Wine production under climate change conditions: mitigation and adaptation options from the vineyard to the sales booth

Gerhard Soja[a], Franz Zehetner[b], Gorana Rampazzo-Todorovic[b], Barbara Schildberger[c], Konrad Hackl[d], Rudolf Hofmann[e], Eva Burger[f] and Ines Omann[f]

[a] *AIT Austrian Institute of Technology GmbH, 2444 Seibersdorf, Austria; gerhard.soja@ait.ac.at*
[b] *Institute of Soil Research, University of Natural Resources and Applied Life Sciences, Peter Jordan-Str. 82, 1190 Wien, Austria*
[c] *LFZ Klosterneuburg, Wiener Straße 74, 3400 Klosterneuburg, Austria*
[d] *Landwirtschaftskammer Niederösterreich, Sigleithenstr. 50, 3500 Krems, Austria*
[e] *IK Traisental, Weinriedenweg 13, 3134 Reichersdorf, Austria*
[f] *SERI, Garnisongasse 7, 1090 Wien, Austria*

Abstract: *The wine-growing region Traisen valley in Eastern Austria was analysed for the potential of mitigation and adaptation measures to climate change. The objective of the project was the identification of measures that can be implemented in the short term and that will raise the awareness for the importance of a sustainable grape and wine production in wine producers and consumers. Representative farms were studied in detail for their greenhouse gas emissions during the whole production chain of grapes and wine and for the downstream processes till the vending to the customer. Greenhouse-gas emissions specific for vineyard soils were analysed by field measurements and carbon cycle modelling. The participating wine-growers were asked to keep an account of all their viniculture-specific activities in a logbook and to answer questionnaires about plant protection measures and other management measures relevant for the evaluation of indirect greenhouse gas emissions. In the analyses of the downstream processes packaging, storage, transport and distribution were investigated. The production risks due to climate shifts and weather extremes were studied by analysing climate trends in the Krems – Traisen valley region from 1971 to 2008. The results show that a decrease of tillage intensity is the most important mitigation measure during grape production, conserving soil carbon or even turning the vineyard soil into a carbon sink. Changing the packaging materials, which currently contribute to 39% of the total greenhouse gas emissions along the wine production chain, represents a further mitigation opportunity.*

Keywords: *Vitis vinifera, grapevine, sustainable development, adaptation, mitigation, agriculture*

Introduction

In Austria, grapevine is an important specialized perennial crop grown on about 48000 ha. Although this is only about 3% of the usable agricultural area, this proportion contributes to about 8% of the total agricultural and to 20% of the crop value added. This is due to a high degree of primary product refinement and an export proportion of about 30%. Due to special climatic requirements for the production of high quality grapes, the effects of climate change in wine-growing regions need to be assessed and are of significant economic and social relevance. Even in the earliest economic assessments of climate change effects, possible effects on winegrowing were included (Lough et al., 1983).

Climate sensitivity of viticulture

Climate conditions have determined the geographic extension of winegrowing and the possibilities for a profitable production since historic times. The "medieval optimum" has made wine growing possible till the South of England or the coastal regions of the Baltic countries (Landsteiner, 1999; Jones, 2004). The dependence of grape maturity on the integrated temperature was used for the reconstruction of weather conditions of past centuries without detailed meteorological records (Ladurie, 2005; Menzel, 2005). Reliable instrumental weather monitoring that has become standard in the 20th century is indispensable for revealing relations between grape harvest, grape quality and specific meteorological parameters or extreme values. Analyses of the relations between weather, growth of vines and grape productivity data during the past decades have identified changes in phenology and yield as responses to differences in atmospheric conditions that allowed for a quantification of climate sensitivity of viticulture (Esteves und Orgaz, 2001; Caprio und Quamme, 2002; Chloupek et al., 2004; Duchene und Schneider, 2005; Lobell et al., 2007; Soja und Soja, 2007; Ramos et al., 2008). The warming trend accelerates budburst more than later phenological stages (Sadras and Soar, 2009), resulting in additional challenges for frost protection in non-Mediterranean climates (Poling, 2008). Accelerated leaf gas exchange and transpiration rates will be a consequence of increased temperatures (Soar et al., 2009). The resulting changes in grapevine water demand, additionally to modified precipitation patterns and intensities, require adaption of vineyard irrigation techniques (dos Santos et al., 2007; Guix-Herard et al., 2007; Morison et al., 2008; Ramos and Martinez-Casanovas, 2009). Even small micrometeorological differences at different locations in adjacent vineyard plots may affect photosynthetic characteristics, speed of growth or carbon yield (Hendrickson et al., 2004). Growth models have been developed to simulate these growth differences as CO_2 balance model (Poni et al., 2006). Direct effects of increased atmospheric CO_2 concentrations will modify physiological characteristics such as increased photosynthetic rates and water use efficiency or altered leaf mineral composition (Moutinho-Pereira et al., 2009).

Climate simulation models and the calculation of long-term future climate scenarios forecast changes with relevant effects on viticulture. Apart from temperature increases, the changes will be characterized by modified patterns of precipitation (Ramos, 2006; Laget et al., 2008), more frequent extreme weather events (Adams et al., 2001) and generally by the adaptation necessity to a higher variability of climate conditions (Hajdu, 1998; Cartalis et al., 2002; Jones, 2004; Belliveau et al., 2006; Lobell et al., 2006).

Adaptation measures to climate change have to consider the conservation of local wine quality, which depends on specific meteorological patterns (Jones und Davis, 2000; Grifoni et al., 2006). Unsuccessful adaptations may lead to overall negative impacts or even to the local abolishment of grape or wine production (White et al., 2006; Webb et al., 2008). However, new wine-growing regions may emerge or old regions can be recovered for viticulture where in medieval times vineyards have been cultivated for the last time (Jones et al., 2005; Gustafsson and Martensson, 2005; Hall and Jones, 2009). The quantification of the climatic suitability of regions for wine-growing is based on the "Geoviticulture Multicriteria Climatic Classification System" (Tonietto and Carbonneau, 2004), which has further developed the classical Huglin-index (Huglin, 1978) and is deployed for regional classifications (Blanco-Ward et al., 2007).

Global climate change scenarios contain large uncertainties for the regional or local scale so they need to be downscaled (Formayer et al., 2004). Such local-scale studies both observed and forecasted a shift of phenological indicators towards earlier maturity and a faster increase of sugar content of the grapes (Stock, 2005; Wolfe et al., 2005; Webb et al., 2007). The regional specifity of Austrian wines is regulated by the DAC-system (*Districtus Austriae Controllatus*) that describes certain cultivars as typical for certain wine-growing regions and that supports marketing efforts. The region-specific taste of a certain wine does not only depend on cultivar, topography and soil but also on the local climate (Wilson, 1998). A climate change-induced shift in temperature and precipitation pattern possibly alters the distinct taste profile that is required by the DAC-system for a certain region. Till now the concept of “terroirs” has focused on soil and geology (Haynes, 1999; Wilson, 2001) because these parameters determine the trace element concentrations (Greenough et al., 2005) and biochemical processes in the grape berries (Deloire et al., 2005). It will be a matter of discussion if the character of a “terroir” can be considered as fixed under the aspect of climate change. In wine-growing regions that are not climate-constrained in the long term, an increase in vintage scores and a decrease in variability has been observed (Sadras et al., 2007). Varying meteorological conditions determine variations in the acid-sugar-ratio and in the ratio of stable isotopes in the grapes (Ingraham and Caldwell, 1999; Bauer, 2008). For regions that produce high quality grapes at the margins of their climatic limits, reaching a balanced grape quality required for existing cultivars and wine styles may become progressively more difficult (Jones et al., 2005). The desired grape maturities will be reached earlier in the year, but the temperature sensitivities are not the same for different cultivars (Petrie and Sadras, 2008). The acid composition was observed to be more sensitive against climate change than the sugar composition (Liu et al., 2006).

Greenhouse gas emissions from grape and wine production

The production and marketing of grapes and wine requires many work steps that cause considerable upstream CO_2 costs. A survey of the viticulture-specific greenhouse gas emissions is still largely missing because mostly the emissions of the agricultural sector are summarized or only split into the contributions of plant production and animal production. A rare exception is the report of Niccolucci et al. (2008) who focused their investigation only on two farms, however. More farms have been included in the study of Kavargiris et al. (2009) who found lower greenhouse gas emissions in organic than in conventional vineyards. The inclusion of regional production characteristics and a wider range of farms would be desirable. Generally, food production causes greenhouse gas emissions in a similar range as mobility (Tukker et al., 2005). Increasing consumer preparedness to buy products which are considered as climate-friendly opens possibilities to introduce more sustainability in food production in terms of lower greenhouse gas emissions.

The carbon footprint generally comprises the greenhouse gas emissions of products or companies by including the complete chain of economic value added such as raw materials, production processes, transport, trade, use, disposal or recycling. Greenhouse gas inventories for the sector agriculture were established for individual countries in the 1990s for the first time, e.g. for Austria (Dersch and Böhm, 1997) or the Netherlands (Kramer et al., 1999). The Kyoto-protocol and the implicated obligations to reduce greenhouse gas emissions have led to the development of countrywise (Schneider et al., 2007; Neufeldt and Schäfer, 2008) or global (Smith et al., 2007) strategies for measures how agriculture can reduce its own emissions. The suggestions focus on the reduction of methane emissions from animal production (Sauerbeck, 2001) and on a decrease of nitrous oxide losses from agricultural soil after nitrogen fertilization. This can be achieved by changes in the nutrient regime and the fertilization technique (Kulshreshtha et al., 2000; Gregorich et al., 2005), the use of nitrification inhibitors (Clough et al., 2007) under consideration of the soil type, soil sink potential and management practice (Henault et al., 2005; Li, 2007; Chapuis-Lardy et al., 2007). Cover crops are effective at adding carbon to vineyard soils (Steenwerth and Belina, 2008a) but may enhance nitrogen mineralization and N_2O-emissions under certain humidity conditions (Steenwerth and Belina, 2008b).

Ideal adaptation measures effectuate both a decrease in vulnerability and a mitigation of greenhouse gas emissions. Although not all measures can serve both objectives, modifications in agricultural management practices and product processing technologies have a good potential to contribute to these objectives without neglecting the principles of sustainability (Howell, 2001; Nendel and Kersebaum, 2004; Tesic et al., 2007).

The optimal adaptation and mitigation measures to climate change in viniculture will not be the same in all wine growing regions. Therefore, this report focuses on a special region, the Traisen valley in Lower Austria. By including a local wine grower association (IK Traisental) and studying the grape and wine production management of their farms in detail, it was possible to derive suggestions for adaptation and mitigation measures most appropriate for this region. This paper presents some of the most essential conclusions for the total wine production and marketing chain in the Traisen valley.

Material and Methods

The study region Traisen valley is a wine growing region in the East of Austria with about 700 ha vineyards located in the rectangle between the coordinates 48°19' to 48°22' North and 15°41' to 15°47' East. Data material about agricultural practices in the vineyards, grape processing, wine production and marketing in the years 2006-2009 was collected from 9 farms on the basis of questionnaires, farmers' logbooks and personal interviews. The results were transformed to CO_2-equivalents according to FIVS (2008), PWC/ECOBILAN (2008), PAS 2050 (2008), Aranda et al. (2005) and Gonzalez et al. (2006).

The vineyard soils of the farms participating in this study were sampled for analysis of basic soil properties, such as texture and organic carbon stocks. The RothC-26.3-Model was used to simulate changes in soil organic carbon in response to tillage intensity, fertilization, residue management and grass/legume cover (Coleman et al., 1997). Model calibration relied on long-term experimental data from Spiegel et al. (2002), and model input parameters were based on analyses of soils and residue inputs at the study sites in the Traisen valley. The tillage intensity factors derived from calibration were in the range of 1 (no tillage) to 1,8 (intensive ploughing) and represent the decomposition intensity of soil organic matter.

The annual emissions of N_2O from vineyard soils were estimated using the following equation (IPCC, 2006):

$N_2O\text{-direkt-}N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \times EF$

where F_{SN} and F_{ON} are the annual N-inputs from synthetic and organic fertilizers, respectively, F_{CR} is the annual N-input from crop residues, F_{SOM} is the annual amount of N from the mineralization of soil organic matter, and EF is the emission factor for N_2O from N inputs (in kg N_2O-N per kg N input). F_{SN} and F_{ON} were calculated from the N contents of fertilizer materials, F_{CR} und F_{SOM} were estimated from measured C:N ratios in connection with the results from the C-modeling using RothC-26.3, and for EF the default value of 0.01 was used (IPCC, 2006). The calculated N_2O emissions were converted to CO_2-equivalents (CO_2e) by multiplication with the factor 296.

Long-term meteorological data were obtained from the station Krems and, if necessary, homogenized with data of the station St. Polten. Grapevine evapotranspiration was assessed according to FAO 56 (Allen et al., 1998); for calculation of the reference evapotranspiration, the ETo-Calculator-software, v.3.1, was used (Raes, 2009). Precipitation runoff was accounted for according to Campbell and Diaz (1988) and interception according to Hoyningen-Huene (1983). For statistical calculations STATISTICA-software (v.7 and v.8) was applied (Statsoft, 2007).

Results

The combination of the RothC-model application with the estimation of soil N_2O emissions (IPCC, 2006) allowed for an assessment of the sink or source activity from the vineyard soils for CO_2 and N_2O. Figure 1 shows that at low soil tilling intensity and high organic carbon input into vineyard soils (through the application of organic amendments such as compost material) the sink activity for greenhouse gases prevails. In this model, a permanent grass/legume cover and a complete return of pruning material is assumed. The intensity of tilling has come out as the main driver of soil greenhouse gas emissions. Even an application rate of 100 kg mineral nitrogen fertilizer.ha^{-1}.yr^{-1} would only result in about 40% of the greenhouse gas emission strength compared to increasing the tillage intensity from low (no tillage) to medium (3-4 tills per year).

By comparing the greenhouse gas emissions for the whole wine production and marketing chain in the Traisen valley, it has become clear that the emissions during grape production in the vineyards constitute only a minor part (about 31 ± 6%) of the total CO_2e-emissions (2.3 ± 0.4 kg.L^{-1} wine as mean ± s.e.). The choice of the wine container, bottle closure, labelling and packaging material is more important and contributes about 39 ± 8% of the total emissions (Figure 2). The processing and maintenance steps in wine production and the wine storage contribute about 17 ± 6% whereas transport costs till the wine reaches the consumer (mainly offered as pick-up service) constitute 12 ± 5%. It should be noted that these relations only apply to the average viticultural practices in the Traisen valley; for transferring these data to other wine-growing regions the possibility of deviations in the practices of grape growing and wine production should be analysed.

Regional climate change scenarios for the East of Austria predict a shift in precipitation patterns from summer to winter without large changes in the overall precipitation (Kromp-Kolb et al., 2007). In combination with the general global trend of increasing temperatures this means an intensification of summer drought stress for crops and more severe soil water deficits. The meteorological data of the study region Traisen valley were used to test if evidence for these model simulation results could already be found in previous decades from calculations of climatic water budgets. However, the analysis of the trends in soil water deficits (calculated as difference between available precipitation and grapevine crop evapotranspiration) revealed a minor but marginally significant trend of less severe summer water deficits (Figure 3). The main drivers of this trend are slowly increasing precipitation sums and meteorological conditions that lower crop evapotranspiration for grapevine. These results do not invalidate model simulation results that were developed for climate scenarios of the mid 21st century but not for the study period 1971-2008.

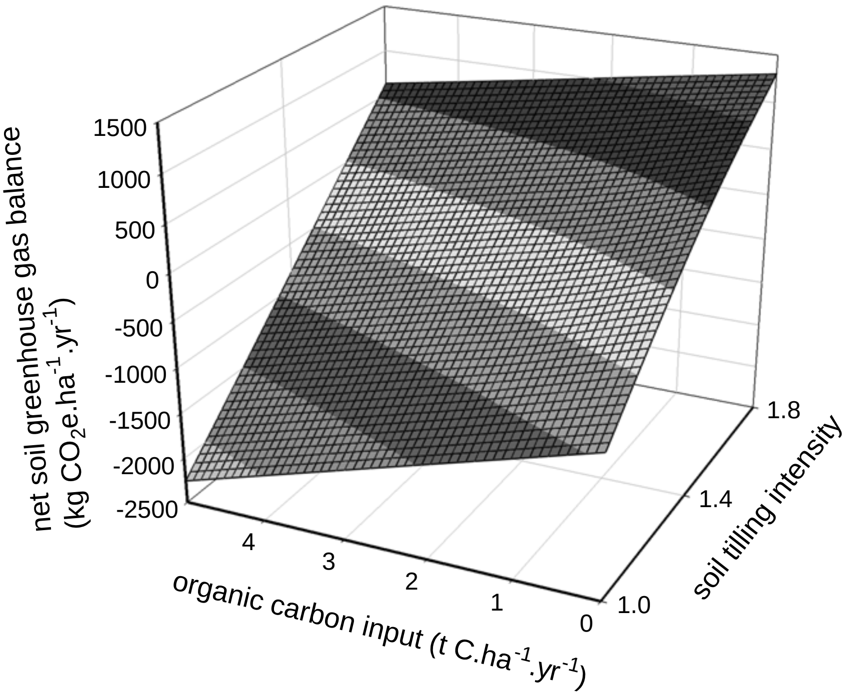

Figure 1. Effect of organic amendments (organic carbon input) and soil tilling intensity on the net greenhouse gas balance of vineyard soils with permanent plant cover. Greenhouse gas balance is given in CO_2-equivalents, calculated as the sum of CO_2 modelled with the RothC-26.3-Model and N_2O according to IPCC (2006). Negative values indicate a carbon sink function of the soil. For explanations of soil tilling intensity see Material and Methods.

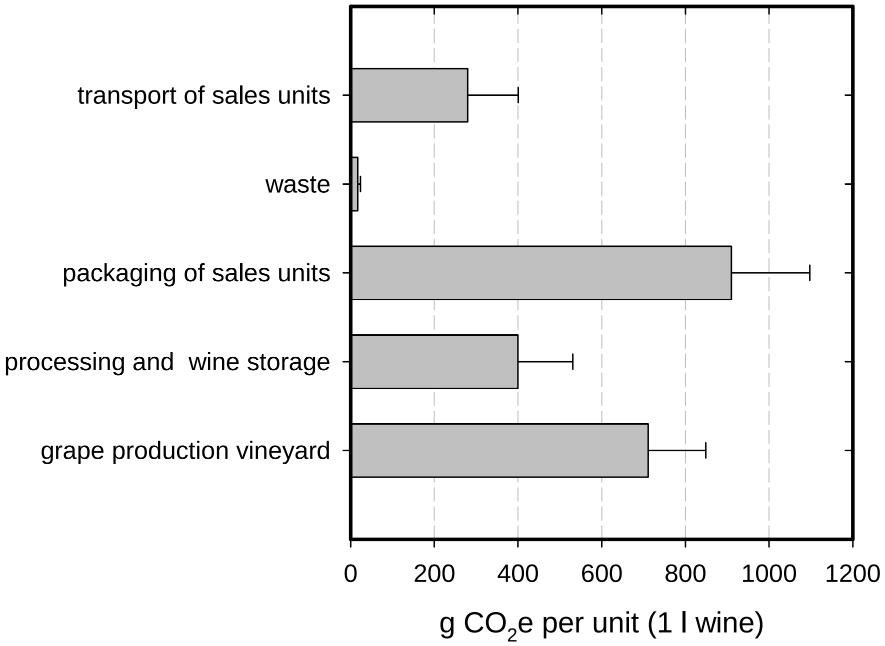

Figure 2. CO_2-equivalent emissions from grape and wine production. Values are means ± s.e. from 7 representative farms in the Traisen valley (Eastern Austria). All results are based on 1 l wine. Production emissions from the vineyards include indirect emissions and soil emissions (CO_2 + N_2O).

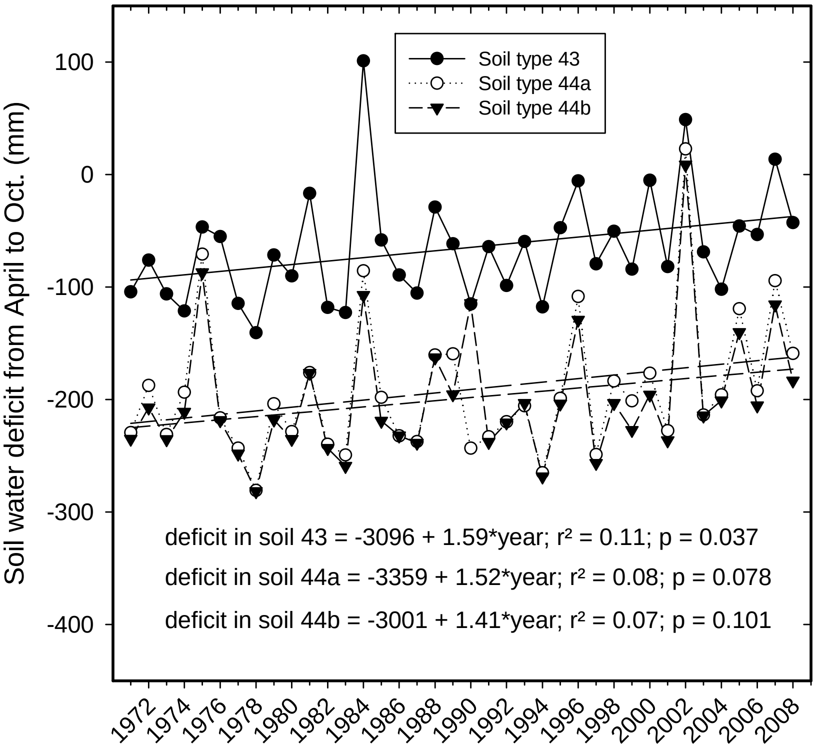

Figure 3. Change of soil water deficit for different soil types in non-irrigated Traisen valley vineyards 1971-2008. Deficit is calculated as usable water (= precipitation minus runoff minus interception) minus crop evapotranspiration (ET_c; Allen et al., 1998) for the period April to October of each year.

Discussion

This study is based on a sample of wine-growing farms that represent typical small-scale private enterprises with individual product marketing and customer sales services. Although this method results in larger variances than an assessment of a whole region or a single large wine producer, it also demonstrates the evidence for greenhouse gas reduction potentials as exemplified in the farms with below-average CO_2e emissions. This variability between farms was an important source for the derivation of possible mitigation measures with a good chance of implementation by the winegrowers. If only one or two farms had been studied in detail as in the analyses of Niccolucci et al. (2008) or Hamm (2009) there would be the risk of questionable transferability of the results to other farms or regions. But also in our study one has to bear in mind that the focus was on the specific situation in the Traisen valley. If the derived suggestions are to be transferred to other wine-growing regions, care has to be given to differences in the wine production and marketing chain. Different customers, transport strategies or packaging materials may cause significant changes to the emissions shown in Figure 2. Suggestions for adaptation measures will have a more general deployment potential because of more or less similar climate change trends in different Austrian wine-growing regions.

Conclusions

The detailed analyses of grape and wine production in representative farms of the Traisen valley have shown several possible measures to reduce greenhouse gas emissions during the production chain. The most promising management changes will be the conservation of soil organic carbon by decreasing the tillage intensity, the reduction of the number of tractor transits through the vineyards and the use of fuel-saving engines. The downstream processes also show significant potential for mitigation measures such as introduction of new packaging methods and materials, e.g. bag-in-box. The trend analyses of past meteorological conditions have shown that in the short term no increased irrigation requirements have to be expected but this may change in the medium or long term. The temperature trends of the past decades have shown significantly increasing trends that will require careful selection of heat-tolerant or slowly maturing strains of existing cultivars as adaptation measure to climate change.

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