Zurich-Basel Plant Science Center

Agriculture and Climate Change: Reducing Food's Footprint

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1.1 Abstract

Agriculture and climate change go hand-in-hand, and changes in one will induce changes in the other. On one hand, agriculture is one of the major causes of climate change through its emission of greenhouse gases, primarily methane and nitrous oxide. On the other hand, climate change, through the alteration of temperature and rainy seasons, among several other conditions, has affected the stability of the overall crop yield. This situation threatens our food security because with potentially lower yields, more land will be required to meet the current demand, which will in return increase the feedback of agriculture into climate change. Therefore, it is of utmost importance to identify agriculture procedures that minimize their contribution to climate change. Nowadays many agricultural procedures have been implemented that are able to increase their sustainability. Here we review the major influences between agriculture and climate change as well as explore which possibilities we currently have in order to mitigate the contribution from agriculture to climate change.

1.1.1 Contribution of agriculture to climate change

According to the Intergovernmental Panel on Climate Change (IPCC), agriculture directly contributes to 24% of the greenhouse gases (GHG) emitted (IPCC, 2014), which is even larger than the direct contribution of industry and thus a major target for GHG reduction. Agriculture consists of a wide range of practices that span from livestock to crop farming. However the significance of each activity to climate change (i.e. GHG emission) is very different. For example the use of synthetic fertilizers contributes to nitrous oxide emission, rice crops and livestock contribute to methane emission and deforestation to carbon dioxide emission (Herzog, 2005). The relevance of the main GHG emitted for each activity relies on the warming potential of each gas once it is on the atmosphere. Compared to carbon dioxide, methane has 25 times more warming potential and nitrous oxide up to 250 times more. Three of the main agricultural techniques (enteric fermentation, manure management, rice crops) that contribute to GHG emissions (65% of all agricultural emissions) release methane into the atmosphere meanwhile the use of synthetic fertilizers (13% of all agricultural emissions) is involved in nitrous oxide emission (FAO 2014). Therefore 78% of all the emissions due to agriculture are based on GHG that have increased warming potential and arise from activities with high demand and thus more efforts should be placed to reduce these emissions.

1.1.2 Mitigation of climate change through agriculture

Besides contributing to GHG emission, agriculture also has the power to incorporate carbon dioxide from the atmosphere into plants and then into the soil. The simplest case is through photosynthesis, which takes six molecules of carbon dioxide and transform them into glucose that can be used as an energy source for any living organism. Thanks to this process, the carbon present in the original carbon dioxide can be cycled through the plants and its surrounding environment increasing the richness of the soil. An example of this is seen in an organic farm in Egypt, where desert lands were cultivated as organic farms and after 5 years the carbon sink in the soil had increased more than five times (Luske, 2009). In fact, according to the Environmental Protection Agency (EPA) of the US, the agriculture carbon emissions account for 550 million m3 CO2eq, while the carbon sequestered for this same period is 750 million m^3 CO_2eq, yielding a net gain of sequestered carbon (EPA 2017). However, this is not the case worldwide as the emissions estimated due to agriculture rise up to 5.3 billion m^3 CO_2eq while the sequestering capability was estimated to be 2 billion m^3 CO_2eq (FAO 2014). In sum, agriculture can be transformed into a powerful tool to mitigate climate change at the same time that it claims new lands for cultivation. Nevertheless, this option has to be wisely implemented because if deforestation occurs, the carbon sink will be directly released into the atmosphere.

1.1.3 Increased temperatures and elevated carbon dioxide levels on crop growth patterns

While agriculture can both contribute to and mitigate climate change, climate change also has both positive and negative effects on agriculture. Worldwide increased atmospheric carbon dioxide concentrations have been shown to increase seed yield and crop biomass growth, while delaying reproduction and potentially reducing certain mineral concentrations (Gray, 2016). The effects of increased temperatures can have regional effects because of varying intensities in changes, but in general, higher temperatures yield faster plant growth and lengthened growing seasons. However, this is in combination with increased difficulties in reproduction due to reduced flowering times (which reduces grain filling times), the possibility of inadequate winter chilling conditions, and reduced pollen viability (Gray, 2016). Regionally, increased temperatures have driver increasing crop yields in more northern latitudes (Valizadeh, 2014), but in other regions, particularly those experiencing increased instances of drought or flooding, yields are decreasing (Gray, 2016).

To accurately measure the effects of a changing climate on crops, several different measurements are necessary. Typically crop yield (mass per unit area) is used as a measurement of how climate change is affecting crops (Iizumi, 2015). This allows for easy clarification of whether crop yield has improved or declined with the changing climate, and therefore whether the changes have been beneficial or detrimental. However, with the lengthening planting seasons and extremely local climate change effects such as stronger, less predictable storms or very localized landslides from extreme rainfall, other means of measuring climate change effects are necessary, as crop yield does not capture all of the information. For example, higher temperatures have allowed for longer growing seasons, which have allowed farmers to harvest potentially two or three seasons of a variety of crops compared to their typical one season. The unit of crop yield isn't applicable here, because it doesn't capture the time over which the crops are harvested. In addition, the unit of area harvested needs to be considered. With increasing arable land, particularly extending into the northern latitudes, crop yield may not change, but rather crop planted area may increase due to climate change (and crop demand). On a more regional level, a farmer may have a portion of his crop destroyed due to landslide caused by unusually excess rain. In this case, seed yield would remain the same, but the damage from the landslide would not be counted unless total crop area was also considered. The effects of farmer's decisions need to also be considered, as they react to changing climate conditions through changing harvest or planting times, changing crop species being planted (perhaps they are more tolerant to higher temperatures), or choosing to harvest damaged crops (Iizumi, 2015).

1.1.4 Which is the best farming approach to reduce GHG emissions?

As described above agriculture is a major contributor to GHG emissions as well as a potential tool to sequester carbon dioxide from the atmosphere. Therefore it is of maximum importance to develop approaches that move towards the mitigation of climate change. The golden standard would be an approach that minimizes GHG emissions while also sequestering GHG, thus mitigating the impact from other activities, however such an easy solution is difficult to achieve. For instance, the carbon dioxide sequestering ability depends on the soil richness. As mentioned before, organic farming increased the carbon sink from 3 ton ha-1 to 18 ton/ha in five years, thus an increase of 3 ton ha-1 year-1 (Luske, 2009). However after 30 years this rate was reduced to 0.9 ton ha-1 year-1 (Luske, 2009) because the soil was reaching its limit for carbon storage. The same effect was seen on a field trial in Switzerland where carbon sequestering in rich soils was of only 0.25 ton ha-1 year-1 (Scholberg and Muller, 2009). This case exemplifies the need for careful evaluation of the situation as well as the feasible targets for GHG mitigation before implementing any approach. In the following subsections we summarize cases of the more effective farming approaches with respect their own GHG targets.

Rice Cultivation: Rice production is directly responsible for 10% of the agriculturally induced gas emissions due to methane emissions from the anaerobic soil associated with rice production (FAO 2014). Underground methane can either be released to the atmosphere through plant-mediated transport or through the soil and water layers through diffusion or ebullition. Studies have found that with increasing functional group biodiversity of plants in wetland systems there was decreasing methane efflux, likely due to the larger root systems and increased rooting depths (Bouchard, 2007). Other studies have found similar results regarding rice wetland systems. In one study, emitted methane amounts from rice pots without weeds were double the emissions from rice pots with weeds, despite higher amounts of methane producing bacteria in weeded pots compared to unweeded ones (Inubushi, 2007). Other studies found that wetland methane emissions could be influenced by other abiotic factors such as soil pH, water levels, available soil carbon, and temperature (Bhullar, 2013, Lai, 2009). Through improved rice growing techniques that include increased plant diversity, different conditions such as adjusted pH, available soil carbon, or changing water tables that allow for increased oxidation of the methane, the methane emitted from rice paddies has the potential to be decreased.

Manure Management: Managing the manure, and its use as a fertilizer, can be an effective way to reduce GHG emissions. Manure left on the pasture is responsible for 15% of GHG emissions, synthetic fertilizers for 13%, manure management for 7%, and manure applied to soils for 3%. Rather than leave the manure on the pasture, it can be collected and anaerobically digested. Depending on the farm and the type of manure storage, greenhouse gas emissions due to manure storage can be reduced by over 50% using manure management techniques such as anaerobic digestion, while concurrently producing biogas and therefore displacing other fuel use (Aguirre-Villegas, 2017). One study evaluated different dairy farm sizes and found that farm manure management techniques had large differences in emissions produced. Results found that large dairy farms could reduce GHG emissions by reducing their manure storage times and allowing for a build up of a natural crust on their stored manure, which was found to reduce emissions by promoting aerobic conditions. It also found that small farms tended to store solid manure as opposed to the more liquid manure stored by large farms. This solid manure tended to be stored in stockpiles, which minimized the emissions because of increased aerobic conditions (Aguirre-Villegas, 2017). In addition to the reduced emissions from improving manure management, manure can be used to replace the synthetic fertilizers that are currently used in conventional agriculture. This will be further discussed in the next section. While manure management has the potential to contribute to greenhouse gas emissions through many means, particularly during storage, collection, and land application. Awareness of the effects of different types and duration of storage practices, anaerobic digestion of manure, and proper timing, quantities, and means of application can all work towards reduction of greenhouse gas emissions, while also providing a natural replacement for synthetic fertilizers.

Organic Farming Techniques: The use of organic farming techniques can both reduce the greenhouse gases produced due to agriculture as well as sequester greenhouse gases through soil carbon storage. Organic agriculture can include many different aspects, such as organic fertilization as opposed to synthetic fertilizer use, intensive crop rotation, the use of cover crops, composting, and intercropping with natural land conditions such as agroforestry. The use of organic fertilizers can minimize the demand for synthetic fertilizers, which is responsible for 13% of agriculture's greenhouse gas emissions (FAO, 2014). One study in the USA found that conventional farming used 30% more energy than a similar organic system, that 8.44 metric tons of carbon dioxide were sequestered per hectare, and organic yields were the same as, or even higher in exceptionally wet or dry years, than conventional yields (Bitnia, 2009). Similarly, other organic agriculture studies found that the carbon storage capability of the soil was very much dependent on initial conditions and sequestration rates changed over time. Organic farming methods are capable of both reducing greenhouse gas emissions by reducing necessary synthetic fertilizer production, due to both organic fertilizer use and intensive crop rotation to preserve soil fertility. It is also able to sequester carbon into the soil, thereby reducing carbon dioxide concentration in the atmosphere, although its ability to do this is limited with increasing soil richness. Crop yields from organic farms are are similar to or even improved in certain conditions.

1.1.5 Actions towards a global solution for climate change

So far we have described approaches that can reduce the impact from agriculture on climate change from the producers' side. However this complex problem cannot be left only to producers or policy makers but also should involve consumers that with simple actions can transform the whole landscape. For example, if consumers reduce meat consumption, then the demand for meat will also be reduced, therefore less land will be required for livestock and could be used for greener agriculture approaches or even for afforestation. Other example involves the reduction of offseason consumption. It has been shown that the production of offseason strawberries in heated greenhouses has an increase of 355% in GHG emissions compared to a non-heated greenhouse (Wernet, 2016). As a final example, around 30% of the food produced is not consumed and becomes waste (Beretta, 2017), nevertheless it has already contributed to GHG emissions. Therefore it is a must to engage consumers into more responsible activities that heavily reduce the food loss. In sum, despite the complex and threatening problem that climate change imposes, we are already empowered with straightforward solutions that make possible to meet the urgent need to reduce GHG emissions.

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