Potential Opportunities in Cereals Production

Major transformations are required to create sustainable food systems, but near-term immediate actions can support longer-term, more fundamental transition to sustainability. For incremental steps to contribute to long-term changes, stakeholders should define sustainability, measure unsustainability, and understand what interests, ideas and institutions contributed to the current structures, ideas, institutions, policies, and practices. Such understanding will enable stakeholders to choose near-term actions that can lead towards sustainability.

The tables, below, are intended to provide a starting point for stakeholders who are working to build sustainable food systems and are considering a range of near-term interventions. Much additional experience and knowledge by farmers, peasants, indigenous groups and other practitioners should be consulted for a full understanding of these and additional potential interventions.

The following tables summarize mitigation opportunities, adaptation potential, and food system implications in cereals production systems in four regions: Central and Latin South America, Africa, North America, and South Asia. Although the opportunity tables focus on mitigation opportunities, the tables identify adaptation potential of most opportunities.

Opportunity Table: Cereals (Intensive; USA)

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Challenges	Food System Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Manure application: Injection	Minimal for CH4, N2O, high for NH3 (Montes 2013). Variable and contradictory results- but Eagle et al. 2012 estimate 0.25 t CO2 e ha/yr potential).	If manure is better incorporated into soil, could increase SOC and water holding capacity for potential drought conditions	Could increase plant nutrient uptake, can reduce odors, may reduce runoff	Expensive, requires new equipment	Shift towards manure injection would require equipment investments with positive benefits for agriculture industries. Costs are prohibitive for many small and medium farms, but potential co-benefits could warrant public investment.
Manure application: Timing	High potential for N2O and NH3 (Montes et al. 2013). Potential of 0.18 t CO2e ha/yr in US (Eagle et al. 2012).	NA	Maximizes when plants will uptake, can reduce N leaching and water quality issues	Requires greater farmer involvement	May potentially involve increased farmer training through industry professionals or extension around timing for a given crop and system. May result in yield benefits for farmers and public benefits through water quality.
Winter cover crops	Has the highest potential in warmer winter regions. Could reduce N2O emissions and increase productivity. Potential of 1.92 t CO2 eq ha/yr. (Eagle et al. 2012)	Can provide nutrient benefits and increase water holding capacity	Cover cropping can reduce soil erosion, improve soil quality and fertility, improve water, weed, disease, and pest management, and enhance plant and wildlife diversity on the farm (Lu et al., 2000; Haramoto and Gallandt, 2004).	May increase NH3 (Montes 2013). Requires increased farmer time, costs and planning.	Cover crop additions would be an increased cost for farmers for inputs and labor, but feedback to provide public and on-farm benefits that may require a time lag to see. Total GHG emissions should be further monitored.

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Nitrification inhibitors	High potential- Nitrification inhibitors (NIs), double inhibitors (DIs: urease plus nitrification inhibitors) consistently reduced N2O emissions compared with conventional N fertilizers across soil and management conditions (grand mean decreases of 38, 30, respectively) (Thapa et al. 2016). a meta-analysis conducted by Gilsanz et al. (2016) found that the nitrification inhibitors DCD and DMPP were effective in reducing emissions; however, the magnitude of the effect differed across fertilizer formulations and soil types. Di and Cameron (2016) found an average reduction of 57% of N2O, ranging from 28 to 86%.	Potential yield benefits	Yield benefits but variable	Variable- may have food safety implications (currently outlawed in New Zealand) Expensive. Lack of long-term ecological studies.	Nitrification inhibitors have been banned in some countries for their potential public health implications as they've been found in milk. Thus, consumer acceptance is important to assess. The cost of such mitigation options is unlikely to work well for extensive systems, but is more feasible in intensive systems. Potential productivity gains would help offset costs, but gains are not universal.
Urease inhibitors	Urease inhibitors reduced N2O emissions compared with conventional N fertilizers in coarse-textured soils and irrigated systems. (Thapa et al. 2016)	NA	Little long term research regarding ecological impact	Variable based on soil type and geography. Expensive	Similar to nitrification inhibitors, there is potential for emission reductions, but they are not universal and long-term ecological feedbacks are unknown. Coupled with current costs, additional research is required.
Slow release/enhanced efficiency fertilizers	Controlled-release N fertilizers (CRFs) in one review reduced N2O emissions by 19% on average (Thapa et al. 2016). Recent work in rice demonstrates half the use of nitrogen with 10% yield gain (Kottegoda et al. 2017)	Potential yield gain	Water quality benefits if nutrient runoff is minimized (Liu 2012; Li et al. 2017)	Costly without a yield gain; variable by geography	Added costs of these fertilizers may prevent uptake without yield benefits, though yield benefits are likely in many places. Further research on specific technologies and yield gains is needed.
Conservation or no tillage	Variable results- reduced tractor time will decrease CO2 emissions; however many studies find that no-till in wet conditions increases N2O emissions. The debate over no-till and its ability to store carbon is also strong- many original early studies found studies weren't taking soil cores that were deep enough. "The most consistent trend in the literature suggests that overall, zero tillage reduces GHG emissions in the long term (c. 20 years), but crucially some uncertainty still exists as to when the positive effects are first recorded and how long these effects can be observed. (Mangalassery 2015)	If there are soil organic carbon gains, this can have positive benefits on soil structure and quality for future adaptation benefits	Reduced CO2 emissions, tractor time for farmers	Not a one size fits all solution- Highly variable by temperature, soil, etc.	No-till agriculture can improve farmer profits by reducing fuel and labor costs. However, it may not consistently provide GHG benefits. No-till is also commonly associated with GMO crops, particularly herbicide tolerant ones, which are associated with increased herbicide use (Perry et al. 2016), which could influence public health and have consumer acceptance challenges.
Integrated Nutrient Management	Involves optimizing fertilizer application rates and timing, utilizing multiple sources of fertilization. Prioritizes organic fertilizers (Wu and Ma 2015). See Chen et al. 2014 for additional details- much of this work is happening in China	Can significantly increase yield without increasing fertilizers. May provide soil health benefits. Increases water holding capacity potentially (Wu and Ma 2015).	Water quality, increased yields, reduced environmental pollutants	Requires greater farmer involvement, testing, etc.	Currently much focus of this work is in China, so greater research elsewhere is needed. Through this dual approach could provide high benefits, but would influence agricultural input industries and require farmer training and Extension as well as potentially costly tests. Both adaptation and environmental and public health impacts could be high.
Eliminate summer fallow	Could be implemented on 20Mha in US- would have small potential GHG reductions (0.44 ha/yr of CO2 eq (Eagle et al. 2012)		Additional food production	Typically employed because of drought and lack of water	May not be feasible if summer fallow is the result of drought or lack of water- maybe potentially increase GHGs if done with intensive cropping and/or significant inputs. However, could provide additional food production and maximize land potential, which would reduce the need for agricultural land expansion and LUC.

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	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Diversify crop rotations	Can potentially increase carbon sequestration, but benefits are small and not significant for corn-soy. Small potential reduction of 0.1 t co2e ha/yr. (Eagle et al. 2012)	Diversification	Soil organic carbon, soil health	Small potential mitigation	Comparatively small potential GHG reductions, but many other potential co-benefits. Likely greatest impact would be coupled with nutrient management and other agroecological practices. Would involve greater farmer planning, time and potential training.
Include perennials in crop rotations	Including a perennial crop like alfalfa or grass hay into an annual crop rotation can potentially increase SOC, but hard to separate the effect from tillage differences. With reduced N fertilizer needs, a net GHG mitigation or 0.7 t CO2 e ha/yr is possible. (Eagle et al. 2012)	Increase SOC, water/drought benefits	System diversification	Could reduce yield. May reduce farmer costs from inputs.	Perennial rotations could reduce farmer time and costs associated with additional inputs while providing potential ecosystem services. Some perennial crops may be water intensive (like alfalfa), and could reduce farmer incomes if harvest times are longer.
Replacing annuals with perennial crops	Can reduce tilling and fertilizer needs. Potential for 1.46 GHG t CO2 e ha/yr possible. (Eagle et al. 2012)	SOC	Soil health	Food production implications- food security impacts?	While perennial crops can provide many ecosystem services, replacement should consider food security implications of perennial systems, since much food is provided through annual systems. Additional research on perennial crops should be conducted to explore future potential.
Switch to organic fertilizers	Has the potential to increase SOC. Studies in the US are variable, ranging from a potential t CO2 eq. ha/yr of 0.7 to 3.50 depending on crop, manure, soil, etc. (Eagle et al. 2012)	SOC	Soil health	availability, unless cropping is situated close to sources of organic fertilizers, it is costly to transport long distances	Organic fertilizers would offset GHGs associated with synthetic N fertilizer production, reducing pre-production emissions. However, such shifts may involve a fundamental transition to more farm or regionally integrated crop and livestock systems, since transporting organic fertilizers long distances is costly (they are heavy). Decoupled crop and livestock systems would prevent scalable implementation of this practice.
Reduce N fertilizer rate	Overall, in the US and other intensive input systems, N fertilizer is overapplied. In tandem with INM, reducing fertilizer rate is a potential GHG strategy in the US with reductions of 0.33 t CO2 eq. ha/yr. Note that the US currently has protocols that would incentivize farmers to reduce N fertilizer rate	NA	Improved water quality, reduced costs for farmers	May require farmer training and extension to assess when and how to reduce inputs. Precision agriculture offers huge opportunity to assist farmers.	Reductions in N fertilizer rates is possible for many farms overapplying without a yield loss. This would save farmers money, and improve water quality. Precision agriculture technologies offer great potential for implementing this strategy, though typically only large farms have this capacity. Agricultural industry may benefit from spread of precision agriculture technologies.
Switch from anhydrous ammonia to urea	N2O emissions decrease of 0.6 t CO2e ha/yr. on average (Eagle et al. 2012)	NA		Input switches- may require agricultural input dealer consultation. Potential increased costs for farmers.	On a pound per nitrogen basis, anhydrous ammonia is cheaper than urea, so this would potentially require an increased cost to farmers. Such costs could be offset if coupled with potential N reductions achievable through precision agriculture.
Organic production	Organic production may use less energy (Smith et al. 2015), but could produce lower yields (Reganold and Wachter 2016). However, organic production used with other agroecological practices such as multi-cropping and crop rotations can reduce yield gaps (Ponisio et al. 2014) and provide mitigation and adaptation benefits	Can increase SOC, and when coupled with other practices spread future risk	Can provide greater ecosystem services, social benefits and farmer profitability (Reganold and Wachter 2016).	May result in yield reductions, but can be overcome. Certification can be costly for farmers, which is often necessary for a price premium.	Shift towards organic production would shift production from input driven to practice and labor driven, which would potentially increase agricultural jobs and require farmer training. If organic production results in price premiums, this could increase food costs for consumers, though in high-income countries organic product demand is growing.

Opportunity Table: Cereals (India)

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Challenges	Food System Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available			Potential feedbacks and interactions
R&D seeds & other inputs	While there are a large varieties of seeds in India, it is **unknown whether the effort around development of new seeds and other inputs takes into the account the climate mitigation impacts of the new varieties**. Based on personal interviews and conversations there is strong focus on integrating climate impacts & developing climate friendly varieties of crops, especially field crops. Several varieties have already been developed and under field testing. Water being the most critical input for managing crop productivity and in the changed climate drought being the most important factor affecting crop productivity, majority of the varieties being developed are focused on this rlationship with water. A few short-duration varieties of wheat capable of withstanding drought at the grain filling stage are already in the field. Agencies are trying to reach the farmers with the seeds of such varieties. ICAR has a strong integrated program entitled NICRA is already in operation. The field level impacts on mitigation need to be better understood	Med-high			
R&D Technology / mechanization	There is a growing effort to develop appropriate technologies for the small holder farmers - from smaller seed drills, , levelers, weeders, low cost drip systems, etc. With the drop in aailability of labout for the farms and the ecxpected broader ddeployment of credit access for the farmers, it is expected this segment with grow rapidly. In the long run, deployment of these technologies at scale can lead to ***significant emission reductions*** **through gained effciency and productivity.**	Mdium-high by reducing economic risk exposure	Economic growth,		
Fertilizer manufacturing	Of the approximtely 130 MtCO2e of annual emission from fertlizers, approximately 50% can be attributed to production. There is scope for reductions in emissions by as much as 20-30% (determine exact source). Ensuring NUE 9reduced future demand) and manufacture processes that use natural gas are the main contributors for mitigation				
Reduce on farm energy use for water;	Low-medium mitigation potential, - eg through use of solar pumps	For farmers some option for navigating low rainfall years; although long term efficacy of such an approach is not well understood. With water tables dropping rapidly in many parts of the country, over long term this approach could exacerbate the problem.			
Manage the timing of N input and organic input	Med mitigation potential. Focus on NUE; use of neem coated urea for slower release of N; application of organic N to improve soil carbon	Improve water retention capacity of soils through increased humus content of soil	Reduced N run off in landscape, economic benefits		
Create ecosystem to increase availability of seed drills, and laser levelers, harvesters, etc	Cereals in India are grown in both irrigated and upland systems. The country seeks to decrease the yield gap between the two - while also improving productivity in both systems. Improved productiity through sustainable intensification offers **significant mitigation potential**. Mechanization can help increaese prodcutivity and in the process, if managed well, can also help reduce yiedl scaled emissions.	Reduced risk for farmers, improved soil health			
Increase avalabilito of technology and training to manage post harvest losses at producer level	With producer level post harvest losses during harvesting, collection, threshing, etc @ ~4% (good mitigation potential)		Improved incomes		
Re-incorporating residue into soil; or using biomass/straw for egenrating energy	Wheat contributes to 25-30% of total (~100 Mt) residue burnedin India. Of the other key cereals, millet and maize are low residue crops.	Med-high (reduces soil nutrient loss)	Health/lower pollution / reduced black carbon		

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Water constraints (likely in the short term) and demand changes (in the long term) will cause this shift. Important to catch it early and actively help manage the shift OR identify incentives that can catalyze this shift	Moderate to high depending on shift. If the producer is shifting cultivation due to water constraints, then early indications are to try and promote tree cultivatiuon (agro-forestry), intercropping, multicropping etc as a way to manage risk explosure to the vagaries of rainfall. embedded within these are many options for mitigation but the quantum of mitigation potential is not well understood.	Moderate to high - opens pathway to reduce water stress			
Education and socialization of the concept of nutritional and environmental value of food	Low-moderate on level of shift. Cereals in India consttute ~13% of the diet and have a low emission footprint (~3%) Biggest gains to be had are from promoting NUE and on farm energy consumption	Moderate to high - opens pathway to reduce water stress; perhaps also improves food security over the long term	Health and nutrition		

Opportunity Table: Cereals (Extensive; West Africa)

Country Examples: Burkina Faso, Mali, Niger, Senegal, Ghana, Nigeria (Sudan Savannah/Sahel Agro-ecology)

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Food Systems Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		
Cultivar development	In the realm of cultivar development, this would include developing varieties that withstand higher temperatures. But it would also include varieties that are resilient to drought, pest, weeds, salinity, flooding, etc. The best new varieties would be ones resilient to more than one threat considering it takes many years to develop and test new cultivars. A recent study on the economic impact of climate change on cereal crop production in Northern Ghana (Bawayelaazaa et. al. 2016) indicated that early season precipitation was beneficial for sorghum, but harmful for maize. However, mid-season precipitation tended to promote maize production. More is being done on Drought Tolerant Maize by IITA.	High temperature levels for all seasons impacted negatively on net revenue for both crops, except during the mid-season, when temperature exerted a positive effect on net revenue for sorghum. Millet and Sorghum: These two crops are among the main staple crops of sub-Saharan West Africa (64% of the total cereal production in 2000; FAOSTAT, 2012 data). On-farm surveys have shown farmers transition more to these dominant traditional crops the suits the environment at the expense of maize and rice as they are heat and drought tolerant (Traore et al., 2011). Besides they do not demand a lot of fertlizer and manure. Drought Tolerant Maize has also been released by IITA and CIMMYT (CCAFS). Other endemic crop varieties that are increasingly being grown by farmers due to climate change are groundnut and Yam. Groundnut is an important crop for Nigeria, southern Mali, Ivory Coast, Burkina Faso, Ghana, and Senegal. Parkes etal.(2015) investigated the benefits of breeding cultivars of ground nuts with heat and water stress resistance as well as the potential of marine cloud brightening to reduce the rate of crop failures in West Africa using the GLAM model. The authors found that climate change will increase mean yields of groundnut and reduce the risk of crop failure in West Africa. Yam is the second most important crop in Africa interms of production after cassava. Srivastava et al. (2015) simulated the advantages of specific adaptation strategies using the EPIC model. They found that changing solely sowing date may less effective inreducing adverse climatic effects thana dopting late maturing cultivars. Cassava: Using the EcoCrop model to investigate the response of important staple food crops for Africa including maize, millets, sorghum, banana, and beans to climate projections by 2030, Jarvis et al. (2012) found that cassava reacted very well to the predicted future climate conditions compared to other crops.	In sub-Saharan Africa, the Drought Tolerant Maize for Africa initiative has released 160 drought-tolerant maize varieties between 2007 and 2013 (CCAFS 2016). These generate yields 25-30% superior to those of currently available commercial maize varieties under both stress and optimal growing conditions (CCAFS 2016).	In West Africa, there is now a trade-off between Maize, Rice and other indigenous crops such as Sorghum and millet. While maize and Rice contribute to climate change markedly. However cassava, yam, and pearl millet show, on average, either little loss or even gains in the area suitable for production due to climate change. Breading and selecting cultivars that are drought tolerant and contribute less to climate change seems to be offering solutions to food security in West Africa. Western Africa appears to be a highly vulnerable region, with significant (>10 %) reductions in suitable area for maize.
Seasonal weather and climate forecasting	With climate information services, farmers will be able to plan their planting and make projections about rainfall distribution patterns and temperature variations. Local ICT companies and meteorological institutions must be supported in providing the most accurate and reliable information to farmers.	Recently, a sound approach was successfully implemented (CCAFS 2016) to designing tailored climate information services and (FAO 2015)) to communicate them appropriately to farmers for their farm management decision making vis-àvis climate variability in Senegal (CCAFS 2015). A collaboration between scientists and the national meteorological agencies of Senegal, Ghana and IT-based service providers allowed developing more accurate and specific seasonal rainfall forecasts and to raise capacity of partners to do longer-term analysis and provide more targeted information for farmers.	A cost– benefit analysis in Burkina Faso by Ouedraogo et al. Ouédraogo et al (2015) showed that farmers exposed to climate information have used less local seed and more improved seed for cowpea and sesame production. They also used less organic manure and more fertilizers forsesame production. Cowpea producers exposed to climate information obtained higher yields while covering lower inputs costs and their gross margins were therefore higher compared to non-exposed farmers.	Choosing the right varieties to grow based on weather and seasonality information acts as safety nets to farmers against total loss of their produce hence enhancing food security. Besides weather can be a contributor to total loss of crop harvests.For maize and beans, two key staple crops in Africa, areas of suitability could decline by 20-40 % relative to the period 1970-2000 due to increase in temperatures. Conversely, across most of West Africa, sorghum, cassava, yam, and pearl millet show, on average, either little loss or even gains in the area suitable for production. The reason why people of this region are turning to growing these crops.

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Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Food Systems Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		
Soil carbon sequestration	Soil organic matter has been known for years to be beneficial to cultivation due to its abilities to improve soil structure and enhance water and nutrien retention. The challenge is to leave enough (or place enough) vegetation for the SOM to increase. Agroforestry is one option, but other possibilities include no-till agriculture, offseason cover crops, use of animal manure and biochar (a by-product of the pyrolysis of biomass under limited oxygen conditions) (Partey et. al. 2016). Although soil carbon sequestration has direct benefits to the farmer and mitigates climate change, increasing SOM may increase the emission of some greenhouse gases. Not all the science on this latter point is settled. However, it is reported that nitrous oxide, a greenhouse gas approximately 300 times more powerful than carbon dioxide, can be emitted during nitrification and denitrification from organic matter (Corsi et. al. (2012; Duxbury, 2016).	Adaptation potential is very high due to emergence of markets for climate change mitigation using soil carbon sequestration (Lipper et al. 2010). Agroforestry and conservation agriculture are some of the adaptation technologies that are being used to sequestre corbon in West Africa countries. Specifically, in Burkina Faso, Mali, Niger, Senegal, Ghana and Nigeria where no till and agroforestry are encouraged (Zougmoré et al. 2016). Some of the conservation technologies that are being adapted in these countries, crop residue retention, cover cropping minimum tillage, crop rotations, water harvesting and nutrient management. Conservation agriculture has the potential to sequester soil carbon, especially when it leads to increased crop biomass production via double cropping (two crops per year), thereby contributing to climate change mitigation (Corbeels et al. 2006).	In addition to mitigating carbon emissions, increasing soil carbon can have profound effects on soil quality and agroecosystem productivity. Soil carbon plays important roles in maintaining soil structure (Bronick and Lal, 2005), improving soil water retention (Rawls et al., 2003), fostering healthy soil microbial communities (Wilson et al., 2009), and providing fertility for crops (Schmidt et al., 2011). These improvements are well documented and have generated a consensus that improvements to soil carbon are key to improving agricultural systems as a whole. While uncertainties may remain about the potential of agricultural soils to act as a carbon sink, the vast number of co-benefits should remain an incentive to modify agricultural practices to increase soil carbon in their own right.	Improved soil fertility due to increased organic matter. Improved crop yields hence food security. Provision of fodder to livestock if fodder trees are used. Extra income to farmars through carbon credits.
Water management	Along with cultivar development, supporting farming techniques should be developed. These might include irrigation and water harvesting. There may be benefits from shifting the focus from large-scale public irrigation to small-scale private irrigation, which may include more efficient management and distribution of water, related to the user actually bearing the costs of the water use, bypassing issues related to equitability and funding in large-scale schemes. Furthermore, one of the critical issues surrounding climate change is the variability in weather, with floods and droughts both becoming more frequent. Water conservation and supplementation are both important to develop when feasible, especially ir marginal areas.Research for development work to build climate-smart farming systems through integrated water storage and croplivestock interventions has been conducted in Burkina Faso, Mali and Ghana (Amole and Ayatunde, 2016).	Through this project, synergies that exist between water retention interventions (such as zaï, contour ridges, dugouts, small reservoirs) and crop-livestock interventions (such as trees and legumes, fodder production, crop residuemanagement) have been identified to improve water availability for crops, livestock and humans throughout every year (Amole and Ayatunde (2016). Development of small reservoirs in Ghana and Burkina Faso (Van de Giesen et al. 2002). Small reservoirs supply rural populations locally with water for irrigation, cattle, household, fisheries, and recreation. By 2005 these small water reservoirs were about 2000 in Burkina Faso ((Liebe et al. 2005). Quite a number had been constructed in the volta basin of Ghana(Faulkner et al. 2008). An alternative to the construction of small reservoirs is the use of groundwater in shallow alluvial aquifers. In northern Ghana, specifically the Upper East Region, shallow groundwater irrigation have expanding spontaneously over, roughly, the past five years.	Water management benefits both crops and lives of crops and livestock. Some cases where we have large ponds fish farming is also being practiced alongside crop production. This improves household food security and income.	Small reservoirs supply rural populations locally with water for irrigation during dry season, cattle, household use, and fish farming. All these supplement the food that required during the dry season (van de Giesen et al 2008).

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Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Food Systems Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		
Agroforestry	Cultivated lands have the potential to contribute significantly to climate change mitigation by improved cropping practices and greater numbers of trees on farms. The global estimated potential of all greenhouse gas (GHG) sequestration in agriculture ranges from 1500 to 4300 Mt CO2e yr 1, with about 70% from developing countries; 90% of this potential lies in soil carbon restoration and avoided net soil carbon emission (Rust and Rust 2013). Tree densities in farming landscapes range from low cover of about 5% in the Sahel to more than 45% in humid tropical zones where cocoa, coffee and palm oil agroforestry systems prevail (Rhodes et al. 2014).	Adaptation potential is very high. A synthesis report by Nyasimi et al. (2014) and Reij et al. (2009) showed that farmers have grown 200 million new trees on cultivated fields in West Africa. Agroforestry practices can provide pathways to ecological intensification and contribute significantly to reduce the yield gap. Recent studies in Niger shows that thousands of farmers now have surplus grain to sell even in drought years and similar trends are noted in Mali and Senegal in the Faidherbia parklands. s. Fortunately, agroforestry farms and landscapes are a major part of Africa's rural landscapes and provide income and environmental outcomes, and a range of other ecological services. In the Sahel, woodfuel account for more than 80% of the region's energy supply, most of these energy need is satisfied encroaching on the rapidly shrinking forest cover. The adoption of agroforestry can reduce the human impact on forest cover and spare more lands to sustain healthy ecosystems and biodiversity. Expansion of crop lands at the expense of trees – have many negative impacts for local livelihoods.	Agroforestry has potential to improve soil fertility through nitrogen fixing trees. The trees contribute to climate change adaption by reducing wind speed and decreasing damage to crops from windblown sand. Taking into account all factors, including enhanced soil fertility and increased food, wood and fodder supply, FNMR can bring an estimated benefit of USD 56 ha−1 year−1(Cooper et al. 2013; Dinesh et al. 2015).	The natural regeneration and the improvements that it brings in soil fertility, fodder, food and fuelwood, have been valued at US$56 ha−1 year−1 or a total annual value of US$280 million. The integration of trees and shrubs with crops and livestock systems – has strong potential in addressing problems of food insecurity in developing countries. Done well, it allows producers to make the best use of their land, can boost field crop yields, diversify income, and increase resilience to climate change. For example, one of the major potential benefits of on-farm trees is their ability to replenish nutrient-depleted soil, and the results of a 12-year study by ICRAF published in September 2012 showed how the planting of a particular tree variety – Gliricidia – as a fertiliser tree alongside maize improved the stability of harvests of this staple food crop in sub-Saharan Africa.Additionally fodder shrubs reduce the cost of meeting dairy cows' protein requirements (many acacia and legume trees are used as fodder trees). Social implications such as the substantial income, mostly for women for Shea butter fruits in Burkina Faso, fruits from Cordyla pinnata in Senegal, Detarium senegalense in Mali, Parkia biglobosa or Nere in all Sahelian countries, Adansonia digitata a or Baboab fruits, Tamarindus are also having a higher market value…can improve poverty alleviation in rural areas. Perennial evergreen agriculture is in that context very promising for the future food security and the build-up of social capital (Mbow 2013).

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	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		
Fertilizer use efficiency	In addition to the use of inappropriate types of fertilizer depending on the soil type and native soil fertility, too much fertilizer, or fertilizer applied at less than optimal levels and times can be wasted, going beyond the reach of the crop. Not only is this economically inefficient, but the fertilizer can be converted to nitrous oxide and emitted to the atmosphere. However, the right type of fertilizer applied at proper times and amounts can be used efficiently by the crops while minimizing emissions. This may involve promoting integrated soil fertility management that seeks, among other things, to enhance the soil organic matter content of the soils, which improves nutrient retention (Zougmoré et al. 2014).	Adaptation potential is high since several organizations are now testing and mapping soil nutrient content in Africa and providing agribusinesses and fertilizer manufacturers with solid data on which to base fertilizer recommendations. Along with improving policy environments and better fertilizer blends (that include secondary and micronutrients), agricultural productivity in Africa is growing and primed for greater success.	In addition to sequestering carbon, appropriately applied fertilizers may prevent deforestation and conversion of other lands into agricultural land. Currently, land conversion is the annual source of 12 percent of all greenhouse gases (IFDC 2016). But by allowing for the production of more food from less land, fertilizers have averted the conversion of about 1 billion hectares of virgin land into agricultural land since 1960.	Fertilizer use in West Africa is far below the world average, leaving farmers without an important input that can significantly improve yields. In West Africa, farmers are employing integrated soil fertility management by applying crop resides, compost, mulch, livestock manure, leaves, and fertilizer. These practices help farmers meet the nutrient needs of the crop while restoring soil organic matter and overall soil fertility, which contributes to sustainable intensification of crop production. Integrated soil fertility management across more than 200,000 hectares resulted in crop yield increases of 33-58 percent over a four-year period. Farmers also saw revenue increases of 179 percent from maize and 50 percent from cassava and cowpea.Farmers in Burkina Faso and Niger are using water-harvesting techniques such as building stone lines and improved planting pits (locally known as zai). These practices help to trap rainfall on crop fields, increasing average cereal yields from 400 to 900 kilograms per hectare (kg/ha) or more. Applying small quantities of fertilizer directly to seeded crops or young shoots early in the rainy season can complement these low-tech land and water management techniques. Combining this “micro-dosing” with practices like water-harvesting has increased millet and sorghum yields from fewer than 500 kg/ha to 1,000 or 1,500 kg/ha (Winterbottom and Reij 2013).
Conservation Agriculture	Conservation agriculture is as an approach to farming that seeks to increase food security, alleviate poverty, conserve biodiversity and safeguard ecosystem services. Conservation agriculture practices can also contribute to making agricultural systems more resilient to climate change. In many cases, conservation agriculture has been proven to reduce farming systems’ greenhouse gas emissions and enhance their role as carbon sinks (USAID 2012).	Adaptation potential is very high.Climate variability and change are increasingly posing a threat to Western Africa’s socio-economic development and environment. The beneficial effects of mulching with crop residues on the soil water balance (through reduced water runof and soil evaporation) may enhance adaptation to future climate change, when rainfall is projected to decrease and become more unreliable (Scopel et al. 2004; Thierfelder and Wall 2010).	Conservation agriculture – or zero tillage - also helps to maintain and improve the environment. Tractor use is substantially reduced when cultivation is eliminated, thus reducing emissions of greenhouse gases and other pollutants. Moreover, under zero tillage, soil moisture conservation and wind and water erosion are reduced because the soil surface is not plowed and residues, crowns, and roots from previous crops and pastures protect the soil. There are even cost benefits: zero tillage reduces the need for tractors and thereby lowers fuel and labor costs.	Conservation agriculture is among a group of practices that provide a “triple win” of increased agricultural productivity, enhanced resilience to climate change, and sequestration of carbon (Mango et.al. 2017)

Opportunity Table: Cereals (Extensive; West Africa)

Country Examples: Burkina Faso, Mali, Niger, Senegal, Ghana, Nigeria (Sudan Savannah/Sahel Agro-ecology)

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Food Systems Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		
Rice water management	With optimal management of water in a rice system, such as alternate wet and dry (AWD), methane emissions can be reduced without adversely impacting yield and potentially increasing yields. It may also prove to be a more efficient use of water in many locales.	The danger of such a system is that if done incorrectly, the nitrous oxide emissions will increase so much that they will negate any gains in methane emission reduction (Amole and Ayantunde 2016)	It may also prove to be a more efficient use of water in many locales. Wetlands are high in plant and animal species diversity, particularly bird and fish populations, and can be found in river basins, lakes, and coastal areas in Western Africa. They provide resources such as fisheries, shellfish, fuelwood, medicine, and agricultural products, and protect human settlements, infrastructure, and various other coastal activities from the impacts of heavy rainfall, storms, and sea level rise. Wetlands are also pertinent to tourism in countries such as Senegal, the Gambia, and Ghana.	Research from West Africa show that irrigated rice is of high quality than upland rice. Besides water from irigated rice can still for other crop production such as vegetables and fish farming. Thus rice water management creates a win-win scenario as far as food systems is concerned. Its contribution to GHG emmissions is equally very low as cclimate compared to upland rice.
Appropriate institutional support:	Regional actors and networks that focus on and fund environmental and climate-change related initiatives in the region include the African Union, African Development Bank (AfDB), Environmental Development Action in the Third World, Organization for the Development of the Senegal River Basin, Niger Basin Authority (NBA), and the Global Water Partnership West Africa. Many initiatives in the region have also been led and/or financed by international agencies, institutions, and NGOs working with regional CLIMATE CHANGE ADAPTATION INWESTERN AFRICA partners.	Adaptation potential is quite high. Here are some of the selected initiatives. (1) Strengthening the Capacities of Permanent Interstate Committee for Drought Control in the Sahel Member States to Adapt to Climate Change (Burkina Faso, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Niger, Senegal) (2) Adaptation to Climate and Coastal Change in West Africa – Responding to shoreline change and its human dimensions in West Africa through integrated coastal area management (Senegal, Guinea Bissau, Gambia, and Mauritania) (3), Seasonal Rain and Flow Regimes Forecast Project in West Africa (4) Africa Water Vision for 2025 – Effective management of droughts, fl oods, and desertifi cation in half of African countries by 2015 and in all countries by 2025	Improved food security, cleaner environment, improved crop and livestock production, and better human health	These regional actors and networks give hopes for large-scale Climate Smart Agriculture adoption for improved resilience to climate change and food security in West Africa. Climate Smart Agriculture is already endorsed for inclusion in the NEPAD program on agriculture and climate change by the African Union, while in the framework of the formulation of the Economic Community of West African States 10 years Policy (ECOWAP + 10), the new common agricultural policy for the region, ECOWAS seeks for a focus on the mainstreaming of climate change and CSA into local plans and policies of member countries (Zougmoré et al. 2016).
Condicive Policy	Governments in West Africa have enacted policies that promote climate smart agriculture. The aim of these policies is to mitigate GHG emission.	There is high adaptation potential given that there is government support	More food security, environmental management.	With financial support from the United Nations the Economic Community of West African States (ECOWAS) are formulating regional policies that will alleviate the the negative impact of climate change on food security, and promote sustainable development in the region. These policies will support the effort of ECOWAS to mainstream climate change information into agricultural policies that will in the end increase food security.

Opportunity Table: Impacts of Climate Change on East and Southern African Crops, their Consumption, and Adaptation Strategies

Cultivation of cereal crops is the main source of GHG emissions in South Africa with 68% of the total emissions from field crops. Totals of 61%, 14% and 25% of emissions from production of cereal crops are from synthetic fertiliser, crop residues and lime, respectively. Production of cereal crops accounts for 73% of national total GHG emissions from application of synthetic fertiliser, 72% of emissions from crop residues and 57% of CO2 from lime. Maize (82%) and wheat (14%) are the main sources of total cereal crop GHG emissions (Tongwane et al.2016). Application of synthetic fertiliser during maize production results in 85% of emissions from cereal crops (Tongwane et al.2016). A total of 84% of emissions are from crop residues left in the field after harvest.

Cultivation of maize (Tongwane et al.2016) and production of this commodity accounts for three quarters of emissions from the addition of lime to the soil (Tongwane et al.2016). Production of wheat contributes totals of 11%, 15% and 17% of cereals' emissions from synthetic fertiliser,cropresiduesandlime,respectively (Tongwane et al.2016). Productions of sorghum account for less than 5% of total emissions from application of manure during cultivation of cereal crops.

Production of legumes and oilseeds contributed 11% of total national GHG emissions from field crops in South Africa. Unlike with other crop groups, application of lime is the main source of emissions with 60% of the emissions from legumes and oilseeds. Synthetic fertiliser and crop residues account for 34% and 5% of the emissions from this group, respectively. Production of soybeans and groundnuts accounts for the largest sources of emissions from legumes and oilseeds with 47%, 30% and 19%, respectively (Tongwane et al. 2016).

Application of synthetic fertiliser during the management of groundnuts is the largest source of emissions for this agricultural input in this group (Tongwane et al. 2016). Similarly, soybean is the major source of emissions from lime application (Tongwane et al. 2016).

No proper data exists for impacts on cassava and sweet potato production.

Opportunity Table: East and Southern Africa

Opportunity and Countries Affected	Adaptation Strategies	Co-benefits and Food Systems Adaptation	Challenges and Climate Change Impacts	Food System Implications
	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Maize, the most widely cultivated staple crop in SSA, is primarily grown by smallholders and 77% of the total production in SSA (excluding South Africa) is consumed as food (Smale et al. 2011). In this report, Ethiopia, Kenya, Uganda, Tanzania, Rwanda, Burundi, Zambia, Mozambique and Zimbabwe.	Scientists are already developing Drought Tolerant Maize for Africa (CIMMYT, IITA in collaboration with National Research Organizations. Conservation agriculture is being promoted alongside organic farming to sequestre carbon in minimize fertiliser use. New maize varieties with improved drought and heat tolerance will play an important role in adapting maize systems to climate change in SSA, however maize yields in this region are currently amongst the lowest in the world. Agroforestry practices are being promoted by World Agroforestry Centre. Water harvesting techniques, and small irrigation is on the increase in the region.Conservation agriculture practices increase stored soil water by improved water infiltration, reduce evapotranspiration and reduce water runoff Verhulst et al. 2010; Thierfelder and Wall 2012).	Farmers are now transitioning to growing more of drought tolerant land races than hybrid maize. Though low yielding, they are more adapted to the environment than high yielding hybrid maize. CIMMYT and IITA have also come up with Drought Tolerant Maize that they are promoting alongside conservation agriculture practices. NGOs are encouraging farmers to practice ecological agriculture and practice more of organic farming to reduce the use of synthetic fertlizers. Farmers are now transition the consumption of maize only and are reverting to consuming more of root, tuber and bananas. This mainly predominant in the east africa region towards the congo basin.	Overall, maize production will decrease under future climate scenarios, though the degree of impact differs among simulations. Using the CERES- Maize model, Jones and Thornton (2003) predicted a 3–19% reduction in maize yield in the FtF countries by 2055 compared to 2000, where Ethiopia and Mozambique were projected to experience the least and greatest decrease in maize yield, respectively. Furthermore, the authors projected spatial heterogeneity for maize production with larger areas experiencing reduced yield as compared to the areas with yield gains in East Africa. Despite large variations in projected impact on maize yield, there is a general consensus that climate changewill adversely affect maize yield in East Africa. Multiple studies indicated that East Africa could lose as much as 40% of its maize production by the end of the 21st century.	Maize is the most important source of dietary protein and the second most important source of calories in eastern and southern Africa (Broughton et al. 2003). However with projected decrease in maize yields due to Climate Change it means many regions in East and Southern Africa will suffer hunger.

Opportunity Table: East and Southern Africa

Opportunity and Countries Affected	Adaptation Strategies	Co-benefits and Food Systems Adaptation	Challenges and Climate Change Impacts	Food System Implications
	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Wheat is generally cultivated as a winter rainfed crop in the highlands of Ethiopia, Kenya, Uganda, Rwanda, and Tanzania and as a winter irrigated crop in Zambia, Malawi, and Mozambique (Negassa et al. 2012).	For crops, such as wheat that are more impacted by heat stress switching to heat- resistant and drought tolerant crops, such as sorghum and millet, may mitigate temperature stress- related crop failure. As an adaptive measure to climate change, farmers in Africa have already begun selecting a combination of crops based on the prevailing climate (Kurukulasuriya & Mendelsohn 2006).	With persistent and prolonged drought in Africa due to climate change, people are changing their eating behaviour and consuming more of wheat product than maize. In Kenya today a 2 kg packet of maize is costing more than a 2 Kg packet of maize flour. This has forced the Kenyan government to subsidise the packet of maize flour imported from Mexico. Not many people consider wheat as a staple food in Kenya other than in urban areas. However maize being a staple crop and having been hit hard by climate variability and change, its flour has become so scarce. Wheat flour which has been considered a luxury and food only for the rich and the middle class is now more abundant in the super markets than maize flour. Besides wheat flour is far more cheaper.	Wheat is a coolseason crop and increasing temperature shortens its growth period by accelerating phonological development, resulting in reduced yield (You et al. 2005 ; Asseng et al. 2011). In SSA, average annual temperature in 1990 was 20.3°C in wheat harvest areas, which already exceeded the optimum wheat-growing temperature of 15–20°C (Liu et al. 2008). The exact level of the effects of climate change differ by location, but some studies suggest that a 1°C increase in temperature above norm reduces wheat yield by 10% (Brown 2009).	The results presented here indicate that wheat is one of the most sensitive crops to climate change. Projected impacts in East Africa vary widely, but without climatechange adaptation, eastern Africa could lose about twothirds of the wheat productivity by the end of the 21st century.
Rice is a vital crop in East Africa where it is primarily grown by smallholder farmers as a rainfed crop (excluding Kenya, where the majority of rice is irrigated). It is the second most important crop in Tanzania and Malawi and the third most important crop in Kenya and Zambia (EUCORD 2002 ; Saka et al. 2006 ; FoDiS 2010). Rice is grown as upland rice, lowland rainfed rice, mangrove swamp rice, floating rice, and irrigated rice (EUCORD 2002).	Rice is very much of a cash crop for small-to medium-scale farmers in the East and Southern Africa (ESA) region. While it is more of resilient to climate change than wheat and maize, still it is projected that about 16% of it will be lost by 21% due to climatic conditions. Africa Rice Centre is developing varieties that can withstand both flooding and also moisure stress (Somado et al. 2008). A perfect example is Nerica Rice developed by Africa Rice Centre (WARDA).	Consumption of rice is gaining ground in the entire Africa continent, given the frequent failure of maize due to climate change. Since Uganda launched the Upland Rice Project in 2004, in which Nerica is a major component, the Ugandan National Agricultural Research Organization (NARO) reports an almost nine-fold increase in the number of rice farmers from 4,000 to over 35,000 in 2007. At the same time, the country has almost halved its rice imports from 60,000 tonnes in 2005 to 35,000 in 2007, saving roughly US$30 million in the process (Somado et al. 2008).	Projections of the impact of climate change on rice in the region vary among studies. Lobell et al. (2008) used 20 GCM models and projected a slight increase (<5%) in rice production in East Africa by 2030 as compared to 1998–2002. Using the Impact model, Ringler et al. (2010) projected a 0.24% increase in rice yield in eastern Africa and a 2.32% reduction in southern Africa by 2050. Overall, rice appears to be more resilient to climate change than maize or wheat. Nonetheless, climate change is projected to have negative impact on rice yield and eastern Africa could lose as much as 16% of its current rice production by the end of the 21st century.	Given that Maize and wheat are more susceptible to climate change, rice offers a better alternative to most urban dwellers where it is preferred. New Nerica varieties can smother weeds like the African parents, resist drought and pests or can thrive in poor soils. Like its Asian parents Nerica rice has a high yield. The grain head holds 300 to 400 grains compared to the 75 to 100 grains of traditional varieties grown in the region. Its strong stems and heads prevent shattering, and the taller plants make harvesting easier. Nerica Rice is offering an alternative to Wheat and Maize in Africa.Moreover, the most popular Nerica lines take only three months to ripen, as opposed to six months for the parent species, thus allowing African farmers to “double crop” it in a single growing season with nutritionally rich vegetables or high-value fiber crops. As a further bonus, some of the new lines contain up to 12 percent protein, compared to about 10 percent in the imported rice sold in the local market.

Opportunity Table: East and Southern Africa

Opportunity and Countries Affected	Adaptation Strategies	Co-benefits and Food Systems Adaptation	Challenges and Climate Change Impacts	Food System Implications
	Qualitative description plus quantitative if available			Potential feedbacks and interactions
In terms of quantity, sorghum is the second most important crop in Africa after maize and is the most important crop in the semiarid tropics (Obalum et al. 2011). Major sorghum- growing areas in FtF countries include much of north central, northwestern, western, and eastern mid- altitude areas of Ethiopia, Rwanda, northern and eastern Uganda, central Tanzania, and the areas in Kenya and Tanzania east of Lake Victoria (Wortmann et al. 2009). The importance of sorghum to Africa lies in its inherent ability to resist drought and withstand periods of high temperatures (Taylor 2003). Maiti (1996) reported the optimum vegetative growth temperature of sorghum is 26–34°C and an optimum reproductive growth temperature is 25–28°C. Currently, most of the sorghum in the region is grown under sub-optimum temperatures. About 54% of the sorghum is produced below 24°C (Wortmann et al. 2009).	Using heat-tolerant varieties of sorghum as a new management practice shows the most potential as an adaptation for maintaining crop yield as global warming raises the temperatures in Africa. Sorghum and millet, which have higher tolerance to drought and heat, could replace maize in most places under threat.	Within ESA, the utilization of sorghum as food is dominated by Sudan and Ethiopia, where consumption in 2009-11 averaged 3 and 2 million t, respectively. Elsewhere in ESA, utilization for food was rivaled by utilization for beer. Opaque beer manufactured by modern breweries (eg, Chibuku shake-shake) is a popular alcoholic drink. In Uganda and Tanzania, the use of sorghum for 'food processing' (mostly opaque beer) equals or exceeds the use of sorghum for food. Generally, sorghum that is not used for food is used to make beer rather than used as feed for livestock or poultry. The only country that seemingly uses sorghum as feed on a significant scale is Sudan, where hybrid sorghum is widely grown with irrigation, maize is not a staple crop and meat is exported to the Middle East (Orr et al. 2016)	Based on Maiti (1996) and Wortmann et al. (2009), sorghum production should increase in the region with slight increases in temperature. However, some researchers have projected climate change to negatively impact sorghum yield. In a global simulation of sorghum yield, Lobell and Field (2007) reported an 8.4% decrease in sorghum yield for 1°C increase in temperature. Similarly, Hatfield et al. (2008) reported a 7.8% decrease in sorghum yield for 1°C rise in temperature from 18.5°C to 27.5°C. Water deficiency is another constraint in the region that has been cited as the most important sorghum production constraint (Wortmann et al. 2009).These findings suggest that sorghum is more resilient to climate change than maize or wheat and will be minimally impacted (<5%) by the middle of this century.	Sorghum has a wide variety of uses. The grain is eaten after boiling the flour to produce foods such as ugali, sadza and uji. In Ethiopia, sorghum flour is used to make injera, a traditional bread made from fermented dough. Sorghum grain is also used for brewing. Varieties of sorghum suitable for brewing have low tannin content since consumers prefer beer with this taste. Although sorghum grain is not usually fed to livestock, sorghum stover is used for fodder as well as fuel and material for building and roofing houses (Orr et al. 2016)
Millet is cultivated mostly in the semiarid tropics and subtropics of Africa; however, it is also cultivated in other drought- prone sub- humid and medium- high altitude areas (Obilana 2003). Millet is a hardy crop that requires few inputs, is less susceptible to pests and diseases, and can be grown in the areas that are too hot and dry for sorghum (Cagley et al. 2009). Pearl millet and finger millet are the most commonly grown millet varieties, where pearl millet is grown in all sub- Saharan countries and finger millet is grown in eastern, southern and central Africa (Obilana 2003). Pearl millet is grown as a dry- land crop in semiarid regions, while finger millet is generally grown in uplands and sub- humid areas (Gari 2002).	Millets (pearl, foxtail and finger millet) are an example of indigenous cereals grown in the dry parts of SSA (Chivenge et al 2015). These crops may have been indigenised to the dry areas due to many years of cultivation, as well as natural and farmer selection. However, now the production of millets is limited to certain areas that are not considered as cereals producing areas in SSA (Chivenge at al. 2015). Across much of SSA, cultivation of pearl millet is mainly practised at a subsistence level by smallholder farmers. It is only grown commercially as forage for animal consumptions in some areas (Chivenge at al. 2015). Millets are an annual C4 plant that can grow on a wide variety of soils ranging from clay loams to deep sands but the best soil for cultivation is deep, well-drained soil. This makes it suitable for cultivation by smallholder farmers in semi-arid areas where deep sands and sandy loam soils dominate. In addition, millets are easy to cultivate and can be grown in arid and semi-arid regions where water is a limiting factor for crop growth (Chivenge at al. 2015).	In Kenya, Tanzania and Uganda, finger millet is widely recognized by consumers as a nutritious cereal, particularly for infants, the sick and the elderly. This has led to growing demand from urban, middleclass consumers. In northern Ethiopia and western Kenya, finger millet remains an important staple cereal, while in southern Africa, farmers in semi-arid areas plant millet alongside maize to insure against crop loss from drought (Orr et al. 2016). In ESA, while in 2009-11 1.5 million tons (68%) was used as food, a relatively high share of millets (0.3 million tons, or 20%) was used for food processing. This reflects the traditional use of millet to produce local beer. Within ESA, food processing is concentrated in Tanzania (0.2 million tons in 2009-11, or 43% of the available supply). In Sudan, the biggest regional producer, no millet was used for alcohol processing since the majority of the population is Muslim. Similarly, in Ethiopia, the second biggest regional producer, only 14% of available supply was used for this type of processing. In ESA as a whole, only 3% of total supply was used as feed in 2009-11 (Orr et al. 2016).	Climate change is expected to raise the temperature in millet growing areas closer to the optimum temperature, leading to a general increase in millet yield. However, similar to sorghum, millet is not expected to gain much from elevated atmospheric CO_2 levels. Overally, millet is more resilient to climate change than maize or wheat but less resilient than sorghum. It is expected that there will be about a 15% yield loss in East Africa by the middle of the century (Knox et al. 2012).	Millets are often referred to as a "high-energy" cereal as they contain higher oil content than maize grains; their protein and vitamin A content are also higher than maize (Chivenge at al. 2015). The fact that millets contain vitamin A, a major deficiency in staple diets, makes it a suitable crop for combating nutritional challenges in these communities. Compared with other staple grains such as maize, wheat and sorghum, pearl millet is less susceptible to pests and diseases. Millets are used almost exclusively for food and for food processing to make local beer. Although South Asia has seen growing demand for pearl millet as poultry feed, the higher price of millet relative to maize has so far prevented the development of this value chain in ESA (Orr et al. 2016).

Opportunity Table: East and Southern Africa

Opportunity and Countries Affected	Adaptation Strategies	Co-benefits and Food Systems Adaptation	Challenges and Climate Change Impacts	Food System Implications
	Qualitative description plus quantitative if available			Potential feedbacks and interactions
In eastern and southern Africa, beans are the second most important source of dietary protein following maize and the third most important source of calories after cassava and maize, with annual consumption exceeding 50 kg per person (Wortmann et al. 1998 ; Broughton et al. 2003). Beans are produced in over 20 countries in eastern and southern Africa covering over four million hectares, where Ethiopia, Kenya, Rwanda, Tanzania, and Uganda are among the major producers (Wortmann et al. 1998 ; Asfaw et al. 2009). Cultivation areas are concentrated in cooler highlands and warmer mid-elevation areas with altitudes greater than 1000 m above sea level. However, due to population pressure, the cropping area is being extended to lower elevations (Katungi et al. 2009).	The ability to fix atmospheric nitrogen makes legumes excellent components within the various farming systems because they provide residual nitrogen and reduce the needs for mineral nitrogen fertilizers by associated non-legumes. Intensification of low-input agricultural production has led to a rapid increase in soil degradation and nutrient depletion in many parts of sub-Saharan Africa, constituting serious threats to food production and food security. Nitrogen depletion in maize-based systems in some farmers' fields in African savanna is estimated to be 36-80 kg N ha^{-1} per year (Sanginga et al., 2001) and it has been obvious since the mid-1990s that fertilizer use is necessary if sustainable agricultural production in smallholder farms is to be raised to levels that can sustain the growing population. Assuming that only seeds are harvested, net soil nitrogen accrual from the incorporation of grain legume residue can be as much as 140 kg N ha^{-1} depending on the legume variety (Giller, 2001). This N tends to be released quickly when legume residues are incorporated into the soil and can contribute to substantial improvements in yield of subsequent crops.	Thus, legumes represent a major direct source of food for man and livestock and, therefore, make a critical contribution to increased food security of subsistence farmers, reduced cost of food for poor consumers and enhanced rural incomes. The opportunity exists to improve yields of legumes in sub-Saharan Africa since current yields are only a fraction of their potential (Giller et al. 2013).	As a C3 crop, beans are expected to benefit from elevated atmospheric CO 2 concentration. Ainsworth et al. (2002) reported a mean increase of 24% in soybean yield with elevated atmospheric CO 2 , which was mainly due to pod number increases. Soybean yield is also affected by precipitation and subsequent moisture availability. In 65% of the bean- producing area in the region, the mean rainfall exceeds 400 mm during the three months after sowing, while in other areas yield is severely impacted by moisture deficit (Wortmann et al. 1998). When precipitation falls below 300 mm during the growing season, yield decline in beans is estimated to be 1000 kg/ha (Wortmann et al. 1998). Hence, in eastern and southern Africa, rainfall variability and soil moisture content, rather than rising temperature, are the crucial factors in determining the effect of climate change in soybean production.	Grain legumes are a key source of nitrogen-rich edible seeds, providing a wide variety of high-protein products and constituting the major source of dietary protein in the diets of the poor in most parts of sub-Saharan Africa. Largely grown as subsistence food crops, they are predominantly crops grown by women and used within the family, with an annual per capita consumption of about 9 kg and providing 88 kcal/capita/day. Legumes such as groundnut and soybean are also major sources of edible oil and other industrial by-products. Residues of grain legumes as well as herbaceous and fodder tree legumes provide an excellent source of high quality feed to livestock especially during dry seasons when animal feeds are in short supply.
Cassava is the most important crop in SSA in terms of caloric intake (Rosenthal and Ort 2012). In East Africa, cassava is also the most important staple food crop in terms of total production, where production is concentrated in mid- altitude areas in the African Great Lakes region and the coastal zones of Tanzania and Kenya (Fermont 2009). Cassava is also traditionally cultivated in the northern part of Zambia, while about 70% of farmers in Mozambique cultivate cassava (Nielson 2009).	Research has shown that cassava tubers become even more productive in hotter temperatures and outperforms potatoes, maize, beans, bananas, millet and sorghum - some of Africa's main food crops. With cassava being the second most important source of carbohydrates in sub-Saharan African after maize its importance for food security is upheld by most scientists (Jarvis et al. 2012). Scientists state that East Africa could increase the cassava production up to 10 percent if temperatures rise as predicted. Likewise production is likely to grow in Western Africa with a slightly smaller increase in production in Southern Africa.	"Cassava is a survivor; it's like the Rambo of the food crops. It can enhance nutrition and reduce climate risk," (Jarvis et al. 2012). It can be consumed both as tubers and leaves. Tubers can be stored in the ground after harvesting for as long as 4 months. Cassava can be prepared and processed for consumption in many different ways, either by just boiling the tuber or by drying and grounding it into powder which can be used to cook sadza (thick porridge) or make bread and which can also be fried as chips (Jarvis, et al. 2012)	The crop is more resilient to climate change due to its tolerance of high temperatures and intraseasonal drought (Jarvis et al. 2012). However, if a prolonged drought period (>2 months) falls during the root thickening initiation state, a root yield reduction of up to 60% may occur (Jarvis et al. 2012). Cassava shows better yield gain than grain crops at higher CO_2 concentrations, can recover from very long drought periods, and exhibits increases in optimum growth temperature under elevated CO_2 levels (Rosenthal and Ort 2012). These qualities make cassava a suitable crop in a future that is projected to experience elevated CO_2 , increased temperature, and variable rainfall patterns. The findings are supported by other researchers who projected minimum impact, if not positive, or at least better performance of cassava than other crops.	Cassava is the second most important source of carbohydrate in sub-Saharan Africa consumed by over 500 million people every day- the highest per capita in the world. It is also used in making industrial products like confectionery and animal feeds.

Opportunity Table: East and Southern Africa

Opportunity and Countries Affected	Adaptation Strategies	Co-benefits and Food Systems Adaptation	Challenges and Climate Change Impacts	Food System Implications
	Qualitative description plus quantitative if available			Potential feedbacks and interactions
One of the most widely grown crops in SSA, sweet potato is an important crop in the areas surrounding the Great Lakes in eastern and central Africa, such as Malawi and Mozambique (Shonga et al. 2013). Sweet potato is a major staple crop in Uganda, Rwanda, and parts of Tanzania, while it is a secondary food source in Kenya and most of Tanzania and Ethiopia (Smit 1997). Mainly cultivated by smallholders, sweet potato is the third most important source of carbohydrates in Uganda, while the country is the third largest producer of sweet potato in the world (Muyinza et al. 2012). Although the crop grows from semiarid lowlands to high- altitude zones, cultivation of sweet potato is most intense in altitudes of 800–1900 m (Smit 1997). Sweet potato is a tropical or a subtropical plant, which has an optimum- growing temperature of 20–25°C, but can be grown in temperatures ranging from 15°C to 33°C (Ramirez 1992).	The studies on the impact of climate change on sweet potato in East Africa are not adequate to draw conclusions on the potential yield impact. However, susceptibility of sweet potato to high temperatures at night and climateinduced water stress suggest that the crop might be negatively impacted in the future.	Sweet potato remains an important root crop of the tropics owing to its versatility (Mukhopadhyay et al. 1990). This is with regards to its suitability to low input systems, drought tolerance and large environmental plasticity which allow it to be planted and harvested at any time of the year, especially in frost free areas Motsa (2015). Within the communities that consume it, both the leaves and root are utilised for human and animal consumption with limited industrial use (Mukhopadhyay et al. 1990; 2011). Its versatility make it an ideal food security crop (Low, 2007) capable of contributing to the food and nutritional security of smallholder farmers residing on marginal production lands (Yngve, 2009).	Studies conducted by Low et al. (2007) in sub-Saharan Africa established that incorporation of orange-fleshed sweet potato varieties in diets of children led to an improved vitamin A status. Amagloh et al. (2012) concurred that due to their relatively high levels of vitamin A, orange-fleshed sweet potato varieties could be used as a complementary food for feeding infants. Several studies by Kulembeka et al. (2005), Laurie and Magoro (2008) as well as Laurie and van Heerden (2012) reported good acceptability of orange-fleshed sweet potato varieties including the leaves. However, more work still needs to be done to improve on acceptance and utilization.	Perhaps the biggest contribution of sweet potatoes lies in the potential of the orange-fleshed sweet potato varieties, which are reported to contain significant concentrations of β-carotene, a precursor for vitamin A. As such, orange-fleshed sweet potato varieties are seen to offer potential to contribute significantly towards Vitamin A deficiency; the nutritional dimension of food security (Chivenge et al. 2015).

Opportunity Table: Cereals (Intensive and Extensive; Central and South America)

Information to come.

Appendix: Methodology

Authors used a systematic approach to review the peer reviewed literature for mitigation opportunities along food systems. The approach followed five main phases and nine methodological steps.

Phase 1. Definition of variables and criteria

1. Identification of important food production systems globally. Cereals, horticulture and livestock were identified as important food systems according to previous reports data which highlighted it relevance for food security and as focus of GHG emissions worldwide (Burney et al. 2010; FAO 2016 a,b; Gerber et al. 2013; Herrero et al. 2013 and 2016; IPCC 2007; Jensen et al. 2012; Leff et al. 2004; Smith et al. 2007 and Weinberger & Lumpkin 2007). Fisheries and aquaculture are important production systems, but are not included in this report.
2. Identification of major food production systems across global regions. Authors made a first attempt to identify food systems categories across four selected regions: Central and South America (CSA), North America (NA), South Asia (SA) and Africa (A) based on existing food production systems reports for Cereals, Horticulture (Dixon et al. 2001, Annex 1) and Livestock (Steinfeld and Mäki-Hokkonen 1995, Annex 2). Major food production systems were defined in terms of coverage (percentage of population, food exports and imports, percent of employment in agriculture), use of resources (area harvested) and GHG emissions from Agriculture, Forestry and other Land of Use (AFOLU) for each of the four selected regions.

Phase 2. Search of technical and scientific information

3. Literature review of mitigation opportunities. A list of potential mitigation opportunities along the three food production systems and four selected regions was developed based on recent scientific and technical literature available until April 2017. Searches were conducted using key words regarding quantification of emissions from food systems worldwide (i.e. mitigation, GHG emissions, livestock, cereals, horticulture, CO2 quantification, Carbon foot prints, Life cycle assessment, etc.) in common scientific and technical database networks (i.e. Google Scholar, Cab Direct, Springer, Elsevier, FAOSTAT, World Bank, International Labor Organization, etc.). Peer-reviewed journals papers, national and international technical reports, books, and research dissertations were included and are listed in the reference section for consultation.
4. Identification of opportunities with mitigation potential. Across the literature review, opportunities were identified with any quantitative or at least qualitative attempt to measure mitigation potential over the emissions of one or several greenhouse gases (Carbon dioxide (CO2), Methane (CH4) and Nitrous oxide (N2O)).
5. Identification of co-variables associated to mitigation potential interventions. In addition to the mitigation potential, the co-benefits, challenges and adaptation potential related with the implementation of the described opportunities, were reported when any qualitative description provide by the cited literature or in consultation with external experts.

Phase 3. Classification of the opportunities along the food systems

6. Identification of mitigation potential opportunities along food systems components and stages. The interventions with mitigation potential were addressed along the five different stages identified for the food systems: Pre-production, Production, Post-production, Consumption, and Waste. The interventions were also organized according to the particular stages (i.e. agronomy practices, grazing management, manure management, waste management, etc.) where interventions are expected to take place inside each food system component (i.e. inside Production stages).
7. Identification of mitigation potential opportunities across global regions. Interventions with quantified mitigation potential were also classified into the four previously selected global regions according the countries where measurements takes place. Data from Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela, were available for Central and South America (CSA); data from India was available for South Asia (SA); data from USA and New Zealand were grouped as North America (NA); and data from Burkina Faso, Mali, Niger, Senegal, Ghana, Nigeria, Kenya, South Africa, Tanzania, and Uganda was available for Africa (A).

Phase 4. Identification of main patterns for intervention with Mitigation Potential

8. Analyses of the distribution of the number of interventions across food systems components. The resulting literature included over 160 potential interventions for mitigation along the three food systems and the four global regions. The number of interventions with any mitigation data were described in terms of the amount of research, expert confidence, cost estimate, implementation time, and scale and action category were summarized based on the specific information by region in consultation with other experts.

Phase 5. Input from Global Scientific and Technical Stakeholders

9. Presentation of the opportunities for mitigation along food systems in an international dialogue. The mitigation opportunities were presented during the 2nd International Dialogue: The Future of Food in a Climate Changing World a Climate Changing World organized by The Global Alliance for the Future of Food on 2-3 May 2017.