2.3 Greenhouse Gas Fluxes from Agricultural Soils

2.3.1 Mineral Soils

2.3.1.1 Carbon Dioxide

The balance between carbon input and decomposition of organic matter determines if a field is a source or a sink of carbon. There is only one study that reports net ecosystem exchange of a field on mineral soil (Lind et al. 2016) and that represents cultivation of reed canary grass which is not an especially common crop. Thus, the available data does not allow for estimation of a full carbon balance of a typical field based on measurements (Table 2.2). Evidence from a 35-year field monitoring points to the direction that cultivated mineral soils on the average lose carbon at an annual rate about 200 kg/ha (Heikkinen et al. 2013). The estimate was based on monitoring of about 500 fields and soil sampling only to 15 cm; thus, it represents changes in the topsoil only. The authors deduced that the declining trend is related to warming climate, changes in cropping (less annual crops and varieties with less crop residues) and the young age of fields that may be still losing carbon from the phase of the preceding land use (forest).

The amount of carbon input depends on choices made in cultivation practices. Decomposition is mainly driven by the climatic conditions although, e.g. tillage practices have a role in that as well. Despite the cool climate restricting decomposition of organic matter, it is likely that conventional agricultural practices result in loss of carbon from soil in Finnish conditions. A long-term field experiment in the neighbouring country, Sweden, showed that returning only crop residues with

Table 2.2 Annual greenhouse gas fluxes of cultivated mineral soils

	Mean (g m^2 $year^{-1}$)	Min	Max	n	Refs.
Annual crop					
Net CO_2 exchange	–	–	–		
C loss as yield (CO_2)	–	–	–		
CH_4 flux	−0.04 ± 0.07	−0.12	0.06	7	1; 2
N_2O flux	0.57 ± 0.23	0.20	1.02	31	1; 3; 4; 5
Perennial crop					
Net CO_2 exchange[a]	−950	−961	−939	2	6
C loss as yield (CO_2)	1183	1228	1137	2	6
CH_4 flux	−0.05 ± 0.03	−0.09	0.03	14	1; 2; 10
N_2O flux	0.43 ± 0.31	0.06	1.13	20	1; 3; 4; 7; 8; 9

n = number of annual flux estimates

[a]Negative value = carbon sequestration, positive value = carbon loss

References: 1 (Syvasalo et al. 2006); 2 (Regina et al. 2007); 3 (Syvasalo et al. 2004); 4 (Petersen et al. 2006); 5 (Sheehy et al. 2013); 6 (Lind et al. 2016); 7 (Regina et al. 2006); 8 (Maljanen et al. 2009); 9 (Virkajarvi et al. 2010); 10 (Maljanen et al. 2012b) no other amendments usually results in the decline of the carbon stock (Katterer et al. 2011). Plant breeding tends to develop varieties with less and less crop residues, which may also complicate maintaining the carbon content of cultivated soils. However, the amount of above-ground plant litter does not seem to be crucial for maintaining the carbon stocks of cultivated soils as the removal or burning of straw did not have an effect in a 30-year field experiment in Southern Finland (Singh et al. 2015).

Converting native ecosystems to agricultural use typically reduces the carbon stock by 20–40%, and the loss of carbon from the soil profile is fastest during the first decades (Guo and Gifford 2002; Karhu et al. 2011). Reaching a new steady state where the carbon input and its loss are in balance may take several decades, and thus it is impossible to say how much of the observed carbon loss is due to the land use change and how much is caused by agricultural management.

2.3.1.2 Methane

Methane is produced microbially in anaerobic conditions and consumed in aerobic conditions. In soils, the conditions can vary from anaerobic to aerobic in time or space. The sites of CH_4 production are the lower soil layers with low oxygen content or soil aggregates favouring anaerobic bacteria. Sites of CH_4 consumption are the topsoil or macropores of the soil. Soil micro- or macroporosity was found to affect the observed rates of CH_4 flux in Finnish clay and sandy soils (Regina et al. 2007). In cultivated soils, the annual balance of CH_4 is usually close to zero most often resulting in more CH_4 being consumed than produced. Emissions of CH_4 have been reported to occur occasionally in wet conditions (Regina et al. 2007), but even then, the annual balance typically indicates net consumption of CH_4. Compared to CO_2, the carbon flows related to CH_4 are minor (Table 2.2). The annual fluxes have ranged from -0.12 to 0.06 g m^{-2} with no clear differences between annual and perennial cropping can be seen. Grazing has been found to change pastures from sink to source of CH_4 emissions due to CH_4 released from the deposited dung (Maljanen et al. 2012b).

2.3.1.3 Nitrous Oxide

In cultivated mineral soils, the most significant gas in the total greenhouse gas budget is N_2O. Average annual emissions of N_2O have been 0.6 g m^{-2} for annual crops and 0.4 g m^{-2} for perennial crops including mostly grass leys (Table 2.2). Annual emissions of N_2O are typically slightly higher from annual cultivation compared to perennial despite the higher fertilization rates on perennial ley production (Regina et al. 2013).

Perennial crops take up nutrients clearly for a longer period annually compared to annual crops and that reduces the amount of nitrogen available for the microbes during the non-vegetated period. The emissions during the period between harvest and sowing represent about 40% of the annual budget of N_2O (Regina et al. 2013) which highlights the importance of the residual nitrogen after harvest in the absence of nutrient uptake of plants. The difference between perennial and annual crops may thus be emphasized in the northern conditions with short growing season of cash crops.

It has been found in many studies that emissions of N_2O are not ceased in the winter time even when the soil is frozen. Availability of nitrate is always good in cultivated soils, and the low oxygen content favours denitrifying bacteria that can be active in microsites with unfrozen water of frozen soil (Teepe et al. 2004). One reason for the high N_2O production at low temperatures can be that N_2O reductase enzymatic activity is inhibited (Muller et al. 2003), and therefore the end product of denitrification is N_2O instead of N_2.

The timing of freezing and soil water content have important effects on the emission of N_2O (Maljanen et al. 2009; Teepe et al. 2004). Also the depth and timing of snow cover can affect N_2O emissions. Snow manipulation experiments have shown that thinner snow cover can lower soil temperatures and increase the extent and duration of soil frost (Maljanen et al. 2009). In frozen soil, N_2O is still produced and accumulated in soil, and it is then rapidly released during thawing (Koponen and Martikainen 2004; Maljanen et al. 2007a, 2009). The N_2O production in frozen soil does not correlate well with the N_2O emitted from soil as a result of the low gas diffusion rate. Therefore, the release of N_2O during winter does not give the correct estimate of N_2O production activity during the winter.

Fertilization rate, especially the amount of mineral nitrogen, has been found to affect the annual emissions when studied in subsets of annual and perennial cropping (Regina et al. 2013). The available data does not allow reliable estimates of the effects of fertilizer type (mineral/organic) on N_2O emissions. Recent evidence shows that external nitrogen inputs induce also emissions of nitric oxide (NO) and gaseous nitrous acid (HONO) that are not greenhouse gases but reactive in the atmosphere (Bhattarai et al. 2018; Maljanen et al. 2007b).

There is some evidence that no-till management increases N_2O emissions from cultivated soils (Sheehy et al. 2013). The increase is related to the more dense structure of the soil and thus higher soil moisture favouring denitrification.

A probable but poorly known hotspot of N_2O emissions are fields on acid sulphate soils. They are located on the former sea bottom of the coastal regions and have large amounts of organic matter in the subsoil due to sedimented materials. The field area on acid sulphate soils is in the range of 43 000–130 000 ha (Yli-Halla et al. 1999). They are characterized by a large stock of nitrogen and high microbial activity that may induce extremely high emissions of N_2O, even of the magnitude of tens of kilograms per hectare when drained for agriculture (Simek et al. 2011, 2014; Petersen et al. 2012; Denmead et al. 2010).

2.3.2 *Organic Soils*

2.3.2.1 Carbon Dioxide

Losses of carbon from organic soils are typically several folds compared to carbon stock changes in mineral soils. Typically 0.5–2 cm of peat is lost from the topsoil of cultivated soils due to peat decomposition annually (Gronlund et al. 2008) and that represents carbon loss of several tonnes per hectare. Although carbon exchange between the soil and atmosphere forms the majority of the climatic impact of cultivated organic soils, full carbon balance estimates are still rare. The annual net ecosystem exchange has varied between −800 and 3000 g m^{-2} in Finnish studies (Table 2.3). As the reported values show, even in organic soils photosynthesis may sometimes exceed carbon loss from the soil, at least in the case of crops with large biomass. The consideration of the climatic impact must, however, include the biomass transported from the field, and in most cases, this turns the field to net source of carbon even if photosynthesis was able to counteract peat decomposition.

Table 2.3 Annual greenhouse gas fluxes of cultivated organic soils

	Mean (g m^2 $year^{-1}$)	Min	Max	n	GWP (t CO_2 eq. ha^{-1} $year^{-1}$)	Refs.
Annual crop						
Net CO_2 exchange*	2080 ± 1150	770	3040	4	20.8	1, 2, 3
C loss as yield (CO_2)	600 ± 180	460	855	4	6.0	1, 2, 3
CH_4 flux	−0.06 ± 0.24	−0.49	0.51	10	−0.02	3, 4, 5
N_2O flux	1.74 ± 0.92	0.84	3.79	11	5.2	3, 6, 7
Total					32.0	
Perennial crop						
Net CO_2 exchange*	560 ± 1210	−780	2750	8	5.6	1, 2, 3
C loss as yield (CO_2)	920 ± 400	280	1570	8	9.2	1, 2, 3
CH_4 flux	0.15 ± 0.34	−0.25	0.91	14	0.05	3, 4, 5, 8
N_2O flux	1.14 ± 1.47	0.04	5.47	19	3.4	3, 6, 7, 8, 9, 10
Total					18.3	

n = number of annual flux estimates
GWP = global warming potential
*Negative value = carbon sequestration, positive value = carbon loss
References: 1 (Maljanen et al. 2001); 2 (Lohila et al. 2004); 3 (Maljanen et al. 2004); 4 (Maljanen et al. 2003a); 5 (Regina et al. 2007); 6 (Maljanen et al. 2003b); 7 (Regina et al. 2004); 8 (Maljanen et al. 2009); 9 (Maljanen et al. 2010b); 10 (Shurpali et al. 2009)

The existing results suggest lower carbon losses from soils under a perennial than annual crop. This is related to the less frequent disturbance of the soil as well as higher carbon input to the soil, especially from high-yielding grass crops.

2.3.2.2 Methane

Similar to mineral soils, fluxes of CH_4 are close to zero also in drained organic soils (Table 2.3). The mean value for annual crops is slightly negative indicating oxidation of CH_4 in the topsoil, whereas it seems that net production of CH_4 is more common in the denser and moister soil under perennial crops. Periods of wet soil conditions have been found to increase the net flux occasionally as reported, e.g. by Maljanen et al. (2013).

Drainage level and functioning of the drains affect soil moisture status and thus largely determine the flux rates of CH_4. In two fields with similar cultivation practices, the field with poorly functioning drainage had mainly net emissions during a 2-year monitoring period, whereas its well-drained counterpart showed net consumption of CH_4 (Regina et al. 2007).

Emissions from open ditches can have a large impact on the total greenhouse balance of a drained peatland (Schrier-Uijl et al. 2011; Minkkinen and Laine 2006). There are limited data on these emissions from Finnish croplands (Hyvonen et al. 2013). As it is known that the nutrient status of the drained area greatly affects the emission rate, it is likely that the open ditches around nutrient-rich cultivated fields are a high source of CH_4 emissions. However, most fields are subsurface drained, and the significance of these emissions is likely minor in the country scale.

2.3.2.3 Nitrous Oxide

In organic soil, peat decomposition is the main source of N_2O emissions and fertilization has minor importance. Mineralization of nitrogen from the peat can have the magnitude of several hundreds of kilograms per hectare annually, and this enables relatively high emission rates of N_2O regardless of fertilization (Leppelt et al. 2014). The annual emissions of N_2O have varied between 0.04 and 5.47 g m^{-2} in Finnish measurements (Table 2.3). The annual emissions are thus several folds compared to mineral soils.

The average annual emission rates have been higher for annual than perennial crops indicating tighter nitrogen cycle in the case of perennial grasses that are able to take up nutrients until late autumn and are tilled less frequently.

Like in mineral soils, the residual nitrogen after harvest is a substrate for N_2O production during the winter period, and about half of the annual emissions can occur between harvest and sowing. Climatic conditions in the winter have a large effect on the annual emissions. It was observed that a warm period in the winter that melted 10 cm of the frost induced a 100-fold increase in N_2O concentration of the soil profile (Regina et al. 2004). There was a clear difference to a similarly managed field in northern Finland where frost was constant, however, and concentrations of N_2O in the soil remained low for the whole winter and no production of N_2O was observed.

2.3.2.4 Climatic Impact

The net climatic impact of a hectare of cropland can be estimated by converting the emissions of CH_4 and N_2O to carbon dioxide (Myhre et al. 2013). The calculated values for net global warming potential of annual and perennial cropping are 32 and 18 t CO_2 eq. ha^{-1} per year suggesting almost double emission rates from annual compared to perennial crops (Table 2.3). However, a valid comparison requires comparing crop types within the same site. This data set is biased in the case of perennial crops as half of the observations come from high-yielding bioenergy crops. Even if this data set is too small for a robust comparison, the results point to the direction that less frequent soil disturbance slows down peat decomposition and thus diminishes the climatic impact of cultivation on organic soils.

2.4 Mitigation Options

Due to the short growing period prevailing in Finland, the most feasible management change to reduce the climatic impact of any type of agricultural soils would be reducing the period of bare fallow after harvest. This has not been studied in field experiments with greenhouse gas emission measurements, but the lower emissions rates from annual compared to perennial crops suggest that the longer the vegetated period annually, the smaller are the environmental effects of a cultivated field. Bare soil is prone to losses through runoff, leaching and gaseous emissions. A growing plant like a cover crop takes up nitrogen and has the potential to reduce leaching losses (Valkama et al. 2015) and potentially losses as N_2O if the risk of increased N_2O emission from the decomposing residues of the cover crop can be avoided. However, the risk of increasing the annual emissions with the presence of a cover crop is evident as revealed in the meta-analysis of Han et al. (2017) indicating that while the after-harvest emissions of N_2O are reduced with the presence of a cover crop, the annual emissions may not be. In any case, the extra crop residues of the cover crop have the potential for carbon stock increment in mineral soils (Poeplau and Don 2015). Including cover crops in rotation would compensate for the current low carbon input in crop residues and thus help to maintain carbon stocks and fertility of croplands. Other means of avoiding losses after harvest would be inclusion of autumn-sown crops in the rotations or spring tillage instead of autumn tillage. The above-mentioned practices may become more common as the climate warms and survival of the vegetation in the autumn period becomes more likely.

Also related to the northern location of Finland, there is the need to renew the grass swards every 3–4 years. If the renewal was done less frequently or selectively on only the poor areas of a field, this would likely reduce the losses related to tillage and bare soil. However, data on the effects of grass sward renewal on N_2O emissions is still scarce, and the results are too short term and show varying results (Buchen et al. 2017).

All measures improving the nitrogen use efficiency reduce available nitrogen for microbial processes and thus the emissions of N_2O. Management options related to this include optimizing fertilizer amount and timing as well as precision farming techniques that take the spatial differences within a field into account. However, the total use of nitrogen inputs in mineral fertilizers has already been reduced by 35% in 1990–2016, and thus further large-scale reductions may affect yields per hectare. This is not a desirable trend as it may lead to the need to clear more field area from native soils to maintain food production.

Reducing tillage intensity has been often found to increase the carbon stocks of mineral soils (Sainju 2016), and there is also some evidence of reduced carbon losses from no-till organic soils (Elder and Lal 2008; Regina and Alakukku 2010). However, in conditions of northern countries with relatively high soil moisture, the emissions of N_2O may increase in the denser topsoil negating part of the favourable effects of minimum tillage (Gregorich et al. 2005; Sheehy et al. 2013). In addition, it is also not evident that reducing tillage would always increase soil carbon stocks as the stock may reduce in the deeper layers resulting in no change for the whole soil profile (Powlson et al. 2014).

In a country like Finland with high coverage of peat soils, the most promising mitigation options are found in management of cultivated organic soils (Klove et al. 2017). With the high hectare-based emissions, expected mitigation effects are higher than in mineral soils. The measures for reducing the climatic impacts of food production on peat soils can be divided into those that reduce the cultivated area and those that reduce the hectare-based emission rates while the cultivation continues. It has been found in many studies that abandoned fields on organic soil can still be relatively high sources of greenhouse gases (Maljanen et al. 2012a, 2013). Thus, it would be beneficial to have well-planned strategies for the after-use of cultivated peat soils instead of uncontrolled abandoning.

Most realistic option for reducing the area of peat soils under cultivation in Finland is afforestation. However, in conventional afforestation management, drainage and evapotranspiration of the tree stand maintain the groundwater table low and peat decomposition continues in the layer above the groundwater table. Also, the emissions of N_2O may continue at a rate similar to cultivated soils (Maljanen et al. 2010a, 2012a). Afforestation could be a preferential strategy for fields that have been cultivated for several decades and already have lost most of the peat layer. Using tree species like alder or birch afforestation with high groundwater table level may also be feasible (Wichtmann et al. 2016).

As the peat has accumulated due to reduced decomposition of plant residues caused by a high groundwater level, evidently the most effective way to reduce the emissions of cultivated peat soils would be to raise the water table as high as possible. Total rewetting is possible for the fields that are not necessary for food production and in locations with abundant water reserves. The risk of high CH_4 emissions (Schafer et al. 2012) and nutrient losses to watercourses (Kieckbusch and Schrautzer 2007) should be taken into account when planning such measures. There are at least two examples of successful rewetting cases on former agricultural soils with the result of emission neutrality or net sink effect (Herbst et al. 2013; Schrier-Uijl et al. 2014), and this option should be studied also in the Nordic conditions.

Some crops resistant to wet soil conditions can be produced in paludiculture (Wichtmann et al. 2016). Paludiculture enables maintaining production while the groundwater level is raised close to the soil surface. However, many crops that are suitable for such production have very limited markets. In Finland, this could be a future option to reduce greenhouse gas emissions in regions where agriculture is an important livelihood, but limited areas of mineral soils are available for agricultural activities.

High groundwater table reduces the yields of most agricultural crops and hinders the use of heavy machinery. Temporary raise of groundwater table is possible using controlled drainage which allows for decreasing the water table level whenever there is a need to use machines on the field (Osterholm et al. 2015). This is a more feasible option to implement greenhouse gas mitigation by raised water table and may become more common in the near future.

2.5 Gaps in Knowledge

The data survey on greenhouse gas emission measurements done in Finland shows that the uncertainties are still high in all categories. An especially high need exists for measurement results ranging over the full year in the case of carbon budget of mineral soils. Almost lacking are measurements of all greenhouse gases from drainage ditches. Acid sulphate soils deserve more attention as a potentially large emission source. Most of the reported flux measurements were done on the most typical crops and practices: grass ley in crop rotation or spring barley with autumn tillage. Thus, there is lack of knowledge on the effects of, e.g. a prolonged vegetated period or spring tillage which could potentially reduce losses to both atmosphere and watercourses after harvest. Also, data on the effects of raised water table on cultivated organic soils and the guidelines on how to manage such fields are largely lacking.

Climate policy drives the development of agricultural policies including more measures affecting the climatic impacts of agricultural production. From the policy viewpoint, mitigation measures are useless if their effects cannot be shown in statistics. It will be necessary to develop methods for reporting the effects of the most prominent mitigation measures in the official emissions statistics. For this,

Chapter 3
Greenhouse Gas Exchange from Agriculture in Italy

Anna Dalla Marta and Leonardo Verdi

Abstract Together with industry, transport and energy sectors, agriculture is one of the main sources of greenhouse gas (GHG) emissions from human activities. In particular, intensive breeding, fertilization and fuel combustion for traction are the most impactful factors in terms of global GHGs. Italy is not an exception, and due to the high variability of environmental and morphological conditions of the country, a wide range of agricultural systems is adopted with different GHG emissions' potential. Italian agriculture accounts for 1.5% of total carbon dioxide (CO_2), 60.6% of total methane (CH_4), 68% of total nitrous oxide (N_2O) and 94% of total ammonia (NH_3) that is an indirect source of N_2O as well as the main source of N-volatilization from agriculture. CO_2 emissions are primarily produced from tractors on croplands, and based on technological level, there are no significant differences along the country. Because of the high concentration of paddy fields and intense breeding, the northern part of Italy is responsible for the majority of CH_4 and N_2O (and NH_3) production. Paddy lands are, in fact, the main sources of CH_4 emissions that are produced by flooded fields from anaerobic micro-organisms. In Italy, paddy lands cover more than 200,000 ha (51% of total EU paddy lands) following the course of Po River. However, N-based emissions are mainly produced by intense breeding, in particular through enteric fermentation and manure storage and spreading. Italian agriculture accounts for more than 138,000 cattle farms (6 million cattle) and 145,000 pig farms (8.7 million pigs) that are principally located in the central-northern part of the country. In addition, the intensive use of fertilizers contributes to N-based emissions through nitrification/denitrification and N-volatilization processes into the soil.

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3.1 Introduction

In Italy, the monitoring of GHG emissions is implemented by Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) for which the inventory of GHG emissions, an official tool for the verification of international commitments on the protection of the atmospheric environment with the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, is an important institutional commitment. In the present section, we reported a review of GHG emissions produced by Italian agriculture based on the most recent census of the Ministry of Agriculture, the last report on the state of the environment (ISPRA) and on the most recent national literature.

In Italy, emissions of GHG are estimated through the adoption of specific emission factors for each emission source. Estimates of GHG emissions from agriculture and Land Use, Land Use Change and Forestry (LULUCF) are implemented according to the IPCC methodology. Based on the requirements of the reference methodology, the inventory of GHG emissions produced by agriculture includes the estimation of two greenhouse gases, methane (CH_4) and nitrous oxide (N_2O). The emission sources for which emissions are estimated are enteric fermentation (CH_4 emissions), the management of manure and slurries (CH_4 and N_2O), agricultural soils (N_2O), the paddy fields (CH_4) and combustion of agricultural residues (CH_4 and N_2O).

Due to the high variability of environments and climate within the country, several agricultural systems are adopted. Italy ranges from typical Mediterranean agroecosystems where drought and high-temperature-resistant crops as citrus and olive are cultivated, to alpine climate where only mountain farming is possible.

In general, the highest amount of CO_2 eq derives from husbandry-related activities (enteric fermentation, manure management/application) and mainly involves CH_4 (Fig. 3.1). Intense livestock systems represent a relevant factor of Italian agriculture with more than 138,000 cattle farms (6 million cattle), 145,000 pig farms (8.7 million pigs), 76,000 sheep farms (6.7 million of sheep) and 80,000 chicken farms (over 157 million of chickens) that are principally located in the central-northern part of the country. In particular, 74% of emissions from livestock are produced by cattle; it is estimated that one cow emits around 2.6 tons of carbon dioxide equivalent (CO_2 eq) per year (compared to 0.9 and 0.1 tons of CO_2 eq from one sheep and one pig per year, respectively) (ISPRA 2017).

Further, Italian agriculture accounts for more than 200,000 ha of paddy lands (51% of total EU paddy lands) dislocated along the course of Po River.

Based on collected data, in 2015 Italian agriculture was responsible of 6.9% of global GHG emissions and represented the third emission source after energy sector and industry production process. In particular, enteric fermentation represented 46.0% of Italian GHG emissions followed by croplands (29.9%), manure and slurries management (17.0%) and paddy lands (5.6%).

Nevertheless, GHG emissions from Italian agriculture in 2015 were 30 Mt CO_2 eq, that is 15.9% less compared to 1990 when emissions were 35.6 Mt CO_2 eq and renewable energy sources had a great impact. In addition, specific founds were dedicated to those agricultural management strategies that aim to reduce environmental pressure of agriculture, increase biodiversity and reduce climate change.

Following IPCC guidelines, by 2030 global agricultural emissions must decrease by 15% compared to present. IPCC also affirms that current mitigation strategies may produce a benefit not exceeding 40% of the set target. So, FAO advises further investments from governments on the definition of modern and more efficient agricultural strategies (precision farming, circular economy, conservation agriculture, etc.). A challenging topic is the maintenance of agricultural productivity to satisfy the increasing food demand with increasing population growth, yet achieving the intended reduction of GHG emissions and conservation of natural resources. In this sense, Italian agriculture, to maintain current food self-sufficiency (80% of national request), must achieve the reduction of GHG emissions without any further reduction in the area under crops and livestock density.

Italian agriculture, as agriculture at the global scale, contributes fairly modestly to CO_2 production. Main sources are represented by soil organic matter oxidation, crop and crop residues combustion and fuels for traction. Nevertheless, these emissions are almost completely balanced by biological uptake, and compared to other gases such as CH_4, CO_2 represents a minor issue for global warming. On the other hand, NH_3, not a GHG but a precursor to N_2O production, represents a relevant loss of N into the atmosphere.

The amount of emissions of the three mentioned gases, CH_4, N_2O and NH_3, varies across the country (Fig. 3.3).

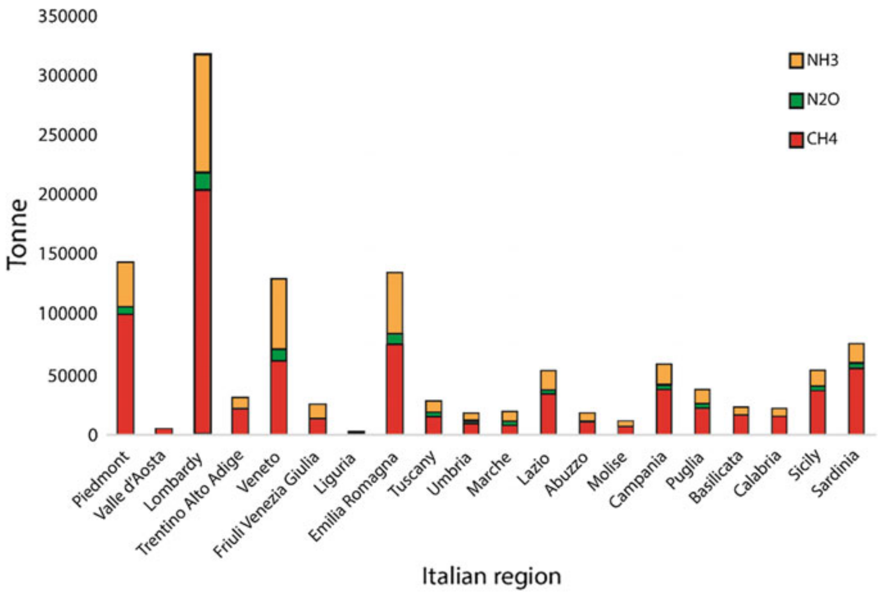

Fig. 3.3 Emissions (Mt) of CH_4, N_2O and NH_3 from agriculture in the different Italian regions (*Source of data* ISTAT 2005)

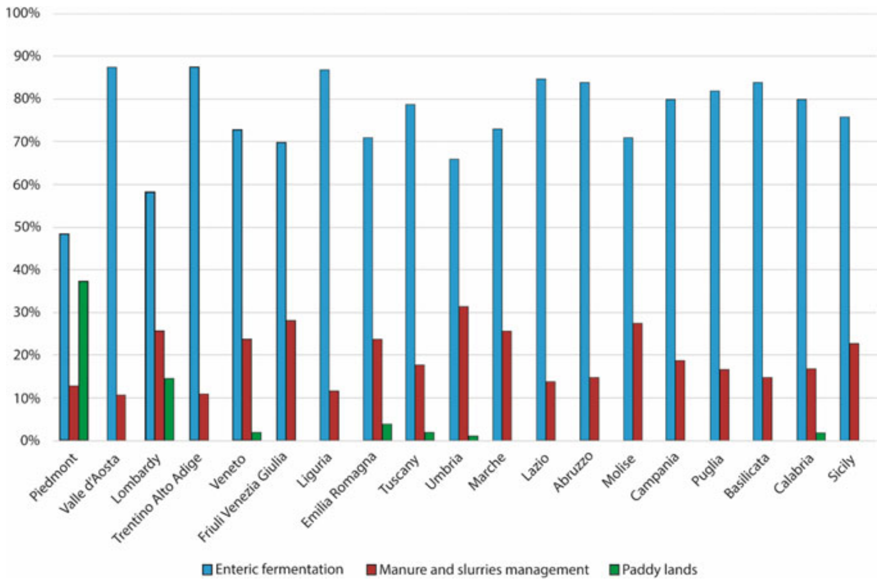

Fig. 3.4 CH_4 emissions in each Italian region from different sources (*Source* Adapted from ISPRA 2017)

3.2 Carbon Emissions Produced by Italian Agriculture

Beside CO_2, CH_4 is the main carbon emission produced by Italian agriculture. One of the most impactful agricultural activities in terms of CH_4 is represented by intense livestock systems that produce CH_4 through the enteric fermentation of animals (70% of total CH_4 emissions from agriculture) and the management of manure and slurries (20% of total CH_4 emissions from agriculture). Another important source of CH_4 (10% of total CH_4 emissions) is rice cultivation; paddy lands are mainly located in the north of the country in Piedmont (37%), Lombardy (14%), Veneto and Emilia-Romagna regions. Thus, Italian agriculture is responsible of 15.3% of total CH_4 emissions produced in the country (Fig. 3.4).

3.3 Nitrogen Emissions Produced by Italian Agriculture

In 2015, N emissions from Italian agriculture accounted for 342.2 Kt with a net reduction of 17.7% compared to 1990 (ISPRA 2017). This reduction is again mainly related to the decrease in the number of livestock, the reduction of croplands, the reduction of the use of N-based fertilizers and the adoption of high-efficiency fertilization strategies. Nevertheless, ammonia (NH_3) is the main

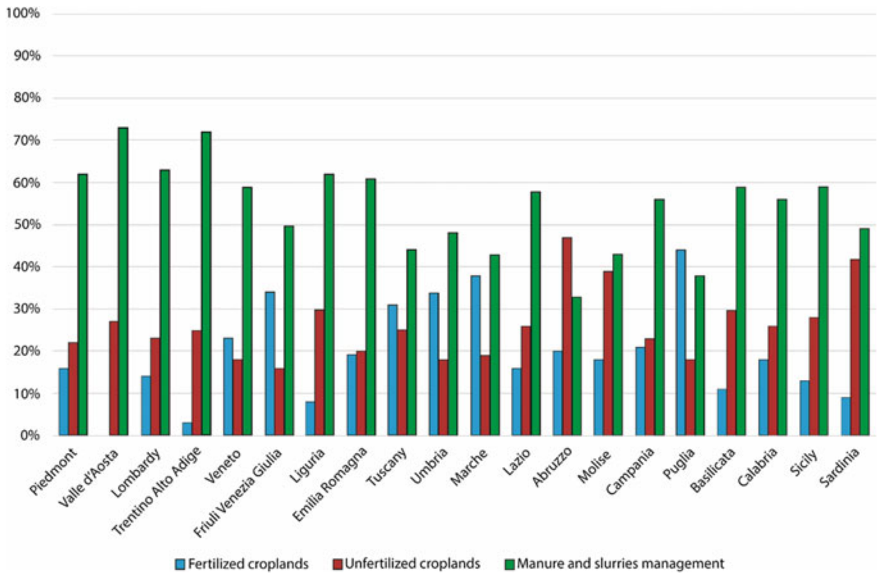

Fig. 3.5 N_2O emissions in each Italian region from different sources (*Source* Adapted from ISPRA 2017)

source of N losses into the atmosphere representing the 90.9% of N emissions, followed by N_2O that is the 6.9% (Fig. 3.5).

NH_3 is mainly produced in the north of Italy, Sardinia and north of Puglia, where intense livestock is more abundant and where the adoption of NH_4-based fertilizer is still relevant. Again, N_2O production is mainly concentrated in the north of Italy where, in addition to the intense adoption of N-based fertilizers, annual precipitation and soil water content are higher compared to the rest of the country. This is also true for the regions in the south of Italy where annual precipitation is lower but the adoption of irrigation is relevant (Fig. 3.6).

3.4 Mitigation Strategies

Due to the high number of intense livestock systems, Italian agriculture in the last few years is showing an intense increase in the number of biogas plants. In particular, the number of plants has grown from 10 to nearly 900 (Fabbri et al. 2013) in a few years, and many more plants are under construction. According to a recent census (Fabbri et al. 2013), at present there are more than 1000 biogas-operating plants (Carrosio 2013) making Italy the second larger biogas producer in Europe after Germany. Biogas production is an excellent way of using organic waste for energy generation, followed by the recycling of the digested substrate (digestate) as fertilizer (Comparetti et al. 2013; Maucieri et al. 2016) with low emissions'

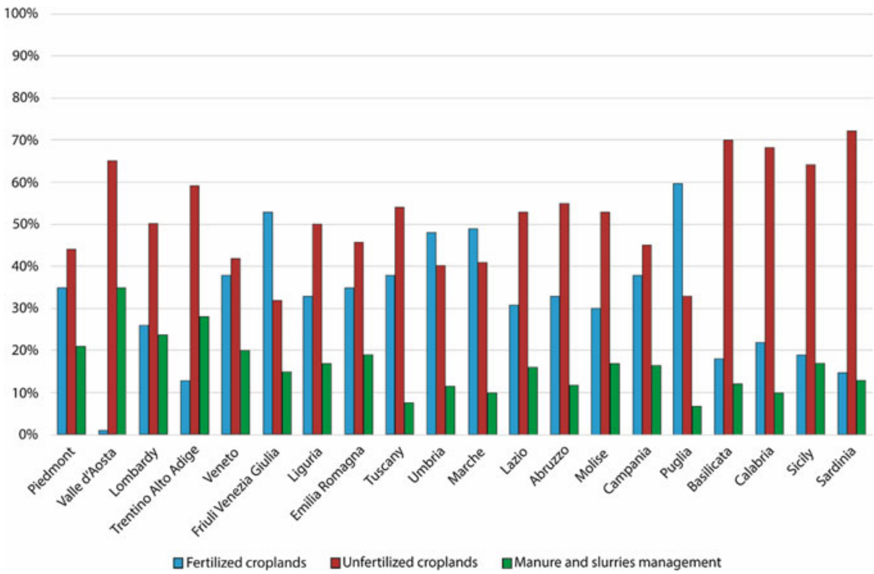

Fig. 3.6 NH_3 emissions in each Italian region from different sources (*Source* Adapted from ISPRA 2017)

potential. In fact, digestate use as replacing fertilizer represents an interesting strategy to reduce GHG emissions from agriculture while maintaining satisfying crop yield levels. Digestate is composed of two phases: a liquid fraction, rich in water and N-easy available compounds for crops, and a solid fraction rich in organic matter. The liquid fraction is the more interesting for fertilization purposes, but special attention should be paid to its management and spreading in order to achieve the highest possible agronomic efficiency while minimizing emissions.

For each Italian region, as well as in the rest of Europe, specific regulations provide guidance on the appropriate techniques for digestate management, and for slurries in general, for the reduction on N losses into the atmosphere. For instance, Tuscany region adopted the Regulation 46R/2008 for the protection of water from pollution by defining the allowed management techniques. The most adopted strategy is the use of different kind of coverages (floating polyethylene systems, clay balls, etc.) for digestate storage lagoons. Dinuccio and Balsari (2011) observed that covering digestate lagoons may reduce NH_3 emissions from 76% up to 99% based on the type of covering techniques adopted.

On the other hand, regional regulations provide information about digestate spreading techniques. In particular, incorporation of digestate into the soil is a mandatory strategy to reduce GHG emissions. Due to its high $N{-}NH_4^+$ content, when digestate is spread on soil surface a relevant volatilization of NH_3-based compounds occurs, with consequent atmospheric pollution and N losses. Moreover, the consequent soil enrichment in organic C and organic N compounds favours micro-organism's activities with a consequent increase of respiration and CO_2 emissions. Thus, incorporation of digestate into the soil instead of surface spreading strongly reduces GHG emissions' risks representing an efficient mitigation strategy.

Concerning paddy lands, a recent study (Lagomarsino et al. 2016) observed that the alternation of wetting and drying is an efficient strategy to reduce CH_4 emissions.

3.5 The Regulation Framework

In Italy, a "National System for the implementation of the National Inventory of Greenhouse Gases" (National System) was established, according to the obligations related to the implementation of the Kyoto Protocol, for the monitoring and accounting of GHGs. The Italian National System was established in 2008 and designated ISPRA as the responsible Institution for the National Inventory of GHGs, as well as the collection of basic data and the implementation of a program to check and guarantee their quality. The national register of agroforestry carbon reservoirs, which is an integral part of the National System, is the tool for the certification of GHGs fluxes deriving from afforestation, reforestation, deforestation and forest management activities, and was established in 2008 at the Italian Ministry for the Environment and Protection of the Territory and the Sea.

Beside the monitoring and accounting by the National System, the policies for the mitigation of emissions in the agricultural sector are part of the European and international framework of climate action.

A legislative proposal presented by the Commission in 2016 (Effort Sharing Regulation) has set national targets for reducing emissions of polluting gases to maintain the commitments of the Paris agreements. In October 2014, EU adopted the 2030 framework for climate and energy. The framework includes the binding target of reducing emissions in the EU by at least 40% by 2030 compared to 1990 levels. In particular, the reduction of emissions in sectors, such as transport, agriculture, buildings and waste, the so-called non-Emissions Trading System (non-ETS) sectors, must be 30% compared to 2005. To ensure that all countries participate in such reduction, the Effort Sharing Regulation has set country-by-country targets. The reduction target for Italy is −33% by 2030, compared to 2005.

Among the financing methods to favour the transition to a low-carbon economy of agriculture, the Common Agricultural Policy (CAP) plays a central role, by establishing an appropriate system of incentives. With the new CAP in fact, the focus on environmental sustainability is guaranteed by the introduction of the "greening", under which 30% of the national budget available for direct payments to farmers should be subject to the compliance with sustainable agricultural practices. Further, another positive boost comes from the implementation of Rural Development Plans (RDPs) called to address the four challenges of the "Health

Check" of CAP which are climate change, renewable energy, water resources management and biodiversity. The majority of RDPs supported measures for the reduction of GHGs and recognized the reduction of N surplus as the main way to fulfil the target. The European Agricultural Fund for Rural Development (EAFRD) includes several measures to encourage investment to improve the performance and sustainability of farms. In particular, with regard to climate action, specific agri-environment–climate measures are designed to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services. The main purpose of agri-environment–climate payments is "the introduction or maintenance of agricultural practices that contribute to mitigating climate change or that promote adaptation to them and that are compatible with the protection and improvement of the environment, landscape, natural resources, soil and genetic diversity", and it is the only mandatory rural development measure for Member States (but voluntary for farmers), Italy included.

The main environmental regulations impacting on the GHG emissions are Nitrates Directive, National Emissions Ceiling Directive (NEC), the Integrated Pollution Prevention and Control Directive (IPPC) and the Water Framework Directive (WFD). Concerning the Nitrates Directive, Italy made many progresses in the last years through the increase of the vulnerable areas (30% of UUA) and the introduction of a Best Agricultural Practices Code adopted by farmers interested by the regulation. The NEC Directive establishes maximum thresholds for each Member State for the main pollutants responsible for acidification, eutrophication and ozone-related pollution. In this sense, NH_3 is the most important pollutant deriving from agriculture. Italy has complied with the national emission limit for NH_3 set for the year 2010 at 419 kt (thousands of tons). The achievement of the objective was mainly due to the emissions trend of the agricultural sector and to the introduction of appropriate technologies due to the IPPC Directive (ISPRA 2017). Although not directly related to GHGs reduction, this addresses the implementation of the best available technologies (BAT) for the control of industrial pollution. For agriculture, the IPPC involves intensive breeding and mainly focuses on NH_3 emissions abatement so that it also impacts on gas emissions.

The revision of the NEC Directive (2016/2284) established the new reduction targets for 2020 and 2030. In particular, for Italy these targets are equal to 400.61 kt of national NH_3 emissions in 2020 (−5% compared to 2005) and 354.22 kt of national NH_3 emissions in 2030 (−16% compared to 2005) (ISPRA 2017).

3.6 Conclusions

Boosted by the new CAP and national guidelines, an intense adoption of sustainable agricultural management strategies is leading to a reduction of the emissions produced by Italian agriculture (ISPRA 2017). The reduction of the environmental impact is mainly related to the adoption of those strategies aiming at reducing agricultural inputs (fertilizers, pesticides, herbicides, etc.) and, consequentially,

Chapter 4
GHG Emissions and Mitigation in Romanian Vineyards

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Abstract In viticulture, the water requirement is low and organic fertilizers such as manure or organic matter from cover crops or compost made from pomace and lees are generally applied. Therefore, some specialists are of the opinion that viticulture is less polluting than other farm sectors. Nevertheless, measures for mitigating GHG emissions from vineyards and associated wine industries need to be adopted to preserve the quality of grapevine by-products. In viticulture, GHG emission mitigation can be achieved through appropriate methods of tillage, fertilization, harvesting, irrigation, vineyard maintenance, transport or wine marketing, etc. Besides CO_2, nitrous oxide (N_2O) and methane (CH_4) are produced from fertilizers and waste/wastewater management, respectively. As main GHG in vineyards, N_2O can have the same harmful impact as CO_2. Carbon is found in grape leaves, shoots, and even fruit pulp, roots, canes, trunk or soil organic matter. C sequestration in soil by using less tillage and tractor passing is one of the most efficient methods to reduce GHG in vineyards. However, many years are needed for detecting the resulting SOC changes. In the last decades, among other methods, cover crops have been used successfully for GHG mitigation and increasing soil fertility in vineyards. There is still limited information on practical methods in reducing emissions of greenhouse gases in viticulture. Therefore, this paper serves as an information base for researchers and industries working in the viti- and vinicultural sectors by providing knowledge concerning GHG dynamics under standard management approaches and principles. This helps ensure businesses are equipped with new information useful to build an efficient strategy to handle and mitigate GHG emissions.

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4.1 Introduction

Global warming is a direct or indirect result of human activities (burning fossil fuels, changing land use, energy consumption, etc.) with an impact on the atmospheric composition (Carlton et al. 2015). At the 19th International Wine and Spirit Exhibition "Vinexpo Bordeaux", organized during 18–21 June 2017, viticulturists addressed different possibilities to save their vineyards and made a call for general mobilization to fight against global warming. Climate change will definitely affect the vine-growing boundaries. High temperatures in the wine-growing area will increase sugar and alcohol rate and decrease acidity, which affect the wine flavour and taste. The result will be a reduction in vineyards in warm areas, while new areas will appear in places that were previously too cold for the vine growing. Fires, late frosts, prolonged drought, diseases and pests, hail and storms are events that will worsen in the future, as warned by John P. Holdren (Harvard Physicist, International Expert in Climate Change and Energy—Holdren 2018).

For greenhouse gas emissions' mitigation, viticulturists and winemakers try new working methods for their own and global benefit. Some successful practices have been proven to be: growing of drought-resistant rootstocks varieties, cover crops, grazing middle rows or straw mulch, expanding vineyards in colder climates, reducing the amount or total abandonment of the use of pesticides and herbicides, improving fertilizer application and irrigation, using green fertilizers, nitrification inhibitors and wastewater treatment, biochar incorporation in soil (not only reduces GHG emissions but also contributes to increased productivity and soil quality). Undoubtedly, interactions of the environment, climate and soil conditions with grape variety needs, floor management are the agricultural practices that can control N_2O and CO_2 release from vineyards.

4.2 Viticulture in Romania

GHG emissions from Romanian agriculture (the equivalent of Mt CO_2 to 1,000 € gross added value in agriculture) are among the lowest in the EU 28. Within the EU 28, Romania ranks fifth among the lowest share of greenhouse gas emissions from agricultural production and for the main components—nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4). Therefore, in many small family farms without financial possibility to buy machinery and chemical fertilizers, GHG emissions are low. The total concentration of all GHG emissions had reached 441 ppm CO_2 equivalent in 2014, which is an increase of about 3 ppm compared with 2013 and 34 ppm compared with data from 2004. Experts believe that even small increases in global warming will reduce crop yields and will increase yield variability in low latitude regions (Scrucca et al. 2018).

4.2.1 Romanian Vineyards

The soils and the climate in Romanian vineyards are diverse. Therefore, different varieties can be grown for table wines or for high-quality wines. Vineyards are planted from 25 m altitudes (Dobrogea area—Black Sea), up to 600–700 m in piedmont areas in Transylvanian Hillsides. Soil type varies from sandy or light soils to clayey or limestone (Toti et al. 2015).

During 2000–2016, world area under vineyards decreased from 7.8 to 7.5 Mha in 2016. Five countries hold 50% of the world vineyards; Spain ranks the first with 14%, followed by China (11%), France (10%), Italy (9%) and Turkey (75); Romania ranks 10th with 191 Kha in 2016. Currently, it has an area of 243,000 ha of vineyards (242,000 ha older and 1,000 ha newly planted vineyards). The wine grapes represent 82% of the total vineyards area with wine production reaching 5–6 million hl/per year (Tamas 2017).

In Romania, grapevine growing is an ancient tradition. During the Roman Empire with the conquests in Dacia (the present territory of Romania), it is certainly known that the grapevine was cultivated in large areas. Romans brought new grape varieties, new winemaking and pruning methods. Even in the years with poor wine production or when the vineyards were affected by the invasion of phylloxera, varieties from the Drăgăşani, Odobeşti, Cotnari or Tarnavele vineyards and the Romanian wines such as Grasa de Cotnari, Tămâioasa, Busuioaca or Black/White Feteasca were appreciated in international markets (Bărbulescu 2017).

Vineyards in Romania (about 37) are grouped into eight viticultural regions, the most extensive of which is Moldavian Hills, which covers almost 70,000 ha. Relief differences (altitude, slope and sun exposure), soil and climate influence the ripening period from one region to another for the same variety. A variety grown in eastern Romania matures earlier by about 1 month than in north-west of the country, and therefore, different wine grape varietals cover each region (Irimia et al. 2017) (Fig. 4.1).

In 2016, vineyard area in Romania was 258 860.83 ha (1.79% of agricultural land), with 8432.39 ha (3.26%) on soil of the first-class quality, 65016.23 ha (25.12%) on soil of the second-class quality, 80346.63 ha (31.04%) on soil of the third-class quality, 79242.80 ha (30.61%) on soils of the fourth-class quality and 25822.78 ha (9.98%) on soil of the fifth-class quality.

Transylvania Plateau vine-growing region (I) includes five vineyards (Tarnave, Alba, Sebes-Apold, Aiud and Lechinta) with 17 vineyards. Main production is white wine (Protected Denomination of Origin (PDO) and Protected Geographical Indication (PGI)), semi-sweet, sweet and sparkling wines.

Moldavia Hills vine-growing region (II) is the largest and includes 12 vineyards (Cotnari, Odobesti, Panciu, Dealul Bujorului, Iași, Cotești, Huși, Covurlui, Colinele Tutovei, Ivești, Nicorești, Zeletin). Most wines are white (PDO or PGI) and sweet. Cotnari wines are included in the catalogue of the best wines in the world. Dry wine can be found in Odobesti, Panciu and Cotesti vineyards. Red wines are produced in small quantities.

Fig. 4.1 Romanian vineyards and wine regions (WRs)

Oltenia and Muntenia hills' vine-growing region (III) includes eight vineyards (Dealu Mare, Sâmburești, Dealurile Buzăului, Ștefanești, Dealurile Craiovei, Plaiurile Drancei, Drăgășani and Severin). In Samburesti are produced mainly red wines, while in the other vineyards, white and red wines labelled PDO or PGI from several varieties are produced.

In Banat Hills' vine-growing region (IV), and those two main vineyards (Recas, Buzias-Silagiu), are cultivated not only wine varieties but also table grapes (such as Chasselas, Black Hamburg, Muscat d'Adda or Victoria). White and red wines are labelled PDO (49%) or PGI (3%).

Crişana and Maramureş hills' vine-growing region (V) cultivates both white and red grapevine varieties, in Minis-Maderat, Valea lui Mihai, Diosig and Silvania vineyards for PDO (10%) and PGI (0.5%) wines and small quantities of sparkling wines.

Dobrogea hills' wine-growing region (VI) is located in the East of Romania near Black Sea and is well known from ancient times. Murfatlar, Istria-Babadag and Sarică-Niculițel vineyards have around 17 342.70 ha, cultivated with table grapes and red/white wine varieties labelled as PDO (51%) and PGI (15%).

Danube Terrace wine growing (VII), can be found along the Danube on sandy soils and includes two main vineyards (Greaca and Ostrov—11 305.34 ha). The main production is table grapes and white wine varieties (PGI 3%).

Sands and other lands from South favourable wine region (VIII) include three vineyards (Calafat, Dacilor, Sadova-Corabia) on 13 029.40 ha cultivated with wine grape varieties labelled PGI (4%) and on small area with table grapes.

In Romania, vineyards cultivated with DOC wine varieties represents 15.1% from total vineyards area; PGI wine varieties from all vineyards hold 84.9%.

In 2015, Romania ranks first in the European Union by the number of vineyard owners (855.000 or 36% from total UE), but Romanian's owners hold the lowest average vineyards area (0.2 ha compared with French owners with 10.5 ha, or Austria—3.2 ha). The share of the vineyards area for table wines was 72.1% in Romania, followed by Bulgaria (38.4%) and Italy (26.2%).

Regardless of the global region that cultivates grapevine, global warming affects the growing area. As in other regions of the world, it is expected that in Romania and South-East Europe as well, climate change will have a major impact on the wine industry (Irimia et al. 2017). In order to cope with these changes, it is necessary to adopt new, adequate technologies that will contribute to the greenhouse gas emissions (GHG) mitigation. Viticulture, although less polluting than other agricultural sectors, has its contribution through fossil fuel consumption for maintenance or transport and energy related mainly to winemaking (Goode and Harrop 2011).

4.3 Greenhouse Gas Emissions in Viticulture

Grapevine, as a perennial plant with large canopy, is able to sequester much more CO_2 than annual crops. Unlike other industries, viticulture is not as polluting, but it is quite difficult to assess the level of greenhouse gas emissions (GHG), taking into account CO_2 emissions from the various management methods and technologies used in winemaking to the transport and distribution to the consumers (Brunori et al. 2016).

Organic soil matter from vineyards includes essential nutrients for plant nutrition and soil health, including carbon and nitrogen which are incorporated into the plant roots, microorganisms, dead tissue from plants or animals. Organic matter plays a major role in ensuring the physical, chemical and biological properties of the soil. The amount of carbon and nitrous oxide emissions from the soil is influenced by soil type, management, temperature, rainfall, vegetation (Suddick et al. 2010). Soil texture influences the carbon cycle; clay-rich soil retains organic matter between the particles and is hardly accessible to microorganisms (Krull et al. 2001).

Vineyard floor management influences the carbon and nitrous oxide loss from the soil and has major contribution in organic matter decomposition. In vineyards, greenhouse gas emissions (GHG—N_2O, CO_2, CH_4) result directly at the farm scale through soil tillage, indirect due to inputs (machines, seeds, fertilizers, pesticides, irrigation), or from grape juice fermentation, electrical power, gas and fuel consumption throughout the year, bottling and transport of wine to the consumers (Colman and Päster 2007).

Manure and compost, chopped and buried pruning debris, improve the carbon level in the soil. However, fertilizers applied in excess, on wrong place or very wet periods, lead to high GHG emissions (Toscano et al. 2013). Less herbicide applied in the vineyard increases plant biodiversity, the amount of carbon in soil and less CO_2 release to the atmosphere (Ball et al. 2014).

Vineyard irrigation contributes to N_2O and CO_2 emissions. Nitrous oxide (N_2O) is 300 times more dangerous for global warming than CO_2. High moisture content in the soil is equal with more N_2O emissions which are generated by microorganisms and organic matter decomposing. However, enough water in soil stimulates canopy growth and more carbon sequestration in plants (Robertson 1993).

4.3.1 Vineyard Carbon Dioxide Emissions and Potential Carbon Sequestration

Carbon atom is found in all organic plant or animals. Unfortunately, according to the latest statistics, Earth has passed the threshold of 400 ppm (parts per million) of carbon dioxide in the atmosphere, and there is very little chance that this limit will ever be lowered. By photosynthesis, plants convert CO_2 and H_2O into oxygen and carbohydrates. At night, photosynthesis stops, but the vine continues to respire. However, the amount of CO_2 released at night is lower compared to O_2 released or CO_2 sequestered over a day (Fraga et al. 2012). Simultaneously with surface photosynthesis, organic matter is decomposed in the soil; organic exudates from the roots, crops debris or the fall leaves are decomposed by the microorganisms and contribute to the soil fertility. Soils in general are a huge organic carbon pool (SOC), which is estimated to be 1 500–2 000 Pg C (1 Pg = 1015 g) till a depth of 1 m and at 2450 Pg till 2 m deep into the soil (about 2/3 from terrestrial carbon). In the same soil layers, inorganic carbon is stored up to 750 Pg (Carlier et al. 2009). It has been estimated that soil can be seized up to 20 Pg in 25 years (Zomer et al. 2017). The carbon stock in the vineyards remains constant without soil and other inputs in the soil (FAO 2017).

According to recent studies concerning winemaking and its life-cycle assessment (LCA) from the Oregon Region, viticultural practices contribute about 24%, winemaking with about 11% and packaging with 23% to the carbon footprint in wine life cycle. Distribution and transport rate of carbon footprint are around 13% but are greatly influenced by distances, type and models of bottling and packaging. Storage, consumption and refrigeration have 18% contribution to carbon footprint (CF), while disposal of wastes and packaging contributes with about 11% (Bonamente et al. 2016; Iannone et al. 2016; Benedetto 2013).

4.3.1.1 Direct and Indirect GHG Emissions

In vineyards and winemaking, there are the activities that result in greenhouse gases emissions and CO_2 sequestration. According to the Kyoto Protocol, OIV covers four greenhouse gases (CO_2, CH_4, N_2O, SF_6) and other two groups of hydrofluorocarbons

(HFCs) and perfluorocarbons (PFCs). Direct gas emission starts with the change of land use from previously forest or pasture ecosystems in vineyards (Suddick et al. 2010). By turning grassland into arable soil, around half of the carbon sink is lost in the early years (Johnston et al. 2017). The reverse process of C sequestration lasts up to 50 years for permanent grassland to accumulate the lost carbon stock. Researches by Garwood et al. (1977) have shown that grassland contains in the first 10 cm of soil a double amount of C compared to tillage soil from vineyards.

Vineyards "produce" CO_2 through vine respiration, soil tillage and fossil fuel, but "consume" CO_2 by photosynthesis. Nearly insignificant in vineyards, methane is released from anaerobic degradation process of organic matter, while nitrous oxide (N_2O) results from nitrogen fertilizers and transformations in the soil (Fraga et al. 2012). In the winemaking sector, refrigerant fluids release gases like hydrofluorocarbons (HFC), PFCs and SF_6; cold extraction and maceration, grape juice refrigeration, debourbage in white wines, pellicular maceration in red wine-making, controlled fermentations, cold storage of finished wines, amicrobic, colloidal and tartaric stabilization or ageing in oak require optimum temperatures (Bernard 1999).

4.3.1.2 N_2O Emissions

The most noxious gas in the vineyards is N_2O, considering the high greenhouse potential of this gas. It contributes to the depletion of the ozone layer in the stratosphere (Portmann et al. 2012). Research results estimate that about 50% of the vineyard pollution is generated by this gas (Wine Institute 2014). Nitrous oxide (N_2O) results naturally by nitrification/denitrification of organic fertilizers and especially synthetic nitrogen application. Ammonia by biological oxidation is transformed into nitrite (nitrification) followed by next step of nitrogen cycle, conversion of nitrite into nitrate. Nitrate ion is one of the most soluble anions in water. All these transformations are strongly influenced by temperature, humidity, pH and carbon amount in soil (Fan and Li 2010). Nitrous oxide (N_2O) release from the soil is influenced by the unstable carbon stock due to the incorporation of green fertilizer, weeds or stubble into the soil and more nitrates combined with soil moisture. A higher amount of labile C and NO_3 from soil leads to a higher amount of N_2O emission in the atmosphere (Butterbach-Bahl and Dannenmann 2011).

On the other hand, the nitrogen application as fertilizer increases the amount of sequestered carbon in the canopy and vine wood, which through leaves and pruning wood is added into soil year after year (Bouwman et al. 2002). The largest amount of nitrogen (nearly 75%) is stored in vine roots, trunks and canes (Bates et al. 2002).

In order to decrease nitrogen emissions, it is necessary to apply fertilizers in the optimum quantity during the active growth of the roots (before bud break and after harvest, respectively) correlated with the optimum temperature and humidity in the soil. Opinions concerning the contribution of soils to N_2O emissions are divided. On the one hand, soil tillage increased emissions as a result of intensive denitrification process (higher NO_3 accumulation), and on the other, cover crops increase emissions after extraction of larger amounts of nitrogen from the soil that is no longer decomposed by microbial biomass (Suddick et al. 2011). Relative equilibrium was found by Garland et al. (2011) in Mediterranean vineyards between soil emissions and no-tillage system.

CO_2 Emissions

Soil carbon is related to soil quality and is strongly linked to the nitrogen cycle, both being components of organic matter in the soil. It has been found that carbon stocks increase with depth due to the addition of organic matter in the deeper soil layers during soil tillage (Suddick et al. 2010). Soil organic carbon ensures fertility and soil health (Smith et al. 2008). As more CO_2 is stored in the soil as biomass or organic matter, lower the concentration of this gas in the atmosphere (Alvaro-Fuentes et al. 2008). The carbon stock in the soil depends on the climate, soil texture, land use and vegetation. Soil covered with natural vegetation accumulates a higher amount of carbon compared to those in which frequent and deep tillage are performed (Krull et al. 2001); CO_2 is released from the soil when organic matter is decomposed and taken up by plants. Direct emissions of GHG are produced mainly from field tractors and equipment, in wineries by diggers, forklifts, water heaters, bottling halls, etc., and electric power consumption. Grapevine is one of the perennial crops that are preserved for decades and can act as a carbon sink through the wood that grows continuously and through the pruning debris which can remain on the ground. Debris and leaves from soil help to increase the carbon stock for a long period of time (Johnston et al. 2017).

Grapevine maintenance and cover crops can increase the amount of organic matter in the soil. Biomass from cover crops or other sources decomposes over time with the release of CO_2. Carbon sequestration in soil is a long process. Climate and soil play a major role in storing carbon in the soil. More carbon amount in the soil is correlated with less N_2O emissions (Garland et al. 2011).

Data on GHG and carbon sequestration in vineyards are scarce, as research requires long time (3–5 years for N_2O and CH_4 and 10–20 years for C sequestration—Carlisle et al. 2010). The accuracy of the research data is relative. For example, Rugani et al. (2013) reported 22% CO_2 emission for the vegetation and packaging cycle, while Bosco et al. (2011) found 7% carbon emissions for planting stage in Italy, with many tractors passes for tillage and planting with a lot of fossil fuel consumption. More conclusively, Marras et al. (2015) specified CO_2 emission of 0.39 kg/1 kg of grapes in South Sardinia (Italy) vineyard.

The amount of carbon sequestered in the soil can be increased by using green fertilizers grown between rows, cover crops or pruning debris. This type of floor management is, however, unclear because plants are competing for nutrients and especially for water with grapevine. Very well-developed root system also leads to an increase of carbon sequestered in the soil. To limit the temperature increase in soil and decomposition of organic matter, resulting in CO_2 emissions decreases and alley-row mulch can be used. Grape berries contain great amount of carbon during fruit set and growing season. Powlson et al. (2011) specify that: "in a temperate environment, organic matter from soil, after one year sequesters only 1/3 carbon from the initial content and the remaining is released in the atmosphere".

Emissions from Wine Closures

Cork closures have a minor impact on carbon emissions (4%), being environmentally friendly and wine consumers' favourites. Some researchers even argue that these corks contribute to GHG mitigation as they are a bio-based product. Cork trees are even considered as an important reservoir for carbon storage in the soil as a result of the conversion of CO_2 into O_2 during photosynthesis and organic matter in cellulose.

According to Pereira et al. (2007) studies in cork forest near Evora from Portugal, 179 g C cm^{-2} are sequestrated annually. In Portugal, 4.8 million tonnes per year or 5% from the entire emissions of CO_2 in the country can be absorbed by the cork forests. The 1-year absorption of these greenhouse gases is equal to total emissions of 490,000 cars (Pereira et al. 2007). The accumulated thickness of all layers of cork removed from a cork tree throughout its life (about 200 years) is 3–4 times larger than a tree from which it has never been harvested. Using aluminium caps involves emission of larger amount of greenhouse gases, followed by plastic closures (10% emissions) that are made usually from recyclable plastic (Marin et al. 2007).

Winery Emissions

In Romania, there are more than 250 wine cellars. From those, 140 produce and sell bottled wine. Wineries are generating greenhouse gases during various activities. To produce the wine, energy is needed for crushing and pressing the grapes, filtering the must, for cooling or heating the fermentation tanks and finally for bottling, storing and transporting the wine (Niccolucci et al. 2008).

In wineries, part of the energy consumption (electric, fossil fuels) can be replaced to a certain extent by solar energy or other renewable sources, for increasing efficiency and mitigation of GHG emissions from lighting, fermentation tanks and filtration, of refrigerators, etc. Night-time cooling tanks, windows and large doors, for shorter gap in temperature reduction, help to reduce energy consumption by up to 15% (case study in Recas vineyards). For barrel wine maturing and sensor quality pattern, most wineries in Romania have built underground cellars that keep constant temperature throughout the year without energy consumption (Șerbulea and Antoce 2016).

Hot water used to wash bottles can be reused for washing other equipment. Recycling of wastewater from wineries can be used to irrigate vineyards with a significant reduction in energy consumption for pumping and bringing water from longer distances. Comandaru et al. (2012) studied wine life-cycle assessment

(LCA) in wine production from north-east of Romania (Iasi County) facility (75,000 hl/year wine production) to set the impact on environment of one white wine bottle. Production stages, energy and transport had significant impact on wine LCA. Winemaking has the major contribution on water consumption due to the large volume of wastewater during wine production. A lot of energy is necessary for removing from wastewater the pollutants until normal limits.

An option for GHG mitigation in wineries is to generate own electricity. For example, Carastelec winery from Salaj County (north-west of Romania) works with green energy: heating and cooling are done with heat pumps, and energy consumption is provided by solar panels; each year (without climate or pest damages), the winery produces 200,000 wine bottles from grapes harvested on 22 ha vineyard.

Stefanesti winery (Arges County, South of Romania) has 25 ha vineyards and is the only one cellar with completely energy autonomy in Romania. Each year, the winery produces 40,000 wine bottles. Electricity is provided by the 102 solar panels installed on the roof with a total of 25 kw (Fig. 4.2). The wine cellar also has a geothermal heat pump, powered by three drillings with 120 m deep. For the water required for the wine cellar, drills were made at 200 metres deep (Grigorescu 2018).

Colman and Päster (2009) calculate the carbon footprint taking into account the agrochemicals, mechanization, water for one tonne of grapes, electricity, natural gas, bottling, transport of bottled wine, etc., for the 2001 wine world production (2,668,300,000 l), and the result was 0.08% of whole GHG emissions. The amount generally not considered impressive is however equal to the emissions of about 1 million cars during 1 year (Colman and Päster 2009).

Transportation is one of the major sources of GHG in wine industry. In the recent year's flex tanks of 25,000 l, bottling and packaging near the market destination are viable alternatives, especially for table wines. Biofuel engine, electric engines for tractors, fewer passes by tractor, two tools attached to tractor (one rear,

Fig. 4.2 Stefanesti winery with 102 solar panels on the roof (*Source* Denis Grigorescu)

one front for two treatments/operations in the same time) reduce the time for tractors use and are options for the future.

Bottling

For bottling the quality wine, energy is consumed for the bottles and boxes production necessary for packaging. To decrease the carbon footprint, there is an alternative to bottling in light bottles. If the weight of a classic bottle of 0.75 cL is currently around 500 g, one lightweight glass is only 300 g (Forsyth et al. 2008).

"Lightweight" glass, as it is called by manufacturers, is made by reducing the thickness of the wall and removing that thick part that is naturally found in the bottom of the glass. Reducing the raw materials such as quartz sand and sodium carbonate led to an overall cost savings of 10%. Manufacturers of such bottles are also advised to use a larger amount of recycled glass, such as glass pellets. In 2003, a Hopland-based wine factory in California decided that their wine would be bottled in over 23 million of such bottles. Thanks to this choice, the amount of greenhouse gases in the USA decreased by more than 14%, more precisely by 2985 tonnes of CO_2 in 2003 from this factory. This greenhouse gas reduction was equivalent to planting over 70,000 trees and raising them for 10 years (Associated Press 2008).

Bag-in-box is an organic way to pack and transport wine with reduced carbon footprint (it was invented in the 1950s in the USA). This type of packaging reduces carbon footprint by 40%. Another advantage is that they are easy to handle and do not break easily. The disadvantage is short shelf-life (up to 9 months), and metallic polyester can crack. Bag-in-box or boxed wines that first appeared on the market in 1960 used for bulk wines were considered cheap at the time. This type of bag has one or more layers of cardboard, flexible and high strength (Yam 2009). Girboiu, Ostrov Domains, Budureasca, Oprisor Wine Cellars, Recas Wine Cellars, Odovidis-Jaristea or Vinarte are just some of the Romanian wineries selling PGI wines and table wines (white, rose and red), dry, semi-dry or semi-sweet, "bottled" in PET or a 3, 10 or 20 l bag-in-box.

Times have changed, and today, this type of packaging is mainly for certain varieties of young white wine. Manufacturers claim that this packaging presents the easiest way to open, compared to all currently available containers on the market. In spite of the efforts being made for global spread, this type of packaging still has the disadvantage of wine oxidation even when it is not opened. Thus, it cannot be used on an industrial scale for the long-term preservation or ageing the wines.

In conclusion, choosing the wine according to the bottling type remains to the consumer. However, it should be known that if wine will be consumed in a year or two, alternative packaging should be used while wine for ageing and storage should be bottled in glass containers (Penela et al. 2009).

In recent years, for cheaper table wine, bottling in plastic (PET) bottles from recyclable material (from 0.25 to 1.5 l) has been tried, to replace the glass bottles and make the transport easier and safer. PET helps to protect against colour oxidation over long periods of time and minimize temperature differences. They are

100% recyclable and 90% lighter than a traditional bottle, and they reduce transport costs and the amount of fuel used by trucks to deliver. However, consumers do not appreciate plastic packaging primarily for environmental reasons, but also the quality of wine that oxidizes much faster than in glass bottles (Imkamp 2000).

One of the most viable alternatives for wine bottling is Tetrapackaging. Tetra pack containers are from paper and weigh 40 grams compared to glass bottles weighing up to 700 grams. The production of these packages is done with about 92% less raw materials and 54% less energy. This means 80% less greenhouse gas emissions and 60% less solid waste. Additionally, these containers can be easily stacked and are resistant to transport and storage because they do not break (Borg 2013).

Unfortunately wines bottled in Tetra Pak, “lightweight” bottles, etc., are for retail selling because the consumer has the impression that the wine is of poor quality and does not realize that the price is lower due to the low cost of the packaging. The bag-in-box has 80% less carbon footprint than glass packaging (the entire production chain from vineyard to the wine bottle). Because producers want to sell their wine, packaging decision is determined by the market and consumer preferences rather than by the winemakers (Colman and Päster 2007).

Globally, 2.7 billion people are affected by water scarcity for at least 1 month each year (Degefu et al. 2018). Water footprint in food is high (e.g. 1 kg of beef requires around 15 thousand litres of water, Gerbens-Leenes et al. 2013). Winemaking industry is not an exception. Ene et al. (2013) evaluated the water footprint of a 750 cl bottle of wine produced in a medium-sized wine cellar in Romania, based on the production chain diagram representing current emissions and environmental impacts. The results of this study indicated that nearly 99% of the total water footprint is related to the use of water in the supply chain. The three water footprints are: green—water from precipitation stored in the root zone and is incorporated by plants, evaporated or transpired; blue—comes from groundwater or surface resources and is incorporated in products or evaporated; grey—is fresh water necessary to assimilate pollutants for meeting water quality standards (Bonamente et al. 2016). GHG emissions decreasing by water, raw materials or energy savings in the winemaking industry from Romania are an actual goal. Several practices are already applied in recent years (vineyards floor management, pest control by novel technologies, wineries waste treatment and monitoring, or increase water resources use efficiency).

4.3.1.3 Ageing Wine in Barrels

Wood barrel will never go out of winemaking. Maturing wine in barriques (225 l barrels, equivalent to 300 bottles of 0.75 l) is very popular in wine cellars that want to market the highest quality wines. The barrels of oak and acacia (for white wines) have been used since ancient times for flavour and preserving the wine quality.

About three and five barrels can be manufactured from one oak tree (depending on size). An oak tree of 100 years old and 20 m height has leaves that cover 1,600 m^2 area, and produces 12.8 kg/day or 4.672 kg/year of O_2 that is necessary for 11 peoples and absorb about 2,265 kg of CO_2 (del Alamo-Sanza and Nevares 2015).

The wine ages in oak barrels for approximately 3 months to 2 years, depending on the wine and the number of barrel use. A barrel can be used 3–4 times. Subsequently, the wood tannins will be exhausted and the pores of the wood get clogged. Between the uses, the barrel is hygienized by repeated rinsing with hot water and sulfation. An interesting observation has been made that Romanian wines improve their aroma and taste qualities in American or French oak barrels, while South African wines are improved in Romanian oak barriques.

Wine Distribution

Wine is produced usually in specific viticultural regions and must be transported to the warehouses, markets and wine drinkers. The transport chain depends on distance (trucks, rails and ship or air cargo) and can thus have a large carbon footprint. Air cargo has the bigger impact concerning carbon emissions (11 times more than 460 shipping, followed by trucking 5 times), according to the research results of Colman and Päster (2007).

4.4 Vineyard Floor Management

Grapevine grows on the same land for at least 30–35 years, and it is an intensive labour crop and over the year requires significant soil tillage. Therefore, vineyard soils are generally anthropic soils, poorly structured, low in humus and capillary porosity, with severe erosion on sloping lands, reduction of soil organic matter; soil compaction after repeated tractor and equipment passing in wet periods; imbalance of mineral nutrition, which generates a high sensitivity to pathogens (diseases, pests, frost, drought, etc.). Correct tillage in the best moment is very important for humus preservation, nutrients accessibility, weed control, chemical and biological activity (Duda et al. 2014). Nearly 60% of the vineyard area is covered by middle rows, an unproductive field but with major impact on grapevine yield and quality. Vineyard floor can be managed by tillage (bare soil), herbicides, cover crops, green manure, mulch, etc. (Dobrei et al. 2014). To avoid soil structure degradation, tractor and additional equipment should be used such that several different management activities are carried out simultaneously. Alleyways with cover crops as buffer between tractors tires and soil, mulching, green manure are only few possibilities to reach higher yield and production and to have a healthy soil.

4.4.1 Bare Soil Tillage

Cover crops are used in vineyards since ancient times, but few data are available about their influence on soil carbon cycle. Until the early 1980s, bare soil was the traditional floor management in viticulture (Pool et al. 1991). Bare soil advantages are more efficiency of water in the soil, increasing the amount of nitrogen, mobile phosphorus and potassium in the soil and enhancing the photosynthesis process in the vine leaves (Murisier 1981). Disadvantages include the acceleration of the humus degradation; destruction of soil structural aggregates as a result of four to five tractor passes per year; increasing soil erosion process; large volume of dust that favours mite development and air pollution; high fuel consumption and expenditure for tillage works (Martinson 2006).

Different floor managements in Burgundy vineyards from the West of Romania, including bare soil under-vines and middle rows or cover crops between rows, confirm other research results concerning cover crops influence on chemical and physical soil traits, vine vigour or crop load and weed control improvement (Dobrei et al. 2015). Nitrogen infiltrates more slowly in the soil with real effect on canopy and grape yield. Soil organic matter is a major component of soil, with extremely important contribution of water and nutrients for plant nutrition and for soil carbon sequestration. Minimum tillage on several soil types (phaeozem, haplic luvisols, chernozem and molic fluvisol) from north-west of Romania increased the organic matter from 0.8 to 22.1% and water stability of soil aggregates (WSA) up to 13.6 from 1.3% in the first 30 cm of soil, compared with bare soil system (Moraru and Rusu 2010).

Extending these results to 50% of the Romanian arable land, it was estimated that 6.9 million tonnes/year of carbon could be stored if minimum tillage is performed. Furthermore, no-tillage or moderate tillage on argic–stagnic faeoziom soil (north-west of Romania) influences the time and the amount of carbon sequestration. Results after 3 years of observations show the effect of soil tillage on daily average soil respiration as follows: no-tillage had the lowest influence (315–1914 mmoli m^{-2} s^{-1}) and 318–2395 mmol m^{-2} s^{-1} for moderate tillage system, respectively, compared with conventional tillage (321–2480 mmol m^{-2} s^{-1}) (Moraru and Rusu 2013). Tractors and equipment used for minimum tillage on argic–stagnic faeoziom in Jucu Experimental Station (north-west of Romania) increased the GHG emission twice compared with no-tillage soils. The smallest rate of CO_2 emission in minimum soil tillage was 1929 ppm, and the highest rate was 8901 ppm. When no-tillage was adopted, the CO_2 concentrations registered were between 1443 ppm and 4880 ppm/day (Marian et al. 2013).

Relation between soil, climate, grapevine and variety influence on wine character is different in each viticultural region. Management of vineyard floor is particularly important in the wine production chain. Soil moisture has a strong impact on grape yield and quality during growing season. In Valea Călugărească vineyards, Fetească regală grapevine located on mollic reddish-brown soil, floor management was evaluated during 2012–2013. Soil moisture was measured, and comparisons among bare soil, straw mulch across vine rows and alleyways (10 cm layer), mulching with pomace compost alleyways (10 cm layer) and minimum tillage were made. During both years of experiment, soil moisture in the first 60 cm was normal and quite equal in the early growing season (April–May), but in summer and autumn time, mulching system plots had positive influence on water evaporation and soil moisture (Serdinescu et al. 2014).

Minimum tillage increases significantly the humus amount in soil by 0.8–22.1% especially on vertic preluvosoil. Hydro-stability of macroaggregates and organic carbon is positively influenced by minimum tillage from 1.3 to 13.6% in the first 30 cm of soil compared with the conventional tillage. Both humus amount and soil structure contribute to increasing soil fertility and have positive influence on soil permeability and water storage in soil as groundwater storage (Duda et al. 2014). Similar results have been observed on Somes Plateau argic faeoziom soils (north-west of Romania), when no-tillage, minimum tillage and conventional tillage were compared for soil respiration. In no-tillage system, the lowest soil respiration (315–1914 mmol m^{-2} s^{-1}) was found. CO_2 release from soil in minimum tillage was (318–2395 mmol m^{-2} s^{-1}), while in conventional tillage, production of CO_2 was the highest (321–2480 mmol m^{-2} s^{-1}). The CO_2 production was maximum in autumn (2141–2350 mmol m^{-2} s^{-1}) and in late spring (1383–2480 mmol m^{-2} s^{-1}). After 3 years, humus amount in soil increased by 0.64% when no-tillage was applied, followed by minimum tillage system with 0.41% humus level in soil (Rusu et al. 2016).

4.4.1.1 Grass Strips Alleyways

Soil is subjected to various degradation processes. Some of these are specific to viticulture: water and wind erosion or soil tillage; compaction; decreasing the amount of organic carbon in soil and soil biodiversity; soil salinisation and sodification; soil contamination with heavy metals and pesticides or excessive amounts of nitrates and phosphates. On clay soils, repeated tractors passing decreases soil porosity in the vine root area from middle rows. The fine soil particles by leaching agglomerate the deep layer resulting in a long-lasting compacting with adverse consequences on the vine vigour and productivity. Symptoms are yellowing or redness of the leaves associated with abnormal deformation of the leaves of vines (Valenti et al. 2002).

Grass strip alleyways and bare soil under-vines in vineyards are a common soil management system and are efficient in areas with more than 600 mm annual rainfall. Weed control on vine row is done by manual hoeing or by repeated application of residual or foliar herbicides; this system is recommended for increasing land slope stability (Murisier and Sbeuret 1986). The advantages of this system application are: reduction of erosion on sloping lands; avoiding hardpan formation; increasing the input of organic matter in the soil; improving soil structure and porosity; avoiding nitrogen runoff and leaching throughout the year; better water infiltration (Colungati and Cattarossi 2013).

Constant tillage exposes the soil to erosion as many of the vineyards are located on slopes with mild or medium slopes. On these lands, the main problem is not the landslides, but the gradual and constant transfer soil which decreases its fertility, causing a "slip" of the roots that are thus forced to expand around to find the necessary nutrients and water in the soil (Kaspar et al. 2001). Grass strips are an alternative for vineyards' middle row soil protection. In organic viticulture, this is the first choice in vineyards floor management for increasing soil fertility and for restoration of degraded or weed-infested soil. Water and wind erode the soil by about 2.5 cm per year (Goulet et al. 2004). Grass strips protect the soil by avoiding leaching, compaction and erosion due to tractors and other equipment traffic (middle rows grass strips favour iron and phosphorus absorption, contribute to less mobile minerals alteration, reduce the rot attacks, make easier the access to the vines, and reduce the maintenance costs (Eynard and Dalmasso 2004).

Grass strips in the middle rows contribute to the improvement of grape quality, by increasing the amount of sugars in berries, vine vigour and grape yield. This system of floor management in vineyards mainly protects the soil from erosion (Goulet et al. 2004). For example, in the Rheingau (Germany) wine-growing region, on slopes ranging from 10 to 32%, grass strips reduced water running after heavy rains up to 1.8% from rainfall volume compared to 50% on the bare soil (Krull et al. 2001). The amount of soil lost by erosion in vineyards with grass strips is insignificant (3.1 kg/ ha), while on bare soil it is between 30 and 100 t/ha, depending on the degree of slope (Emde 1990). Grass strips enhance soil aggregates stability in the first 10–15 cm (Condei and Ciolacu 1991). In vineyards from many countries (Austria, Germany, Switzerland, Italy, France, Romania, etc.), middle rows are covered with mixtures of plant species. This floor management system is recommended in regions with annual rainfall of 600–700 mm, of which at least 250 mm occur between May and August (Valenti et al. 2002).

Well-structured soils store a lot of water, air, heat and nutrients, ensuring favourable conditions for vine growing and fruit set. Vineyards' middle raw soil maintenance with permanent grass cover crops improves the structure and physical properties of the soil due to the organic matter addition and increasing microbial biomass through the biological activity (Bandici 2011; Dobrei et al. 2016).

Under high or too low soil moisture, tractors' passing has negative impact on soil physical and chemical properties (Dobrei et al. 2008). Besides financial advantages, the permanent grass strips also provide advantages such as protection against soil erosion and degradation, allowing phytosanitary treatments in favourable stages, reduced water loss. (Dobrei et al. 2009).

The extended grass roots contribute to the soil loosening by adding organic matter transformed into humus that contributes to the activation of microbial life. Both the root mass and the above-ground plant contribute to humus restoration, the beneficial effect of dead plants being influenced by their chemical composition and diffusion in the soil (Bernaz and Dejeu 1999).

Grasses' extent root system prevents soil erosion on sloping lands and is exposed to wind damage. Perennial plants can absorb nitrogen from the soil, but unlike legumes can only contribute to soil improvement by supplying biomass. Annual grasses such as rye, oats, barley or triticale sown in autumn are mowed or buried in spring to protect against frost. Therefore, the soil absorbs more heat over the day and releases it at night. Stubble left after mowing competes with weeds and contributes to decrease dust level and soil compaction after multiple tractors passages (Christensen 1971). However, besides advantages, natural vegetation or seeded plants can become competing for water and nutrients with vines. This competitiveness depends on the climatic conditions (especially the rainfall amount), grapevine requirements for water, the water absorption capacity of the cover crops species and the type of soil (Sicher et al. 1993). The disadvantage of natural vegetation is also derived from slowly and unevenly growing and clear space for weeds (Sicher and Dorigoni 1994).

Alternate Clean Cultivated and Grass (Legumes) Strips Alleyways

Floors managed with alternate clean cultivated and grass (and legumes) strips alleyways are recommended in vineyards with at least 350 mm rainfall during summer season (April–October) (Piţuc 1989). This system limits water runoff, soil erosion, increases the input of organic matter into the soil, allows tractors passing on wet weather, and reduces fuel consumption and the manual work (Condei and Ciolacu 1991). Usually after spring tillage, short species such as lawn grass (Lolium perenne—12–14 kg/ha), white clover (Trifolium repens) or species with spread roots like oilseed radish (R. sativus var. oleiferus or Raphanus sativus) are seeded. These plants can improve the soil structure, water drainage and fast root development (Bernaz and Dejeu 1999).

Grass mowed during the growing season is left on the ground as mulch. After 8–9 years, the grass strips are dissolved by tillage and the alleyways are changed with bare soil. Growing grass between vine rows for long period is not advisable because the soil becomes compacted, as emphasized by multiple tractor passing which increases soil stress. Therefore, the soil is loosened and reseeding is recommended every 4 or 5 years (Bernaz and Dejeu 1999). Once the symbiosis process of the legume plants starts, elements like nitrogen, phosphorus, potassium, iron and other minerals are released and absorbed by the soil. The vigorous root system that can reach 2–3 m underground helps to loosen soil, soil oxygenation and drainage of excess water resulting from heavy rains, snow melting, etc. Under dry and high temperature period, the well-developed leaves protect the soil from the sunburn, thus avoiding dehydration.

Plant species sown as cover crops are different for each viticultural region, climate and slope. For example, in vineyards from the Galati region (south-east of Romania), on dry and medium humidity areas with slope $\leq 10\%$, alleyways were covered with green manure (mixture of common vetch—Vicia sativa (120 kg/ha) and oat (60 kg/ha)) alternate with clean cultivation alleyways. In the same vineyard have been tested alternate alleyways of green manure (grass and legumes mixture) alternate with natural vegetation (Enache 2007).

Smooth brome (Bromus inermis Leyss.) strips, 1.2-m wide, were tested in sloping vineyards from the Moldavia region for water runoff and soil erosion control. The amount of soil loss during 1 year was estimated at 1.2 m^3/ha, which is considered tolerance value. The fibrous root system contributes to reduce soil erosion and remove excess nitrogen from the soil (Enache 2007).

Peas (150–200 kg/ha), lupine bean (150–200 kg/ha), broad bean (150–200 kg/ha), soybean (150–200 kg/ha), grass legumes mixture (60 kg oat/ha + 120 kg peas/ha), rye (80–100 kg/ ha), vetch (120 kg/ha) are recommended as green manure (Enache 2007). They are fast-growing crops, with the possibility of atmospheric nitrogen fixation. Green manure is recommended in vineyards with annual rainfall over 600 mm, as well as in irrigated vineyards with large middle rows (3.0–3.6 m). Because of this, the soil is enriched in organic matter and nutrient mobility increases; excess moisture is taken by plants during the first stage of growing, and soil erosion reduces by using green mulch (Duda et al. 2014). Green manure is recommended for sandy soils. Mustard or rape on clay soils is recommended and peas on acidic soils. Lupine and clover are suggested as green manure on sandy soils. Debris is added by tillage into first 10–20 cm on sandy soils in early spring and 5–10 cm on clay soils depending on the soil type, moisture and amount of biomass. It is not advisable to incorporate green manure into the soil shortly after rain (Dobrei et al. 2016). Organic manure increases the biological activity in soil and, therefore, the fertility. About 3–50 tons/ha manure or grape pomace compost is recommended for optimum plant nutrition, yield and production after decomposition and transformation in humus by microorganisms (Vătămanu 2012).

Benefits for soil are different depending on the C/N ratio and the burring stage (young, mature, or old plants). Young plants with a low C/N ratio produce a small amount of organic matter but significantly stimulate soil biological activity (as source of minerals for microorganisms found near roots). However, mature or old plants with a high C/N ratio give an increased contribution of organic matter in soil (Moraru et al. 2015).

In vineyards from Danube terraces with rainfall over 600 mm, annually the green manure alleyways are recommended, for proper soil water balance and less soil erosion, with positive influence on organic matter in soil and less fuel consumption of 20–24 l/ha/year. Similar results have been observed on Somes Plateau argic faeoziom soils (north-west of Romania), when no-tillage, minimum tillage and conventional tillage were compared for soil respiration.

Fuel Consumption

In wine industry, fuel consumption is one of the major sources of GHG emissions. It is already known that fuel consumption represents among 25–40% from total energy input in a crop. Floor management in both alleyway and under-vines requires a lot of fossil fuel and contributes to the exposure of organic matter to microbial decomposition and consequently to the CO_2 release (Carlisle et al. 2009). Less soil tillage contributes not only to the reduction of fossil fuel consumption but also to soil erosion and to the increase in carbon, nitrogen oxide and water supply into the soil.

Most vineyards are found on hillside lands with gentle slopes (always slopes to the south are preferred), sheltered from winds and warm in the growing season (April–October) (Gasso et al. 2014). Fuel consumption is different depending on the region, size of vineyard, tillage system, soil type, strength and moisture, land slope or altitude (Sørensen et al. 2014). Fuel consumption was variable on different soil types from Apahida, Cluj County (Stănilă 2014). On the same soils, depending on slope deep, fuel consumption is higher up to 21% on 9 to 14° slopes compared with flat land fuel consumption (Stănilă 2014).

Soil tillage by mouldboard plough at depth between 18 and 35 cm consumes fuel from 14.61 to 20.67 l/ha (Moitzi et al. 2014). By machinery traffic control in the vineyard, and suitable tillage method, total emissions of GHG are reduced, and soil compaction and runoff decrease. Therefore, in conventional tillage fuel consumption can be decreased by less soil tillage depth or by substitute conventional with minimum or no-tillage systems. Comparing conventional tillage with minimum tillage system, fuel consumption can be decreased from 72.93 to 48.26 l/ha (Stănilă et al. 2013). Performing two or three tasks in the same pass increases efficiency and decreases fuel consumption.

4.5 Conclusions

Nowadays, the effects of climate change and especially of climatic variability are becoming obvious with disastrous consequences, mainly as a result of anthropogenic actions. The wine industry generates GHG, especially during the winemaking, bottling, preservation and transport to consumers. Fortunately, viticulturists have begun to look for solutions to reduce energy and fuel consumption, which are major causes of environmental pollution. In many vineyards, manual work is still being used for pruning and canopy maintenance over the year, but also for row under-vine tillage. In many wine-growing regions, cover crops, grass alleys or other environmentally friendly methods to increase soil fertility and provide natural fertilizers have been adopted. Night-time cooling tanks, windows and large doors, underground cellars that keep constant temperature throughout the year without energy consumption, heating and cooling done with heat pumps, energy consumption provided by solar panels, deep wells for water required in the wineries, are some of the solutions already applied in few wineries from Romania. In the recent years, bag-in-box wine and wine bottled in plastic (PET) bottle are beginning to be used on a small scale to assess consumer preferences. Manual labour is still being used in vineyards for tillage, pruning or harvest; the use of agricultural machinery is still limited, thus reducing the use of chemicals and fossil fuels. These are some of the factors that render Romania a country with the lowest GHG emissions from agriculture in the EU.

Chapter 5
Agricultural Cropping Systems in South Africa and Their Greenhouse Gas Emissions: A Review

Mphethe Tongwane, Sewela Malaka and Mokhele Moeletsi

Abstract South Africa is a major emitter of greenhouse gases (GHGs) and accounts for 65% and 7% of Africa's total emissions and agricultural emissions, respectively. South Africa has a dual agricultural economy, comprising a well-developed commercial sector and subsistence-oriented farming in the rural areas. The country has an intensive management system of agricultural lands. Agriculture, forestry and other land use sector is the second largest producer of GHG emissions in the country with 12% of the national total emissions. This review presents characteristics of GHG emissions from crop management in South Africa. It establishes trends of emissions from data collated from the literature. Main sources of GHG emissions from cropping systems in South Africa are maize, sorghum, wheat and sugarcane productions. Although the emissions from the application of synthetic nitrogen (N) fertiliser to agricultural land show a slight decrease with time, this remains the main sources of emissions from cropping systems in the country. On the other hand, national emissions from urea fertiliser are increasing. Emissions from management of crop residues are low. Conversion of land to croplands is a net source of CO_2 emissions in South Africa. Lack of investment in biofuels and production preference given to previously disadvantaged farmers has slowed their uptake. All stakeholders have to contribute actively to address the current poor status of linkages between agricultural research and policy in the country in order to reduce the current growth of agricultural emissions.

Keywords Crop management · Agricultural lands · Field crops
Biofuels · Mitigation strategies

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5.1 Introduction

Anthropogenic greenhouse gas (GHG) emissions are mainly driven by increasing demand for human food, economic activity, lifestyle, energy use, land use patterns, technology and climate policy (Thornton 2010; Vermeulen et al. 2012; FAO 2014; IPCC 2014). The population in Africa has just passed the one billion mark and is expected to double by 2050 (Branca et al. 2012). It is growing at 1.2 to 1.4% per year in South Africa and sub-Saharan Africa as a whole (Thornton 2010; Statistics South Africa 2017). Since the middle of the twentieth century, global agricultural output has kept pace with the rapidly growing population (Burney et al. 2010), with agriculture being the primary sector of most African countries (Saghir 2014).

South African agriculture is dualistic in nature, consisting of the less developed smallholder and well-developed commercial sectors (Vink and Kirsten 2003; DEA 2016). Commercial agricultural activities range from the intensive production of vegetables, ornamentals and other niche products to large-scale production of annual cereals, oilseeds, perennial herbaceous crops and tropical, subtropical and temperate fruit crops (DEA 2016). There are over 3 million smallholder farmers and 30,000 commercial farmers in South Africa (Armour 2014). Cultivated soils are generally very low in organic matter and are susceptible to wind erosion (FAO 2005; Du Preez et al. 2010).

5.2 Agricultural Land Use and Cropping Systems in South Africa

5.2.1 Agricultural Land in South Africa

More than 80% of South Africa's land is classified as either semiarid or arid, and 18% is dry sub-humid (FAO 2005). About 80% of total land in the country is used for agricultural purposes (DAFF 2015; FAOSTAT 2018), and only 14% of the agricultural land is arable (Fig. 5.1) and receives sufficient rainfall for crop production (FAO 2005; DAFF 2015). It was estimated that 12.2% of the land in the country was under cultivation in the year 2000 (FAO 2005). Croplands include annual commercial crops, annual semi-commercial or subsistence crops (DEA 2014). Field crops occupy 92% of the arable land and maize alone accounts for 51% of the land (FAO 2005). Over 90% of the cropland in the country is used to produce cereals. Perennial crops (orchards, viticulture and sugarcane) contribute about 8% towards the cropland area (DEA 2014). In South Africa, maize is the most important grain crop, being both the major feed grain and the national staple food (DAFF 2013). The total area planted to deciduous fruit amounts to 74,246 hectares (NAMC 2007). The forestry sector is well regulated in the country (Blanchard et al. 2011).

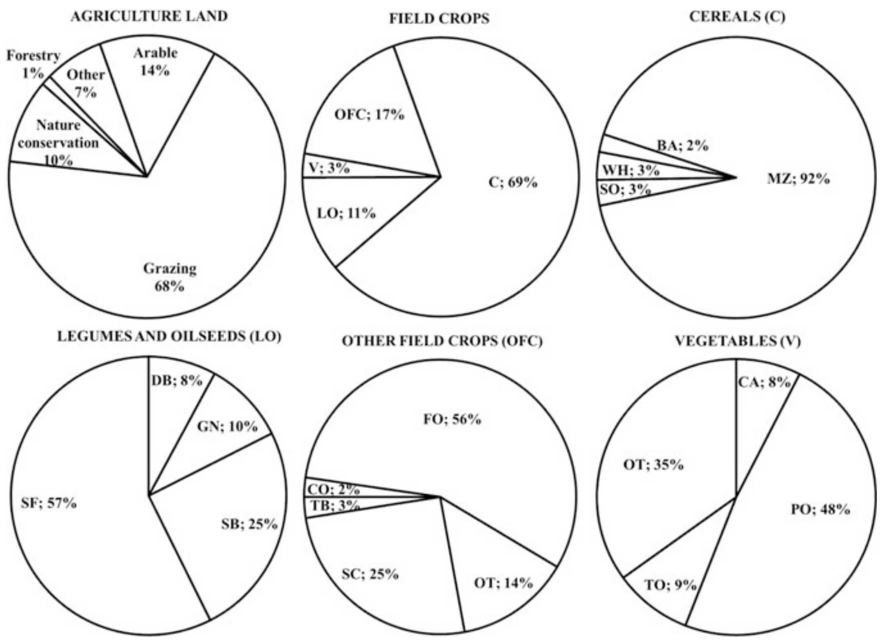

Fig. 5.1 Proportions of agricultural lands (DAFF 2015) and field croplands (Tongwane et al. 2016) in South Africa. Field crops: Cereals (C) [BA—barley; MZ—maize; SO—sorghum; WH—wheat]; legumes and oilseeds (LO) [DB—dry bean; GN—groundnuts; SB—soya bean; SF—sunflower]; other field crops (OFC) [CO—cotton; FO—fodder; OT—other; SC—sugarcane; TB—tobacco]; vegetables (V) [CA—cabbage; OT—other; PO—potato; TO—tomato]

Croplands are increasing with time in South Africa due to conversions from other land types (DEA 2014). Cropland and grasslands are estimated to have increased by 16.7% and 1.2%, respectively, between 2000 and 2010 (DEA 2014). There was a 1.2% increase in the transformed land between 1994 and 2005 (Dippenaar-Schoeman et al. 2013). According to the national land-cover data, there was only a 2.8% increase in the land used to cultivate subsistence crops between 1990 and 2013/14 (DEA 2016). During the same period, there was a further 10.6% and 16.2% increase in the land used to produce commercial permanent orchards and vines respectively. Furthermore, there was a 220.2% increase and a 7.6% decrease in the land cultivated to classes of pivot annual commercial crops and non-pivot commercial crops respectively during the same period (DEA 2016). The main drivers of land use change include environmental, political and socioeconomic challenges (DEA 2016).

5.2.2 Manure Management in Cropping Systems in South Africa

Various types of synthetic fertiliser are used during crop production in South Africa (Tongwane et al. 2016). A generic total amount of synthetic nitrogen (N) used in the country in 2012 was 0.4 million tonnes (Mt) (Tongwane et al. 2016). The application of synthetic nitrogen N fertiliser, lime application rates and area planted varied per crop (FAO 2005; Tongwane et al. 2016; Du Plessis 2003). Maize crops and sugarcane consume the highest N fertiliser and lime due to their respective large planted areas (Table 5.1). Consumption of synthetic fertiliser grew from 0.2 Mt in 1955 to 1.2 Mt in 1981 (Vermeulen et al. 2012). Various types of synthetic N fertiliser that include ammonium and nitrate concentrates are used during crop production (Tongwane et al. 2016). Maize, sugarcane and fruits account for 62%, 9% and 7.6% of national N consumption, respectively, and vegetables and wheat use 5.1% each (DEA 2016; IFA 2013). Generally, maize accounts for between 40 and 49% of the total use of fertiliser (FAO 2005; IFA 2013; Smale et al. 2011). Sugarcane accounted for 18% of fertiliser use, the second highest after maize, and contributes 10% to the total value of production (FAO 2005). The horticultural and fruit crop sectors account for 20% of fertiliser consumption (FAO 2005). Burning in sugarcane is practiced to facilitate stalk harvest and transportation, and this practice is the main source of non-CO_2 emissions (Galdos et al. 2009; Thompson 2012). Very little work has been done in South Africa to quantify GHG emissions from burnt and trashed sugarcane systems (Eustice et al. 2011).

5.3 Crop Management Practices and Greenhouse Gas Emissions in South Africa

5.3.1 Total GHG Emissions

Total GHG emissions from crop management increased from 24.3 Mt CO_2 equivalent (CO_2e) in 2000 to 28.3 CO_2e in 2010. Emissions of N_2O from the application of synthetic N fertiliser to agricultural soils in the country are the largest source of the emissions accounting for 90% of the total emissions in 2000 and 73% in 2010. A total of 81% of the synthetic N fertiliser emissions is N_2O, while CO_2 from urea accounts for 19% of the emissions from this agricultural input (Tongwane et al. 2016). Although overall emissions grew by 1.5% per annum, the largest increase by GHG type was CO_2 with 40% per annum. Total CH_4 and N_2O emissions increased and decreased at an annual rate of 0.4% and 0.6%, respectively. The emissions from soil management between 2000 and 2010 increased from 14.9 and 17.8 Mt CO_2e in 1990 and 1994, respectively (Blignaut et al. 2005). Production of field crops alone emitted a national total of 5.2 Mt CO_2e emissions in 2012 which account for approximately 17% of average annual emissions from agriculture,

Table 5.1 Average synthetic N fertiliser and lime application rates in South Africa, and area planted to selected main crops between 2000 and 2010

Crops	N fertiliser rate (kg/ha)	Lime (tonnes/ha) [after years][b]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
			Area planted ($\times 10^3$ ha)[d]										
Maize	55[a], 52.8[b], 40[c], 30[c], 20[c]	2.0 [4.0]	3189	3533	3651	3204	3223	2032	2897	3297	2896	3263	2859
Wheat	30[a,b]	1.9 [3.0]	934	974	941	748	830	805	765	632	748	642.5	558.1
Sunflower	15[a,b]	1.7 [3.0]	522	668	606	530	460	472	316	564	636	635.8	397.7
Sorghum	30[b]	2.3 [2.0]	88	75	95	130	86	37	69	87	86	87	69
Dry bean	24.9[b]	2.4 [4.0]	78	45	51	56	49	55	51	44	44	44	42
Soya beans	7[a], 19[b]	2.7 [3.0]	134	124	100	135	150	241	183	165	238	237.8	311.4
Sugarcane	92[a], 76[b]	3.3 [3.0]	429	432	430	427	425	428	420	423	389	382	376
Barley			78	73	72	84	83	90	90	73	68	75	83
Tobacco	38[a]	2.0 [3.0]	15	14.7	13.6	11.5	9.2	6	6	3.4	3.6	4	5.4
Cotton	36[a], 43.6[b]	2.0 [2.0]	57	39	23	36	22	18	11	9	6.8	5.1	13.1
Groundnuts	180[a,b]	2.0 [5.0]	165	94	50	72	40	49	41	54	55	57.4	55.1
Canola			19	27	31	44	44	40	32	33	34	35	34.8

[a]FAO (2005)
[b]Tongwane et al. (2016)
[c]Du Plessis (2003). Values depend on row width
[d]DAFF (2012)

forestry and other land use (Tongwane et al. 2016; DEA 2013). Maize, wheat and sugarcane are the main producers of the emissions by land area. Retaining of crop residues in the field after harvest accounted for 13% of the total national emissions from field crops (Tongwane et al. 2016).

5.3.2 Total CO_2 Emissions

Despite the general increase of GHG emissions, croplands were net sinks between 2003 and 2005 (DEA 2014, 2016). Croplands varied from a weak sink of 0.5 Mt CO_2 and a source of 7.5 Mt CO_2 between 2000 and 2010 (Fig. 5.2) (DEA 2014). Land conversions to croplands during the 2005–2010 period were responsible for the increased CO_2 emissions (DEA 2014). Land conversions that occurred in 2005 created a CO_2 source of 0.7 Mt in 2006 (DEA 2014). The release of N by mineralisation of soil organic matter as a result of change of land use or management contributes to an additional source of emissions (IPCC 2006). Cropland accounts for less than 1% and 21% of the national total GHG emissions and agricultural emissions, respectively (DEA 2014). The previous GHG emission report (DEA 2011) had estimated that cropland was a sink of 7 Mt in 2000. The emissions from croplands have high uncertainty levels as a result of constraints to activity data being publicly accessible and slightly different categories that are used by different data sources to classify this land use (DEA 2011, 2014, 2016; Stevens et al. 2016). More detailed cropland data that includes pivot and non-pivot systems needs to be used during estimations of the emissions (Stevens et al. 2016).

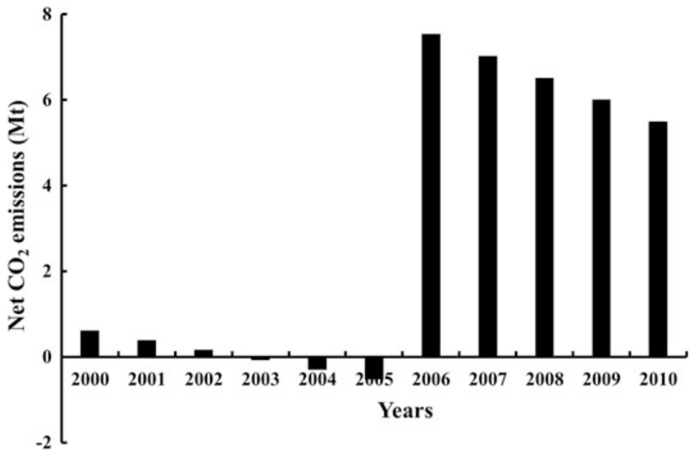

Fig. 5.2 Net CO_2 emissions from croplands in South Africa between 2000 and 2010. *Data source* DEA (2016)

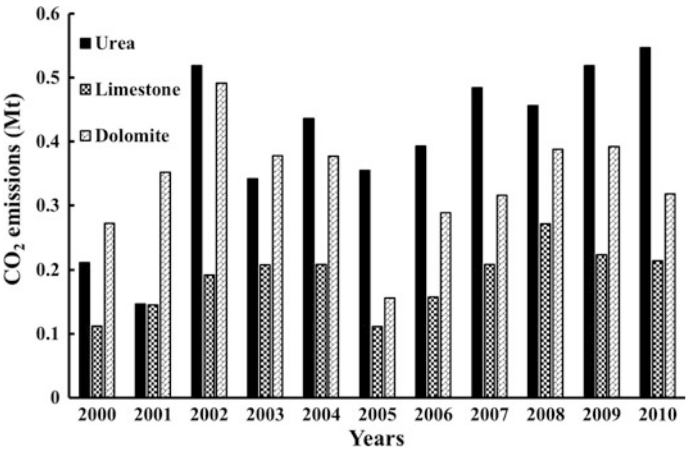

Fig. 5.3 CO_2 emissions from urea, limestone and dolomite in South Africa between 2000 and 2010. *Data source* DEA (2014)

Emissions from urea increased by 14.4% per annum from 0.2 Mt CO_2 in 2000 to 0.5 Mt CO_2 in 2010. Increases in market prices of urea post-2000 were lower than the prices of other types of synthetic fertilisers in the country (Grain SA 2011) and that could have enhanced its overall consumption and ultimate emissions. However, emissions from urea may be overestimated due to high uncertainties in the urea amounts used in the fields (DEA 2014, 2016; Grain SA 2011). Emissions from limestone and dolomite increased by annual rates of 8.4% and 1.5% between 2000 and 2010, respectively (DEA 2014) (Fig. 5.3). CO_2 from liming shows high annual variability that may be influenced by seasonal rainfall, but the general trend shows a slow increase of emissions from this agricultural activity (DEA 2014, 2016; DAFF 2010). Contribution of lime to total CO_2 emissions in 2010 is lower than in 2000 (Fig. 5.4) due to increases of emissions from net cropland and urea. Annual CO_2 emissions from the application of lime in agricultural lands contribute an average total of 1.5 Mt per year (Tongwane et al. 2016). Cereal crops, especially maize, are the major sources of emissions from this agricultural input (Tongwane et al. 2016). Emissions from urea and lime are highest in the regions that predominantly produce cereals (Free State, Mpumalanga and North West provinces) due to increasing croplands in these areas (DEA 2016).

5.3.3 Aggregated Non-CO_2 Emissions

Non-CO_2 emissions contributed 95% of the total GHG emissions in 2000 and 77% in 2010. There is generally a slight decline of N_2O emissions from crop management in the country, from 22.0 Mt CO_2e in 2000 to 20.6 Mt CO_2e in 2010.

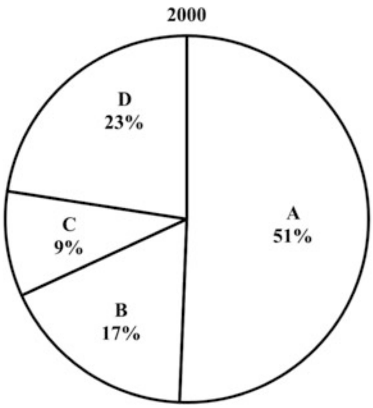

Fig. 5.4 Comparison of CO_2 sources in South Africa, 2000 and 2010 [A—cropland; B—urea; C—limestone; D—dolomite]

Applications of N fertiliser to soils are main sources of N_2O emissions (DEA 2014; Tongwane et al. 2016). Direct N_2O emissions fluctuated annually with the year 2000 having the highest and 2009 the lowest emissions of 16.1 Mt CO_2e and 14.6 Mt CO_2e, respectively (DEA 2014). The emissions of N_2O occur directly from the soils to which the N is added and through two indirect pathways (i.e. (i) volatilisation of NH_3 and NO_x from managed soils and from fossil fuel combustion and biomass burning and (ii) leaching and run-off of N from managed soils) (IPCC 2006).

Application of synthetic fertiliser to soils is the main source of GHG emissions from production of field crops in South Africa with a national total of 3.0 Mt of CO_2e (Fig. 5.5) (Tongwane et al. 2016). High emissions from synthetic fertiliser are

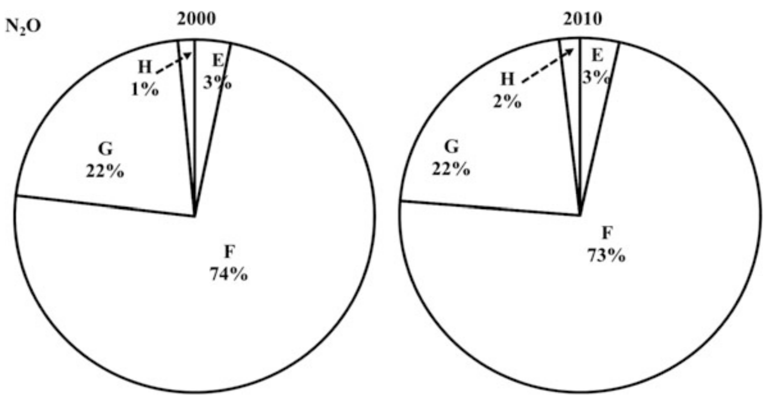

Fig. 5.5 Sources of N_2O emissions from crop production in South Africa, 2000 and 2010 [E—biomass burning; F—direct soil emissions; G—indirect soil emissions; H—manure management]

Table 5.2 Direct N_2O emissions (Mt) from synthetic N fertiliser in South Africa between 2000 and 2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Maize	2.76	3.05	3.16	2.77	2.79	1.76	2.50	2.85	2.50	2.82	2.47
Wheat	0.81	0.84	0.81	0.65	0.72	0.70	0.66	0.55	0.65	0.56	0.48
Sunflower	0.45	0.58	0.52	0.46	0.40	0.41	0.27	0.49	0.55	0.55	0.34
Sorghum	0.08	0.06	0.08	0.11	0.07	0.03	0.06	0.08	0.07	0.08	0.06
Dry bean	0.07	0.04	0.04	0.05	0.04	0.05	0.04	0.04	0.04	0.04	0.04
Soya beans	0.12	0.11	0.09	0.12	0.13	0.21	0.16	0.14	0.21	0.21	0.27
Sugarcane	0.37	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.34	0.33	0.32
Barley	0.07	0.06	0.06	0.07	0.07	0.08	0.08	0.06	0.06	0.06	0.72
Tobacco	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.05
Cotton	0.05	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.01
Groundnuts	0.14	0.08	0.04	0.06	0.03	0.04	0.04	0.05	0.05	0.05	0.05
Canola	0.02	0.02	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Total	4.93	5.27	5.24	4.73	4.69	3.69	4.22	4.65	4.50	4.73	4.84

as a result of high application rates that are aimed at improving soil fertility and crop productivity (Tongwane et al. 2016). However, emissions from synthetic N fertilisers (Table 5.2) have generally not increased since 2000 (DEA 2014) probably due to high costs of these inputs. The prices of N fertilisers are directly related to the price of natural gas which, on the other hand, is highly influenced by the crude oil prices (Grain SA 2011). Contributions to total national GHG emissions from field crops vary significantly between different crops (Tongwane et al. 2016).

Direct and indirect N_2O emissions from the application of synthetic N fertiliser on managed lands vary slightly from year to year, depending on the planted area (Tables 5.2 and 5.3). For field crops, maize production is the largest source of

Table 5.3 Indirect N_2O emissions (Mt) from synthetic N fertiliser in South Africa between 2000 and 2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Maize	0.28	0.31	0.32	0.28	0.28	0.18	0.25	0.28	0.25	0.28	0.25
Wheat	0.08	0.08	0.08	0.06	0.07	0.07	0.07	0.05	0.06	0.06	0.05
Sunflower	0.05	0.06	0.05	0.05	0.04	0.04	0.03	0.05	0.05	0.05	0.03
Sorghum	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
Dry bean	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soya beans	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.03
Sugarcane	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03
Barley	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07
Tobacco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cotton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundnuts	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.49	0.53	0.52	0.47	0.47	0.37	0.42	0.47	0.45	0.47	0.48

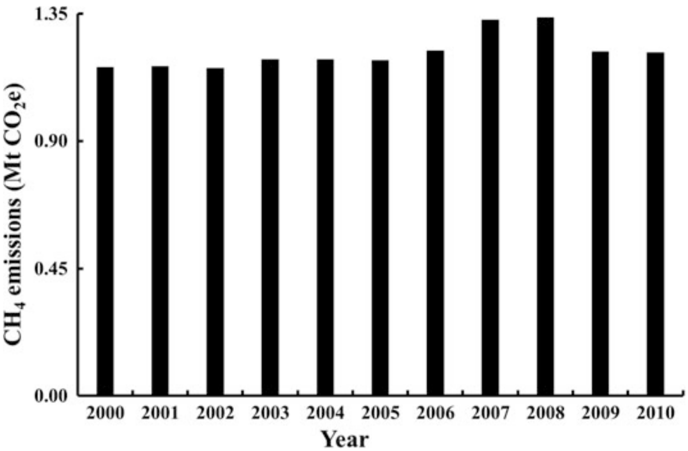

Fig. 5.6 CH_4 emissions from burning of agricultural biomass between 2000 and 2010. *Data source* DEA (2016)

emissions (Tongwane et al. 2016). However, due to a general decrease of N fertiliser applied to managed lands (DEA 2014), there is a reduction of emissions from this input. The production of maize has been declining over the last two decades, and with maize being the biggest consumer of N fertiliser, the emissions from this input have slowed (DEA 2014). However, due to increasing production area of soya beans in the country (DAFF 2015), emissions from this crop commodity show a rapid increase. Synthetic N fertiliser contributes more than half of the total emissions from field crops (Tongwane et al. 2016).

Burning of agricultural biomass resulted in annual CH_4 emissions of approximately 1.2 Mt CO_2e per year between 2000 and 2006 (Fig. 5.6) (DEA 2014). The emissions increased and peaked in 2007 and 2008 with 1.3 Mt CO_2e as a result of increased average percentage of area burnt (DEA 2014). The burning of biomass is classified into the six land use categories defined in the IPCC guidelines (forest, grassland, cropland, wetlands, settlements and other land) (DEA 2014). It is estimated that croplands contribute 14.6% of emissions from biomass burning.

Total N_2O emissions from management of crop residues are gradually decreasing over time (Table 5.4). There is a decline in emissions despite a general increase of emissions from management of maize residues. Main decreases of emissions are from wheat and sugarcane as a result of reduction of production areas of these crops over time. On the other hand, emissions from maize residues increased due to improved yields. The share of maize residues to the total emissions from crop residues increased from 22.0% in 2000 to 38.0% in 2010, while the contributions of wheat and sugarcane decreased from 9.0% to 7.0% and 61.0% to 49.0%, respectively, during the period. The emissions from residues of sunflower and sorghum are variable with time and do not show a clear trend with regard to their overall share to the total emissions from management of crop residues.

Table 5.4 N_2O emissions (Mt) from management of crop residues in South Africa between 2000 and 2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Maize	0.362	0.469	0.451	0.453	0.547	0.323	0.341	0.612	0.585	0.624	0.508
Wheat	0.149	0.153	0.149	0.095	0.103	0.117	0.129	0.117	0.132	0.120	0.088
Sunflower	0.044	0.062	0.044	0.043	0.041	0.035	0.020	0.058	0.053	0.033	0.057
Sorghum	0.009	0.011	0.011	0.019	0.013	0.005	0.008	0.012	0.013	0.009	0.007
Dry bean	0.007	0.004	0.005	0.006	0.005	0.005	0.003	0.004	0.005	0.004	0.003
Soya beans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sugarcane	0.984	0.872	0.948	0.841	0.787	0.867	0.836	0.813	0.793	0.769	0.660
Barley	0.004	0.005	0.007	0.009	0.007	0.009	0.009	0.009	0.009	0.008	0.007
Tobacco	0.029	0.027	0.031	0.021	0.019	0.012	0.010	0.007	0.008	0.010	0.001
Cotton	0.020	0.011	0.010	0.017	0.013	0.009	0.007	0.006	0.005	0.005	0.010
Groundnuts	0.017	0.010	0.005	0.010	0.006	0.007	0.005	0.008	0.009	0.008	0.006
Canola	0.001	0.002	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.003	0.003
Total	1.626	1.626	1.663	1.516	1.544	1.391	1.371	1.649	1.614	1.593	1.351

5.4 Mitigation of GHG Emissions from Cropping Systems in South Africa

5.4.1 Agricultural Baseline Emissions

Agricultural baseline emissions are predicted to increase from 50.6 Mt CO_2e in 2010 to 69.6 Mt CO_2e in 2050 (DEA 2016; Stevens et al. 2016). Projections indicate that the area planted to yellow maize will exceed that planted to white maize in the near future given current consumption patterns that result in a flat demand for white maize in the food consumption market, compared to the continued growth in demand for animal feed (DEA 2016). This suggests that fertilisation rates will increase accordingly. Future baseline estimates show a gradual linear increase of emissions from synthetic N fertiliser and lime (Fig. 5.7). Emissions from urea are projected to increase exponentially. The largest increase in the baseline emissions comes from emissions from urea application; however, the urea consumption data is highly variable and comes with high uncertainties as it

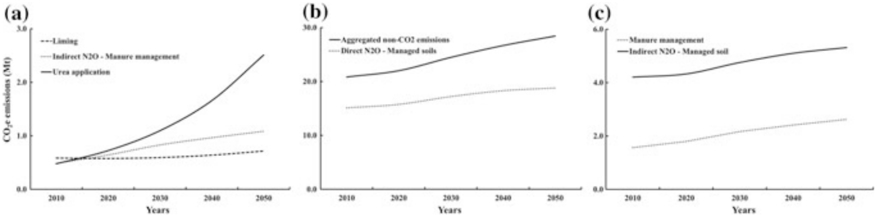

Fig. 5.7 Baseline emissions for the agricultural sector in South Africa between 2010 and 2050. *Data source* Stevens et al. (2016)

determined from import and export data with the assumption that all urea is being applied to the field (DEA 2016). Because of demand for human food and animal feed, field crops are expected to be the main sources of these emissions.

Direct N_2O emissions from managed lands are the largest contributor to the baseline emissions from aggregated and non-CO_2 emissions (DEA 2016). In terms of reducing non-CO_2 emissions from management of soils, options available to the country include improved fertiliser usage and an increase in production of legumes (DEA 2016). The principal biological N-fixing crops are soya beans, groundnuts and lucerne (DEA 2014). Mitigation strategies to lower the N_2O emissions from the agricultural sources should be put in place and be promoted among farmers. In order to reduce emissions, the improvements in agricultural technologies and practices need to achieve sustainable agricultural production, accrual of additional benefits to the farmer and agricultural products that are accepted by consumers (IPCC 1996).

5.4.2 *Biofuels*

In Africa today, as in most parts of the world, the biofuel industry is receiving serious attention in view of the vast land available and the favourable climate for growing many of the energy crops (Marvey 2009). Biofuels are among the highest renewable energy sources in South Africa, with an estimated contribution of 9.0–14.0% (Sawahel 2016). South Africa was the first southern African country to develop a formal biofuel strategy (Blanchard et al. 2011). The National Biofuels Industrial Strategy focused on a 5-year pilot programme to achieve a 2.0% penetration of biofuels in the national liquid fuel supply or 400 million litres per year—to be based on local agricultural and manufacturing production capacity (Blanchard et al. 2011; DME 2007). The strategy aimed to achieve economic and social development in rural areas via the agricultural development in the former homeland areas (Blanchard et al. 2011). Canola, sunflower and soya beans are promoted as feedstocks for biodiesel, while sugarcane and sugar beet are the choice of feedstocks for bioethanol (Marvey 2009; Pradhan and Mbohwa 2014). However, with the exception of canola which is a dry land winter crop suitable as a rotational and complementary crop for existing oilseed crops, the production figures of oilseeds indicate a general decline in yields and a corresponding decrease of the area planted (Marvey 2009). Maize is excluded from these feedstocks because its use may compromise national food security (Marvey 2009; Pradhan and Mbohwa 2014). Several companies showed interest to invest in biofuel projects (Marvey 2009). However, progress in the development of the country's biofuel industry remains slow at present (Van Zyl and Prior 2009). The South African strategy is generally considered to be conservative, tempering the international drive towards large-scale biofuel production with a pragmatic approach (WRC 2009). As a result, the South African government faces the challenge of showing a strong commitment to the biofuel industry through their policy regulations and incentives (Marvey 2009).

Incentives were only provided for locally based processing plants that relied on feedstocks being acquired via contractual agreements from small-scale farmers (Blanchard et al. 2011). The combination of the preference given to previously disadvantaged farmers and the exclusion of maize as feedstock has slowed down the establishment of an agriculture-based biofuels industry in South Africa (Letete and Von Blottnitz 2012).

Biofuel developments are still at an early phase, and ongoing research to optimise feedstocks and processing techniques may well promote feedstocks not mentioned in the strategy (Blanchard et al. 2011). The ability of biofuel crops to mitigate GHG emissions varies widely between crops, management practices and the nature of the land where the biofuel crop is grown (Von Maltitz 2017). About 30.0% and 50.0% reduction in GHG emissions can be achieved from ethanol and biodiesel, respectively (DOE 2013). Biofuels may have a restorative capability, increasing soil productivity and biodiversity within an agro-ecological system (Blanchard et al. 2011).

5.5 Conclusions

Crop management practices affect GHG emissions in South Africa. Application of synthetic fertiliser to the soil resulted in the highest GHG emissions with 57% of the total national emissions from production of field crops in the country. Application of lime during production of field crops and crop residues retained in the field after harvest resulted in 30.0% and 13.0% of the total emissions from field crops, respectively. Cereal crops are responsible for 68% of the national total emissions with maize contributing 56.0% of the national total. Production of maize, wheat and sugarcane resulted in the highest commodity GHG emissions in the country in 2012. Crop management practices that include use of improved technologies and fertilisation rates have a considerable effect on the amount of GHG emissions from crop production. However, agricultural croplands that are intensively managed offer many opportunities for reducing GHG emissions through changes in agronomic practices.

References

Armour J (2014) Dualism in SA agriculture. In: Proceedings of the FERTASA 54th annual congress, 10 June 2014, Johannesburg, South Africa

Blanchard R, Richardson DM, O'Farrell PJ, Von Maltitz GP (2011) Biofuels and biodiversity in South Africa. S Afr J Sci 107(5/6), Article no. 186

Blignaut JN, Chitiga-Mabugu MR, Mabugu RM (2005) Constructing a greenhouse gas emissions inventory using energy balances: the case of South Africa for 1998. J Energy S Afr 16(3):21–32

Chapter 6
Agricultural Greenhouse Gases from Sub-Saharan Africa

Kofi K. Boateng, George Y. Obeng and Ebenezer Mensah

Abstract Climate change has variously been diagnosed as perhaps the most challenging issue that confronts the twenty-first century, and especially for sub-Saharan Africa (SSA), the impacts of a changing climate have already been felt in most regions and in various sectors of the economy principally, agriculture. Agriculture on the subcontinent, although still very rudimentary in terms of management practices and production efficiency, provides the mainstay for majority of the people and is heavily climate dependent. This makes climate change an issue requiring immediate and effective interventions, viz. adaptation and resilience building to safeguard the livelihood of over a billion people. This chapter looks at sub-Saharan African agriculture, its contribution to the emission of greenhouse gases and their pathways by using the FAOSTAT system and the other literature on emission research from peer-reviewed journals. An attempt is also made to gauge the effects of a changing climate on SSA agricultural productivity. The contribution of SSA agriculture to the socio-economic well-being of its people is also discussed. Adaptation and resilience building among the dominating smallholder farmers in the region are captured, and the factors that hinder the effective scaling up of strategies aimed at ameliorating the effects of climate variability on local agriculture.

Keywords Sub-Saharan Africa agriculture · Climate change · Greenhouse gas emissions

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6.1 Sub-Saharan African Agriculture

The FAO puts agriculture in sub-Saharan Africa (SSA) as the major source of livelihood for a population of approximately 1 billion people (Alexandratos and Bruinsma 2012) as it contributes immensely to the economies of most economies in the region (Jerven and Duncan 2012).

Although agricultural contribution to GDP has generally declined over the years in most sub-Saharan African economies as a result of economic diversification, the agricultural sector still remains the major employer in most of these countries. According to the International Monetary Fund (IMF), agriculture in SSA is responsible for the direct employment of half of the sub-region's labour force. For the rural populations, it remains the mainstay for a significant proportion of people as smallholder farmers form 80% of production and this is estimated to give direct employment to approximately 176 million people on the subcontinent (IMF 2012).

The agriculture sector in terms of total employment employs 42% of Ghanaians, 28% of Nigerians, 62% of Kenyans, 75% of Mozambicans and Rwandese and 68% of Zimbabweans. Overall, the agricultural sector employs 55% of sub-Saharan Africans (Schlenker and Lobell 2010a). Contrary to the importance of the agricultural sector to sub-Saharan African countries, the sector is the least developed in terms of infrastructure and production levels. Production remains at the smallholder level in most SSA countries with the use of crude farming tools still very dominant. Value addition to primary farm products to semi-finished and finished products remains a challenge to the sector resulting in huge post-harvest losses. Food losses equated to post-harvest losses alone in sub-Saharan Africa exceeded 30% of total crop production equivalent to USD $4 billion annually (OECD/FAO 2016) (Fig. 6.1).

Irrigation, considered as an important factor for agricultural growth in low-income countries, is insufficient in most parts of SSA making agriculture extensively rain-fed (Müller et al. 2011). Generally, irrigated area in sub-Saharan Africa makes up just 5% of its total cultivated area and two-thirds of this area is in three countries Madagascar, South Africa and Sudan. Thus, SSA lags significantly

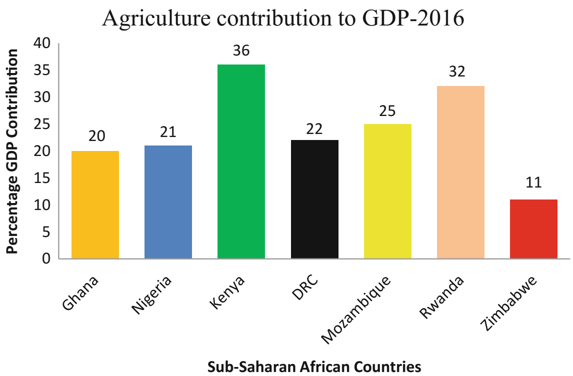

Fig. 6.1 Agricultural contribution to GDP (OECD/FAO 2016)

behind Asia and Latin America with 37% and 14% of their cultivated area under irrigation, respectively (You 2008).

In Ethiopia, irrigated agriculture constitutes only 1.1% of the total cultivated land (Bewket and Conway 2007) and less than 3% of the current food production in Ethiopia (Awulachew et al. 2005). In Ghana, of the 14,038,224 hectares of total agricultural land, 30,345 ha representing 0.4% is under irrigation (Ministry of Food and Agriculture 2013).

Overall, agriculture in SSA is predominantly rain-fed at 96% of overall crop production making agricultural production in sub-Saharan Africa particularly vulnerable to the effects of climate change (World Bank 2015; Yéo et al. 2016).

6.1.1 Climate Change Effects on Sub-Saharan African Agriculture

The Intergovernmental Panel on Climate Change (IPCC) identifies Africa as continent most vulnerable to the impacts of climate change (IPCC 2014). Projections that have been made for SSA point to an increasingly warming trend in the form of frequent occurrence of extreme heat events, increasing aridity and changes in rainfall patterns (Serdeczny 2016).

Climate change projections for SSA indicate a warming trend which will significantly distress natural and human systems, especially in the inland tropics where frequent occurrence of extreme heat events, changes in rainfall patterns, increasing aridity are expected to be pronounced (Serdeczny 2016). Agriculture in SSA is at significant risk under changing climate primarily due to its overdependence on rain as well as observed crop sensitivities to high temperatures during the growing season (Schlenker and Roberts 2009; Lobell et al. 2011). The lack of adaptive capacity, small farm sizes, low capitalization and limited use of improved technologies lowers the resilience and increases the vulnerability of smallholder farmers in the sub-region to the negative effects of climate change (Morton 2007:6).

Important crops grown in SSA in terms of the provision of calories, protein and fat for a significant percentage of the population are maize, cassava, rice, sorghum, wheat and millet in the order of their importance (FAO 2009). However, the most important crops grown in SSA in terms of area harvested are millet, maize, sorghum and cassava, cultivated on 50% of total harvested land (Blanc 2011). There is a high possibility that the total effect on yields from major crops in SSA due to climate change will be negative and devastating (Niang et al. 2014). In a study that modelled the impacts of climate change on sub-Saharan agriculture (Schlenker and Lobell 2010b), a negative growth to the extent—of 22, 17, 17 and 8% in the production of maize, sorghum, millet and cassava, respectively, has been projected by the middle of this century.

Overall, Africa is expected to experience mainly negative climate change impacts, in terms of an increase in the already high temperatures and a decrease in the largely erratic rainfall in its context of widespread poverty and low development (Speranza 2010). It is, therefore, important that appropriate climate adaptation and resilience building strategies are developed and effectively implemented so as not to exacerbate SSA climate risks.

6.1.2 Sources and Contribution of GHG Emissions from SSA Agriculture

On a global scale, GHG emissions from SSA agriculture are significant. The sector is the largest emitter of GHGs and currently accounts for 27% of the total emissions from the whole continent. The biggest emission sources in SSA agricultural sector include the conversion of forest to cropland and pasture, livestock manure and digestive processes, burning of savannah, cropland management and cultivation (management) practices (Hogarth et al. 2015).

This is evident from a review and synthesis of greenhouse gas emissions from 22 SSA countries (Kim 2015). GHG emission levels from natural and agricultural lands are shown in Table 6.2. Factors that were found to affect the emission levels included soil physical and chemical properties, rewetting, vegetation type, forest management and land-use changes (Table 6.1).

For levels of cropland GHG emissions, soil amendments with crop residues, inorganic fertilizers as well as manure are major determinants. Management practices employed by farmers, therefore, become critical in any emission reduction strategy.

East Africa has the highest level of emissions due to agricultural production for both methane and nitrous oxide. Current emission data indicates that the high level

Table 6.1 SSA emissions and sources (Kim 2015)

GHG	*Range*		
Carbon dioxide (CO_2)	3.3–57.0 Mg ha^{-1} $year^{-1}$		
Methane (CH_4)	−4.8 to 3.5 kg ha^{-1} $year^{-1}$		
Nitrous oxide (N_2O)	−0.1 to 13.7 kg ha^{-1} $year^{-1}$		
General sources of GHG emissions			
	CO_2	CH_4	N_2O
Aquatic systems	5.7–232.0 Mg ha^{-1} $year^{-1}$	−26.3 to 2741.9 kg ha^{-1} $year^{-1}$	0.2–3.5 kg ha^{-1} $year^{-1}$
Croplands		−1.3 to 1566.7 kg ha^{-1} $year^{-1}$	0.05–112.0 kg ha^{-1} $year^{-1}$
Vegetable gardens	73.3–132.0 Mg ha^{-1} $year^{-1}$	–	53.4–177.6 kg ha^{-1} $year^{-1}$
Agroforestry	38.6 Mg ha^{-1} $year^{-1}$	–	0.2–26.7 kg ha^{-1} $year^{-1}$

Table 6.2 Regional emission levels in $GgCO_2e$ (Kim 2015)

Region	CH_4	N_2O	Total agricultural emissions
West Africa	116,959	93,600	210,560
East Africa	204,275	172,238	376,512
Central Africa	51,418	55,937	107,355
Southern Africa	22,984	24,268	47,251
Total	395,636	346,042	741,677

of emissions in the region is attributable to the high livestock activity (enteric fermentation) in the region.

6.1.3 Enteric Fermentation

Livestock rearing is an important aspect of agriculture in Africa with an estimated herd of 981 million cattle, goats and sheep (Hogarth et al. 2015). The herd size is projected to increase as a result of high demand for meat and milk owing to rapid population growth. Most of this growth in livestock population is expected to occur in East and Western Africa exacerbating their enteric emission footprints (Herrero et al. 2008) (Fig. 6.2).

6.1.4 Paddy Rice Cultivation

For the West African sub-region, crop cultivation is the major source of agricultural greenhouse gas emissions, especially paddy rice cultivation. Methane (CH_4) and

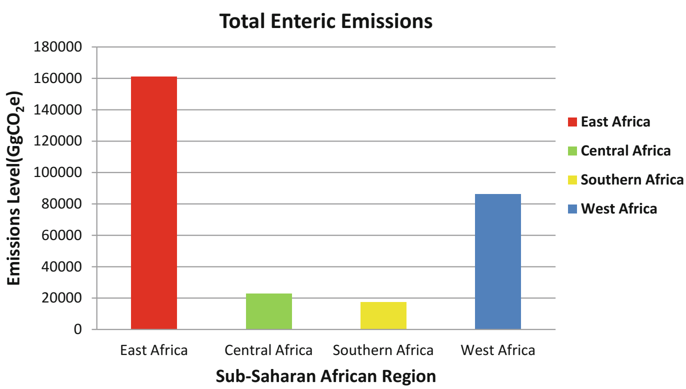

Fig. 6.2 2016 enteric fermentation (livestock emissions) (FAOSTAT 2016)

nitrous oxide (N_2O) emissions are enhanced in paddy rice cultivation through flooding and fertilizer application regimes, two key management practices farmers employ.

For most regions of SSA, rice remains a critical staple food for most households and its demand outstrips all other cereals except maize (Tollens 2006). The demand for rice on the subcontinent continues to outpace local production. The region, however, is only able to meet 50% of this growing demand. Paddy rice production in SSA with a total harvested area of 11,815,947 ha currently stands at 26,116,184 tons (FAOSTAT 2016). Western and Eastern Africa lead in production with 66% and 30%, respectively. The combined production total of Central and Southern Africa is less than half the production of East Africa, the second largest paddy rice production area on the subcontinent. For most countries in SSA, rice production has become an important sector with many countries having drawn up national rice development strategies to bolster production. West Africa currently leads in emissions from paddy rice production at 15991 $GgCO_2e$, and with rice production projected to grow to meet an increasing demand, it is expected that emissions from rice production will also increase (Fig. 6.3).

6.1.5 *Emissions from Synthetic Fertilizer Use*

The primary GHG that is emitted from synthetic fertilizer use is nitrous oxide, and it is produced by the microbial process of nitrification and denitrification. This process gives rise to direct N_2O emissions. Indirect N_2O emissions arise when volatilization and leaching processes commence (Linquist 2012; Liang 2013; Xia 2016). Agriculture is responsible for 85% of N_2O emissions globally (Syakila and Kroeze 2011; Signor et al. 2013).

The use of synthetic fertilizers is low in sub-Saharan Africa compared to other regions of the world. Currently, SSA agriculture consumes 15 kg of fertilizer per hectare of arable land (World Bank 2016). As a consequence, emissions from

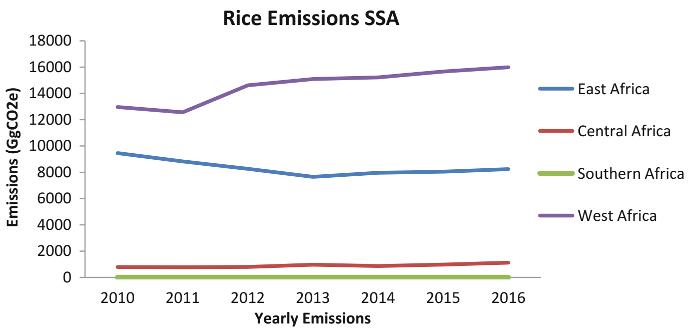

Fig. 6.3 SSA emission trends 2010–2016 (FAOSTAT 2016)

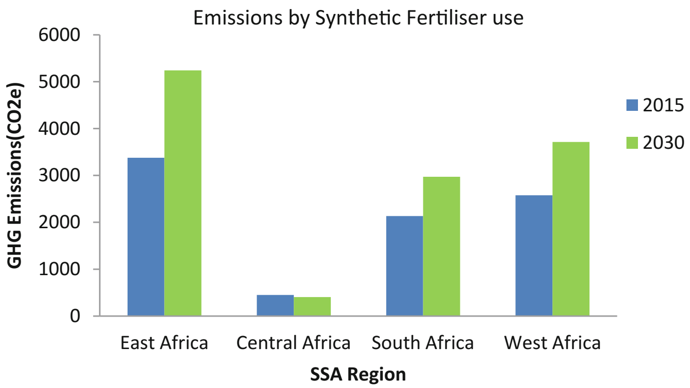

Fig. 6.4 Emissions by synthetic fertilizer use (FAOSTAT 2016)

synthetic fertilizer use are low in SSA. Future projections of emissions point to an average increase in emissions by 25% with East and West Africa emissions being the highest (FAOSTAT 2016) (Fig. 6.4).

Synthetic fertilizer use is projected to increase due to the pressure on food production to increase to meet the demand of a growing population in SSA. The traditional fallow periods required for the recovery of depleted soil nutrients is no longer a viable nutrient management option due to the long period it takes for soils to replenish lost nutrients. Synthetic fertilizer usage, therefore, becomes the best alternative to boost food crop production. The challenge, therefore, for SSA agriculture is to avoid the negative effects and the extensive use of synthetic fertilizer usage. High nutrient use efficiency has been advocated as an effective means of ensuring that SSA increases crop production with synthetic fertilizer use without maximizing its adverse effects including N_2O emissions. An approach to efficient fertilizer use through a 4R guide as described in the following has been proposed (Richards 2016):

1. Use the **right** source of nutrients (the right composition of nutrients, including other than NPK),
2. Applied at the **right** rate (based on economic criteria and soil fertility status),
3. Applied at the **right** time (relative to crop needs and weather),
4. Applied at the **right** place (targeting plant roots and minimizing losses).

It is essential to apply good agronomic practices alongside efficient use of nutrient input to achieve high nutrient use efficiency (Richards 2016). Examples of such agronomic practices include the use of improved, high yielding varieties that can adapt to the local environment, application and recycling of available organic matter (crop residues and farmyard manure), water harvesting and irrigation under drought stress conditions, and lime application on soils with acidity-related problems.

6.1.6 Emissions from Manure Left on Pasture and Manure Applied to Soils

Manure (organic fertilizer) provides another alternative for farmers in SSA to improve soil fertility. The use of manure is, however, confined to play a complimentary role to synthetic fertilizers that provide significant amounts of readily available nutrients required to fuel the expansion of agriculture on the subcontinent (Richards 2016).

Current and projected emission levels from manure applied to soil and manure left on field have East Africa leading in emissions followed by West Africa. Projections (2030 estimates) of emissions from these two sources are expected to remain relatively same as current levels. The focus on integrated soil fertility management is, therefore, important to keep emission levels from synthetic fertilizer soil amendments to the minimum (Fig. 6.5).

6.1.7 Burning of Savannah and Crop Residues

Burning of savannah, a common practice in sub-Saharan Africa, involves the setting of fires to burn trees cut from forests for the development of agricultural lands. Fire is also set on existing agricultural land for nutrient mobilization, pest control and the removal of brush and litter accumulation (Ten Hoeve et al. 2012). Greenhouse gas emissions from burning of savannah consist of methane (CH_4) and nitrous oxide (N_2O) gases produced from the burning of vegetation biomass in the following five land cover types: savannah, woody savannah, open shrublands, closed shrublands and grasslands (FAOSTAT 2016) (Fig. 6.6).

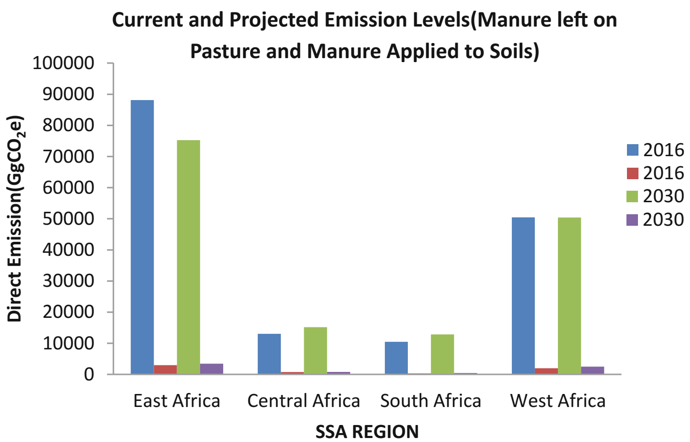

Fig. 6.5 Manure emissions from SSA (FAOSTAT 2016)

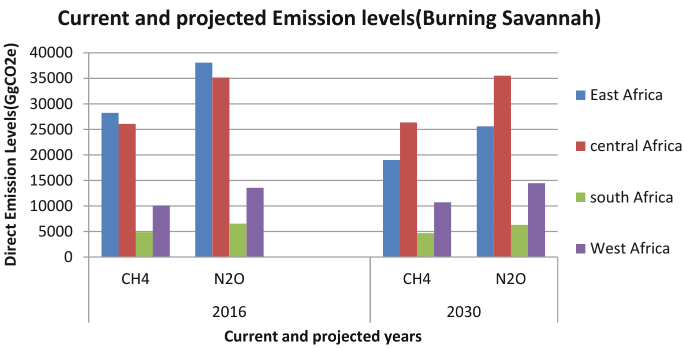

Fig. 6.6 2016 and 2030 emission levels from SSA savannah burning (FAOSTAT 2016)

Crop residues are generated in large quantities on the field seasonally after harvest. Typical crop residues include cereal straws, husks, leaves, semi-woody and woody stalks. Significant crop residue is also generated when farm produce is processed by milling. Many regions in sub-Saharan Africa use these crop residues for various purposes such as feed for animals, fuel for domestic as well as industrial use and also as thatch to roof rural homes. However, a significant amount of crop residues is left on farms whose disposal poses a great challenge for farmers in SSA. Burning of these residues on the field, therefore, presents a cheap and inexpensive way to get rid of the volumes of residues left on their farms after harvest in preparation for the new season. Greenhouse gas (GHG) emissions from the burning of crop residues consist of methane (CH_4) and nitrous oxide (N_2O) gases produced by the combustion of a percentage of crop residues burnt onsite. Air pollutants (CO_2 NH_3, NOx, SO_2, NMHC, volatile organic compounds), particulates matter and smoke are also produced as a result of the burning, thereby posing threat to human health (Jain et al. 2014).

The emissions from two important crops in SSA, maize and rice are represented below. Current emission levels (2016) indicate high methane emissions from maize

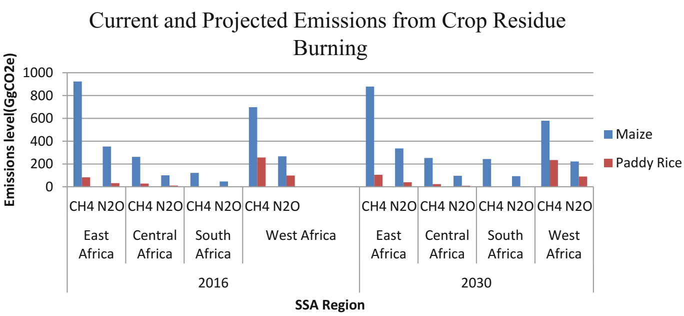

Fig. 6.7 Current and projected emission levels (2016 and 2030). *Source* (FAOSTAT 2016)

residue burning at 923 $GgCH_4CO_2e$ and 698 $GgCH_4CO_2e$ for East and West Africa, respectively. The year 2030 projections for methane emissions for the two regions, East and West Africa, are expected to slightly drop to 879 $GgCO_2e$ and 579 $GgCO_2e$, respectively (Fig. 6.7).

6.2 Adaptation and Resilience Building

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation from two perspectives, human systems and natural systems. In human systems, adaptation is defined as the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities and in natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate (IPCC 2012). Efforts and strategies aimed at aiding SSA adapt effectively to climate risks hampered by a weak adaptive capacity of dominant smallholder farmers in the region (Parry et al. 2007). By adaptive capacity, reference is made to the strengths, attributes and resources available to an individual, community, society or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm or exploit beneficial opportunities (IPCC 2012). Assisting smallholder farmers in SSA to strengthen their social, economic and ecological resilience will enable them to effectively adapt.

Resilience is the ability of a system to deal with stresses and disturbances, while retaining the same basic structure and ways of functioning, capacity for self-organization and capacity to learn and adapt to change (Field et al. 2012). In view of the above definition for resilience, (Stringer et al. 2012), for adaptation to be effective in countering the adverse effects of climate change in SSA, efforts should be directed at making adaptation strategies resilient, i.e. adaptations that can stand the test of current and future climate risks.

Sub-Saharan Africa has to imminently deal with the current climate risk it faces, while preparations are made to deal with the predicted future climate scenarios. In the light of the above, a two-way climate adaptation approach is proposed. First, it is important to have **a coping adaptation strategy** to deal with imminent risks faced by farmers. For the long term, effective **adaptation strategies** need to be developed to deal with evolving future climate scenarios that have not been experienced yet by farmers (Cooper 2013; Burton and van Aalst 2004).

By coping adaptation strategies, we refer to those strategies that farmers have employed to deal with climate stressors overtime and have understood its application and effectiveness, whereas adaptation strategies herein refer to long-term strategies that have to be developed, tested and introduced to farmers through effective extension delivery services (World Bank 2010).

Many SSA governments have developed policy documents to guide the strategic steps needed to be taken to counter climate change impacts on their economies. For example, Ghana has developed the National Climate-Smart Agriculture and Food

Security Action Plan (2016–2020) whereas Nigeria has the National Adaptation Strategy and Plan of Action on Climate Change.

A major issue that has slowed down the implementation of most adaptation initiatives in SSA has been financing. It is estimated that an annual cost of at least $18 billion is needed for adaptation to climate change programmes in SSA between 2010 and 2050 and this is exclusive to funding necessary to put SSA in the low carbon development category (Nakhoda et al. 2011). There is a general consensus that the level of financing currently reaching African countries is nowhere near enough to meet demonstrated needs, especially for immediate adaptation measures (Richards et al. 2018).

6.3 Conclusions

GHG emission levels from SSA agriculture remain low compared to other regions of the world. However, with a projected increase in intensification of agriculture to boost food production on the subcontinent, emissions especially of N_2O are most likely to surge. The surge will be attributable to the expected increase in synthetic fertilizer use for crop production. Strategies should, therefore, be centred on nitrogen use efficiency as this will ensure low emissions and also reduce production cost for already constrained smallholder farmers.

Quantification of in situ GHG emission climate change and its impact on the continent must be collaborative.

For sub-Saharan Africa to be able to cope with current and future climate risks, robust climate financing sources should be developed to sustainably fund the process of climate adaptation strategies. These financial resources when acquired should not be utilized to isolate farmers, but rather substantial investments made in their activities to improve their production efficiency and consequently reduce emissions (Cooper et al. 2008). To ensure robustness of quantified emission levels from SSA, there is the need to standardize emission quantification methodologies and wean emission research in SSA of the emission factor method, which currently dominates research on emission measurements. Efforts should, therefore, be geared towards training researchers on the use of the low-cost closed chamber, gas chromatograph method in emission measurement research on the subcontinent.

References

Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision, vol. 12, no. 3. ESA Working paper, FAO, Rome

Awulachew SB, Merrey DJ, Kamara AB, Koppen BV, Vries FP, Boelee E (2005) Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia. International Water Management Institute (IWMI), Colombo, Sri Lanka

Bewket W, Conway D (2007) A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. Int J Climatol 27:1467–1477