) temperatures can be turned off at high (25 °C) temperatures (Gregory et al. 2009).

Increase in production of autumn sown cruciferous oil seed crops will give rise to new disease problems that are currently negligible for spring sown cultivars. In the1950s, when autumn sown oil seed crops were grown in Finland, *Typhula setipes* (Grev.) Berthier, among other low temperature fungi, caused serious winter damage (Jamalainen 1954). Wilt caused by *Verticillium longisporum* (C. Stark) Karapapa, Bainbr. & Heale is a very serious problem for autumn sown oil seed crops in Denmark and southern Sweden (Johansson et al. 2006), but is currently very rare in Finland in spring sown oil seed crops (Hannukkala unpublished). However, in the future Finland may face a similar problem because the Finnish climate at the end of this century could resemble that of current day Denmark and southern Sweden (Peltonen-Sainio et al. 2009b).

In addition to the problems arising from increasing possibilities for cultivating overwintering crops, new possibilities for spring crop rotations may also cause problems with pathogens that have not been recorded in Finland. For example, introduction of maize into crop rotations with wheat could increase the importance of particular mycotoxin-producing *Fusarium* species, especially *Fusarium graminearum* Schwabe, as recorded elsewhere (Osborne and Stein 2007). *F. graminearum* under certain conditions produces the mycotoxin deoxynivalenol (DON) among other toxins (Birzele et al. 2002). *F. graminearum* is already present in Finland but other *Fusarium* species predominate (Uhlig et al. 2007). A warming climate and modified host range might also substantially change the propagation biology of the pathogen by favouring its sexual stage (*Gibberella zeae* (Schwein.) Petch) and increasing intra-population genetic diversity (Xu 2003).

Intensive agricultural systems encourage rapid evolution of plant pathogens. The plasticity of some agricultural systems could help to minimise negative impacts of climate change, for example, through new adapted cultivars (Chakraborty et al. 2000). Disease management strategies are designed with reference to the environment and could be affected by climate change. Fungicide residue dynamics could be affected by changes in temperature and precipitation, and changes in plant morphology or physiology resulting from climate change can influence the efficacy of fungicide action (Ghini et al. 2008). There is also evidence that some forms of disease resistance might be overcome more rapidly following changes in levels of CO_2, ozone and UV-B. The greatest concern over the durability of host resistance is accelerated pathogen evolution (Chakraborty et al. 2000). Understanding the host-pathogen biology is the first step toward minimising the risks represented by novel plant diseases. Durable, race non-specific resistance incorporated into high yielding genotypes is the main method for managing obligate parasites of cereals. In addition to disease resistance, improved crop management methods, including crop rotation, will be necessary (Duveiller et al. 2007).

Examples of possible increased pest risks

Climate change will have a number of effects on developmental rate and phenology of crop plants that will alter the proliferation of associated pest species. The degree of damage suffered by a crop will depend on the synchrony between pest abundance and the most susceptible developmental stage of the crop (Van Emden and Way 1973). Direct climate change or changes in cropping practices, e.g. a shift in sowing time, could result in crops suffering variable levels of pest attack at vulnerable seedling stages (Huusela-Veistola et al. 2006). During warmer autumns damage by frit fly (*Oscinella frit* L.) and Hessian fly (*Mayetiola destructor* Say) in winter cereals will probably increase (Tiittanen 1959, Huusela-Veistola et al. 2006). Longer and warmer periods in autumn also enable extended flights of plant virus vectors such as *Rhopalosiphum padi* L. and *Psammotettix alienus* Dahlb. (Huusela-Veistola and Lemmetty 2005, Ewaldz et al. 2007). Therefore, the risk of BYDV (*Barley Yellow Dwarf Virus*) and WDV (*Wheat Dwarf Virus*) developing in winter cereals is likely to increase in the future (Harrington 2007, Huusela-Veistola 2007). However, viruses, vectors, host plants and abiotic factors are continuously changing and their interactions are complex and challenging to predict or manage (Harrington 2007, Canto et al. 2009).

Changes in crop production systems are likely to alter the composition of pest complexes. New crops represent new host plants and habitats and therefore pest problems are likely to increase as a new crop becomes widely grown. Climate change may increase the importance of some existing pests or enable colonisation by new pests previously restricted by unfavourable low temperatures or shortage of suitable host plants. For example, the European corn borer, *Ostrinia nubilalis* Hübner, which nowadays feeds on alternative host plants in southern Finland, is likely to become a pest of maize as its cropping range expands northwards (Tiilikkala et al. 2010). Furthermore, frit fly and aphids, which are common insect pests of cereals in Finland, can also damage maize. In addition, the abundance of *Rhopalosiphum maidis* Fitch, which is vector of the RMV strain of BYDV, could increase in tandem with increased maize cropping and climate warming (Harrington 2007).

Increased cropping of winter oilseed crops could change the status and phenology of pests of cruciferous crops. For example, cabbage seed weevil (*Cheutorrhynchus assimilis* Payk) is phenologically synchronized with winter oilseed rape (Kevväi et al. 2006), whereas pollen beetles (*Meligethes aeneus* Fab.) are more problematic in spring oilseeds (Veromann et al. 2006). At present the number of important pest species of oilseed rape is higher in Denmark than in other Nordic countries (Menzler-Hokkanen et al. 2006). It is likely that pest problems and the need for insecticides in oilseed cropping will increase with climate change also in Finland. That will be problematic because pollen beetles resistant to insecticides (pyrethroids) have already been recorded in Sweden (Ekbom and Kuusk 2001) and in Denmark (Hansen 2003), and insecticide resistance is likely to develop also in Finland (Tiilikainen and Hokkanen 2008). Overall, selection of available insecticides is narrow. Pyrethroids are commonly used against pests of all field crops, which increases risk of pesticide resistance for other pest insects as well.

In the long run, climate change, especially warming of winters, could enable survival of year-round parthenogenetically reproducing anholocyclic forms of *Rhopalosiphum padi*, which are nowadays common in the UK (Tatchell et al. 1988) and France (Dedryver and Gellé 1982, Simon et al.1991) and have recently also been recorded in Poland (Ruszkowska 2007). Anholocyclic clones are important vectors of BYDV in winter cereals (Harrington 2002). Increased capacity for long-range migration and rapid rate of population increase make aphids effective colonists and important pests (Van Emden and Harrington 2007) that will have to be monitored more carefully in the future. On general, climate change will increase risk of entry and establishment of invasive alien pest species in Finland (Vänninen et al. 2011)

Frequency and amplitude of pest and pathogen outbreaks vary considerably in time and space. Climate change could increase variation among species, populations/strains of the same species, different seasons and localities, and therefore complicate forecasting of plant protection problems. Climate change will not only affect the distribution and abundance of pest populations, but also those of their host plants, competitors and natural enemies. Due to varying conditions and time scales definitive effects of these interactions will be difficult to predict (Thomson et al. 2009).

Climate change in conjunction with changed crop composition could indirectly affect plant protection. For example, in UK, winter oilseed rape provides a suitable overwintering habitat for anholocyclic peach aphid, *Myzus persicae* Sulz. (Cocu et al. 2005), which is the most important vector of potato virus Y (PVY) (Radcliffeand Ragsdale 2002). In Nordic countries, many other aphid species, such as *Rhopalosiphum padi, Aphis fabae* Scopoli*, A. frangulae* Kalt.*, A. nasturtii* Kalt.*, Brachycaudus helichrysi* Kalt.*, Acyrthosiphon pisum* Harris*, Phorodon humili* Schrank*, Metopolophium dirhodum* Walker and *Cryptomyzus galeopsidis* Kalt. are more important PVY vectors at the moment (Kurppa and Rajala 1986, Sigvald 1989, Kirchner et al. 2009) but comparable vicarious effects as in the case of peach aphid in UK are possible and unforeseeable when crop assortment and weather conditions alter. Moreover, although forage grasses and legumes incur minor pest damage they can act as a reservoir for slugs, aphids and BYDV, which can cause problems in neighbouring winter cereals. Overall expansion of winter oilseed crops, winter cereals, perennial grasslands and different winter vegetation management, such as undersown catch crops, could create "green bridges" for pests and pathogens. In parallel, the peak of chemical control is likely to change from early summer to autumn, which can increase leaching of pesticide residues. Increased need of chemical control with climate change in tandem with risk of pesticide resistance and restrictions of pesticide use create more challenges for plant protection. Therefore, integrated pest management methods and alarm systems that support decision making in plant protection, as well as resistant cultivars and adequate crop rotations should be used to minimize the problems caused by increased need for plant protection.

Conclusions

While the predicted climate change generally improves crop production possibilities in Finland, the accompanying threats represented by pests and pathogens have to be taken into account when making predictions and developing adaptation practices for Finnish crop production. Because of the huge range of interactions and outcomes associated with a changing climate and different cropping systems it is important to avoid drawing overly simplistic conclusions (Morecroft et al. 2009). However, an increased use of overwintering crops in particular poses substantial challenges for Finnish crop production. E.g. emphasis of chemical control is likely to change from early summer to autumn, which can increase leaching of pesticide residues, especially as winter temperatures and precipitation are predicted to increase. In addition to environmental problems, increased need of chemical control in tandem with risk of pesticide resistance and restrictions of pesticide use are likely to create more challenges for plant protection. Therefore, integrated pest management methods and alarm systems that support decision making in plant protection measures have to be used efficiently in order to realise the benefits of improved crop growth conditions in the future. Resistant cultivars, adequate crop rotations and sustainable control methods are crop management practices that can be used to minimize plant protection problems and adverse effects of the protection measures to the environment.

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