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Technical options to reduce greenhouse gas emissions from croplands and grasslands in China[1]

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Executive Summary

- Technical mitigation potential of different management practices that could reduce GHG emission from Chinese agriculture system were estimated using a bottom up assessment of mitigation potential i.e. Meta-analysis of peer reviewed published data from China.
- Mitigation measures with greatest mitigation potential for rice agriculture were water saving irrigation and shifting from mid season drainage to more intermittent irrigation, conservation tillage, integrated rice-fish or duck farming, N- inhibitor application, use of Ammonium sulphate instead of urea, recycling of organic manure such as livestock manure and biogas residue with more controlled irrigation, avoid straw application to rice field and biochar application. Reducing N application to rice field had less potential but it is an important measure as overuse of N fertilizer has other environmental implications and reducing N fertilizer demand would reduce indirect GHG emission due to fertilizer manufacture.
- For upland grain crops combined application of chemical and organic fertilizer, practice of conservation tillage, reduction in N fertilizer application, N inhibitor use and biochar application could be mitigation measures with huge mitigation potential. Though straw return to upland crops could be a potential mitigation measure, due to plant protection needs, as well as labor unavailability, straw return is becoming increasingly limited in croplands.
- Reduced N fertilizer application and N inhibitor use are great mitigation measures for vegetable crops as current practice of excess and inefficient use of N fertilizer in vegetable crop is worst.
- Grassland degradation either due to overgrazing or conversion to other land uses such as croplands is the major cause of current soil carbon loss from grasslands of China. Restoration of these degraded grassland either by reseeding, reducing grazing intensity, grazing exclusion or conversion of low yielding croplands to grassland are mitigation measures with great mitigation potential.

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Introduction

China is one of the largest current emitters of human related greenhouse gases (GHG) globally, and currently emits around 20% of global GHGs (Leggett et al., 2008). China's GHG emissions are growing rapidly and, even with policy interventions designed to reduce emissions, are expected to rise until at least 2030. Agricultural GHG emissions have been estimated at 17% of China's national emissions (IEA 2007). China has a number of initiatives in place to reduce GHG emissions, mainly in the green energy sector, and also wishes to reduce GHG emissions from agriculture, while maintaining food security for its very large population (>1300 Million). GHG emissions from agriculture must be reduced in a way that will not compromise the food security and increasing chemical fertilizers use . In this policy brief, we present the outcomes of a bottom–up assessment of mitigation options in an attempt to quantify technical potential of different mitigation options for Chinese agriculture. A policy brief describing the economic potentials and barriers to adoption has already been published (SAIN Policy Brief No. 8). We describe the technical potential available for mitigation options in different sectors of agriculture: cropland (rice and upland), and agricultural grasslands. Livestock mitigation options will be the subject of another policy brief.

Mitigation options and potential for croplands

Nearly 90% of the mitigation potential in annual crop-based agriculture lies in reducing net GHG (CH_4, N_2O or CO_2) emission or in sequestrating CO_2 in the soil organic matter of mineral soil (Smith et al., 2007a; 2008). CH_4 and N_2O emission from rice agriculture or upland crops mainly depends on management practices, but changes in management regime also offers possibilities for mitigation. However, when selecting a mitigation measure it is important to consider the effect of the measure on the net global warming potential (GWP) of different GHGs because often a practice affects more than one gas, by more than one mechanism, and often in opposite ways, so that net benefits depend on the combined effects on all gases. It is also important to consider the impact of the mitigation measure on the crop yield because most farmers in developing countries are smallholders who will have to prioritize farm practices that enhance their food and livelihood security (Smith and Eva, 2012).

Mitigation options and potential for rice agriculture

Mitigation options were selected based on their effect on CH_4, N_2O and CO_2 emission and their total GWP. Mitigation potentials for CO_2 represent the net change in soil carbon pools, reflecting the accumulated difference between carbon inputs to the soil after CO_2 uptake by plants, and release of CO_2 by decomposition. Emissions during the growing season of rice can be reduced mostly by water management, nutrient management, tillage management, cropping system management and integrated farming. Emissions during the non growing rice season or fallow period can be mostly reduced by keeping the field dry especially for those waterlogged in winter-early spring from south China rice paddies. Proposed actions to decrease total GHG emission from rice agriculture include:

- **Water saving irrigation or controlled irrigation**: The local irrigation practice during the growing season of rice in China is to apply midseason drainage and reflood (F-D-F) the field after drainage. This practice is a better option compared to continuous flooding. But more controlled irrigation after midseason drainage, keeping the field moist (F-D-F-M) instead of waterlogged, could further decrease total GWP by 208% compared to prevalent current practice (F-D-F), when both irrigation methods are compared to continuous flooding as the control.Shifting from mid season drainage to intermittent irrigation i.e. with either keeping the field water logged or moist in between the drained period can save 1.25 t CO_2-eq/ha/yr. The benefit of water saving irrigation is particularly noticable when organic manure or straw are added, since under continuous flooding, addition of organic matter increases CH_4 emission significantly.

- **Stop straw application to rice fields:** Straw addition stimulated CH_4 emission by 108% and inhibited N_2O emission by 21% compared to plots with chemical fertilizer (N, P, and K). Straw application decreased N_2O emission and increased soil carbon (C) sequestration (0.73 t CO_2-eq/ha/yr) , but the magnitude of its effect on CH_4 increase is so high that the GHG benefit with decreased N_2O emission or SOC sequestration is negated; so stopping straw application to rice fields could be an effective measure. However, applying intermittent irrigation with straw application can be a good mitigation measure (0.88 - 1.43 t CO_2-eq $ha^{-1}yr^{-1}$) compared to continuous flooding with straw application (3.80 t CO_2-eq $ha^{-1}yr^{-1}$).

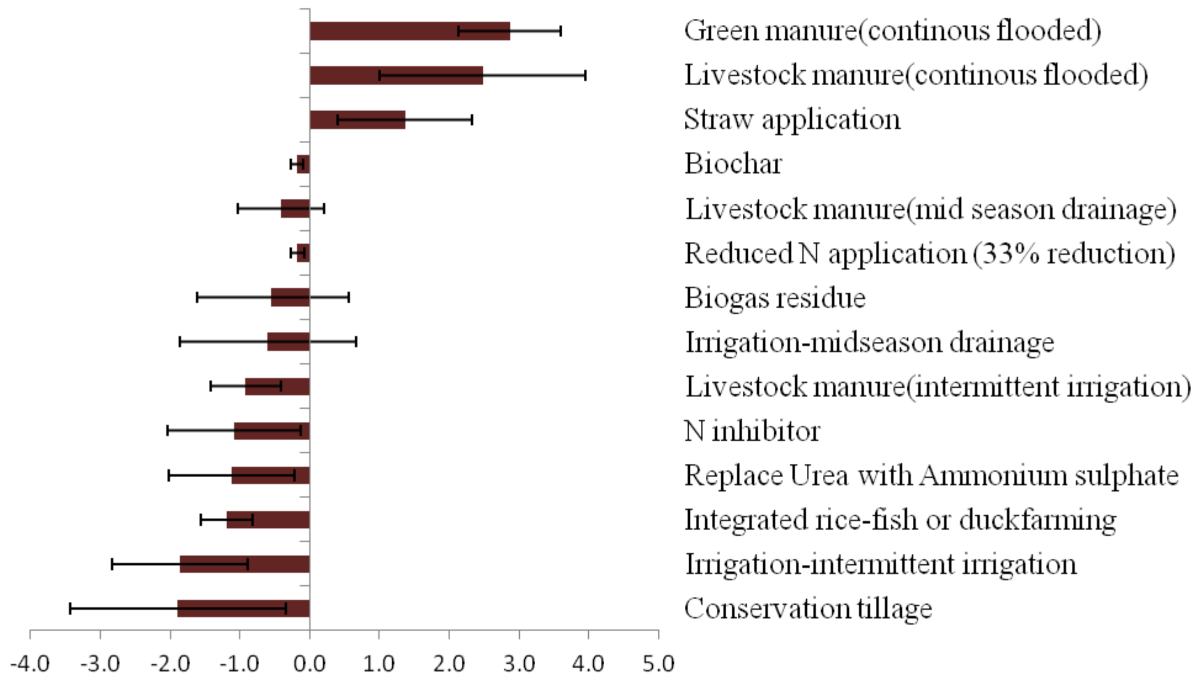
- **Reduce synthetic N fertilizer application:** Application of N fertilizer decreased CH_4 emission significantly by 27% (35% – 18%) and increased N_2O emission by 42% - 170% when applied at the rate of 100 to 250 kg N ha^{-1} $season^{-1}$ compared to control treatment without any N application . Application of N fertilizer increased annual soil C sequestration by 0.06%, 0.23% and 0.44% when applied as N, NP and NPK respectively . However with growing concern on overuse of N fertilizer and its environmental implications, our aim was to see the effect of reduction of N fertilizer application on GHG emission. The average N fertilizer application rate in rice in China is 150 – 250 kg N ha^{-1} which is 67% above the global average (Peng et al., 2010). Reducing N fertilizer application rate to an amount that would not decrease the crop yield could be a potential mitigation option, not only to decrease N_2O emissions, but also to reduce demand for N fertilizer which would lead to less indirect emission of N_2O during N fertilizer production. Reduction in N fertilizer had no significant effect on CH_4 emissions, but a 10% to 70% reduction in N fertilizer application resulted in 8% to 57% reduction in N_2O emission. A 33% reduction in current average N application rate for rice in China i.e. 231 kg N ha^{-1} (Li et al., 2010), would result in 27% decrease in N_2O emission and mitigation potential of -0.12 t CO_2-eq $ha^{-1}yr^{-1}$. This mitigation measure could be particularly applied in the provinces with large rice sown area and high synthetic N fertilizer application such as Liaoning, Jiangsu, Guangdong, Fujian, Hubei and Sichuan (Chai *et al.*, 2013).

- **Replace Urea with Ammonium Sulphate:** Replacing Urea with Ammonium sulphate (AS) can reduce CH_4 emission by 40% and increase N_2O emission by 34%. With the assumption that replacement of Urea with AS has no impact on C sequestration potential, the overall technical potential of this management is -1.12 t CO_2-eq $ha^{-1}yr^{-1}$ and could be a good mitigation measure.

- **Use N inhibitors or slow release fertilizers:** Use of N inhibitors or slow release N fertilizers is a win-win situation, as this measure decreases both CH_4 and N_2O emission from rice. Application of inhibitors i.e. urease inhibitor, nitrification inhibitor or urease + nitrification inhibitor decreased CH_4 and N_2O emission by 21% (11−29%) and 24 % (8−37%) respectively. Due to lack of data the analysis is based on 10 data points for CH_4 and 9 data points for N_2O; however our analysis shows significant decrease in CH_4 and N_2O emission with inhibitor.

- **Use Biochar in rice fields:** Application of biochar produced with crop straw pyrolysis can increase C sequestration by 22% yr^{-1} (i.e.6.14 t C $ha^{-1}yr^{-1}$) compared to plots without biochar application; however the above mentioned value is based on short term experiments. Application of biochar increased CH_4 emission by 39% and decreased N_2O emission by 35%.Because of lack of studies on long term impact of biochar on SOC, here we don't consider the impact of biochar on C component while calculating the technical potential. With possible positive impact on SOC and significant reduction in N_2O emission, technical potential of biochar addition was -0.18 t CO_2-eq $ha^{-1}yr^{-1}$.Biochar addition could be a way forward to decrease GHG emission. But long-term impact of biochar on soil physical, chemical and SOC sequestration rates is unknown and should be studied further before policy decisions are taken.

- **Convert from conventional to conservation tillage:** Changing from conventional to conservation tillage which aim to reduce tillage and soil disturbance in rice based cropping system such as Rice-wheat or rice- rape system could sequester 0.78 t CO_2-eq $ha^{-1}yr^{-1}$. With adoption of conservation tillage practice, CH_4 emission decreased by 17% and N_2O emission increased by 48% compared to conventional tillage. With total technical potential of -1.89 t CO_2-eq $ha^{-1}yr^{-1}$, adoption of conservation tillage in rice based cropping system could be a good mitigation option.
- **Integrated rice-fish or rice-duck farming:** Integrated rice-fish, rice-duck or rice-fish-duck farming can reduce CH_4 emissions by 23% and increase N_2O emissions by 4% compared to rice only cropping system. With numerous other advantages, such as greater yield, pest and weed control, disease resistance, increased nitrogen efficiency, integrated rice-fish or duck farming could deliver GHG benefitsas as well as economic benefits.
- **Organic manure application:** Our analysis shows application of fermented biogas residue increased CH_4 emission only by 42% while not composted or unfermented manure increased CH_4 emission by nearly 112-138%. With the additional carbon benefits acquired by displacement of conventional fossil fuel energy with biogas, use of biogas residue in rice field can provide soil fertility with less CH_4 emission. Application of livestock manure decreased N_2O emission by about 46% while green manure increased N_2O emission by 56%. Increase in CH_4 emission with livestock manure depends on water regime. Livestock manure application had a significant negative effect on N_2O emission, positive effect on CH_4 emission and SOC sequestration and technical potential of livestock manure application with different water regime i.e. continuous flooded, mid season drainage and intermittent irrigation was 2.48, -0.41 and -0.92 t CO_2-eq $ha^{-1}yr^{-1}$ respectively.



Total climate forcing impact (t CO_2-eq $ha^{-1}yr^{-1}$) of different management practices in rice agriculture in China

Mitigation options and potential for upland crops

Managing upland agricultural systems to optimize soil C storage and minimize N_2O can have a significant effect on the future radiative forcing. Proposed actions to decrease total GHG emission from upland crops include:

- **Apply straw to upland crops:** Returning straw or residue back to field is an important way to improve soil organic carbon storage. Straw incorporation increased soil C sequestration significantly by 0.73% $year^{-1}$ compared to crops with only chemical fertilizer application (NPK) and the rate of C sequestration with straw application was 0.294 t CO_2-eq $ha^{-1}yr^{-1}$. Incorporation of straw during the wheat or maize growing season decreased N_2O emissions by 8% but the effect was not significant. With an overall technical potential of -0.294 t CO_2-eq $ha^{-1}yr^{-1}$, straw application in upland crops is a potential mitigation measure. However, due to intensified cropping systems and plant protection needs, as well as labor unavailability, straw return is increasingly limited in croplands.

- **Biochar application:** Short term studies on the effect of biochar on C sequestration potential shows addition of biochar can accumulate nearly 5.268 t C $ha^{-1}yr^{-1}$. Application of biochar significantly decreased N_2O emissions in upland crops by 15%, and thus makes biochar addition a possible mitigation option with technical potential of -0.122 t CO_2-eq $ha^{-1}yr^{-1}$. About 40% reduction in emission factor was realized with biochar application for wheat and maize crop. Due to unavailability of long term data on effect of biochar on SOC, for technical potential calculation we only considered the effect of biochar on N_2O emission and not on the C component . Manufacture of compound biochar -chemical fertilizers reduce N use and reduced N_2O emission from the applied fields, thus make a significant contribution to net

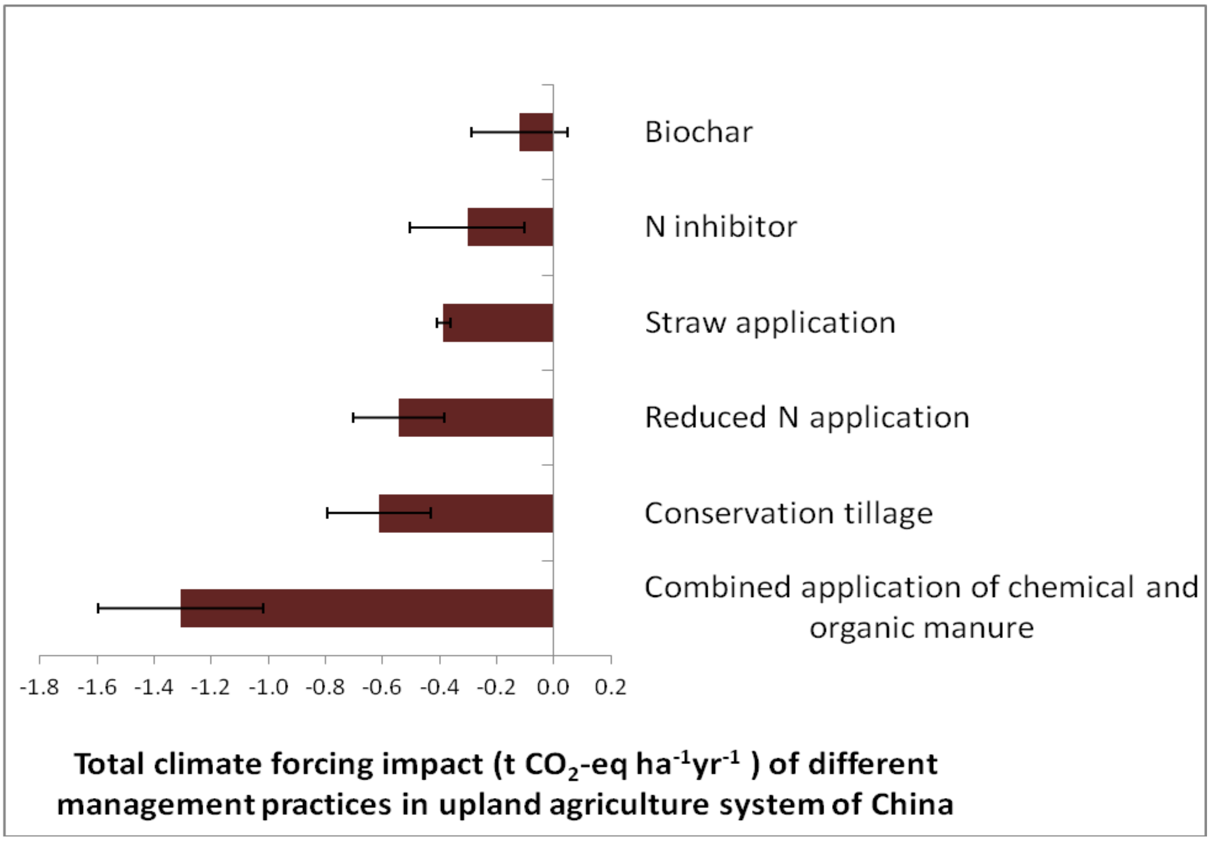
GWP reduction when taking into account of the avoided emission from N fertilizer manufacturing and N_2O emission reduction from fields.

- **Reduce synthetic N fertilizer application:** The excessive and inefficient use of N synthetic fertilizer has a range of negative impacts such as increased GHG emissions, increased water pollution, widespread soil acidification, reduced national energy efficiency and reduced net farm income (SAIN Policy Brief no 5). The average N application rate for wheat and maize is nearly 60 % – 150% higher than the recommended rate (Norse et al., 2012). Application of 0-150, 150-300 and > 300 kg N fertilizer increased N_2O emission from upland crops by 93%, 244% and 400% respectively as compared to control plots without any N fertilizer application. From 1998 to 2009, grain yields in China has increased by 10% while consumption of N fertilizer has increased by 49 % and that indicates large increase in fertilizer nutrient inputs did not result in a corresponding yield increase in the past decade. Reducing the N application rate to an optimal level where a sustainable yield can be achieved while getting some GHG benefits is an important option to decrease GHG emission from upland crops of China. Conventional fertilizer inputs for greenhouse vegetables are more than 2 to 8 times of crop nutrient uptake (Fan et al, 2010). Based on linear regression equation for % reduction in N fertilizer to % reduction in N_2O emission, a 10 to 30% reduction in N fertilizer would decrease N_2O emission by 11% – 22%, 17% - 30% and 27% - 45% in wheat, maize and vegetable crop respectively. A 18%, 16%, 10% and 15% reduction in N fertilizer from the current national average N application rate for wheat, maize, open field vegetable and greenhouse vegetable i.e. 229, 273, 315 and 656 kg N ha^{-1} (Li et al., 2010), will result in overall mitigation potential of 0.155, 0.267, 0.387 and 0.939 t CO_2-eq $ha^{-1}yr^{-1}$. This analysis does not include reduction in GHG emissions due to fertilizer production or other losses through NH_3 volatilization or NO_3 leaching.

- **Combined application of chemical and organic manure:** Combined application of organic manure with N fertilizer sequestered 1.435 t CO_2-eq $ha^{-1}yr^{-1}$ and increased N_2O emission by 75% compared to NPK alone. Higher C sequestration potential neutralises the negative impact of organic manure application on N_2O emission and gives an overall technical potential i.e. -1.306t CO_2-eq $ha^{-1}yr^{-1}$, and thus could be an important mitigation option**.**

- **N inhibitors or slow release N fertilizer:** Slow release fertilizer (SRF) either physically altered (coated or encapsulated urea), chemically altered (urea formaldehyde or isobutylidene diurea) or of a biochemical type (inhibitor) have been proposed as an alternative to conventional N fertilizer, as they can increase the efficiency of nitrogen use to obtain a high yield. Use of N inhibitors such as DCD, NBPT, HQ can decrease N_2O emission from maize by 50% compared to Urea-only treatment. Use of chemically altered SRF decreased N_2O emission from maize by 44% but physically altered SRF did not decrease N_2O emission from maize significantly.

- **Adoption of conservation tillage:** Practice of conservation tillage in upland cropping systems increased soil carbon content significantly, and the rate of C sequestration was nearly 0.915 t CO_2-eq $ha^{-1}yr^{-1}$. N_2O emissions with conservation tillage practice increased by 46% compared to conventional tillage .The overall technical mitigation potential was -0.612 t CO_2-eq $ha^{-1}yr^{-1}$, so adoption of conservation tillage is a potential mitigation option.



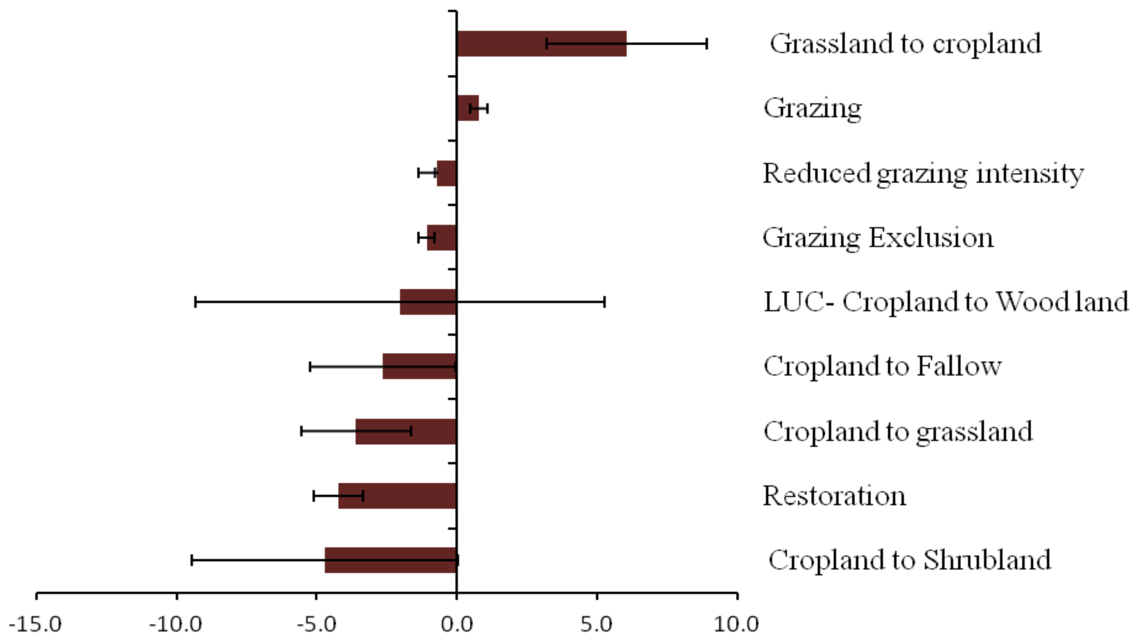
Mitigation options and potential for agricultural grasslands

Soil organic carbon (SOC) under grasslands in China has declined by 3.56 Pg from 1980s to 2000s and the major cause of this loss is increased area of degraded grassland (Xie et al., 2007). Degradation of grassland has occurred mainly due to overgrazing, change in land use (such as conversion of grassland to cropland) and various other ecosystem management strategies. However, good management practices to rehabilitate these degraded grasslands can increase SOC storage and decrease GHG emissions.

- **Reduced grazing intensity:** Though moderate grazing is thought to have the potential to increase SOC stocks, overall, grazing has decreased SOC stocks, CH_4 uptake and N_2O emission from grasslands of China. Grazing intensity has an important role in determining the rate of SOC loss; heavy grazing (HG) decreased SOC content significantly. Our analysis shows that effects of light (LG) to moderate grazing (MG) have no significant effect on SOC content, but when grazing intensity is reduced from heavy to light or moderate grazing, SOC contents increased by 0.771 t CO_2 ha^{-1} yr^{-1}. Conversion from HG to LG, MG and WG sequestered 0.825, 0.656, 0.363 t CO_2 ha^{-1} yr^{-1}, respectively. Reduction in grazing intensity from heavy to light or moderate intensity, decreased N_2O emissions and increased CH_4 uptake. So reducing grazing intensity or avoiding heavy grazing can not only increase SOC sequestration, but can also decrease GHG emissions. It is important to suggest a region-specific, grassland-specific stocking density for light to moderate grazing intensity to have an overall GHG benefit.

- **Grazing Exclusion:** Grazing exclusion could increase SOC content by 1.48% yr^{-1} or can sequester 1.06 t CO_2 ha^{-1} yr^{-1}. The amount of C sequestered depends on where the exclusion practice is being implemented; grazing exclusion in heavily grazed degraded grassland can provide maximum benefit. Grazing exclusion can be adopted as a practice to restore heavily degraded grassland, though food security must be maintained.

- **Land use change:** Land use plays a major role in determining the level of soil C and the direction of change in status (soil as a source or sink). Conversion of grassland to cropland decreased SOC content by 1.50% yr-^{1} i.e. loss of 6.05 t CO_2 ha^{-1} yr^{-1}. Conversion of croplands to grassland, shrub land, and woodland sequestered 3.94, 4.74 and 2.03 t CO_2 ha^{-1} yr^{-1}, respectively. Cropland abandonment increased SOC content by 1.60% yr^{-1} and sequestered 2.99 t CO_2 ha^{-1} yr^{-1}. Conversion of low yielding cropland, particularly on slopes, to shrub land or grassland can sequester more C and could be a promising option to decrease soil erosion.
- **Restore degraded grassland:** Restoring degraded grassland either by grazing exclusion, reseeding or afforestation on average can sequester 4.22 t CO_2 ha^{-1} yr^{-1} or an increase in SOC content of about 10% yr^{-1}. Light to moderately degraded grassland can revert to their initial state by grazing exclusion, but heavily degraded grassland with no native vegetation could only be restored by vegetation restoration either by reseeding and vegetation plantation. Forestry plantations, either sparse plantations or shelter forest plantations, on degraded grassland increased SOC sequestration by 44%. Reseeding of native species such as *Elymus natans*, *Poa crymophila* and *Festuca sinensis* increased SOC sequestration by 3.63%.



Total climate forcing impact (t CO_2-eq ha^{-1}yr^{-1}) of different management practices for grassland ecosystem

Conclusion

Based on the technical mitigation potentials assessed, the management options with great mitigation potential for rice agriculture are controlled irrigation, conservation tillage, replace urea with Ammonium sulphate, N inhibitor application and integrated rice fish or duck farming, reduced N fertilizer application. Combined application of chemical and organic fertilizer, conservation tillage, reduced N application are the possible measures that can reduce overall GHG emission from upland crops. One of the important mitigation measures for agricultural grasslands could be conversion of low yielding cropland, particularly on slopes, to shrub land or grassland and could be a promising option to decrease soil erosion. Apart from restoration of degraded grassland, grazing exclusion and reduced grazing intensity can increase SOC sequestration and decrease overall GHG mitigation. The above results presented here are based on technical potential, and do not consider economic constraints or barriers to adoption. An updated policy brief has been published (SAIN Policy Brief No 8) which describes the actual potential of these mitigation measures and their effect on yield, the social and economic barriers to implement these measures and the role of policy change to bring these measures to reality.

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