# Crop volunteers and climate change

Effects of future climate change on the occurrence of maize, sugar beet and potato volunteers in the Netherlands

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Wageningen

This report was commissioned by COGEM. The contents of this report are the sole responsibility of the authors and do not necessarily reflect the views of COGEM.

## Foreword

COGEM has commissioned a research project on the effect of the possible future climate change on the occurrence of volunteers. One of the aspects that is considered in the risk assessment of GM crops is whether this crop is able to survive and/or establish in the Netherlands. Climate change could possibly facilitate the survival of a conventional or GM crop. This research project was carried out to investigate whether the survival of maize, potato and sugar beet could change as a result of future climate change in order to allow a timely adjustment of COGEM's advices if needed.
The investigators reviewed available literature to identify the climatic factors that are most important for volunteer occurrence. Subsequently, the four KNMI climate scenarios that describe the possible climate of the Netherlands in 2050, were used to estimate whether the number of maize, potato and sugar beet volunteers and hence the survivability of these crops would change.
The research was carried out by Plant Research International B.V. and Praktijkonderzoek Plant & Omgeving B.V. (Applied Plant Research). The content of the report does not necessarily reflect the opinion of COGEM. In an accompanying letter COGEM's view on the obtained results is expressed.

I hope you enjoy reading this report and find its content of interest,

Dr P.M. Bruinenberg (AVEBE U.A.)
Chairman of the advisory committee

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# Summary

Future climate change may impact occurrence of crop volunteers, which is of relevance for weed control in crops in general and for management measures in field trials with genetically modified (GM) crops because volunteers are a potential alley along which crop genes can escape from cultivation. This report presents a literature review on the relationship between volunteer occurrence of the crop species maize, sugar beet and potato and climatic conditions, and compares the results with the four climate scenarios for the Netherlands in 2050 made by KNMI. The important climate factors for volunteer occurrence are (1) soil moisture conditions after harvest, since these influence volunteer seed depletion by germination and subsequent removal by winter conditions or control measures (maize and beet), and seed dormancy development (beet), (2) frost conditions during winter, which determine survival of reproductive plant parts, particularly groundkeepers (beets (roots) and potato tubers), and (3) temperature and soil moisture conditions during the growing season, which are important for growth and reproduction of volunteers. The changes in temperature as expected in the four future climate scenarios could benefit volunteer development, *i.e.* higher winter temperatures increase chances of survival of groundkeeper potatoes and higher summer temperatures promote seed production in weed beets. On the other hand, the different climate scenarios show partly contradictory results with regard to precipitation in summer and autumn and results for soil moisture conditions are even more uncertain so that their impact on volunteerism could not be well assessed. We conclude that attention should remain to be paid to volunteer control in sugar beet and potato, as technical control measures are basically the overriding factor for volunteer occurrence. Maize does not show volunteerism in the Netherlands, even with the already on-going warming of the climate. Comparisons of future climate scenarios and climatic conditions in areas where maize volunteers are presently prevalent in Southern Europe may imply a low likelihood of future volunteerism in maize in the Netherlands, but such comparisons need to be interpreted with the utmost care.

## Samenvatting

Toekomstige klimaatverandering kan het optreden van opslagplanten van landbouwgewassen beïnvloeden. Dit is van belang voor onkruidbestrijding in gewassen in het algemeen en voor beheersmaatregelen in veldproeven met genetisch gemodificeerde gewassen, omdat opslag een mogelijke route vormt waarlangs gewasgenen kunnen ontsnappen vanuit de cultuur. Dit rapport presenteert een literatuuroverzicht over de relatie tussen het optreden van opslag van de gewassoorten maïs, suikerbiet en aardappel en klimatologische omstandigheden, en vergelijkt de resultaten met de vier klimaatscenario's die het KNMI heeft opgesteld voor het Nederland van 2050. De belangrijke klimaatfactoren voor het optreden van opslag zijn (1) bodemvochtigheid na de oogst, aangezien dit het verdwijnen van zaad door kieming en vervolgens verwijdering door wintercondities en/of bestrijding (maïs en biet), en ontwikkeling van kiemrust (biet) bepaalt, (2) optreden van vorst gedurende de winter, wat bepalend is voor overleven van reproductieve plantendelen (bieten en aardappelknollen), en (3) temperatuur en bodemvochtomstandigheden gedurende het groeiseizoen, die van belang zijn voor ontwikkeling en reproductie van opslagplanten. De temperatuurveranderingen die volgens de vier klimaatscenario's verwacht worden, zouden het voorkomen van opslag kunnen bevorderen, d.w.z. hogere wintertemperaturen bevorderen de overlevingskansen van op het veld (in de bodem) achtergebleven aardappelknollen en hogere zomertemperaturen bevorderen de zaadproductie van onkruidbieten. Aan de andere kant geven de klimaatscenario's deels tegenstrijdige resultaten met betrekking tot neerslag in zomer en herfst en resultaten voor bodemvochtigheid zijn met nog meer onzekerheid omgeven, zodat de invloed daarvan op opslag niet goed geëvalueerd kan worden. We kunnen concluderen dat er aandacht moet blijven voor opslagbestrijding, aangezien dit de overheersende factor zal blijven om opslag te voorkomen. Ondanks al optredende opwarming vertoont maïs geen opslag in Nederland. Vergelijkingen tussen klimaatscenario's en klimaatomstandigheden in Zuid-Europese gebieden waar maïsopslag momenteel voorkomt, lijken toekomstige opslag in Nederland minder aannemelijk te maken, maar deze vergelijkingen moeten met bijzondere voorzichtigheid bekeken worden.

# 1. Introduction

Climate change can have many implications for crop cultivation, such as changes in the sort of crops that can be grown and the occurrence of plant diseases and pests. For instance, the recent return of the Colorado beetle in potato in Northern Europe may be related to warmer conditions. In the Netherlands, a recent increase in ambient temperature is already reflected in the increased occurrence of thermophilic plant species in the Dutch flora according to a study by Tamis *et al*. (2005).

The development and survival of crop volunteers are dependent on weather conditions as well. Crop volunteers are plants spontaneously arising on arable fields from reproductive parts left in the field after harvest. For instance, potato has two ways by which volunteerism may occur: during their cultivation period, plants can set seed that is shattered on the ground and during harvest, tubers may be left in the field. Both seeds and tubers may survive a following winter period and produce plants in a following growing season. Volunteers may cause weed problems in subsequent crops.

In the Netherlands, winter cold is an important limitation to survival of potato groundkeepers, as the plants from tubers left in the field are often called. This raises the question whether changes in climate as extensively assessed by a large international panel of experts (IPCC, 2007), could also change the occurrence of volunteers. Since winters are predicted to become warmer in North-Western Europe, one could for instance expect this to lead to higher survival rates of potato groundkeepers. This could have consequences for management measures needed in relation to volunteers that may occur as a result of field trials with genetically modified (GM) crops. In such cases, volunteers need to be carefully monitored and controlled, because they are a potential alley along which crop genes can escape from cultivation.

Research on environmental factors important to volunteer occurrence has not only taken place in relation to GM crop cultivation but also in earlier days, with regard to weed control and sowing seed production, the latter requiring high levels of varietal purity. Climatic factors that will be important to volunteer occurrence are (1) autumn and winter temperature and soil moisture impacting survival of reproductive parts, and (2) spring and summer temperature and soil moisture influencing volunteers' growth and seed set during the cropping period. With the focus in this study on climate impacts, it should be kept in mind that there are many more factors influencing volunteer occurrence, among which other varieties, other crops in the rotation and agronomic measures. The latter, often summarized as Good Agricultural Practice, are often the overriding factor determining whether volunteers can persist. In the case of potato, volunteer control is not only called for in relation to avoiding weed impacts on yield, but is even obligatory because volunteers can provide hiding places for harmful diseases, such as late blight (*Phytophthora infestans*) and nematodes. The efficacy of control measures, however, can also be affected by weather conditions (*e.g.* the possibility of using machinery on wet soils or the effects of herbicides sometimes depend on humidity) and this will be addressed in this study where appropriate.

In this review, we summarize knowledge of the influence of weather conditions specifically on the occurrence of volunteers in the crop species, maize, sugar beet and potato, and relate this to expected changes in the climate of the Netherlands. The report does not address broader issues, such as gene flow with wild relatives of crops, general changes in plant distributions and other phenological observations as a consequence of changes in climate. For information on general practice in the cultivation of the three crop species in the Netherlands with regard to dispersal and gene flow, we refer to the recent report by Van den Brink *et al*. (2008). For this study, we performed a search of both the scientific and applied literature. Since for this agronomic topic not all practical knowledge might be available in the literature, we additionally consulted experts in the Netherlands and surrounding countries. In the following chapters, we first discuss the three crop species with their specific characteristics separately in order to identify climatic factors important to each crop's volunteer prevalence. Subsequently, we explore the climate scenarios drawn up by the Dutch Royal Meteorological Institute, KNMI, for the expected future changes in these climatic factors (Van den Hurk *et al*., 2006; Klein Tank & Lenderink, 2009). Finally, we discuss the possible relevance of the results to measures to be taken to ensure effective GM volunteer control.

## 2. Maize

In the Netherlands, about 85-90% of the maize (*Zea mays* L.) area is occupied by silage maize, in which the whole plant is harvested for feed. Silage maize varieties are late-ripening and generally not producing mature grains before harvest in autumn. Grain maize, which is harvested after maturation of the grains, is only grown on a small area in the southern part of the country (Groten, Wageningen UR-PPO, pers. comm.). Maize can produce volunteers through grains (the seeds, also named kernels) remaining on the field after harvest. For that reason, silage maize with its generally immature grains at the time of harvesting is less likely to produce volunteers. Moreover, maize is a cold-sensitive crop with limited dormancy in its seeds. Due to extensive domestication, maize is also not a strong seed disperser as grains are enclosed in the ear. Volunteers can however also germinate from (parts of) ears left in the field. In maize, usually hybrid varieties ($F_1$) are used and so maize volunteers ($F_2$ and possibly later generations) will often show poor development due to the loss of hybrid vigour. Palaudelmàs *et al*. (2009) confirmed this in their study on maize volunteers in Spain: volunteers mostly failed to produce an ear and also tassel (male inflorescence) development was poor, but sometimes fertile pollen was produced. In the US, volunteerism has increased in maize with the advent of herbicide-tolerant GM varieties, particularly so in the predominant Roundup Ready (RR) variants that have tolerance to glyphosate (Roundup), as they are often rotated with soybean having the same RR trait, in which the same herbicide, glyphosate, is used. Thus, maize volunteers containing the RR trait are not controlled in these subsequent RR soybean cultivations (Davis *et al*., 2008) and this apparently compensates to some degree for the disadvantages of lost vigour in hybrid's progenies. Also, the conservation tillage facilitated by the RR trait may promote volunteerism in maize. In the EU, RR crops are presently not approved for cultivation.

*Observations of volunteer occurrence with relation to weather conditions*

Palaudelmàs *et al*. (2009) have published about the occurrence of GM (Bt) maize volunteers in the Foixà region of Spain in the period 2003 to 2006.

Volunteer incidence was higher in 2005 than in 2004 and 2006. The maximum number of volunteers in 2005 was 8,728 per ha while the maximum numbers in 2004 and 2006 were 1,025 and 2,115 per ha, respectively. The high number of volunteers in 2005 was attributed to the dry autumn of 2004. If the autumn is wetter, the seeds left in the field after harvest are more likely to germinate. These volunteers will be destroyed by frost or by tillage operations in the next growing season. If the autumn is dry, kernels may remain in the field until the next season.

In the sowing seed production regions in the southwest of France, occurrence of maize volunteers is monitored because they could be a source of undesirable varietal impurities in sowing seed lots. Maize volunteers have been observed in densities up to 100 plants per ha in this region (Angevin, INRA, pers. comm.). Technical rules for seed production stipulate that volunteers, like off-types, should be destroyed before flowering. In grain and silage maize production, no systematic monitoring of volunteers is performed in France. From incidental observations, volunteers are not known from parts of France with colder winters than to the south of Bordeaux (Les Landes), such as the Auvergne production region, near Clermond Ferrand. Nevertheless, in 2008, INRA has incidentally observed volunteers in the surroundings of Paris (Angevin, INRA, pers. comm.). Most of the times, when volunteers occur, they originate from pieces of ears, and not from single grains detached from the ear, left in the field.

In Germany, maize volunteers normally do not occur. However, maize volunteers were observed in the spring of 2007 in a field in Werne (in Nordrhein Westfalen, about 150 km from Nijmegen) used for testing GM maize (both grain and silage lines) (http://www.haerlin.org/Mais_Durchwuchs.pdf). The presence of volunteers in the field was attributed to the mild winter of 2006/2007. However, the incidence of volunteers was also related to aberrant cultivation measures. Maize plants were chopped and ploughed into the soil, which is common practice with GM field trials but is not a logical way of treating normal production fields at harvest. Thus, in this particular example, it is possible that kernels that were more or less protected from wetting by ear remnants and had not germinated in the autumn, subsequently survived for lack of winter cold penetrating the soil, and finally germinated in the next spring. Maize volunteers were also observed in Tachenhausen (Baden-Würtemberg) in 2007, in Oberboihingen (Baden-Würtemberg), and in Heilbronn-Biberach (Baden-Würtemberg) in 2003, in all cases on fields used previously for experiments with GM maize (http://www.landtag-bw.de/WP14/Drucksachen/1000/14_1612_d.pdf, http://www.murschel.de/landtagsweb/PDF/pm037_Durchwuchsmais.pdf). Thus, in all these cases, occurrence of volunteers appears to be related to the specific management applied to these GM field trials in Germany.

In the Netherlands, occurrence of volunteers in agricultural practice has to our knowledge not been found, nor has it been reported for the Netherlands in scientific literature. Volunteerism is also less likely, as most maize is grown for silage, in which grains usually do not attain maturity within the cultivation period. This could change in the future with a warming climate, since this could allow more profitable grain production. In recent years, Wageningen UR-PPO researchers encountered maize volunteers in two of their research fields in Valthermond (Province of Drenthe), which however also contained lines of types that are not normally grown in the Netherlands (Groten & Timmer, pers. comm.).

Little research literature was found with systematic data on dependence of volunteer occurrence on weather conditions. In a review on the effects of low temperature on maize cultivation, Miedema (1982) mentioned frost damage of maize kernels to be dependent on the moisture content. Kernels with a moisture content below 15% withstood $-22^{0}$C for at least 4 months but all kernels with more than 25% moisture content did not show germination anymore, confirming the importance of dry conditions after harvest for volunteer survival mentioned above.

*Other factors involved in volunteer occurrence and their possible interaction with weather conditions*

Grain loss is depending on the type and efficiency of the harvesting machinery used. Grain loss also depends on the condition of the crop at harvesting time. Plants can suffer wind damage before harvest, with ears falling below the level of collection of harvesting machines (Palaudelmàs *et al*., 2009). The moment of tilling in the next season is also important for volunteer persistence. Tilling for late sowing, for example, removes most volunteers, whereas preparing fields for early sowing often allows normal germination of volunteers. Maize volunteer problems are more severe when tillage is reduced (Beckett & Stoller, 1988; Davis *et al*., 2008). Presently, there is a trend to decrease tillage in the Netherlands in order to achieve improvements in soil conservation. Crop rotation is another factor affecting volunteer occurrence. Maize volunteers are easily controlled in crops such as sugar beet, potatoes and cereals.

The efficacy of herbicide programmes for controlling volunteers sometimes depends on weather conditions. For instance, Laube & Arnold (1982) reported that volunteer control with fluazifop-butyl was best with rainfall at 2 and 8 hours after application whereas rainfall had no effect with the other herbicides tested, chlorazifop and Dowco 453. Paul & Knake (1983) reported that volunteer responses to herbicide treatment were smaller under dry conditions (in the absence of precipitation).

*Conclusions*

From the above, the following climatic factors appear to be important to volunteer occurrence:

- Freezing temperatures at ground level during winter are restrictive for survival of plants and seeds. For seeds, also below-ground level freezing temperatures are important in the case that they have become buried by post-harvest treatments.
- Moisture conditions of the soil after harvest are important for two reasons:
    - Wet conditions after harvest stimulate germination of grains left in the field and these seedlings have a low likelihood of survival, a.o. due to frosts in following winter;
    - Survival during winter of seeds that did not germinate during autumn also depends on humidity levels as the lower the seed moisture content the better its survival under winter cold.
- Wind frequency and intensity are relevant in case they reach a level where plants are damaged leading to ears falling outside of reach of harvesting machinery.

## 3. Sugar beet

Sugar beet (*Beta vulgaris* L. ssp. *vulgaris*) can produce volunteers through groundkeepers and seeds. Groundkeepers grow from (parts of) beets remaining in the soil after harvest. Groundkeepers (beets surviving to the next growing season in which plants emerge from them) are relatively rare, but volunteers from seeds became a common phenomenon in Northern Europe in the 1970s. Sugar beet is usually grown during a single growing season and then does not flower as it normally only flowers in the second year of growth. However, occasionally it can become vernalized during early growth leading to bolting during the first year, depending on the sensitivity of the variety. However, this is not a likely source of volunteers arising from seeds. The most profuse source of volunteer seeds is weed beets. Based on molecular-genetic (DNA) data, weed beets were shown to have originated in the sowing seed multiplication areas in Southern Europe through unintentional hybridization of maternal plants with local annual ruderal beets or wild sea beet (*Beta vulgaris* ssp. *maritime* (L.) Arcang.) instead of the desired paternal line (Boudry *et al*., 1993; Desplanque *et al*., 1999). In this way, seeds produced for sowing in the beet production areas of Northern Europe, acquired a dominant bolting (B) allele that leads to flowering in the same year as germination. When not controlled by removal of all bolting beet plants, these weed beets can persist through locally produced seeds ending up in the soil seed bank and become a serious problem in subsequent beet cultivations, as they cannot be controlled by selective herbicides. Weed beet is present in more than 70% of the sugar beet fields in the United Kingdom and according to Darmency *et al*. (2007), 5% of the sugar beet production area in France is severely infested. Also in the Netherlands, there are fields infested with weed beet (Wevers, 2006). However, during the last years in which the area grown with sugar beet was decreasing, many infested fields are no longer used for sugar beet production, as the yield of sugar beet was relatively low on these fields, also because of the occurrence of beet cyst nematodes (Wevers, pers. comm.). On these fields, the seed bank will become exhausted by germination and subsequent control measures in other crops. Weed beets are not reported outside of arable fields in the Netherlands.

*Observations of groundkeeper occurrence with relation to weather conditions*

Pohl-Orf *et al*. (1999) performed field experiments on different locations in the Netherlands and Germany in the period 1994–1997 to evaluate winter survival of sugar beet lines and hybrids. The following locations were included: Breskens, Aachen, Cologne, Mainz, Stuttgart, Brunswick and Dresden. Survival rate of the plants was correlated with temperature, in this case presented as the coldsum below -4$^0$C (sum of all daily average temperatures below -4$^0$C). Survival rate in Breskens was ca. 85% in 1995/96 compared to zero in Aachen and Mainz in the same winter. The winter of 1994/1995 was uncommonly mild, with coldsums of around -20$^0$C: survival rate was ca. 90% in Cologne and ca. 65% in Aachen.

However, in standard cultivation of sugar beet, harvesting is done in autumn and plants are normally not grown across winters in Northern Europe. Survival of plants as described for the experiments by Pohl-Orf *et al*. (1999) suggests that also groundkeepers could survive winters with few frost days. Nevertheless, according to Sester *et al*. (2004), groundkeepers are usually rare in France and have little chance of producing seeds. Groundkeepers are practically unknown in the Netherlands. We are only aware of one observation in 2008 of bolters in a maize field near Zeewolde (Province of Flevoland) that grew from beet parts remaining from the previous year (R. Groeneveld, Wageningen UR-PRI, pers. comm.).

*Observations of volunteers from seeds with relation to weather conditions*

Seeds from crop bolters and weed beets can remain viable in the soil seed bank, in one case shown for up to 47 years (Desprez, 1980). Seed survival could be influenced by cold: for instance, seeds with 50% water content were killed by alternating weekly regimes of 2$^0$C, -10$^0$C and -25$^0$C (Anonymous, 1977). Seed bank mortality also depends on soil depth and on the dormancy induced by burial. In addition, seed bank decay can be due to seed predation or seed germination after which plants are lost to diseases/herbivory or tillage and weed control activities. Reported estimates of yearly mortality vary. Landová *et al.* (2010) reported a yearly loss of 75% in the Czech republic, IRS (2010) 33% (by combining 25% mortality and 50% germination of seeds in the upper 4 cm of the soil), and Longden & Breay (1995) 30% in the UK. In studies at Dijon in France by Sester *et al*. (2006), seed mortality and germination were studied separately. The weed beet seed bank followed cyclic periods of seed decay, depending on the season. In autumn, approximately 20% of the seeds were dying. During the rest of the year seed decrease was negligible, so winter conditions apparently did not have a significant role in seed mortality. Seed mortality in autumn resulted from seed rot due to a long period of moisture and diseases.

Occurrence of volunteers also depends on opportunities for new seed development during crop cultivation in summer. Bolting of the beet crop itself is induced by vernalization, *i.e*. by temperatures below $12^0$C, but this is reversible by alternation with warmer periods up to June. Therefore, varieties prone to bolting should not be sown before the beginning of April, but the varieties that are used in the Netherlands usually have a high resistance to bolting. Higher spring temperatures will result in less vernalization of sugar beet plants and consequently less bolters from the crop itself. On the other hand, higher spring temperatures could also elicit earlier sowing, which would compensate the effect on bolter prevalence. However, as mentioned in the introductory paragraph, crop bolters are hardly contributing to volunteer occurrence. Bolting of the far more important weed beets begins from the end of May and flowering sets on from the end of June or early July. The plants develop large racemes on which open flowers are encountered for a period of about thirty days, and in this way, individual plants produce some 1500 seeds on average. The first viable seeds can be expected by the end of July or early August; 350 degree days from flower opening were estimated to be necessary. Seeds are shed from mid-September onwards in the United Kingdom (Longden, 1993a), where the main sugar beet growing regions are located in East Anglia, East Midlands and the South West. Also in the UK, Cussans & Bastian (1981) determined that for viable seed formation, flowers had to be open before mid-August in 1978 whereas in 1979 flowers could open up till the beginning of September. Based on these observations, 800 degree days were thought to be necessary for full seed maturation. For these degree days, Cussans & Bastian (1981) simply used summing of daily average temperatures. With calculating degree days, also a base temperature above which the targeted growth phenomenon starts, can be included. Longden's (1993a) calculation of their 350 degree days (day$^0$C) for seed maturation is not clear from the publication so that this figure cannot be compared to the one by Cussans & Bastian (1981).

Longden (1993b) related resurgence of weed beets in the UK in 1993 to exceptionally good summers with the previous beet crop in the rotation, 1989 and 1990. In these years, temperatures in July and August were 2 and 3$^0$C, respectively, above average and rainfall was 10 and 25 mm, respectively, below average. Local 25-year averages for July and August at Broom's Barn (Suffolk, UK) were 21$^0$C, and 46 and 55 mm, respectively. The average temperature of 21$^0$C appears to be high compared to other sources; perhaps, data in Longden (1993b) refer to daily maxima. Long term 25 year average temperatures for July and August in the South east of the UK are 16,1$^o$C (Haylock *et al*., 2008). Similarly, Landová *et al*. (2010) observed an eighty fold increase of the weed beet seed bank in 2007 versus only a threefold increase in 2006 in their field studies in the Czech Republic, which coincided with annual mean temperatures being 1.6$^0$C above average in 2007 versus 0.7$^0$C above average in 2006, while precipitation was about normal in both years. The local long-term annual average (1961-1990) was 8.2$^0$C and 502 mm, respectively. The long term (1971-2000) average annual temperature in the Netherlands is 9.7$^o$C (Kattenberg, 2008), the long term average temperature for July 17.2$^o$C and for August 17.1$^o$C (http://www.knmi.nl/klimatologie/maand_en_seizoensoverzichten/index.html).The Dutch long term average annual precipitation (1971-2000) is, with values above 700 mm, significantly higher than the average for the Czech Republic (Kattenberg, 2008). The long term average precipitation (1971-2000) for the Netherlands in the months July and August is 66 and 59.5 mm, respectively (http://www.knmi.nl/klimatologie/maand_en_seizoensoverzichten/index.html). Thus, in light of the differences in precipitation related to the more continental climate, comparisons with results from the Czech Republic are difficult. However, the results from the UK, which also has a maritime climate, may be more relevant: though the UK long-term summer average is about one degree C lower, the temperatures related to higher incidence of beet volunteers in the UK were two to three degrees higher than the long-term average; precipitation levels were below local UK averages, which were lower for July and not much different for August compared to the Netherlands. In conclusion, summer temperatures in combination with precipitation levels are important for volunteer seed production.

*Other factors involved in groundkeeper occurrence and their possible interaction with weather conditions*

In the Netherlands, groundkeepers are rare. Sugar beets are harvested by machines which are giving low harvest losses. Root parts left on the field are in general lost by rotting during winter, which thus depends on moisture conditions after harvest. Whole roots can survive during winter, but their number is low. Moreover, groundkeepers are usually controlled by ploughing and by the herbicides used in the most important crops grown in rotation with sugar beet, *i.e*. cereals, potatoes, maize and onions. In crops in which the same herbicides are used as in sugar beet, industrial chicory and vegetable "witlof" (*Cichorium intybus* L.), control of sugar beet volunteers is sometimes less optimal, but in practice, these crops are rarely grown after sugar beet.

*Other factors involved in volunteer occurrence from seeds and their possible interaction with weather conditions*

Important other factors for weed beet control are post-harvest treatments, tillage methods, moment of tillage in spring, subsequent crop rotation and herbicide efficacy. Post-harvest treatments affect dormancy of the weed beet seeds, the level of which is important to their survival in the soil seed bank. In the studies by Sester *et al.* (2006), approximately 65% of the seeds showed primary dormancy directly after seed shedding. Burial in the soil (*e.g*. by ploughing) will induce secondary dormancy. However, if the seeds are imbibed by rain after harvest and are stimulated by light before being buried, the level of dormancy will be lower and so will be their chances of survival. Thus, moisture conditions before and during post-harvest treatments are an important factor in building up of a weed beet seed bank. Presently, weather conditions in the Netherlands during harvesting period of sugar beet are already wet. The long term average precipitation for the Netherlands in the months

September, October and November is 235 mm (1971–2000, De Bilt; http://www.knmi.nl/klimatologie/maand_en_seizoensoverzichten/index.html).

The moment of the first tillage in spring is an important factor for occurrence of weed beet (IRS, 2010, Sester *et al*., 2007), together with the tillage method, including the treatment used in the previous autumn. Since only seeds in the upper 5 cm layer of the soil are prone to germination (Desplanque *et al*., 2002; Sester *et al*., 2006)), shallow tilling will keep more seeds in this top-layer and thus lead to quicker depletion of the seed bank by germination. Delayed tillage in spring and delayed sowing of the next crop then is helping to decrease weed beet occurrence in the crop, because of destroying the weed beet seedlings. IRS (2010) reported that indeed in late-sown sugar beet less weed beets are occurring. Emergence of weed beet seed furthermore mainly depends on soil temperature and moisture (Sester *et al*., 2007). If temperatures in spring are higher, more weed beet seed will emerge and will be destroyed by delayed tillage.

In the crop rotation, weed beets are controlled by herbicides and/or impacted by competition from the other crops, such as cereals and potatoes. The efficacy of different herbicides used in the other crops is depending on weather conditions, particularly moisture levels. Soil-acting herbicides are less effective if the soil is too dry.

*Conclusions*

From the above, the following climatic factors appear to be important to volunteer occurrence:

- Autumn temperatures and moisture conditions affect mortality and dormancy of weed beet seed; wetter conditions increase the likelihood of seed rot before they have acquired higher dormancy levels and thus increased survival in the seed bank.
- Higher spring temperatures and moisture conditions would lead to higher weed beet germination coinciding with tillage and weed controlling operations in spring.

- Higher summer temperatures could raise seed production on the weed beets that escaped control.
- Winter temperatures are relevant for groundkeeper survival, but these are an insignificant source of volunteers compared to seeds. For seed survival, winter temperatures are insignificant compared to autumn survival.

## 4. Potato

With potato (*Solanum tuberosum* L.), tubers are the most important source of volunteers. After harvest, a considerably larger number of tubers (mostly smaller than consumption sizes) than planted at the start of the season can remain in the field (20 to 300 thousand per ha, Lumkes, 1974) and these can lead to weed problems in subsequent crops. Seeds (often called true seeds to distinguish them from the seed potatoes used for starting normal cultivations) can also be a source of volunteers, but seedlings are smaller than groundkeepers and hence more sensitive to competition from the crop and normal weed control activities. Seed formation also is highly dependent on the variety used as there is a large variation in fertility between varieties. In addition, seeds from the same variety may vary genetically in persistence due to the high level of heterozygosity of the otherwise clonally propagated crop.

*Observations of volunteers from seeds with relation to weather conditions*

Seeds can remain viable in the soil seed bank for at least 7 years (Askew, 1993). Harsh winters with long periods of frost such as are prevalent in Finland are lethal for tubers but not for seeds, and these seeds could in principle form tubers despite the short growing season (Mustonen *et al.*, 2009). With dry storage, seed remained viable for 20-28 years at 1-3$^{0}$C (Towill, 1983). In the UK, seeds germinate from early May to September and in case that the seedlings did not appear later than June, they have enough opportunity to develop tubers that can remain as groundkeepers into the following growth season (Lawson, 1983). Weather conditions also play a role with seed set. Flowering starts end of June and continues till September, with berry formation up till the end of September. Quiet, sunny weather gives more berries and seeds per berry; rainy and windy periods during and after flowering decrease berry and consequent seed production (Wijnholds, Wageningen UR-PPO, pers. comm.).

*Observations of groundkeeper occurrence with relation to weather conditions*

Tubers will survive in the soil during mild winters, with tuber ambient temperatures above -2$^0$C. Lumkes (1974) determined 50 frost-hours (e.g. 25 hours of -2$^0$C) to be lethal to tubers. Mustonen *et al*. (2009) tested tubers under laboratory conditions and showed that low numbers of tubers were just able to survive at -1$^0$C for 4 days, at -2$^0$C for 3 days or at -3$^0$C for 2 days. A treatment at -3$^0$C for 72 hours significantly lowered survival, which went down to an average of 8% versus some 60% at -2$^0$C. From the two cultivars tested, Asterix was more resilient than Saturna. This could be due to the relatively higher sugar content of cv. Asterix. Whether freezing of tubers actually occurs in the field depends on soil type (drainage/aeration and water content enabling freeze-thaw cycles), depth of burial and weather conditions (snow cover). Lumkes (1974) concluded for the Netherlands that temperatures below -2$^0$C were attained at 10 cm below the soil surface only in 7 winters in the period 1940-1970 and at 20 cm only in 4 winters in this period (but see below the discussion on supercooling from Boydston *et al*., 2006 and temperature variability due to soil structure and moisture). In the UK, temperatures at 5 cm below surface rarely came below 0$^0$C despite regularly reaching -2 to -8$^0$C at the surface (at 55-83 and 2-10 days per winter, respectively). Thus even in severe winters, tubers at 10-15 cm depth will still survive (Lutman, 1977). In field trials in Finland, tubers did not survive in the winters of 2005 and 2007, when temperatures went down to -5$^0$C at 10-20 cm below the soil surface for several weeks, but 2% of tubers survived the winter of 2006, due to a 40 cm snow cover even though soil temperatures reached -0.4 to -0.9$^0$C for several weeks during late winter (Mustonen *et al*., 2009).

Low temperatures (2-4$^0$C) during the harvesting period in autumn will raise sugar content in the tubers, a phenomenon also happening in tubers detached from the rest of the plant, and thus increase surviving ability in the subsequent winter. Since high sugar contents affect processing quality negatively, growers are advised not to harvest tubers at ambient temperatures below 8$^0$C. However, when a cold period is followed by a warmer one (12-15$^0$C) before winter, sugar levels in the tubers will be lowered again (Pressey & Shaw, 1966). As the change of the starch composition into a single form in GM amylopectin potato lines could be hypothesized to change carbohydrate metabolism in a manner affecting frost sensitivity of tubers, this possibility was tested by Heeres *et al*. (1994). They did not find a significant change in tuber sensitivity to frost, however. Their average FKT (frost killing temperature) was -2$^0$C for 24 h for the transgenic lines and their parental variety (Karnico), which is in line with the 50 frost hours of Lumkes (1974) mentioned at the beginning of this section.

Boydston *et al*. (2006) tested under controlled conditions whether supercooling (undercooling, i.e. cooling below the normal freezing point without ensuing ice nucleation and consequent damage to the tuber) may play a role in survival. Supercooling turned out to be possible in dry soil but was only slight with a normal 7% SWC (soil water content). Under field conditions, soils are unlikely to be fully dry as in the test conditions used by Boydston *et al*. (2006). Soil moisture content is an important factor, for water has a higher heat capacity than air or the soil itself. Wet soils therefore are better conductors and stores of heat leading to more stable soil temperatures than dry soil, and as a result, tubers are more likely to be killed by frost in dry soils according to Boydston *et al*. (2006). The relationship between the amount of soil moisture and soil temperature, however, is complex. When temperatures of soil drop below zero, a part of the water remains unfrozen. This unfrozen water remains in crevices between particles and in pores of a sufficiently small diameter (Spaans & Baker, 1996). This will also apply to the space immediately around the tubers, which depends on the interaction between tuber morphology and soil structure. The soil structure is therefore an important factor influencing the soil freezing and moisture characteristics, which makes it difficult to draw general conclusions on the precise relationship between weather conditions and the likelihood of freezing of tubers in the soil. Boydston *et al*. (2006) found more mortality in their field studies than predicted by Lumkes' (1974) 50 frost-hours: some mortality at soil temperatures of -1.5 to -1.9$^0$C, and extensively at -2.8$^0$C.

Kim *et al*. (2010) compared volunteerism between a GM line containing *ABF3*, a gene conferring tolerance against abiotic stresses, such as drought and cold, and a non-GM isogenic line. No striking differences were found between the GM and the conventional line, and all tubers were killed by winter frost, which was below -2$^0$C at 10 cm depth for 4 consecutive days in the particular case of this field trial.

In Denmark (Bødker, DPASU, pers. comm.) and Northern Germany (Peters, Versuchsstation Dethlingen, pers. comm.), volunteerism was thought to have increased over the last 30 years, which could be attributed to milder winters with less protracted frost periods. However, this was only based on rough estimates and there were no quantitative data to back up this statement. The winter of 2010 was colder but with lots of snow cover so that there was little freezing of tubers in the soil. Similar observations were made for the winter of 2010 in the Netherlands (De Boer, DLV Plant, pers. comm., Wijnholds, Wageningen UR-PPO, pers. comm., Bruinenberg, AVEBE, pers. comm.). Also here, there may have been an increase in volunteers with the milder winters, but again there were no quantitative data available. For Ireland, it was more difficult to conclude about recent developments in volunteer occurrence. At least, the last few colder winters did not lead to lower numbers of volunteers; it appeared that the potato volunteers were more successful than other weeds and thus even thrived better (Mullins, Teagasc, pers. comm.). As on the continent, there was snowfall in these winters.

Lutman (1977) studied groundkeeper emergence in cereal cultivations, which occurred from late April to late July in the UK. Volunteer emergence coincided with rising soil temperatures during spring. About three weeks after reaching 8-10$^{0}$C, 50% of tubers had emerged from bare soil in field experiments. However, competitive crops, such as wheat, cause large delays up to about two months, particularly in combination with situations of drought (Lutman, 1977). More potato plants grew where the cereal crop was irrigated but re-growth after crop harvest was greater where earlier growth in May and June had been restricted by dry weather or crop density (Lutman, 1979).

*Other factors involved in groundkeeper occurrence and their possible interaction with weather conditions*

Similarly to sugar beet, post-harvest treatments and control measures during the crop rotation are pivotal to limit volunteer persistence. This starts already with the capabilities of the harvester and the skills of the tractor driver to bring down the number of tubers left in the field.

Furthermore, cultivation immediately after harvest can best be minimal, since tubers remaining at the soil surface are prone to rot from wet conditions and are subject to predation, e.g. by waterfowl (which are otherwise not really welcomed because of some side effects for following crops, such as wheat), and to frost later on during winter. With tubers already buried in the soil, ploughing could influence survival as they could become partly lethally damaged and partly brought back to the surface. Thus, in an experiment by Lutman (1977), 57% of tubers buried 2.5-20 cm below the surface survived a mild winter in the UK, when cultivated afterwards, as opposed to 90% without any cultivation. The subsequent crop also impacts persistence, with leeks and onions being least competitive, and cereals, particularly winter wheat, and grass being most competitive, while maize and sugar beet are somewhere in between. Volunteers in poorly competitive crops can be difficult to control by standard herbicide methods, but they can be removed by tipping with broad spectrum herbicides, such as glyphosate.

*Conclusions*

From the above, the following climatic factors appear to be important to volunteer occurrence:

- Winter survival of tubers is determined by whether or not temperatures below -2$^0$C reach tubers in the soil for a protracted period of time (>24 hrs), which is in turn influenced by soil moisture and structure, and the presence of a snow cover.
- Dry conditions during spring affect the ability of tubers to develop plants negatively, particularly in competition with cereals.
- Dry conditions after harvest affect tuber survival positively, in that tubers remaining at the surface are more prone to rot under wet conditions.

## 5. Climate change scenarios for the Netherlands

In this chapter, we describe the expected changes in the climate of the Netherlands. We start with a description of the available climate scenarios and the uncertainties within these scenarios. Finally, we will focus on the climatic conditions that are important for the occurrence of volunteers of the crop species maize, sugar beet and potato. In this review, we will focus on the changes in temperature and precipitation, the variables most important for crop growth.

*KNMI '06 scenarios*

During the last decade, many studies regarding climate change have been performed. Several scenarios have been developed for various regions in the world. Climate change scenarios provide us with plausible pictures of the possible changes in our climate for the future.

The KNMI (Royal Dutch Meteorological Institute) has developed four possible scenarios for the change in the Dutch climate, the KNMI '06 scenarios (Van den Hurk *et al*., 2006). These scenarios describe the most likely changes of the climate around 2050 (*i.e*. the period 2036-2065), as compared to around 1990 (*i.e*. the period 1976-2005). The four scenarios give a description of the changes of important climate variables such as temperature, precipitation, wind and sea level for winter and summer periods.

In 2009, KNMI performed an additional study to evaluate the KNMI '06 scenarios with respect to recent scientific developments regarding the following aspects (Klein Tank & Lenderink 2009):

- $CO_2$ emissions
- Global temperature
- Storms
- Observed temperature rise in the Netherlands
- Soil dehydration
- Intensity of summer precipitation

- Coastal precipitation in summer and autumn.

The 2009 additional study also provided more details on changes in temperature and precipitation patterns for spring and autumn, as well as for the individual months. Values were obtained by interpolation of the winter and summer data (Klein Tank & Lenderink, 2009). No scientific basis was established triggering the development of new scenarios.

The KNMI '06 scenarios were obtained by combining knowledge of global and regional climate change models and observations to determine which climate models gave the best description for Western Europe (Figure 1). Also, the observations were used to translate the model output into local weather characteristics.

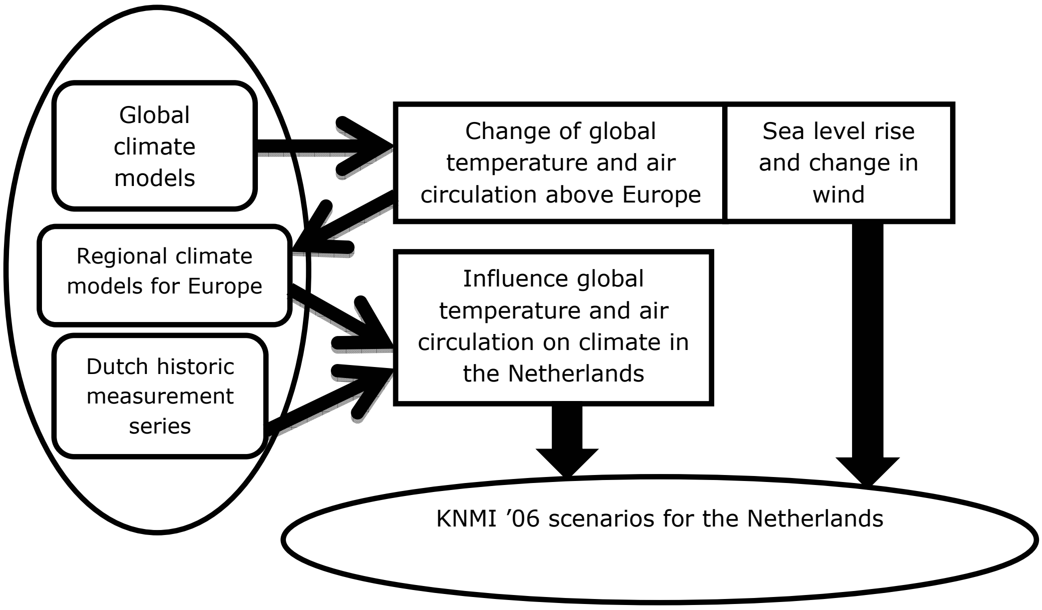


*Figure 1. Schematic representations of the methodology used to construct the KNMI '06 climate scenarios (Van den Hurk* et al.*, 2006; Klein Tank & Lenderink, 2009). Global climate models were used to provide a range of possible changes in global temperature and air circulation above Europe. The output of the global models is used as input for Regional climate models for Europe and provide information on the influence of the global temperature and air circulation on the Dutch climate. Together with Dutch historic measurement series and information on sea level rise and change in wind this output was used to construct four scenarios.*

The IPCC (Intergovernmental Panel on Climate Change) studies (2007) showed that climate models differ considerably in their calculation of global temperature rise. Nevertheless, most global climate models expect a global temperature rise of at least 1 and at most 2°C around 2050 (Van den Hurk *et al*., 2006). Therefore, the KNMI used a global temperature increase of 1 or 2 °C as input for the regional climate models. Furthermore, climate models showed that air circulation patterns above Europe have a strong influence on the local climate in the Netherlands. Therefore, the Dutch scenarios are based on two possibilities of the worldwide temperature increase and on two possible patterns of air flow for Western Europe (Van den Hurk *et al*., 2006, Figure 2). The Dutch historic measurement data series used were from the period 1976-2005. These scenarios have an equal likelihood to occur, there is no best estimate. The four possible scenarios are called G, G+, W and W+ (Figure 2). The G scenarios are based on a global temperature increase of 1 °C, the W scenarios are based on a global temperature increase of 2 °C. The scenarios indicated with a + (G+ and W+) are based on a changed air flow pattern in Western Europe.

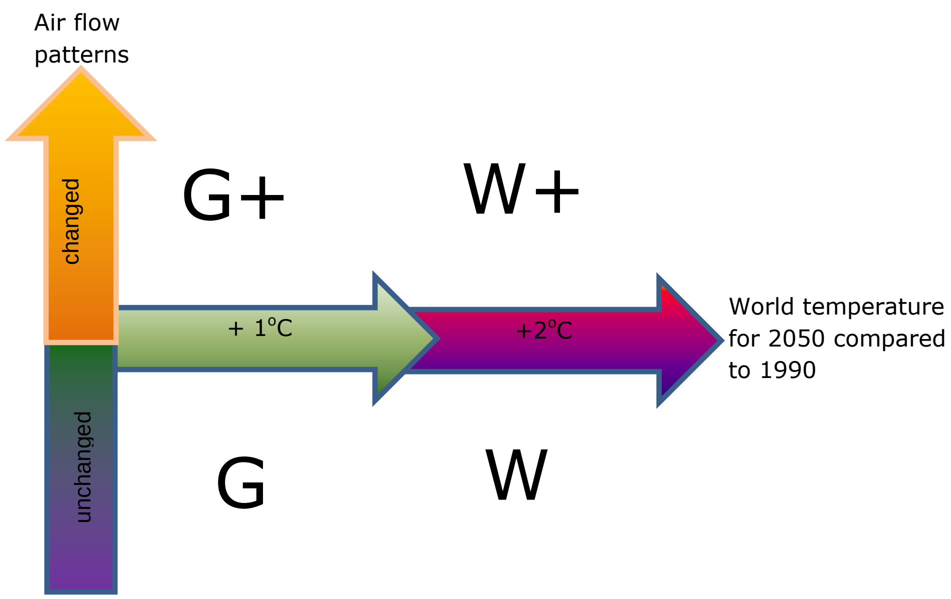


*Figure 2. Four possible climate scenarios, G, G+, W and W+. G indicates a scenario with an unchanged air flow pattern and a global temperature increase of 1°C, W+ indicates a scenario with a changed air flow pattern and a global temperature increase of 2°C around 2050. The other two scenarios (G+ and W) describe the other possible combinations of changes. Source: www.KNMI.nl*

*Temperature*

The KNMI ’06 scenarios show that we can expect an average increase in temperature in the Netherlands, compared to around 1990, varying from 0.9 to 2.3$^0$C in winter, from 0.9 to 2.6$^0$C in spring, from 0.9 to 2.8$^0$C in summer and from 0.9 to 2.7$^0$C in autumn (Table 1) (Klein Tank & Lenderink, 2009). Temperature extremes are also expected to change and in some cases, these may be most relevant for volunteer occurrence, for instance, strong freezing temperatures for tuber survival. In that regard, the coldest winter day shows elevated temperatures to a slightly higher degree than the average temperatures (varying from 0.1 to 0.6$^0$C).

*Table 1. Average temperature and precipitation change in the Netherlands around 2050 per season compared to around 1990 for the four KNMI '06 scenarios (Klein Tank & Lenderink, 2009)*

| | | Scenario | | | |
|---|---|---|---|---|---|
| **Season*** | **Climate parameter** | **G** | **G+** | **W** | **W+** |
| Winter | average temperature (°C) | +0.9 | +1.1 | +1.8 | +2.3 |
| | coldest winter day per year (°C) | +1.0 | +1.5 | +2.1 | +2.9 |
| | warmest winter day per year (°C) | +0.8 | +0.9 | +1.6 | +1.7 |
| | average precipitation (%) | +4 | +7 | +7 | +14 |
| | wet day frequency (%) | 0 | +1 | 0 | +2 |
| Spring | average temperature (°C) | +0.9 | +1.2 | +1.8 | +2.6 |
| | coldest spring day per year (°C) | +1.0 | +1.4 | +2.0 | +2.8 |
| | warmest spring day per year (°C) | +1.0 | +1.5 | +2.0 | +2.9 |
| | average precipitation (%) | +3 | +1 | +6 | +3 |
| | wet day frequency (%) | -1 | -3 | -2 | -5 |
| Summer | average temperature (°C) | +0.9 | +1.4 | +1.7 | +2.8 |
| | coldest summer day per year (°C) | +0.9 | +1.1 | +1.7 | +2.3 |
| | warmest summer day per year (°C) | +1.0 | +1.9 | +2.1 | +3.8 |
| | average precipitation (%) | +3 | -10 | +6 | -19 |
| | wet day frequency (%) | -2 | -10 | -3 | -19 |
| Autumn | average temperature (°C) | +0.9 | +1.3 | +1.8 | +2.7 |
| | coldest autumn day per year (°C) | +1.0 | +1.3 | +2.0 | +2.6 |
| | warmest autumn day per year (°C) | +1.0 | +1.8 | +2.0 | +3.6 |
| | average precipitation (%) | +3 | -3 | +6 | -6 |
| | wet day frequency (%) | -1 | -5 | -1 | -11 |

**) Winter: December, January, February; Spring: March, April, May; Summer: June, July, August, Autumn: September, October, and November.*

According to Kattenberg (2008), since 1950, the temperature in the Netherlands and surrounding countries has increased twice as much as the global temperature. The increase is especially noticeable in the most recent years (2003-2008). This increase appears to be systematic and not due to natural fluctuations. Various causes are mentioned for this stronger increase in Western Europe compared to the global temperature increase. The main cause in the winter is the increase of westerly winds. The main cause in the summer is the increased incoming solar radiation due to a reduction in cloudiness, which is probably a result of the drying above the European continent, combined with a cleaner air (a reduction of the aerosols). The climate models do not take these changes sufficiently into account and as a result the local warming in the Netherlands has been underestimated for the past 50 years (Klein Tank & Lenderink, 2009). The processes causing the increase of westerly winds and the reduction of cloudiness are not fully understood, which makes an extrapolation to the future impossible. Since 2000, no further reduction in the number of aerosol particles has been observed. It is expected that the level of aerosols will remain stable until around 2050. The W and W+ scenarios account best for the strong local temperature increase in Western Europe (Klein Tank & Lenderink, 2009).

*Precipitation*

The average amount of precipitation in the winter period will increase with 3.6 to 14.2%, depending on the scenario. At the same time, the scenarios show a small increase in wet day frequency in winter (Table 1). The wet day frequency is the number of days in which precipitation exceeds 0.1 mm, divided by the total number of days in the season. This implies that the average increase in winter precipitation is due to an increase of precipitation on wet days, not of an increase of the number of days with precipitation. Several climate models show different results regarding the occurrence of 10-day precipitation extremes in winter (10 days of precipitation in a row). A change in the occurrence is possible according to some models, but highly uncertain. Therefore, the scenarios assume that the 10-day precipitation extremes in winter will increase as much as the daily extremes (Klein Tank & Lenderink, 2009).

In spring, all scenarios show an increase of the average precipitation and a reduction of the wet day frequency (Table 1). This implies that showers will occur less frequent, but with a higher intensity.

In the summer period, the average precipitation in the scenarios without air flow changes (G and W) is expected to increase. At the same time, the wet day frequency for these scenarios decreases. So, the expected average summer precipitation increase is due to an increase in the amount of precipitation on wet days (Table 1). In the scenarios with changes in the atmospheric circulation (G+ and W+), summer precipitation occurs at a lower amount and less frequently, but heavy showers that do occur become more intense, just like the showers in the G and W scenarios. This is due to the fact that air can contain more water vapour at high temperatures and the temperature increase on heat wave days is stronger than on average summer days. When the relative humidity of the atmosphere will not change, the amount of atmospheric water vapour will increase with 7% per degree of Celsius temperature increase. However, during recent measurements in De Bilt the measured increase was 14% per degree of Celsius, instead of the expected 7%. It is likely that this stronger increase is not only caused by the increased temperatures, but also by a strong turbulence in a shower cloud. For the future, it is likely that the rainfall intensity per hour will increase more strongly than the extreme of the rainfall amounts per day. Showers will become more intense, while their duration will decrease (Klein Tank & Lenderink, 2009). The KNMI ’06 scenarios assume that the hour intensity increases as much as the daily amounts. This is probably not correct for the extreme showers in summer. The increase in the extreme precipitation intensity per hour is probably underestimated in the G+/W+ scenarios. The other two scenarios have relatively large margins and will probably be correct (Klein Tank & Lenderink, 2009).

In the autumn, the scenarios without a change in the airflow pattern (G and W) indicate similar changes in precipitation as in spring: more precipitation on less days. The scenarios with a change in air flow patterns above western Europe indicate both a reduction in the average precipitation as well as in wet day frequency: precipitation will reduce in amount and frequency.

The KNMI ’06 scenarios assume one single value for the temperature and precipitation changes for the Netherlands. However, different amounts of precipitation have been observed for the coastal area. The reason is the influence of the North Sea on the coastal precipitation. During last years, the North Sea temperature has increased. For every increase of 1 degree of Celsius of the North Sea, the precipitation at the coast can increase with 15%. This effect can mainly occur in the second half of the summer and in autumn. The KNMI ’06 scenarios do not make use of models that realistically include the North Sea temperature. The G/W scenarios sufficiently account for a warm North Sea because they are based on the upper limits of the model used. The G+/W+ scenarios may underestimate coastal precipitation because they are based on models that show a strong drying above land but ignore the presence of the North Sea as a source of moisture (Klein Tank & Lenderink, 2009).

*Soil moisture*

The temperature rise will cause an increase in evaporation when soil moisture is sufficient and the net radiation does not change. According to the KNMI ’06 scenarios the evaporation will increase with 3 to 15% in summer. When this is not compensated by increased precipitation or measures, the soil will dry out. For the Netherlands different models show different outcomes. The drying of the soil can cause a stronger increase in summer temperatures and an increased likelihood of heat waves in summer (Klein Tank & Lenderink, 2009). Another possible result is an increase in the occurrence of easterly winds in Western Europe. Drying of the soil and related temperature increase in the South of Europe can cause changes in the air circulation patterns and an increase in easterly winds. The G+/W+ scenarios take these changes best into account.

*Storms*

The KNMI ’06 scenarios describe a small climate change effect on the storm climate of the Netherlands. A storm is an event with ≥6 Beaufort (Bft) inland or ≥7 Bft along the coast. The Netherlands is too small and the observation series too short to detect changes in the occurrence of heavy storms (≥ 10 Bft). The $G^+$ and $W^+$ scenarios describe a small increase of the annual maximum daily wind speed of 2% for 2°C global temperature rise. The G and W scenarios describe no change (Van den Hurk *et al*., 2006). New model information shows that the natural variations in the storm climate exceed the changes caused by the global warming processes. Therefore, the KNMI '06 scenarios still hold for the occurrence of storms (Klein Tank & Lenderink, 2009).

*General Limitations and assumptions of the KNMI '06 scenarios*

The climate models used by the KNMI to construct the four scenarios for the Netherlands make use of several emission scenarios. However, the emission of greenhouse gasses and particulate matter is strongly determined by socio-economic developments, which are very hard to predict. One of the uncertainties in the scenarios is therefore the socio-economic development. Other important factors that are a source of uncertainty on the global level are the solar activity itself and possible volcanic eruptions (Klein Tank & Lenderink, 2009).

The four KNMI '06 scenarios assume that the Dutch climate is homogeneous between different regions in the Netherlands. However, the Netherlands is characterized by regional climate differences. Furthermore, no differences between rural and urban areas are assumed; changes in the city are assumed to be equal to changes in the countryside (Klein Tank & Lenderink, 2009).

The four scenarios were constructed using regional climate models and historic measurement data (Figure 1) from the period 1975-2005. The effect of using a time scale of 30 years is that the inter-annual variability is levelled out. The inter-annual variability in the 20th century is however for some climate variables, such as precipitation and wind, larger than the seasonal mean changes foreseen by the model calculations. A quantitative estimate of the future inter-annual variability of seasonal means is not yet possible due to a lack of thorough understanding of all relevant processes (Klein Tank & Lenderink, 2009).

*Comparison of the KNMI ’06 scenarios with the current climate in other European regions*

In order to obtain further insights in what possible climate change for the Netherlands might mean for volunteer occurrence, we made an attempt to find regions in Europe where present climate conditions look most similar to that possible climate change for the Netherlands. Volunteer occurrence in those purportedly similar climatic regions then may provide clues to future volunteer occurrence in the Netherlands. For instance, the present lack of maize volunteers in the Netherlands and their more frequent occurrence in southern regions of Europe (see Chapter 2), raises the question to what extent a comparison of the current climate in (southern) European regions with the KNMI ’06 scenarios for the Dutch climate around 2050 can be made. We discuss three studies with relevance for this question.

As a first approximation, Figure 3 shows the average annual temperatures in the Netherlands in 2006 and 2007 in comparison to temperature zonation recorded in France in the period 1961-1990 (Kattenberg, 2008). The measured temperatures in the period 2003-2008 in the Netherlands (De Bilt) were significantly higher than the long term averages for the Netherlands (De Bilt). Dutch temperatures were comparable to the annual temperatures in central France of the period 1961-1990.

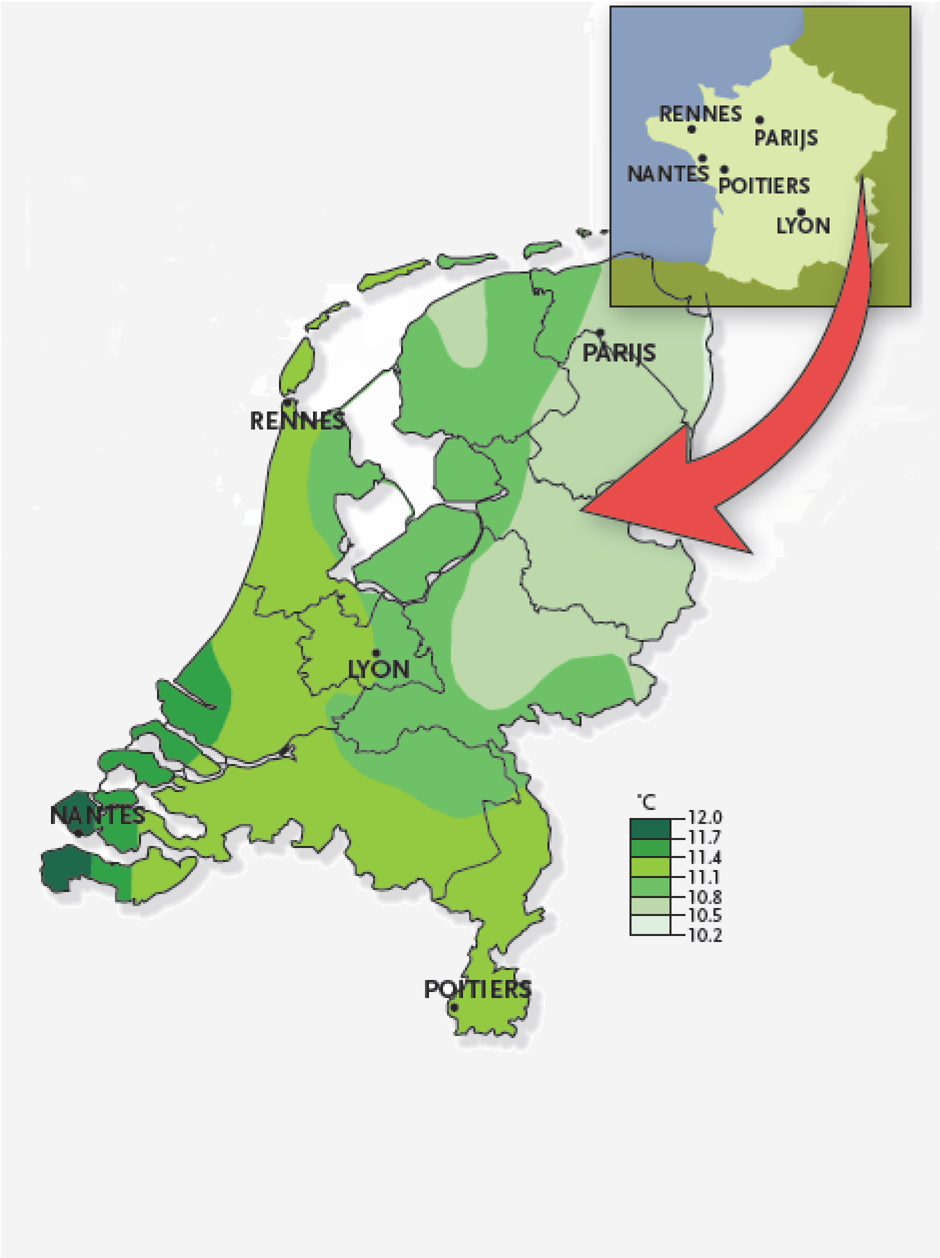


*Figure 3. The average yearly temperature measured in 2006 and 2007 in the Netherlands was equal to the long term average (1961-1990) in central France (from: Kattenberg, 2008).*

As this is only a rough comparison of annual temperature averages, its predictive power is questionable. Unfortunately, the possibilities to make more complete comparisons of the current climate in certain regions with the climate scenarios for around 2050 are very limited. Climate is not just the average temperature or precipitation. Certain areas in Europe can have a current average temperature that is similar to an average temperature of one of the KNMI ’06 scenarios, but a completely different precipitation pattern or extreme temperatures. In general, a comparison of one or two climate variables between regions can be made, but a comparison of climates between regions not (pers. comm. KNMI helpdesk). In this paragraph, we will refer to two studies in which temperature and precipitation in the Netherlands in 2050 according to one or more of the KNMI ’06 scenarios, have been compared to the current averages of the same climate variables in other European regions.

In the first study, which only addressed the summer season, the average climate variables in the Netherlands at present and in 2050 according to the four KNMI ’06 scenarios were compared with the current climate in Paris (www.knmi.nl/klimaatscenarios/faq/index.php#Inhoud4). This comparison shows that the average daily temperature, the maximum temperature and the number of summer days in scenarios W and W+ are comparable to the average long term values for Paris (Table 2). The percentage of days without precipitation in Paris in summer at present is close to the percentage in the W+ scenario. The total current precipitation in Paris is however lower than the precipitation in one of the scenarios.

*Table 2. Description of an average summer (June to August) in the Netherlands (De Bilt), at present and around 2050 and the current summer climate in Paris. The minimum and maximum values per variable for the period 1976-2005 are presented between brackets (www.knmi.nl/klimaatscenarios/faq/index.php#Inhoud4)*

| Variable | De Bilt (1976-2005) | G 2050 | G+ 2050 | W 2050 | W+ 2050 | Paris (1976-2005) |
|---|---|---|---|---|---|---|
| Daily temperature (°C) | 16,8 (15,3-18,7) | 17,7 | 17,6 | 17,9 | 19,6 | 19,3 |
| Max. temperature (°C) | 21,7 (19,8-24,6) | 22,6 | 23,1 | 23,4 | 24,5 | 23,9 |
| Summer days (max. temperature ≥ 25 °C) | 24 (4-48) | 30 | 34 | 39 | 47 | 45 |
| Tropical days (max. temperature ≥ 30 °C) | 4 (0-13) | 7 | 9 | 10 | 14 | 9 |
| Total precipitation (mm) | 214 (72-352) | 220 | 193 | 227 | 173 | 147 |
| Average maximum summer day precipitation per year (mm) | 27 (11-51) | 29 | 27 | 32 | 29 | 27 |
| % days without precipitation | 51 (33-75) | 52 | 57 | 54 | 61 | 63 |

The second study investigated the resemblance of the KNMI '06 scenario with the largest changes, the W+ scenario, with the 20$^{th}$ century climate measured at weather stations across Europe (Böing, 2007). Monthly means of two climate variables (temperature and precipitation) were used to calculate a similarity index for each weather station in Europe between 20W and 28E and 30N and 65N. The similarity index is a measure for the (scaled) deviation of the mean monthly temperature and precipitation measured at a European weather station from the mean monthly temperature and precipitation calculated for De Bilt for the W+ scenario in the period 2086-2115. The result is shown in Figure 4. Red areas are those that show a high degree of correlation to de Bilt. The central Italian climate seems to come quite close to the W+ scenario. However, the climate has been defined in terms of monthly means of temperature and precipitation. The probability distribution of precipitation and temperature over the months is not taken into account and is important as an indicator for drought risk (Böing, 2007). However, also note that the W+ scenario for the period 2086-2115 was used, reaching beyond the year 2050, which takes us beyond the period that is the focus of this report.

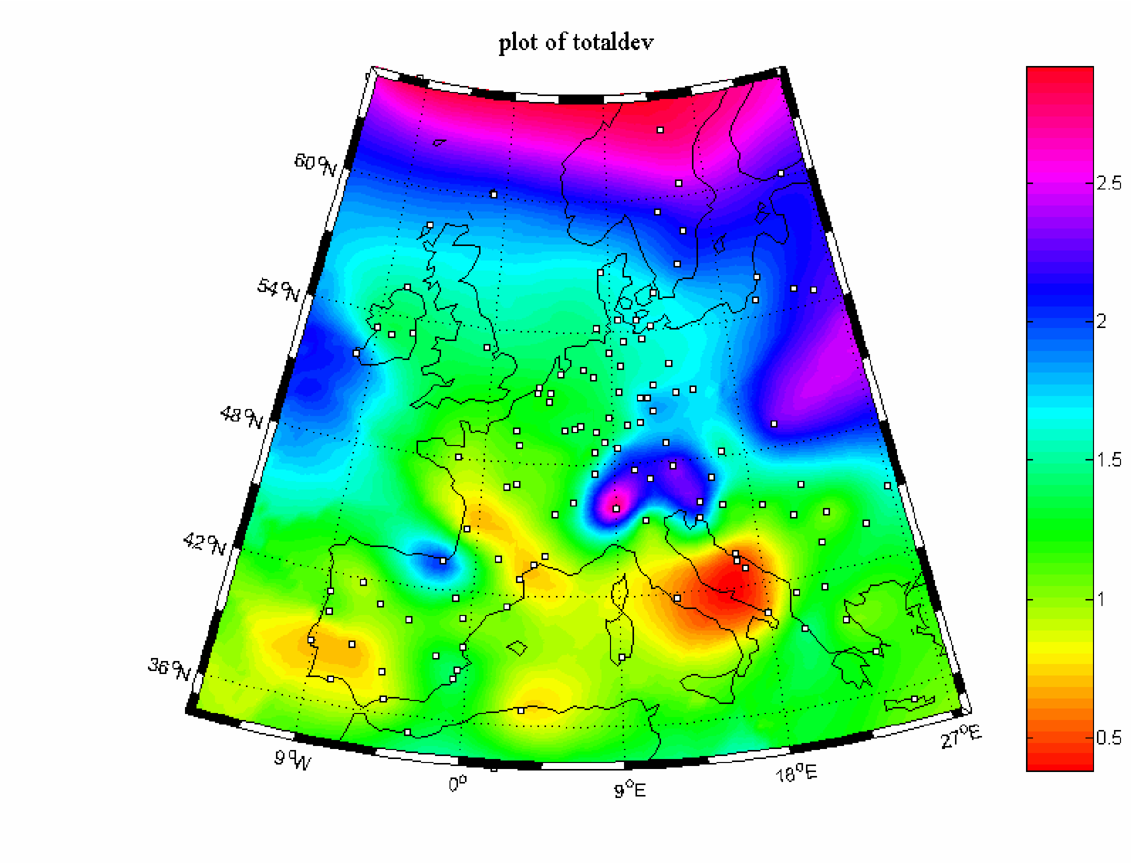


*Figure 4. Similarity index based on standard deviations of the monthly mean precipitation and temperature of European weather stations in the 20$^{th}$ century to that of de Bilt in the W+ scenario in the period (2086-2115). White dots indicate measurement points. Red areas indicate a high correlation with De Bilt. From: Böing, 2007.*

Possible changes of climatic conditions important to the occurrence of crop volunteers:

- The average winter temperature will increase and the temperature on the coldest winter day will increase more than the average winter temperature (Table 1).
- The average summer temperature will increase and the warmest summer day will increase more than the average summer temperature (Table 1).
- The number of wet days will decrease in summer and autumn for all scenarios. Average summer and autumn precipitation will increase according to scenarios G and W (scenarios without changes in air circulation patterns). Under these two scenarios the amount of precipitation on a wet day will increase. The average summer and autumn precipitation will decrease according to the scenarios G+ and W+ (Table 1). The intensity of extreme rain showers in summer will increase in all scenarios.
- The average amount of precipitation in the winter period will increase. At the same time, the scenarios show a small increase in wet day frequency in winter (Table 1).
- The average amount of precipitation in spring will increase, and the number of wet days will decrease: the amount of precipitation on a wet day will increase (Table 1).
- It is uncertain whether soil moisture levels will increase or decrease. According to some models the land will dry out due to an increased evaporation resulting from higher temperatures. However, this can be compensated by increased precipitation, which differs under different scenarios. Furthermore, the presence of the North Sea as a source of moisture is not accounted for in the scenarios.
- The KNMI ’06 scenarios cannot give any information on the occurrence of periods of snow coverage during winter. The scenarios are only suitable to indicate possible amounts of precipitation and number of days on which precipitation will fall (personal communication KNMI helpdesk).

## 6. Discussion and conclusions

In the last decades, climate has already become warmer in the Netherlands, but it has not become clear from this review of the literature whether this has already led to changes in volunteer occurrence. This is also due to the fact that to our knowledge, there has not been any systematic monitoring of volunteer numbers in the Netherlands. In the past, there have been mainly studies on volunteers in the context of weed problems. More recently, some more studies have been performed in the context of coexistence of GM and non-GM cultivations. Impacts of weather conditions on volunteer occurrence from these studies have been discussed per crop species in the chapters 2-4. The important climate factors for volunteer occurrence, as they emerged from these chapters, are (1) soil moisture conditions after harvest, since these influence seed depletion by germination and seed dormancy development, (2) frost conditions during winter, which determine survival of reproductive plant parts, particularly groundkeepers, and (3) temperature and soil moisture conditions during the growing season, which are important for growth and reproduction of volunteers. The impacts on the occurrence of crop volunteers of the future changes in these factors as expected from the KNMI climate scenarios for the Netherlands around 2050, described in Chapter 5, are discussed here per crop species. These expected impacts need to be viewed with care because future climate change is accompanied by considerable uncertainties, which are in part already apparent from the differences between the four KNMI scenarios. For instance, the scenarios show contradictory trends for precipitation levels in some seasons.

*Maize*

The areas where maize volunteers are presently prevalent, are for instance in the southern part of France and in Spain. Two attempts to relate future climate scenarios for the Netherlands with present day climatic conditions elsewhere in Europe pointed at other regions with comparable climate conditions, *i.e*. the surroundings of Paris and central Italy, respectively. However, the relationship with central Italy was for one scenario W+, for a period (2086-2115) beyond the focus period of this report around 2050. These comparisons have to be treated with care for all sorts of variability in local climates, even if only for the variation of radiation with latitude. There were recent reports of incidences of maize volunteers further north in France and a few isolated cases in Germany and the Netherlands. The cases in Germany did relate to a mild winter with few frost days, but also to special experimental field circumstances, that is, GM plant parts, including ears, were not harvested but ploughed into the soil and were thus better protected from adverse conditions. The cases in the Netherlands related to maize lines that are normally not used in commercial farming.

Maize seeds are prone to rot under wet conditions after shedding, as the grains do not show dormancy. Maize grains are also sensitive to frost, depending on their moisture content (the wetter, the more vulnerable). In this regard, there are relevant developments described in the climate scenarios. The number of wet days in autumn is expected to decrease, with a highest figure of 11%. However, wet day frequency at present is 67%, and wet day distribution (i.e. likelihood of continuous dry periods) is unclear from the scenarios. Furthermore, the total autumn precipitation would decrease under two of the scenarios (G+ and W+), but increase under the other two scenarios (G and W). Overall, effects on soil moisture were found to be poorly predictable in the KNMI scenarios. Therefore, it is also difficult to predict any net effect of projected climate change in autumn on seed survival to the next growing season. In addition, precipitation levels during winter will become higher in all scenarios, which might compensate for any advantages to seed survival encountered during autumn.

A change in frequency of storms could lead to different levels of grain losses on the field due to damaging/bending of stems. However, only the $G^+$ and $W^+$ scenarios show a small increase of the annual maximum daily wind speed. The natural variability in storms appears to exceed expected future changes due to global warming. Therefore, wind conditions do not appear to be a likely factor leading to changes in maize volunteerism.

Presently, there is a tendency in cultivation practice to explore the possibilities of reduced or zero tillage for the purpose of soil conservation. It is not clear if reduced or zero tillage will have an effect on survival of lost maize seeds during winter. When lost seeds or ears remain at the surface, they will be more prone to rotting, although for ears, this is not completely clear. In the Netherlands ca. 80% of the maize crop is grown on sandy soils, on which generally, no ploughing is done before winter and lost maize seed are thus already kept above the soil during winter.

Up till now, the great part of the maize area in the Netherlands is occupied by silage maize, which is produced for feed and is usually harvested before maturing of the grains has completed. Since this style of cultivation also is related to temperature limitations during the growing season, there could be a trend towards more grain maize cultivation with future climate warming. By itself, this could increase the possibilities of volunteer occurrence. However, as explained above, the net effect of climate change on the likelihood of a new occurrence of volunteers in the Netherlands is not easily assessable.

*Sugar beet*

For sugar beet, groundkeepers may have better chances of survival during relatively mild winters, but they are currently not a relevant source of volunteers, not even in warmer areas of Europe, such as in France. The main route for volunteerism is through seeds and mild winters with few frost days may also improve the chances of survival for seeds, but for them, the conditions during (late) autumn have been shown to be a determining factor. Once seeds are in the soil in a dormant state, they are relatively hardy, but at the surface shortly after shedding they can perish by rot or by germination and subsequent removal. This could be promoted by higher temperatures in autumn. However, precipitation patterns in autumn are also a highly important factor, but as explained under maize above, there are contradictory predictions on their future development in the different KNMI scenarios.

Higher spring temperatures will result in less vernalization of sugar beet plants and consequently less bolters from the crop itself. However, this effect could become counteracted by a tendency to sow the beet crop earlier, since this could well lead to higher yields. On the other hand, especially on clay soils, earlier sowing may not always be possible, since increased precipitation during winter could lead to the soil becoming not suitable for using machinery timely enough. Higher temperatures in May and June will result in more de-vernalization. Also this effect will result in less bolters. Seeds from bolters nevertheless are not as important a source of volunteers as weed beets. For the weed beets, higher temperatures in late winter and in spring could result in earlier and increased germination of their seeds. These weed beets will then be mostly destroyed by tillage operations for the crop to be sown that spring or by the herbicides applied in that crop. In this way, the weed beet seed bank could be exhausted more quickly.

AS wet day frequency in spring will decrease, this could mean that the top-layer of the soil will be dry over a longer period. As a result, soil-acting herbicides used in other crops would have a reduced effect on weed beets. Longer dry periods in spring would also have a hardening effect on sugar beet volunteers. This would also result in a reduced control of these volunteers by contact-herbicides. On the other hand, overall, precipitation levels are expected to increase in spring. In addition, the scenarios only provide information on numbers of wet days, not on the extent and length of continuous dry periods. So again, the net result for weed beet prevalence is difficult to assess.

Another important factor in weed beet success was shown to be the production of seeds by bolters during the growing season. Studies in the Czech republic and the UK showed that increases in average summer temperatures of the order of 1 to $2^0$C already led to significantly higher rates of seed production on weed beets and this in turn gave rise to higher numbers of volunteers in subsequent beet crops. The long term summer averages in the UK, which is climatically more similar to the Netherlands than the Czech Republic, were at the time about $1^0$C lower than in the Netherlands. Therefore, from these data, at least some room for higher levels of seed production on weed beets could be inferred under increased summer temperatures in the Netherlands.

Although the net effect of climate change on seed survival is hard to predict, higher summer temperatures will likely lead to higher seed production of weed beets. This means that bolter control, being the most effective measure against weed beets (Sester *et al*., 2008; Van de Wiel & Lotz, 2006), will remain an important point of attention for farmers and GM field experimenters also in the future.

Unlike with maize and potato in Europe, for beet, occurrence of ruderal forms is reported, *i.e*. in Southern France and elsewhere in the Mediterranean area. This raises the question whether also weed beets could occur outside of arable fields in the Netherlands as a consequence of climate change. To look into this, future behaviour and/or natural occurrence of ruderal or wild forms will be most relevant. For exploration of future geographic distributions of wild species, climate envelope approaches have been developed, based on the species' climatic requirements, such as temperature and precipitation levels. However, species distributions may also be limited by other factors, such as competition with other plant species or pathogen pressures (Pearson & Dawson, 2003; Sutherland, 2006). The wild form of beet, sea beet, is nowadays occurring in a particular coastal habitat in North-Western Europe. There are indications that sea beet is on the rise in northern parts of the Netherlands and the Baltic area (Den Nijs, UvA, pers. comm.), and it has been newly recorded in the southern part of Norway from 1991 onwards (Engan, 1994; Pedersen, 2009), but all these observations refer to its normal coastal habitat. Based on "neutral" molecular-genetic markers, the ruderal beets occurring in Southern France have been shown to be more closely related to Mediterranean wild sea beets than to Atlantic sea beets. Although showing indications of gene flow from local weed beets in sugar beet cultivations, ruderal beets are thus genetically distinct from weed beets (Arnaud *et al*., 2009). It is not clear to what extent this is related to any ecological difference between weed beets and ruderal beets or wild beets from either the Atlantic or Mediterranean area. Taken together, these observations on wild beets and ruderal beets lead to the following conclusions: (1) although a modelled climate envelope for sea beet would likely not contradict inland occurrence, this has not yet been observed for Atlantic sea beets, and it is unclear to what extent ecological behaviour of sea beet is representative for that of weed beet; (2) ruderal beet could be hypothesized to be more representative for weed beet ecology, but there are no ecological data to support this and neutral genetic markers imply that ruderal beets are distinct from weed beets, although they are involved in their ancestry (see Chapter 3). Therefore, it is difficult to make a prediction about any possibility of future feral behaviour of weed beets or inland movements of sea beet, although both phenomena do not appear likely. As described for maize volunteers in the previous section, the ruderal beets are nowadays prevalent in areas that have not been implied as comparable in climate with the KNMI future scenarios for the Netherlands (except perhaps for the W+ scenario for around 2100), but as mentioned there, such comparisons need to be treated with the utmost care.

*Potato*

With potato, seeds are a relatively unimportant source of volunteers as compared to groundkeepers (tubers). Seed set varies considerably between varieties and plants from seeds are more vulnerable to control measures and competition from crops. Groundkeepers are sensitive to frosts below -2$^0$C during winter. Therefore, the higher average winter temperatures expected in all scenarios will increase the likelihood of survival of groundkeepers. Occasional downward extremes in temperature in some winters could still occur and wipe out tubers, but such conditions were already relatively infrequent in the past. In the future scenarios, the complete eradication of tubers by winter cold could be expected to become even rarer, since the coldest days are expected to become warmer at a higher rate than the average winter temperatures. However, this varies with the individual scenario, with the relative change being small, particularly in the G scenario. Furthermore, insulation against extreme temperatures from snow cover is also an important factor in tuber survival. Winters are expected to become wetter, but will also have a lower frequency of ice days. The climate scenarios are unable to describe what this will mean in terms of future snow coverage.

Volunteer emergence in the growing season is important for long-term survival as tubers are a far less persistent reproductive structure than seeds. During spring and summer, volunteer emergence is affected by drought conditions, but it is not clear what future developments in soil moisture levels will occur: In spring, there would be higher precipitation levels falling on fewer days and in summer, precipitation levels vary between scenarios (an increase in G and W versus a decrease in G+ and W+); in addition, soils could lose more water through increased evaporation as a consequence of higher temperatures. Overall, with the poor predictability of moisture conditions, in combination with variability due to soil type, in the growing season, future growing conditions for potato volunteers are not clear. However, their likelihood of survival during winter will increase according to the scenarios. Therefore, volunteer control will remain a point of attention for farmers and GM field experimenters.

*Conclusions*

The changes in temperature as expected in the four future climate scenarios for around 2050 for the Netherlands could benefit volunteer development, *i.e.* higher winter temperatures increase chances of survival of groundkeeper potatoes and higher summer temperatures promote seed production in weed beets. On the other hand, the different climate scenarios show partly contradictory results with regard to precipitation and soil moisture conditions so that their impact on volunteerism could not be well assessed. However, moisture conditions do have an important effect on volunteer occurrence, for instance through the impact on weed beet seed decay in autumn and on volunteer growth in potato. We conclude that attention should remain to be paid to volunteer control in sugar beet and potato, as technical control measures are basically the overriding factor for volunteer occurrence. Maize does not show volunteerism in the Netherlands, even with the already on-going warming of the climate. Comparisons of future climate scenarios and climatic conditions in areas where maize volunteers are presently prevalent in Southern Europe may imply a low likelihood of future volunteerism in maize in the Netherlands, but such comparisons need to be interpreted with care. Assessing trends in volunteers of beet and potato up till now was hampered by a lack of quantitative data, as there has not been any systematic monitoring. It might be useful to consider some form of monitoring in the future, in which paying attention to any possible new occurrence of maize could be included.

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