Climate Change and Agriculture: Mitigation and Adaptation

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Abstract

Human activities have changed the composition of the atmosphere resulting in rising global temperatures and sea levels. Agriculture contributes significantly to climate change through the emission of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Continuation of the trends of greenhouse gas emissions will result in a further increase of global warming in the coming decades. The most recent projections indicate a global warming of 1.1-6.4°C by the year 2100, but in North Western Europe warming is expected to be even higher. This will result in a sea-level rise of up to 0.8 m by the year 2100. Field vegetable production systems contribute to climate change through emission of the greenhouse gases CO_2 and N_2O. Since field vegetables like all other plants fix atmospheric CO_2, the net emission of CO_2 from vegetable production systems will be insignificant, especially when high-yielding varieties are used, crop residues are not removed from the field, inorganic fertilizers are replaced by organic manures and reduced tillage is applied. N_2O emission can be reduced by increasing the efficiency of N use by the vegetables. Field vegetable production systems will have to adapt to changing weather conditions, such as dryer summers and wetter winters. This implies that crops or varieties have to be used that are more stress tolerant to drought and salinity.

INTRODUCTION

Human activities especially burning of fossil fuels, deforestation and agriculture have changed the composition of the atmosphere resulting in a rise of global temperatures and sea levels. Greenhouse gases trap the heat radiated from the earth's surface in the atmosphere. Without atmosphere the ambient temperate would be around -18°C instead of +15°C. Changes in temperature occur as a result of internal variability within the climate system (El Niño, solar variation), the production of volcanic aerosols and anthropogenic factors (burning of fossil fuels, land use changes). These factors affect the climate system through radiative forcing which is the balance between radiation entering the atmosphere and radiation leaving the atmosphere. On average positive radiative forcing tends to warm the surface of the Earth, whereas negative forcing tends to cool the surface (IPCC, 2001a).

The current atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are 379 ppm, 1774 ppb and 319 ppb, respectively. The rate of increase over the past century in the combined radiative forcing from these three well-mixed greenhouse gases is very likely to be unprecedented in at least the past 16,000 years (IPCC, 2007a). Global increases in atmospheric CO_2 concentrations are primarily due to fossil fuel use, but also to land-use change. It is likely that the observed increase in atmospheric CH_4 concentration is predominantly due to agriculture and fossil fuel use. Since growth rates of CH_4 emission have declined since the early 1990s, total CH_4 emissions from anthropogenic and natural sources have been nearly constant since then. The increase in atmospheric N_2O concentration is primarily due to agriculture. Globally, agricultural CH_4 and N_2O emissions increased by 17% from 1990 to 2005 (Smith et al., 2008).

Currently there is general agreement that the human activities since 1750 have lead to global warming (IPCC, 2007b).

Continuation of the trends of greenhouse gas emissions will result in a further increase of global warming in the coming decades. The most recent projections indicate a global warming of 1.1-6.4°C by the year 2100 (IPCC, 2007a), but in North Western Europe warming is expected to be even higher. This will result in a sea-level rise of 0.2-0.6 m by the year 2100, but it must be noted that in the literature there is large uncertainty on the speed of the process. Especially an increase in the melting rate of the ice sheets in Greenland and the Antarctic could result in much higher sea-level rises at the end of the 21^{th} century. When the West Antarctic Ice Sheet collapses current sea levels could rise by 5 metres over the next 200 years (Vaughan and Spouge, 2002). Pfeffer et al. (2008) argue that more plausible but still accelerated conditions lead to a total sea-level rise by 2100 of about 0.8 meter. Definitely, low-lying countries, such as the Netherlands and Belgium, will have to address sea level rise not only with respect to safety but also to agricultural production, as saline intrusion will occur having a negative impact on the quality of water to be used by agriculture.

Addressing climate change is not an easy task. The effects of climate change are felt by almost all economic sectors. Strategies to dramatically reduce emissions of greenhouse gases are needed to reduce the impacts. But equally urgent are adaptation strategies to respond to the changing conditions both to counteract negative effects and also to exploit possible opportunities.

Climate change is changing the way we view and manage our land. Current management practices are already being challenged by changes in societal demands and markets. Climate change is an additional aspect that has to be taken up by the agricultural sector. Agricultural land use has a dual relation with climate change. Firstly, changes in temperature, precipitation and CO_2 concentrations have an impact on yields. In some cases these changes stimulate productivity, but in other cases they have directly or indirectly a deteriorating effect via changes in the occurrence of pests and diseases. Secondly, agricultural activities contribute to climate change through the emissions of greenhouse gases, notably CO_2, CH_4 and N_2O.

After general information on climate change has been presented this paper will focus on management strategies for mitigation and adaptation in field vegetable production systems.

CARBON AND NITROGEN CYCLES

Plants convert atmospheric carbon dioxide (CO_2) into carbohydrates through the process of photosynthesis using solar radiation as energy source. The carbohydrates can be used to synthezise proteins together with nitrogen (N) taken up by plant roots from soil. Plant roots are able to absorp nitrate (NO_3) and ammonium (NH_4), but not organic nitrogen. Some plants, notably leguminious plants, are also able to fix atmospheric N_2 through a symbiotic relationship with the bacterium Rhizobium. Since carbon (C) and N are thus required for the biosynthesis of proteins in plants and also in animals and humans after feed and food intake, C and N are present in plants, animals and humans and thus C and N cycles are coupled.

In agricultural systems the major steps in the C cycle are:

- absorption of atmospheric CO_2 by crops (during the day)
- absorption of plant material by livestock
- absorption of plant and animal material by humans
- emission to the atmosphere from plants (at night), livestock and humans
- export in non-food agricultural produce
- transfer to soils via crop residues and livestock excreta contributing to soil organic matter build up
- emission of CO_2 from soil to the atmosphere through soil organic matter decomposition
- emission of CH_4 from soils and ruminants to the atmosphere.

The major steps in the N cycle of agricultural systems are:

- absorption of soil NO_3 and NH_4 by plant roots
- fixation of atmospheric N_2 by leguminous crops
- absorption of plant material by livestock
- absorption of plant and animal material by humans
- export in non-food agricultural produce
- transfer to soils via crop residues and livestock excreta contributing to soil organic matter build up
- production of soil NH_4 through soil organic matter decomposition and subsequently N_2O and NO_3 through nitrification
- emission of ammonia (NH_3) derived from soil NH_4 to atmosphere (ammonia volatilization)
- emission of soil N_2O produced during nitrification of NH_4 and denitrification of NO_3
- emission of soil NO_3 to ground water and surface waters through leaching
- emission of N_2O from ground water to soil during denitrification of NO_3 in ground water.

In Figure 1 the C and N cycles in agricultural systems are presented schematically.

GREENHOUSE GAS EMISSIONS

Agricultural activities (including conversion of land cover, soil and fertiliser management, use of fossil fuel for machines and cooling and storage, and animal husbandry) are sources of N_2O, CH_4 and CO_2 emission to the atmosphere. In the EU27 the contribution of the agricultural sector to the total greenhouse gas emissions is about 10% (http://dataservice.eea.europa.eu/; August 5, 2007).

Agricultural lands occupy 37% of the earth's land surface. Agriculture accounts for 52 and 84% of global anthropogenic methane and nitrous oxide emissions. Agricultural soils may also act as a sink or source for CO_2, but the net flux is small (Smith et al., 2008). IPCC (2007c) reports that despite the large annual exchanges of CO_2 between the atmosphere and agricultural lands, the net flux (excluding emissions related to electricity and fuel use) is estimated to be approximately balanced, with CO_2 emissions around 0.04 $GtCO_2$/yr only.

The contribution of the field vegetable sector is not clear but is most likely relatively low given the small area (less than 5 million ha in Europe), but as most field vegetable production systems are highly intensive (annual N inputs of up to 1000 kg/ha), the per unit area contribution to the greenhouse gas budget will be high. Moreover, in field vegetable production CO_2 emission from soil is relatively high due to intensive and frequent soil tillage which promotes soil organic matter decomposition. This is especially the case in vegetable production systems on organic soils.

The emission profile or carbon footprint of products is already part of the marketing and sustainability agenda. Consumers and retailers, such as Albert Heijn and Tesco, will most likely use the carbon footprint to benchmark products and production systems. Getting a grip on the greenhouse gas balance of production systems is part of the challenge that vegetable producers face.

ADAPTATION

Adaptation is an intrinsic part of agriculture. Without adjusting to changing environmental and market conditions agriculture would not have been in the position where it is today. Climate change is an additional aspect that has to be taken up by the sector. Adaptation is needed to reduce adverse impacts but it also should focus on exploiting possible opportunities via technological, institutional and societal innovations (IPCC, 2001b). In agriculture adaptation strategies are strongly linked to mitigation strategies, both should be evaluated in coherence and not in isolation.

Agriculture, being a climate sensitive sector, is vulnerable to climate change. This is particularly the case for agricultural systems in marginal environments, often found in tropical regions. Agricultural productivity in North Western Europe could actually benefit from a moderate rise in temperature, but a high rise (more than 2 or 3 degrees compared to the 1960-1990 average temperature) will on average have a negative impact on agriculture.

Next to temperature relevant climatic parameters are amount, frequency and period of precipitation, hail storms, heavy storms, late frost, and atmospheric CO_2 concentration. The impacts related to these climate parameters are region and systems specific. For agriculture the direct, e.g., via temperature and rainfall and indirect, e.g., via flooding, saline intrusion or changes in the occurrence of pests and diseases, effects on yield and quality of harvested products and farm buildings are important. With increasing temperatures and heavy rains during the growing season the risk of nutrient leaching and decomposition of soil organic matter will increase.

Farmers in Europe have been successful in dealing with market and environmental changes. The adaptive capacity is relatively large as knowledge, skills and financial resources are sufficient. Gradual changes in temperature and precipitation will not pose large problems. However, the rate and magnitude of climate change are not clear. Consequences of rapid climate changes are not well understood, but they have the potential to undermine current agricultural practices (Van Ierland et al., 2007).

Adaptation in agriculture is not new. Agriculture has a tradition in responding to change. Adequate responses, however, require a functioning knowledge network including research, farmers, the private sector and governments. Actions should focus on formulating sector-specific risk-management strategies to deal with new challenges. Research efforts are needed to address the major unknowns that are related to extreme events and changing patterns of pests and diseases.

MANAGEMENT STRATEGIES IN FIELD VEGETABLE PRODUCTION SYSTEMS FOR MITIGATION AND ADAPTATION

In this section we will present management strategies in field vegetable production systems for mitigation of greenhouse gases and adaptation to climate change. Mitigation aims at reducing or stabilizing the concentration of greenhouse gases in the atmosphere.

Mitigation

1. Strategies to Increase Carbon Sequestration. Any management strategy that increases crop yields and generates higher inputs of crop residues can lead to increased C storage in soils. Strategies that can be applied in field vegetable production include the use of high-yielding crop varieties (Freibauer et al., 2004; Smith, 2004), extending crop rotations to limite the fallow period (West and Post, 2002) and the use of cover crops such as Italian ryegrass in the period of the year that vegetable crops cannot be grown (Freibauer et al., 2004). When crop residues are not removed from the field but are incorporated in the soil, they contribute to carbon sequestration because they are the precursors for soil organic matter, the main store of C in the soil. Replacing inorganic fertilizers by organic manures also contributes to carbon sequestration because they contain C which is added to the soil organic matter pool (Freibauer et al., 2004).

2. Strategies to Decrease CO_2 Emission. Reducing fossil fuel consumption or substituting fossil fuel by renewable energy sources directly contributes to lower atmospheric CO_2 emission.

Less intensive crop production systems, such as low-input and organic farming, reduce CO_2 emission indirectly, because they rely less on pesticides and fertilizers which have a high greenhouse gas emission during their manufacture. For the supply of N low-input and organic farming systems generally include leguminous crops in their rotation. This legume N, however, can also be a source of N_2O emission (Rochette and Janzen, 2005).

Reduced tillage or even no tillage may reduce CO_2 emission since soil disturbance tends to stimulate CO_2 emission through enhanced decomposition of soil organic matter (Smith et al., 2008). Adopting reduced tillage methods may also affect N_2O emissions, but the effects are inconsistent: in some areas N_2O emission is promoted and elsewhere

N_2O emission is reduced or not affected (Marland et al., 2001).
3. Strategies to Decrease CH_4 Emission. CH_4 emission from field vegetable production is in general low. Production systems on organic soils or those with high application rates of organic manure can emit CH_4 but given the low emission rates management strategies are not required to reduce the emission of this greenhouse gas.
4. Strategies to Decrease N_2O Emission. N applied in fertilizers and organic manures is often not efficiently used by crops. The unused and leached N may be a source of N_2O emission (Bouwman et al., 2001). Improving the N-use efficiency may thus result in lower N_2O emission to the atmosphere. The N-use efficiency can be improved by simply decreasing N-application rates, which will also result in less emission of CO_2 from N-fertilizer manufacture, and by a better synchronisation and synlocalisation of N supply and crop N demand (Van Noordwijk and Wadman, 1992).

A better synchronisation of N supply and demand can be obtained by adjusting N-fertilizer application rates to mineral N already present in the soil and to N that is likely to be mineralized during the growing season from soil organic matter, organic manures and residues of the preceding crop (Neeteson and Carton, 2001; Neeteson and Whitmore, 1997). Applying N fertilizer in two or three doses during the growth period is also an option to better synchronise N supply and demand, while adjusting the rates to soil mineral N and crop N concentration (Neeteson et al., 1999).

Through row application of N fertilizer a better synlocalisation of N supply and demand can be achieved, be it that the gain as compared to broadcast application will be relatively small due to the high mobility of nitrate in soils.

Adaptation Strategies

Selecting crop varieties and genotypes for specific environmental conditions is a common adaptation strategy. Summer vegetables, leaf vegetables, flower bulbs, fruit and tree crops are among the most drought-sensitive crops. Saline water can result in substantial yield reduction, and for some crops to visual damage to the leaves which results in a lower economic value (Van Dam et al., 2007).

With increasing drought risk and salt water intrusion new efforts are required to create stress-tolerant crops. Notably agriculture in southern Europe will have difficulties in maintaining production levels when the occurrence of periods of water shortage will increase (Oleson and Bindi, 2002). In greenhouses in southern Europe extreme high temperatures will necessitate additional cooling, which is difficult and costly.

With changes in types and abundance of pests and diseases the need for plant protection will have to be realigned to the new conditions. Which pest and diseases will emerge is not clear, but warmer climates will allow insects to complete more reproductive cycles. Mild winters will most likely result in earlier and higher pest and disease pressure at the onset of the growing season.

Part of the operational management at the farm level will have to adjust to new weather patterns. Shift in timing of operations should not cause too large problems. A wetter autumn, however, could cause problems for harvesting products. Especially harvesting root crops such as carrots will become more difficult.

Insurance is the most important anticipating adaptation strategy (Kok et al., 2001). Damages caused by extreme rainfall, hail storms, heavy storms and floods are expected to have the largest impact on farm buildings and crops. Uncertainties in how extreme events will change with a changing climate are large. Research is ongoing to reassess damages related to extreme events and to revisit current insurance systems (Werners et al., 2004).

CONCLUSIONS

Field vegetable production systems contribute to climate change through emission of the greenhouse gases CO_2 and N_2O. Since field vegetables like all other plants fix atmospheric CO_2, the net emission of CO_2 from vegetable production systems will be insignificant, especially when high-yielding varieties are used, crop residues are not removed from the field, inorganic fertilizers are replaced by organic manures and reduced tillage is applied. N_2O emission can be reduced by increasing the efficiency of N use by the vegetables. Thus all strategies used to reduce N losses in field vegetable production systems contribute to decreasing N_2O emission.

Emission reductions can be achieved by better N management, but new and smarter ways to manage and monitor emissions are needed as the greenhouse-gas balance will play an increasingly important part in the competition profile of the value chain. Using a comprehensive precision agriculture approach in which farmers and scientists jointly try to improve soil and fertiliser management can yield an innovative way to reduce in-field emissions of greenhouse gases.

Field vegetable production systems will have to adapt to changing weather conditions, such as dryer summers and wetter winters. This implies that crops or varieties have to be used that are more stress tolerant to drought and salinity and that, e.g., root crops should be grown earlier in the season to avoid harvesting in too wet soils. With climate change the competition between farms and agricultural regions will also change. This can provide opportunities to introduce new crops and farming systems.

It should be noted that the strategies that best reduce emission of greenhouse gases or adapt to climate change depend on local conditions and thus may vary from region to region. Adaptation and mitigation are complementary strategies to manage risks and opportunities related to the impact of climate change. Combining the two strategies at the field and farm level in an integrated soil-crop management approach is clear. This requires transparent methods to assess trade-offs and synergies of interventions in the N and C cycle to the vulnerability and resilience of soil and crop systems and vice versa.

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Figures

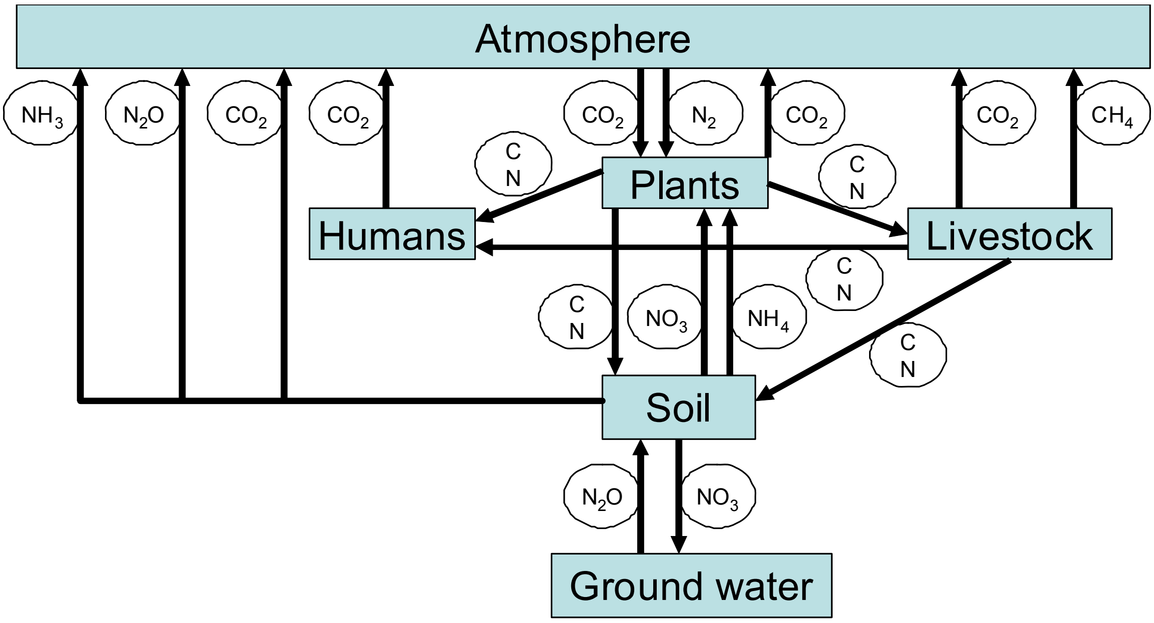

Fig. 1. Schematic representation of C and N cycles in agriculture.