TOWARDS CLIMATE RESILIENT AGRICULTURAL AND PASTORAL PRODUCTION SYSTEMS
A synopsis of programme design considerations under the constraints of select natural resources, capacity and climate in Burkina Faso, Mali and Niger
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Cover photo: Women in Barsalogho, Burkina Faso, after harvesting leaves from a pollarded baobab tree © TREE AID/Mike Goldwater
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1. INTRODUCTION

BUILDING RESILIENCE WITHOUT BORDERS in the Sahel (BRWB) is a project developed by CARE International, RBM, SNV and TREE AID for the Building Resilience and Adaptation to Climate Extremes and Disasters (BRACED) programme funded by the UK Department for International Development (DFID). The project brings together the experience of the four consortium members with technical partners AGRHYMET (the regional centre for drought control in the Sahel) and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) to work alongside local stakeholders in an integrated approach to building climate resilience.

BRWB aims to build the climate resilience of almost 1 million women and men in Burkina Faso, Mali and Niger by facilitating change in three key areas:

- improving relevance of, access to and use of climate information services for planning and risk management;
- scaling up access to and adoption of sustainable and climate-resilient livelihood options; and
- promoting equitable, sustainable and climate-resilient governance of natural resources.

This document provides a synopsis of potentially relevant technologies and approaches for climate resilient agroforestry and crop production in a geographical target area that spans agro-pastoral and pastoral zones from eastern Mali, through northern Burkina Faso to north-western Niger. It includes a review of the local socio-ecological context for implementation of such options.

The assessment was conducted by independent professionals with a knowledge base of and practical field experience in conservation agriculture and an understanding of field-based/farm-based decision-making on water management and natural resource conservation. The authors reviewed scientific and grey literature as relevant as possible to the context of the project beneficiaries in the Sahel. AmbioTEK and the Department of Geography at Kings College London analysed spatial datasets and produced the suite of maps for the project.

![Figure 1. The intended geographical target areas considered in the project development phase covering Central and North-East Mali, Northern Burkina Faso and Western Niger. The coordinates for the boundary points defining this area are: 15°44'34.20"N, 4°23'33.10"W; 13°56'7.97"N, 4°6'9.58"W; 13°30'47.68"N, 3°57'58.24"W; 13°9'48.83"N, 3°27'21.63"W; 13°40'36.37"N, 2°52'44.69"W; 13°19'48.09"N, 1°15'24.01"E; 14°4'47.69"N, 1°33'2.56"E; 15°17'48.75"N, 1°28'39.38"E; 16°57'48.87"N, 0°20'19.92"W; 16°43'48.73"N, 3°4'48.43"W.](image-url)
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area using their mapping tool, WaterWorld (see page 12). TREE AID related the outputs into context for agroforestry and alternative livelihoods and drew upon the knowledge base from other partners in the consortium.

1.1 CONTEXT IN THE SAHEL
Climate variability, including drought events, is a defining feature of dryland ecosystems in the Sahel. The people of the Sahel have evolved their livelihood strategies to manage this variability, through mobility, diversification of income generating activities and traditional land management systems. However, their inherent resilience has been progressively undermined by a range of factors that includes: poor governance and management of natural resources; marginalisation of traditional institutions; population growth; inadequate or inappropriate policies; market and price instability; and growing insecurity. The result is chronic poverty, malnutrition, decreasing assets and increasing debt, leaving people with limited options to manage during climate extremes.

1.2 TRENDS IN CLIMATE AND NATURAL RESOURCES
The project target region experienced severe droughts in 1973-1974 and 1984, which led to widespread famine and loss of livestock. Many households still have not recovered from the 1984 drought, which was devastating in its impact on health, nutrition and losses to the household asset base. Less-severe droughts occurred in 1988 and 1993, and the region has experienced a number of abnormally dry years since then. In general, communities have reported land degradation, decreasing vegetative cover, pasture and crop yields and increasing tensions over the critical resources of water, wood and pasture. Mobility is restricted or constrained to avoid potential conflict. The frequency of dry years is increasing, leaving people with little time to recuperate from one crisis before the next one arrives.

In agro-pastoral and agricultural areas, dry periods undermine crop productivity, in some seasons resulting in complete harvest failure. Fish stocks are also said to be decreasing. For the men, women and children who depend on livestock, agriculture and fishing, these effects have serious consequences for food and income security, with ensuing effects on nutrition, health, education and social cohesion.

In northern areas where pastoral production dominates livelihoods, the impacts of low rainfall and drought on livestock are an immediate concern, disturbing the balance between stocking rates and regional carrying capacity. Consequent constraints on access to water and fodder have negative impacts on animal health and productivity, in the worst cases forcing sale of animals at low value or causing livestock death.

Biodiversity is under pressure or over-harvested. Communities have observed the disappearance of various indigenous plants, animals and birds, from systems which should be well adapted to recurring droughts. Water availability is an increasing concern where rates of abstraction exceed recharge for surface water bodies and the local water table. Indirectly, droughts and low rainfall can exacerbate land degradation when people cope by adopting destructive land use and resource harvesting which damage soil fertility and tree resources.

When climate extremes affect food and income security, people are driven to seek alternatives. Pastoralists who have lost their livestock are forced to settle and begin farming in an effort to feed their families and earn money to reconstitute their herd, while farmers with dwindling yields seek other sources of income such as diversification into livestock herding or migration for work in an effort to meet food needs throughout the year. Migration to neighbouring countries for paid work (seasonal or longer-term) is a key strategy to earn income for food and other basic needs. Sale of livestock (beyond planned sales) or the sale of other assets is also common. This is not an option for the poorest women and men, who are forced to engage in manual labour or to seek aid in the form of food or cash, or to over-exploit common resources. When all else fails, people resort to collective prayer. These latter responses are symptomatic of narrowing options consequent from recurrent shocks, erosion of the household asset base, increasing pressure on natural resources, inequities in decision-making power and access to and control over resources.

1.3 THE CONTEXT FOR WOMEN AND GIRLS IN THE REGION
Climate extremes particularly impact Sahelian women. They carry primary responsibility in the household for coping with growing food insecurity and chronic malnutrition. This increased burden is exacerbated by gender inequality, which in turn limits women’s adaptive capacity. Their empowerment over household or community resources is out of balance with their increasing role in responding to the effects of climate change. Unequal division of labour or an unbalanced time budget for women is compounded by the additional barriers to securing rights over productive assets (notably land and labour).

Reliance on highly climate-sensitive resources can aggravate inequality (for example, when food is scarce,
families may be more anxious to arrange marriages for young girls). Early marriage and childbirth constrain the ability of women to access education, develop skills, accumulate assets and engage in productive activities, resulting in persistent female illiteracy.

Experience has shown that gender dynamics vary across the project area based on ethnicity, livelihood system and socio-economic status. Barriers to protecting or diversifying livelihoods and building resilience are context-specific. Often there is a clear differential between women and men and the perceived roles each should play. This is an important consideration in assessing the appropriateness of different technologies and approaches for agroforestry and crop production and the impact of their adoption on the welfare and nutritional security of women and their children.
The term ‘resilience’ may be defined as the ability of a system to absorb disturbance and still retain its basic function and structure. It may therefore incorporate the concept of sustainability whereby current demands are met without eroding the potential to meet future needs (Walker and Salt 2006). The term can be applied both to ecological systems, for example, a response in an ecological system after a wildfire; and to social systems, for example, how people and governing bodies respond to shocks and stresses currently and their preparedness for the future under potential climate change scenarios.

In a region such as the Sahel livelihoods are intricately linked to the productivity of the land for smallholder farmers and communities. Productivity is highly vulnerable to the vagaries of temperature and precipitation (cereal crops, village level livestock production), and the movements of animals and people in turn respond to shifting productivity (extra-village livestock production and nomadic pastoralists). Therefore a resilient socio-ecological system is necessary at all levels, from household, community and commune, to national and cross-border governance.

It is important to note that ‘optimising yields’ (intensive farming) can represent short-term gains but that options are limited. It is the converse of maximising the resilience of a socio-ecological system’s response to change (eg maintaining crop varieties that can be favoured under a particular year’s climatic conditions) and maintaining diversity to prevent thresholds being crossed which may tip a system irrevocably (eg soil nutrient loss, desertification). Resilience thinking suggests a diversification of options and a spreading of risk to ensure sustained productivity. Otherwise intensification to maximise production and returns based on a limited range of crop varieties or income sources can only be realised under a narrow range of conditions. Similarly, access to a diversity of models and information as a predictor of change should confer greater resilience than placing trust in a single source. Walker and Salt (2006) cite several case studies and offer suggestions for governance and threshold monitoring at multiple levels and various scales. They contend that resilience thinking may not be a panacea but it provides a foundation for achieving sustainable patterns of resource use.

2.1 System Productivity and Livelihood Resilience in the Sahel

Environmental sustainability is of course a key factor in selecting specific livelihood options at community level in a region where productivity is in a delicate balance and there are a variety of demands for the yields (ie human or animal consumption, compost and mulch, sale for cash). The Sahel, with less than 500mm annual rainfall, is a zone of rangeland where livestock herding is the primary activity, complemented with growing crops of millet and drought-resistant cowpea. In the northern portion of the project target area, the probability of a failed growing season is 53%. Farther south in the project target area, in the Sudano-Sahelian vegetative zone covering most of Burkina Faso and a small part of Mali, between 500 and 900mm of rainfall occurs per year. Millet and sorghum are the main crops in northern Burkina Faso, while maize is important in the western part of the country where it benefits from fertiliser input, and where cotton is also grown. Cash income is supplemented by growing groundnut crops and raising cattle locally. The drought risk is estimated at 24% (Lemoall and Condappa 2009). Therefore for the project target area careful consideration should be given to the implications of increased agricultural development or ‘extensification’ and of livestock numbers on the quality of, and access to, common resources such as forest, pastures and water bodies.

Extensification of the land under farming by smallholder farmers or the diversification into farming by pastoralists may seem like good approaches to increase income and diversify livelihoods but there are environmental costs in a land with shrinking land-use options and viability. Reducing fallow periods between crop planting (intensifying yields) and the loss of permanent vegetation when replaced by crops leads to the deterioration of soils, soil erosion by wind and floods, and a negative water balance on the land.

Relative costs and benefits of techniques for improving and diversifying agricultural and pastoral production systems are largely determined by the existing adaptive capacity of people and productivity under the constraints of: the soil and natural resources available; the capacity
of people to adapt (labour and capital resources); and
behavioural barriers or resource limitations to building
and maximising resilience within all systems and at
various scales (household, community, cross-border).

2.2 EXPLORING RESOURCE AND MANAGEMENT PRACTICES
FOR THE SAHEL

There is a growing body of scientific and grey literature
about agro-silvo-pastoral techniques and choices
in India, in the drylands of sub-Saharan Africa, and
increasingly in West Africa and the Sahel. Drawing on
this literature, risks and opportunities for improving
and diversifying systems are summarised below, with
due consideration of the costs and benefits of different
water management technologies, different approaches
to climate-resilient agricultural production, and different
demands on the time and labour of poor and vulnerable
women and men.

Crop technologies (crop varieties and cultivars,
microdosing)

Farmers will need to continue to improve their crop
systems under an increasingly variable climate, making
judgements about the benefits and disadvantages of
modified plants maturing faster, giving higher yields and
having increased vigour against higher temperatures.

Agricultural water conservation and management

On-farm water management practices for increased
water-use efficiency and retention in the land need to be
reconciled against the costs and benefits of other micro-
irrigation techniques.

Soil conservation and management (conservation
agriculture)

Soil management measures and agro-ecological production
to increase soil fertility and reduce erosion can be further
promoted and scaled up beyond local practice, eg soil
bunds, organic manure pits.

Agroforestry and tree species management

Mixing trees and crops in production systems that enhance
agricultural production, soil fertility and groundwater
recharge is not yet practised at sufficient scale nor are
drought-adapted indigenous trees regenerating to prior
densities.

Integrative land use planning

Forest and range protection and regeneration can reduce
overgrazing and provide soil stability and nutrients;
and integrated plans/agreements can prevent conflicts
between agricultural extensification and livestock grazing
needs, promoting off-farm water, soil and nutrient
management (eg tree- and fodder-banking for times of crisis).

In practice, at a micro-level (household and community), costs and benefits need to be assessed in terms of potential impact on:

- income and expenditure at household level;
- income and expenditure for individuals within a household, disaggregating impact by gender;
- protection and accumulation of household productive assets;
- protection and accumulation of common productive assets held at community level.

At a meso-level, impacts on income and expenditure and assets must be interpreted across disaggregated vulnerable groups within the wider community and the commune mosaic of household types (eg wealth status, principle source of livelihood, current farming or herding system, ethnicity or landlessness).

Other factors beyond natural resources and climatic conditions will enhance livelihood opportunities derived from productive systems and will influence choices. These include access for the region’s residents and their supporting institutions to: goods (agricultural inputs, off-farm food supplies); services such as climate early warning systems, micro-finance, markets offering fair prices and reached by safe and efficient routes; and methods for risk assessments and decision-making at household, commune, regional and cross-border levels.

In figure 2 (see previous page), the darker blue areas in the south and along roads show the highest population densities. This coincides with the areas of the highest vegetation density in the region (figures 13 and 15).

The road network (see figure 3 below) is most extensive in the most densely populated areas although roads traverse the project area and also run alongside many of the riverine corridors. Roads and access to buyers and markets can be an important factor for livelihoods. Managing water run-off from roads could become increasingly important.

*Figure 3. Road network in the project target area (Data source: UN FAO GIEWS World road trails. Whole world’s roads and railways, Base imagery source: Google and Terrametrics).*
CLIMATE EXTREMES AND RESPONSES to them may degrade resources and impair productivity and regeneration over time. Examination of both the current state of natural resources in the project area and the implications of climate change projections revealed the following key findings.

**Widespread land degradation**

Earlier remote-sensing studies delivered ambiguous conclusions on the effect of increased overall precipitation in the Sahel in recent years. However, a 2012 ICRAF/UNEP (World Agroforestry Centre/United Nations Environment Programme) analysis of the productivity of vegetation (NDVI – normalised difference vegetative index) considering the ‘rain normalised’ productivity (inter-year rainfall variability – RNNDVI) indicates widespread land degradation in the Sahel (UNEP 2012). The measure of productivity indicates that the vegetation has not been able to sufficiently utilise increases in rainfall. This is illustrated in figure 4, and specifically within the project target area, the analysis shows a decreasing trend in RNNDVI (productivity) represented on the map from weak (orange) to strong (red).

Vegetative cover is low over most of the project target area, except in the south-west

Beyond the Niger inland delta on the western extremity of the project target area, herbaceous ground cover is 50% or lower whilst tree and shrub cover rarely rises above 1% (see figures 13 and 15). Protection against further degradation is crucial.

**Plants are under water stress for the great part of the annual cycle**

Evapotranspiration is defined as the loss of water to the atmosphere by the combined processes of evaporation from surface water and transpiration from plants. In the project target area, figure 5 (see next page) illustrates that, on average, evapotranspiration exceeds rainfall/water availability over a year (areas coloured red). This is not unusual in an arid system, but plants are under water stress as a result for most of the annual cycle of seasons. Climate change threatens to increase seasonal variability in water availability, leading to unpredictable periods of water stress.

![Figure 4. Trend in rain-normalised annual average NDVI (RNNDVI) for 1982-2006, after UNEP 2012, p88 Fig 7.2A. Orange to red colours indicate that despite overall increases in rainfall year to year, negative trends are occurring in NDVI (plant productivity) when rainfall variability within years is taken into account (rain normalised, RNNDVI). This indicates lower productive vegetative cover or 'land degradation'.](image-url)
‘Water balance’ is rainfall + fog minus actual evapotranspiration and is the water available for infiltration into the soil and for generating run-off. The ‘seasonality index’ is a measure of the extent to which rainfall is concentrated in a short rainy season. This is represented in figure 6 (see next page).

In areas to the north of the project area, where rainfall is currently low and erratic, there is no well-defined wet season (yellow areas). Southwards a marked rainy season is evident (dark orange and red areas). Higher seasonality is a constraint to agricultural and natural vegetative productivity. Forecasted higher seasonality in the project target area suggests a limited growing season for both crops and livestock fodder, while northward in the target area projections indicate low potential for agricultural and natural vegetative production.

The climate modelling exercise revealed that in the future, to the north and south of the project area the combination of higher rainfall and higher temperature may increase the water balance, but in the project area the impact of high temperatures will outweigh the gains in increased rainfall, trending to a negative water balance. Therefore water stress may remain largely as at present throughout the project area but in the core project target area water stress may increase (as indicated by the lighter shades in figure 7 – see next page).

WATERWORLD

WaterWorld is a widely used and peer-reviewed model for assessing ‘water balance’ by mapping baseline and potential water resources scenarios in relation to land and water management and use (see Mulligan and Burke 2005, Mulligan 2013. Example applications: Mulligan et al 2010, Bruijnzeel, Mulligan and Scatena 2011, van Soesbergen and Mulligan 2013). The version 2.92 used here calculated water balance as wind-driven rainfall + fog minus actual evapotranspiration and was applied to the study area at 1km resolution.

In addition to baseline conditions (representing the climate mean 1950-2000), we examined the impacts of the IPCC AR4 scenario A2a for an ensemble of 17 general circulation models (GCMs) to present ensemble projections for the impact of climate change. We present the ensemble mean and the ensemble mean plus and minus one standard deviation to give an indication of the impacts of GCM uncertainty (especially in precipitation projections).

Figure 5. Actual baseline (mean 1950-2000) evapotranspiration (mm/yr) according to the WaterWorld Model (data source: www.policysupport.org/waterworld). The blues indicate lower actual evapotranspiration, reflecting low water availability and vegetation cover. The reds indicate higher evapotranspiration in more vegetated and less dry environments.
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Figure 6. Baseline (mean 1950-2000) seasonality of water balance calculated by WaterWorld according to the Walsh and Lawler (1981) metric. Walsh and Lawler (1981) is a unitless index that varies from <0.19 (precipitation spread throughout the year) to >1.20 (extreme seasonality with almost all precipitation in 1-2 months), (data source: www.policysupport.org/waterworld). ‘Low seasonality’ (<0.2) indicates that rainfall is evenly spread through the year (including areas where rainfall is close to zero throughout the year). Areas with values >0.5 are considered ‘rather seasonal’. The project area is very seasonal with highly constrained rainfall and a short growing period.

Figure 7. Change in water balance (mm/yr) from baseline (1950-2000) to scenario for the AR4 A2a 2050s, 17 GCM ensemble mean (data source: www.policysupport.org/waterworld). Negative values (red) indicate a decrease of water balance into the future, while blue areas indicate an increase of water balance (increased rainfall compensates for increased evapotranspiration due to warming temperatures). The light pink shade indicates trending to a negative water balance.
The climate models for the future show seasonality decreasing in the north of the project area in the Transhumant and Nomad Pastoral zones (blue areas in figure 8) due to a predicted increase in rainfall over the year. Note that this does not necessarily mean that the growing season will increase, rather that periods of rainfall may potentially become dispersed throughout a given year. Thus plant productivity could become spatially and temporally variable. Transhumant pastoral production will remain a favoured option in these circumstances, but combining this with opportunistic crop production may be even more difficult than at present.

In the area farther south, in the core of the project area where cereal production is critical to livelihoods, the seasonality increases (red and pink areas in figure 8) – meaning that the difference between the wet season and the dry season could become more marked, ie the dry season will be even drier, whilst the wet season will become wetter.

**Growing season length in the area may change**

‘Growing season’ or ‘growing period’ in agro-ecological zones may be defined as a period of days when rainfall exceeds half the potential evapotranspiration (FAO 1978).

The current average growing season length (www.policysupport.org/waterworld, 2014) is

- 3.6 months (Bandiagara, Mali)
- 3.2 months (Seno Plain, Mali)
- 2-2.4 months (Djibo, Burkina Faso; Douentza, Mali)
- 1.2 months (Diré, Mali)
- 1.8-2.4 months (Tillaberi, Niger).

With increased seasonality the median future climate forecasts indicate a largely unchanged or slightly longer growing season in the core of the project area. Crop farmers would still have a relatively short or unpredictable period over which they could take advantage of any increase in total rainfall (2-4 months). The choice of crop variety and how farmers can diversify options to build resilience are discussed below in 4.1 Crop technologies and 4.3 Soil conservation and management (conservation agriculture).
There is significant variability in GCM (General Circulation Model) outcomes so it is worth considering better and worse case scenarios for planning purposes. Some models show a reduction in growing season length and others show an increase. Growing season is sensitive to rainfall and temperature. At the drier, less warm end of the spectrum of climate scenarios, the length of the growing season may be curtailed by as much as one month over a significant part of the project target area (see red areas in figure 10 – see next page), from the present three-month maximum growing season. In other areas growing season length is unchanged (white).

At the wetter, warmer end of the spectrum of climate scenarios (figure 11 – see next page), growing season length may increase over much of the project target area by 1-2 months (light blue) and by as much as four months in the north-east (medium blue). Farther south in the project target area there are substantial areas where no change is anticipated (white).

Figure 9. Change in growing season length (months) from baseline (1950-2000) to scenario for the AR4 A2a 2050s, 17 GCM ensemble mean (data source: www.policysupport.org/waterworld). Growing season is defined by WaterWorld as months with a positive water balance and temperature > 6°C. In areas with increased rainfall, growing season increases by up to two months whilst in areas with decreased rainfall growing season decreases by up to two months.
Figure 10. Change in growing season length (months) from baseline (1950-2000) to scenario for the AR4 A2a 2050s, 17 GCM ensemble mean minus one standard deviation (data source: www.policysupport.org/waterworld). This represents the drier and cooler end of the GCM projections. Growing season is defined by WaterWorld as months with a positive water balance and temperature > 6°C. In areas with decreased rainfall, growing season decreases by up to one month (red areas) whilst in other areas seasonality remains approximately the same (no colour).

Figure 11. Change in growing season length (months) from baseline (1950-2000) to scenario for the AR4 A2a 2050s, 17 GCM ensemble mean plus one standard deviation (data source: www.policysupport.org/waterworld). This represents the wetter and hotter end of the GCM projections. Growing season is defined by WaterWorld as months with a positive water balance and temperature > 6°C. In areas with increased rainfall, growing season increases by up to four months (blue colours).
3.1 IMPLICATIONS FOR CLIMATE RESILIENCE

The review of extant natural resources together with interpretation of the climate models suggests important implications for farming household choices and wider integrated planning.

- Under current land use practices herbaceous ground cover rarely exceeds 50% and tree and shrub cover rarely rises above 1%. There appears to have been widespread degradation of vegetative productivity over recent decades. Local ecosystems and the people that depend on them can ill afford further degradation of the vegetation. Erosion prevention and maintenance of soil nutrients equates to banking for the future.

- The climate modelling exercise revealed that north and south of the project area the combination of higher rainfall and higher temperature will increase the water balance but in the project target area, the impact of high temperatures will outweigh the gains from increased rainfall. Water stress will result throughout the project area.

- Currently, the demand for water exceeds supply up to 80% of the time. Under some climate change scenarios both the deficit and seasonal variability will increase, so predicting water availability will become more difficult. Adopting techniques that harvest, capture and retain water is a paramount necessity. Improved understanding of current and future water balances and groundwater recharge is a short-term imperative.

- The risk of a failed growing season is 53% in the Sahel zone and drought risk is estimated at 24% for the Sudano-Sahelian zone farther south. The models for the future show less dramatic seasonality in the Transhumant and Nomad Pastoral zones, due to increased rainfall over the year. This does not necessarily mean that the growing season will increase, rather that periods of rainfall may become dispersed throughout the year. The growing season in the project area will likely remain short and unpredictable in the north, with increased spatial and temporal effects on plant productivity. This puts a premium on maintaining mobility for efficient livestock production.

- In the core of the project area where cereal production is critical to livelihoods, seasonality in rainfall is projected to increase, leading to marked differences between the intensity and length of wet and dry seasons. Maintaining crop and natural vegetative productivity, along with soil health, requires the adoption of wider-scale soil, water and vegetation management to accommodate the effects of variable rainfall levels and higher temperatures.

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**Figure 12.** Land use classes (data source: www.policysupport.org/waterworld). The area is dominated by the non-forest natural class, though there is some mosaic cropland and mosaic pasture in the south. Very few pixels have sufficient tree cover over 1km² to be considered forest.
• Even if/where increased rainfall extends the length of the growing season, higher temperatures can be expected to reduce plant maturation rates/time to flowering, with concomitant negative impact on grain/seed yield.

• At the drier, less warm end of the spectrum of probable climate scenarios, growing season may be reduced from three to two months in over half of the project target area. At the wetter, warmer end of the spectrum of climate scenarios, growing season may increase by one to two months over the majority of the project target area, with up to a four month increase in the north-east portion of the project target area.

• The median future climate forecasts indicate that crop farmers may have a shorter period over which they could take advantage of any increase in total rainfall. Thus the choice of crop varieties will not be a matter of simply selecting faster growing or higher yielding varieties given the complex interactions between the physical environment and plant physiology. The farmer’s choice must be informed by an understanding of the innate characteristics of each crop variety and how these may express themselves across a range of variable and unpredictable field conditions.

• Historically the maintenance of tree cover in the farming landscape has provided numerous environmental and economic services, serving as an important element of traditional drought-resilient land-use strategies. To protect and restore such services there is no practical alternative to the application of agroforestry approaches within food production systems.

Based on projections and the local context within the project area, a development programme can take on a twin pillar approach to build resilience thinking:

• In the short term, support informed decisions on how to better cope with current risks due to weather-induced effects.

• In the medium term, promote the adaptation of farming systems to a new set of weather-induced risks and opportunities. This implies adoption of complementary on-farm and off-farm livelihood options to spread risk.

The implications described above help to delineate the relevance of technical options and approaches for sustained utilisation of vegetative, water and soil resources set out in section 4.
4. WHAT ARE THE OPTIONS TO BUILD RESILIENCE IN THE SAHEL UNDER NATURAL RESOURCE CONSTRAINTS?

4.1 CROP TECHNOLOGIES

4.1.1 Crop varieties and cultivars

Given uncertainty in both regional climate predictions and crop response to a changing climate, choosing which crops and cultivars will perform best under future conditions is exceedingly challenging. The literature on predicted impacts suggests widely varying results for cereal crop yields in Africa, with the range between maximal possible increase or loss at well over a 100% spread (Müller 2011). This significant variation among potential outcomes is largely due to the choice of parameter values selected for the General Circulation Model (climate model), the temporal scale used and the method of down-scaling to the given region. Indeed, in line with the larger body of research, the modelling results presented earlier (figures 7-11) suggest divergent patterns for both water balance/seasonality and growing season length depending on the choice of model parameters. As a result there is marked spatial variation in predicted outcomes across the proposed project area. The lack of a clear pattern for future climate scenarios presents significant obstacles for decision-making, especially at the local scale where farmers must choose what and when to plant based upon anticipated growing season dynamics.

However, despite the wide range of predicted impacts, it is clear that in the near future, temperature will have an equal if not greater influence than precipitation on crop production, which is in direct contrast to historical trends for the Sudano-Sahelian vegetative zone (Sultan 2012). As such, even for climate scenarios that suggest an increase in total precipitation or increased length of the growing season, the concomitant temperature increase (≥2°C) will have deleterious effects on crop production capacity, and thus total grain yields.

As Sultan et al (2013) note, based on an extensive set of climate and crop simulation models using six crop varieties typical to the region (three sorghum, three millet), increased temperature affects three key biological processes: (1) an increase in evapotranspiration reducing moisture availability; (2) crop cycle length is shortened as higher temperatures stimulate rapid maturation; (3) an increase in metabolic respiration per unit of biomass leads to an overall reduction in total biomass. Acting through a combination of induced water stress and physiological phase changes, the increased temperature will reduce both grain yield and total biomass, thus having implications for both human and livestock food.

One important caveat to consider in regard to much of the published literature for simulation studies is that the

Photosensitivity versus photoinsensitivity (many modern cultivars)

Photosensitivity refers to the relative influence that daylight length has on physiological processes that determine growth rates in crops. Photosensitive plants adjust growth rates to prevailing light levels, thus naturally offering some flexibility in sowing date as they can compensate for seasonal differences in light levels and farmers can better take advantage of good conditions when they arise. In the Sahel, for example, the majority of traditional sorghum and millet varieties grown are photosensitive (eg sorghum can range from 70-130 days to mature). Photosensitive plants tend to have longer growing times to maturation, but they offer greater total biomass such as leaves for animal fodder, though not necessarily more grains. A disadvantage is that with a slower maturation rate, they are also subject to environmental conditions throughout the growing season, so may be out-competed by weeds which tend to be fast growing and drought-tolerant. They may be vulnerable to terminal drought if the rains end before the flowering/fruiting phase.

Conversely, photoinsensitive plants, which are day length neutral, have ‘fixed’ growth rates, thus produce grain yields along set schedules. Photoinsensitivity has been endorsed in the past as a solution to meeting productivity demands. However they do not offer the same flexibility in sowing date and as such may perform sub-optimally in rain-fed agriculture where timing of precipitation is less predictable. They also require high inputs (ie fertiliser) and produce less biomass and therefore are less useful for producing fodder and mulch (ie, a dual purpose production system). A number of modern cultivars are photoinsensitive, bred for rapid maturation and higher grain yields.
models typically do not incorporate tools available to help mitigate the negative consequences of a changing climate, nor do all the models simulate the sum total of decision-making at farm level such as choice of cultivar, addition of agricultural inputs or other on-farm management options (see sections 4.2-4.4).

Where there has been consideration of adaptive traits and strategies in the literature, the following points emerge:

- Where the growing season is predictably short and dry, modern cultivars bred for high yields under decreased rainfall and increased temperatures can produce optimal yields. However, these kinds of short duration cultivars, bred to escape terminal drought, have limited utility in areas where rain is expected to increase or become more seasonal in nature, or where farmers have limited access to agricultural inputs. A number of studies have found that modern cultivars underperform when humidity levels are high or rainfall is unpredictable (Dingkuhn et al 2006, Kouressy et al 2007, Sultan et al 2013). The majority of modern cultivars are photoinsensitive and display fixed growth characteristics that require relatively stable conditions for optimal performance.

- Where seasonality of rainfall is erratic, photosensitive varieties have a competitive advantage over photoinsensitive types as they synchronise flowering with the end of the rainy season, thus avoiding common problems associated with modern cultivars given current extensive, low-input farming practices (eg incomplete ‘grain filling’ or grain production). Grain yields of photosensitive plants are more stable under elevated temperature because growth rates are strongly influenced by day length, which does not vary with temperature change (Sultan et al 2013). The allowance for variability in sowing date afforded by a crop able to synchronise with environmental factors confers greater flexibility in decision-making for farmers as they can seasonally adapt to predicted forecasts and labour availability.

- Biofortified crop varieties (cultivars which are engineered to boost content of key minerals and micro-nutrients) will not confer any specific adaptation or resilience in terms of climate. Indeed they are likely to have a narrower genetic base which may imply a narrower range of climate tolerance and less flexibility in field application. However the nutritional benefits could outweigh these limitations in some circumstances, although evidence of impact is limited (Turner et al 2013).

- Capitalise on intra-varietal genetic diversity to provide an effective buffer against future climate change. Genotypic diversity underlies phenotypic plasticity, the physical characteristics of the plant which can be influenced by their environmental conditions. There is already considerable adaptive potential across the region given observed levels of heterozygosity in crop genomes, farmers’ choices in developing varieties and the way in which plants have adapted recently. For example, in select millet landraces, Vigeroux et al (2011) document a naturally occurring shift towards shorter maturation time and plant size under increasingly dry conditions during the last 30 years. This adaptive potential could be further exploited using farmer-assisted selection to encourage traits favourable to a range of predicted outcomes. Building hybrid vigour by crossing landraces from across West Africa (Haussmann 2009, Rattunde et al 2013) has proven beneficial for increasing yields under variable conditions, as has the creation of dual purpose cultivars which combine traits amenable to traditional farming practices (eg variable sowing date via retention of photosensitivity) with modern characteristics required for higher yields (Dingkuhn et al 2006).

- Promote intra-varietal genetic diversity within crop stands where adaptive traits would differ across sets of plants, thus buffering against high inter-annual variability in precipitation and temperature (Haussmann et al 2012). This is essentially a hedging strategy that seeks to minimise potential losses by ensuring that at least some portion of the total crop planted will be productive under prevailing conditions. This is the converse of selecting for an individual phenotype able to produce optimal yields under specific conditions.

Maintaining flexibility in both choice of cultivar type and sowing date is key to building adaptive capacity both within and across years. At a minimum, making those choices necessitates access to relevant forecasting information at appropriate temporal and spatial scales. Given the likelihood of variability in seasonality across the project area, alongside significant uncertainty as to which climate scenario will unfold, it is unlikely that a single strategy will suffice nor be applicable across a broad geography. Therefore deciding between choice of cultivar or adaptive strategy is context-specific, and will need to address the inherent trade-offs between seeking to optimise yields versus seeking to stabilise yields under uncertain
weather conditions. It is thus equally important to the decision-making process to have an understanding of, and incorporate, a farmer’s risk tolerance for uncertain outcomes.

4.1.2 Microdosing

Farmers across the Sahel typically practise extensive, low-input farming resulting in crop yields well below potential. Sandy soils, which dominate the region, are generally low in nutrients like phosphorus (P), nitrogen (N) and potassium (K), and have limited water-holding capacity and organic matter. Naturally low fertility, coupled with poor on-farm management practices which essentially ‘mine’ the soil of its nutrients, results in unsustainable production practices as evidenced by the declining trend in per-capita food production documented since the late 1970s (Bationo et al 2001). Reversing this trend will require making significant investments in improving soil fertility management, and a number of promising technologies and approaches exist (Bationo et al 2012). Developing a deeper understanding of the efficacy of these technologies, along with the socio-economic factors that may impede or speed their adoption, is imperative if we are to identify beneficial means for building adaptive capacity to changing conditions (Cooper et al 2008).

Microdosing, which involves applying small amounts (4-6g) of inorganic fertiliser to each seed/seedling planted, is one means to improve soil fertility and increase crop yields. The technique, pioneered by ICRISAT and the University of Hohenheim, has been introduced into Southern and West Africa with mostly positive results. In Zimbabwe, Twomlow et al (2010) indicate that cereal yields increased between 30-50%, even with significant variation in on-farm practices and during a time of drought. Tabo et al (2011), based on field trials in Mali, Burkina Faso and Niger, report yield gains between 43-107% depending on cereal type and country. Bagayoko et al (2011) investigated both grain yield and stover production for millet in Burkina Faso, Mali and Niger. Averaged across years, microdosing led to increased grain yields of 240-300kg/ha across the three countries, with greater benefits returned in years of higher rainfall. Similar trends were observed for stover production (eg a doubling in yield recorded in Burkina Faso) which could have additional economic benefits when packaged and sold as fodder or provide benefits to soils when used as mulch.

From an efficiency perspective, farmers would want to invest in only as much fertiliser as is necessary to produce positive value-cost ratios (VCR). Based on limited work in this regard, microdosing appears to yield positive values for crops typical to the Sahelian region. The VCR is a relatively simple calculation that considers the value of the additional yield produced with fertiliser use divided by the cost of that amount of fertiliser. Note that the cost denominator does not consider other variables such as labour. It is a useful tool, however, for identifying recommended levels of fertiliser use that farmers are more likely to adopt. The likelihood of adoption is believed to be positive at a VCR of 2 or more. Some consider a VCR of 3 or 4 to be requisite when risk is high for either production or price volatility (Kelly 2006). In a comprehensive evaluation of microdosing trials across Niger, Pender et al (2008) calculated a VCR of 3.35 for millet crops, and Tabo et al (2006) estimated VCRs between 2-5 for on-farm trials of both millet and sorghum across sites in Mali, Niger and Burkina Faso.

Microdosing increases labour requirements, though less so relative to other methods such as broadcast distribution of fertiliser. As the technique was first developed, dosing is recommended alongside seed planting, a time when labour shortages are often most acute as farmers struggle to complete planting immediately after the first rains. Additional labour may be in short supply as many may have left to seek off-farm employment during the dry season, or be too costly as farmers are often cash poor at the beginning of the cropping season. While there is an additional labour cost, Hayashi et al (2008) found that microdosing is robust enough such that farmers can adjust the timing of dosing millet, up to 60 days post-sowing, and still obtain positive benefits (VCRs ranging between 3.74 and 4.48 with an adjusted formula that includes labour). This provides the farmer some flexibility in managing labour shortages, as well as cash flow. The considerable delay in post-sowing application also provided the ancillary benefit of being able to fertilise only those plants that had emerged, thus increasing overall efficiency.

Paradoxically, given the positive results obtained thus far, adoption of microdosing has been limited – indeed soil fertility treatments generally have not broadly been employed across the region (Kelly 2006). Much research suggests that the causal factors behind low adoption rates include limited access to financial resources or credit to facilitate purchasing power, limited or no access to markets and favourable pricing, and production risks created by erratic or low rainfall.
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Pender et al. (2008), in an evaluation of the FAO’s Projet Intrant, found that increasing proximity to a fertiliser source (i.e., point of sale), improving access to credit via a warrantage system, and providing training demonstrations increased purchase both of seeds and fertiliser for microdosing.

Tabo et al. (2011) note that another important consideration for improving uptake is marketing products that are sensitive to customers’ financial constraints. Specifically, they found positive gains in fertiliser sales and use when sold in small, affordable packets (e.g., 1, 2, and 5 kg bags) as opposed to 50 kg bags which are priced well beyond the means of most farmers. As reported in Pender et al. (2008), field observations suggest that farmers are actively engaged in developing minor, yet novel adjustments in the method of application to reduce labour costs or render the technique more complementary to traditional farming practices. All these methods are relatively simple, and thus understanding of how to appropriately use this technology is easily transferred.

While augmenting soil fertility via microdosing is of clear benefit, yields are also much affected by seasonality and total amount of precipitation. To reduce the financial risk posed by investing in costly inputs when benefits could be negated by drought or flood requires a complementary investment in improved on-farm water management. Similarly, over the longer term, continued usage of inorganic fertilisers may result in negative impacts to soil ecological processes. As grain yields increase under microdosing with little organic matter returned to the soil this effectively results in ‘soil mining’ and over time leads to diminishing returns (Tabo et al. 2011). Conservation agriculture practices could help reduce this risk (see section 4.3).

In summary, microdosing is characterised by:

- Good prospects for net positive returns, but where these are cited in literature they are based on simple analyses excluding labour. Labour is an important factor in the burgeoning demands on women and on-farm livelihood choices so the suite of choices and investments needs to be farm-specific.
- General compatibility with traditional farming practices.
- Some flexibility for the farmer in decisions on labour and cash flow.
- Lower investment in training than with other technologies.
- Labour costs that are relatively high. There may be some cost efficiencies where clusters of farmers can increase their collective buying power to reduce fertiliser costs at wholesale prices and share labour costs.
- Capital costs are modest, but still significant to poor farming households.

Therefore other on-farm methods may be worth exploring to cater to the range of farming household (relative) wealth categories in the region, to the labour available on-farm including gender variability in time budgets, and to livelihood diversification (such as inter-cropping for complementary production, needs for fodder production and long-term nutrient inputs and soil water retention).

4.2 AGRICULTURAL WATER CONSERVATION AND MANAGEMENT

Widespread loss of vegetation and land degradation has significantly eroded ecological processes supporting the capture, storage and productive use of water in both ecological and agricultural systems across the project area. While predictions of water availability have wide margins of error, the modelling exercise presented earlier (figures 6 and 8) suggests that by 2050 trends in water balance and seasonality may have negative effects on livelihoods as higher temperatures increase in areas of the project target area where crops are produced (centre and southern) and evapotranspiration is likely to result in water stress to crops. Under current land use and vegetation profiles there may also be periodic flooding with substantial losses in water availability due to surface run-off and low levels of water capture within soils. Given that rain-fed agriculture dominates both household and regional economies, there is an immediate need to consider more efficient means of managing water both on-farm and in the watershed. For those engaged in pastoralism, access to both water and fodder will need to be managed such that short or medium duration dry periods do not result in these resources falling below subsistence levels for livestock. Similarly for farmers, access to water during dry spells is requisite to avoid crop failure or severely curtailed yields.

In the near future there will be increasing demands placed on the Sahel’s water resources to support the needs of growing urban and rural populations, intensified agriculture and possibly for energy development. Productive water resources are already at a minimum, and groundwater reserves, while potentially considerable, should not be overly used in an effort to make up for other deficiencies. For arid and semi-arid regions, Wilson (2011) suggests that
water development should focus on “recharge, harvesting and conservation of surface water and not on deep tube wells”.

Thus, going forward, a premium should be placed on production systems that:

- are less demanding and more efficient in terms of water use;
- capture water in productive green infrastructure (vegetation) or grey infrastructure (man-made);
- balance short-term returns and private interests with longer term impacts and conservation of common resources (notably ‘bluewater’ sources ie lakes, rivers and groundwater reserves).

Farmer production is roughly 30% of obtainable yield for commonly planted crops across sub-Saharan Africa, and approximately 25% and 28% in Burkina Faso and Niger respectively (Rockström et al 2007). Improved water and soil management could greatly reduce the gap between potential and realised productivity. While water scarcity affects production potential, the negative impact of poor management of soil and water resources is of greater significance.

**Agricultural water conservation is critically dependent on productive use of ‘greenwater’ in soils**

Water management planning needs to move beyond emphasising bluewater-based solutions, heavily focused on groundwater, lakes and rivers, to promoting the development of greenwater solutions by making more effective use of rainfall percolation through soils. Strategies to improve greenwater management include rainwater harvesting (RWH) technologies designed to increase both water availability (eg storage adjacent to farms) and improve saturation in situ (eg water conserved on crop area via stone bunds or Zais). Other greenwater technologies include those designed to increase plant capacity for plant water uptake capacity such as agronomic practices promoted under conservation agriculture as discussed in later sections.

**Agricultural water conservation underpins risk management to justify investment in improved seed and fertiliser technologies**

Falkenmark and Rockström (2004) characterise ‘dry spells’ as stemming from poor on-farm practices that can reduce plant-available water to as little as 40% of rainfall, causing intermittent dry spells that reduce farm productivity. True drought is a meteorological event. High variability in rainfall with concomitant dry spells introduce a form of uncertainty that strongly influences decision-making, especially as relates to the adoption of technologies and practices that could improve or stabilise yields. Appropriate on-farm water management can ameliorate those risks by acting synergistically to boost yield gains and thus improve cost-benefit ratios.

**In situ RWH technologies and their potential for scaling up in the Sahel**

Mati et al (2011) provide a comprehensive assessment of RWH technologies and applications for sub-Saharan Africa. They note that conservation of water though a variety of structures and crop management practices can increase water productivity between 50% and 100%, depending on the technologies employed. Barry et al (2008) tested a mixture of RWH technologies, some coupled to fertilisation treatments, in Niger and Burkina Faso and found that across all technologies, crop yields increased, soil water increased and was conserved at deeper depths, and soil fertility either increased or the rate of loss of key minerals was reduced relative to traditional practices. Both Mati et al (2011) and Barry et al (2008) raise several points worth considering in the promotion of RWH technologies:

- Despite their relative simplicity, monetary and labour costs may be prohibitively expensive, relative to the gains achieved. Seasonal labour availability can be limiting, as can obtaining or affording the equipment needed to undertake construction of stone bunds or other earthen structures. Barry et al (2008) were able to improve the cost-benefit ratio by applying fertility treatments such that crop yields surpassed the required threshold to recoup the investment in RWH measures.
- Group or ‘cluster farming’, possibly within existing farmer associations, may make some of these technologies more affordable as monetary costs and labour can be shared.
- Consideration of the bio-physical context is important for understanding the potential benefits of RWH applications. For example, Zai usage in areas of higher, more stable rainfall proved disadvantageous to crop yields.
- Secure land tenure is a prerequisite as farmers are unlikely to engage in modification of existing practices if their investment can be transferred without consent to another individual.

**Supplemental irrigation to mitigate the negative impacts of dry spells**

Even with greenwater conservation measures in place, intermittent dry spells can reduce crop yields or contribute
to crop failure. These impacts may be mitigated through the targeted addition of supplemental water via irrigation. To date, low cost, low technology drip irrigation methods, primarily gravity-fed from water storage units, have delivered greater benefits in Asia relative to Africa. Survey studies suggest that equipment failures, labour requirements and limited technical support in best practice were major factors behind low adoption rates (Maisiri et al 2005). Water capture and storage are often the primary costs in developing these systems, but can vary with the type of materials employed.

While not all designs have proven to be feasible, some have produced positive returns on the investment. Working in Burkina Faso, Fox et al (2005) documented the potential for drip irrigation to produce substantial yield gains in cereal crops relative to purely rain-fed plots. Considering labour and material costs, and using the most economical storage technology, farmers were able to realise a net profit of US$390 per year per hectare. Similarly, ICRISAT, though the African Market Garden programme, which pairs drip technology with horticultural training, reports significant benefits to farmers in labour savings, higher yields and financial profits relative to both traditional and enhanced farming techniques using manual delivery of water (Woltering et al 2011). Many of these participants engaged in cluster farming where a number of individual farms are serviced by a single storage tank. Using a solar-based pump system to access water, Burney and Naylor (2011) also demonstrated a positive return on investment for farmers in Benin as the operating costs associated with fuel purchases were removed. They documented an overall increase in the standard of living for participating households and improvements to the household asset base relative to non-participating households, though the latter was not statistically significant. As with RWH, a few key points emerge:

- Adoption by individual farmers is unlikely as capital and maintenance costs are high. When able to invest as a group, success rates appear to be higher. Cluster and communal farming designs facilitate group adoption.
- Cluster farming and other group-oriented approaches promote knowledge transfer through peer-to-peer engagement, and may lead to novel institutional arrangements. For example, women’s irrigation groups in Benin formed ‘self-help’ societies that facilitate other community members to participate in irrigation schemes and other means to improve livelihoods.
- Crop diversification through the production of high value or niche crops greatly influences the potential for net profit, as opposed to simply achieving household food security.
- Integrating the dissemination of best management practices in agronomy alongside water conservation improves outcomes.
- Higher quality irrigation kits, though more expensive initially, have greater likelihood of being adopted (where economically possible) as they do not have the high maintenance costs and build confidence in the approach.

Planning and intervening at the scale of small catchments

Rockström et al (2010) posit that the scale at which most water management planning occurs, typically river-basin level, is insufficient for addressing the needs of small-scale farmers. Therefore management planning should occur at micro-catchments across watersheds to more effectively support investments in rain-fed agriculture. Catchments could be defined by a set of ecological, demographic, economic and geographic criteria as with the Integrated Community Watershed Model developed by ICRISAT in India (Wani et al 2006).

Linkage with integrated approaches to landscape management

Wani et al (2006, 2009) promote a systems-level approach that capitalises on potential synergies between actors and sectors within the agricultural domain, and that is centred on improved water management as a key entry point for agrarian livelihoods. They advocate for expanding the purview of integrated watershed management (IWM) programmes from “technological interventions for soil and water conservation, to include multiple crop-livestock-tree and market-related innovations that support and diversify livelihoods”.

Trade-offs between alternative uses of water

Significant investments need to be made in improving the management of rain-fed agriculture, indeed water management more generally, to accommodate both increased agricultural production and to address possible trade-offs between alternative uses of water across the region. Balancing these trade-offs is essential to achieving long-term resilience in both the resource and the livelihoods that depend upon them. As Rockström et al (2010) point out, innovations in policy and technology need to happen at multiple scales, and these investments should be guided by a more integrated perspective that
recognises opportunities across a continuum of rain-fed to irrigated agriculture. Whilst RWH has been relatively neglected, the authors point out that without soil and crop management practices making effective use of the harvested rainwater, improved RWH technologies provide diminishing returns.

4.3 SOIL CONSERVATION AND MANAGEMENT
(CONSERVATION AGRICULTURE)

With the constraints and unpredictability identified in section 3 and the variable capacity for farmers or pastoralists to maintain livelihoods within different income, labour and gender classes to adopt techniques discussed in sections 4.1 and 4.2, there are also other approaches to consider for productive agricultural and livestock production systems. These are discussed in sections 4.3 and 4.4.

4.3.1 ‘Climate-smart’ and conservation agriculture

Climate-smart agriculture (CSA) systems aim to utilise the resilience and mitigation properties that sustainable agriculture can have on climate change. The FAO suggests CSA can “increase sustainability, resilience and reduce agriculture’s contribution to climate change and therefore enhance the achievement of national food security and many of the goals of intergovernmental groups such as the MDG” (FAO 2011). The FAO divides CSA into three examples: conservation agriculture, agroforestry, and integrated forest, farm and fish systems.

A common system in sub-Saharan Africa that has potential to increase resilience in the Sahel region is conservation agriculture (CA). CA follows three principles:

1. Continuous minimum mechanical soil disturbance (i.e., no tilling and direct planting of crop seeds);
2. Permanent organic soil cover with residues and cover cropping; and
3. Diversification of crop species grown in sequence and associations (FAO 2013). Silici et al. (2011) suggest that, “compared to conventional tillage-based production systems, CA leads to higher net profitability, greater environmental sustainability and – especially important in Africa – higher food security”. There is much literature suggesting CA increases ecological and social resilience, particularly in sub-Saharan Africa (Friedrich and Kassam 2009, Kassam et al. 2009, FAO 2010, Marongwe et al. 2011, Marongwe et al. 2012, Silici et al. 2011). Ecological resilience is realised via increased soil quality and water availability, and economic and social resilience is delivered via increased productivity (Kassam et al. 2009). In Zimbabwe CA has been shown to “significantly increase yields and agricultural productivity in a sustainable manner even for poorly resourced farmers, improving their food security and often enabling them to sell surpluses” (Marongwe et al. 2011).

4.3.2 Benefits of conservation agriculture

- Empirical evidence of an increase in yields with successful CA adoption across Africa including arid areas. (Friedrich and Kassam 2009, Mazvimavi and Twomlow 2009, Hobbs 2007, Marongwe et al. 2011)
- Empirical evidence of increased soil moisture particularly through using mulch.
- Increased soil nutrients through use of compost and rotating crops, particularly using legumes in the rotation. (Mando et al. 2002, Bagayoko et al. 2000)
- Zai pits used in the Sahel with compost and mulch improve water retention in arid areas. (World Bank 2005)
- Rotation and crop diversity spread risk and increase social and ecological resilience.
- Poor and marginalised people can adopt CA. (Mazvimavi and Twomlow 2009)

Conservation agriculture has many benefits associated with sustainability and livelihood productivity. There is quantitative evidence of increased yields from the use of CA across much of Africa, particularly in Zimbabwe where the technique has been used for decades, including in arid zones in the south of the country. In the Sahel the traditional Zai technique (see also section 4.2 above) has been incorporated into CA approaches and has been shown to hold water as well as collect fertile windblown dust, protect seeds and organic matter from being washed away, concentrate nutrients and reanimate biological activities in the soil (World Bank 2005).

Mulch has been shown to dramatically increase water content in the soil. It does this by reducing runoff, increasing infiltration, increasing the porosity of the soil, and decreasing compaction as well as reducing soil temperature and reducing soil erosion by wind and water (Erenstein 2003). The benefits of mulch have been empirically shown in Burkina Faso (Buerkert et al. 2000, Mando et al. 2002). Bayala et al. (2012) indicate that on sites with an annual rainfall of less than 600mm mulching is the most consistent conservation agriculture technique for increasing crop yields.

Conservation agriculture must be conducted to a high standard in order to reap the benefits. Some have coined the phrase ‘precision conservation agriculture’ which has been used in low-potential zones such as the Sahel (Twomlow et al. 2009). The idea of being precise means...
maximum efficiency is reached, reducing inputs per output, saving costs and increasing yields. This idea is reflected in the Zai pit approach which concentrates resources around the plant. Crop rotation and diversity increase resilience through reducing risk (Zorom et al 2013, Bagayoko et al 2000). The ‘Greening of Darfur’ programme taught farmers to spread risk by planting different species. Other studies have also shown how landscape diversity increases environmental resilience (Harris 2011, Mijatović et al 2013). Using legumes, such as groundnuts, has the further advantage of increasing the nutrient content in the soil (Bagayoko et al 2000). Studies have shown how adoption of CA is not affected by gender, income or HIV status, allowing marginalised and vulnerable groups to adopt CA techniques and become more resilient (Moyo et al 2012).

4.3.3 Challenges in realising the potential benefits of conservation agriculture

- Poor standards lead to poor harvest and reduction in resilience. (Giller et al 2009)
- Farmers unlikely to change practices conducted for centuries.
- Potentially a yield penalty in first few seasons as farmers get used to techniques. (Giller et al 2009)
- Increased labour burden for women – in relation to gender roles, increased weeding and land preparation.
- Lack of, and competition with livestock for, residues and organic matter leads to lack of mulch and compost materials.
- Knowledge intensity is a barrier to adoption by farmers who lack formal education.
- Lack of legume seeds and markets reduces likelihood of successful rotations and crop diversification.
- Lack of materials and equipment to make compost. (Mando et al 2002)

Critics of CA suggest that it cannot be used as a one-technique answer to much of Africa’s problems. CA is often conducted to poor standards, meaning the benefits are not reaped – in fact farmers can even become less resilient (Giller et al 2011), but technical performance at field level is but one of the determinants of adoption. For various reasons, all of the CA principles are not always fully implemented by farmers and results not as favourable as expected. At farm and village levels, trade-offs in the allocation of resources become important in determining how CA may fit into a given farming system. At a regional level, factors such as the market conditions, interactions among stakeholders and other institutional and political dimensions become important. At each level, opportunities or difficulties emerge that enhance or impede development, adaptation and adoption of CA. One study has shown how there is a yield penalty in the short term as farmers convert and adopt CA because they are not used to doing the techniques, and digging basins is much harder work and more time-consuming the first time. Whilst they spend time adapting to the techniques their yield is reduced in the short term. This is sometimes difficult for farmers to accept and cope with, as vulnerable people have short-term priorities and cannot contemplate long-term solutions such as CA.

There are also some studies suggesting a change in the labour burden from men to women (Giller et al 2009). This is particularly in relation to weeding, traditionally a woman’s job. Labour is reduced at certain times of year, such as ploughing, as land preparation is spread across the whole of the dry season which reduces the man’s workload. Weeding, however, is increased leading to women generally having more work to do (Wall 2007).

CA has been described as knowledge intensive where the many parts require knowledge of different techniques and standards. A study revealed how more educated people were more likely to adopt CA which could reduce the impact it can have on uneducated, marginalised farmers in the Sahel. Rotations in CA require knowledge of growing different crops as well as access to new seeds. This has been seen as a limiting factor when trying to increase rotation and diversity. Some communities have trouble accessing legume seeds, as well as selling them when sometimes there is no market compared to that for grains.

One of the main constraints for CA in arid areas like the Sahel is that there is little material to use for mulch or compost. Residues are traditionally used for livestock fodder, and so this creates competition for use as mulch. Using residues for mulch dramatically alters the flow of resources in a farm system (Erenstein 2002, 2003). Again this is also linked to traditions or to the perceptions of farmers about the use of materials.

4.3.4 Lessons learned

- CA needs to be implemented specific to environmental and social context, understanding agroecological limitations as well as cultural practices that could affect adoption. (Wall 2007)
- Need to understand farmers’ perceptions of no till / mulch use / rotations, as adopting CA could be changing centuries of ways of doing things. (Giller et al 2009)
Towards climate resilient agricultural and pastoral production systems

- Zai pits are similar to traditional techniques in the Sahel as a good option in terms of social perceptions. (World Bank 2005)

- Need to understand the roles of men and women in the farm system and how CA may change them, for example land preparation and weeding.

- Need to make sure people understand the extent of work needed to change to a CA system, such as the high standards and precision needed as well as the change in labour demands.

- Demo plots in communities help change perceptions.

- When using organic material for mulch and compost the flow of resources in the system must be understood and accounted for. (Erenstein 2003)
  - For example, growing evergreen shrubs and trees to increase nutrients in soil as well as coppicing them and using the branches and leaves as mulch. (Lahmar and Triomphe 2008)

- Seed and fertiliser subsidies from NGOs often increase adoption but should not be the main reason for adoption as this encourages reliance on aid and does not change perceptions of the CA techniques and the problems it addresses.

- Access to legume seeds as well as legume markets is needed in order to support adoption of rotations and crop diversity. (Mazvimavi and Twomlow 2009)

4.4 AGROFORESTRY AND TREE SPECIES MANAGEMENT

4.4.1 Role of trees, especially parkland agroforestry practices, in the agricultural development model

Agroforestry, or the integration of trees into crop systems, is a traditional farming practice widely used in tropical developing countries. Over the last 15-20 years the value of traditional agroforestry practices has gained greater recognition in the scientific community, and their value as a development tool is now widely acknowledged (Nair 2011). The term agroforestry covers a wide range of practices including the integration of shade trees into cacao farms in the humid tropics, the protection of scattered indigenous fruit trees in the Sahel (Garrity et al 2010), and the use of shelter belts and ‘set-aside’ land in Australia (Barton 1999).

Willemen et al (2013) produced a literature review of tree-based ecosystem approaches (TBEA) which are practised at scale (ie adopted by a large number of land managers within a large area) and the drivers behind the uptake of TBEAs and evidence of impact. They also give the historical

![Tree cover (%)](image)

Figure 13. Tree cover (%) (Data source: Hansen, M., R. DeFries, J.R. Townshend, M. Carroll, C. Dimiceli, and R. Sohberg 2006, Vegetation Continuous Fields MOD44B, 2001 Percent Tree Cover, Collection 4, University of Maryland, College Park, Maryland, 2001). The highest per-pixel tree cover percentage in the area is around 15% but mostly values are close to 0%.
context of modern land use models and agricultural practices globally during the 20th century that promoted the segregation of trees and crops in landscapes. Narrowing the range of crops such as grains grown in monocultures disregards the highly biodiverse and tree-dependent systems that could supply food, fibre, medicine, tree fruits and nuts. As production requirements and commercial agriculture pressures increase in the Sahel, resistance to monoculture production and fertiliser inputs will need to be strengthened by maximising productivity and promoting product diversity in smallholder farmer communities. ICRAF was established in 1978 and has been amassing evidence and techniques for intercropping ‘multi-purpose trees’ in agricultural systems (Willemen et al 2013). ICRAF’s holistic programming approach is discussed in section 4.5.

In the Sudano-Sahelian vegetation region of sub-Saharan Africa, agroforestry practices are widely recognised to provide multiple social, environmental and economic benefits to the local communities. Trees in the landscape provide:

• A variety of ecosystem services – including carbon sequestration, biodiversity conservation, soil enrichment and improved air and water quality (Manning et al 2006, Jose 2009, Brown et al 2011).
• Non-timber forest products (NTFPs) which can form an important part of the livelihood of rural communities – as a source of cash, significantly increasing a household’s annual income (Schrekenberg et al 2006, Garrity et al 2010, Brown et al 2011) or forming a significant part of it (39% in northern Benin, Heubach et al 2011; 17-35% in Burkina Faso and Mali, SECAM 2012).
• A readily available source of fertiliser that can more than double yields under some conditions (Garrity et al 2010, Ajayi et al 2011), though care has to be taken in the combination of tree species and crop used (Anthofer et al 1997, Kamara et al 1999).

4.4.2 Use of agroforestry within production systems

The use of agroforestry within production systems in the project target area needs to be explored and scaled up to reverse the trend of land degradation. In the Sahel, the adoption of agroforestry practices presents a cost-effective strategy that could increase the resilience of local communities and provide social (including nutritional health), economic and environmental benefits. Coping strategies employed today in the region include the use, especially by women, of native tree foods in forest patches (leaves, nuts, fruits) as an important source of nutrition and, increasingly, of cash income for several months of each year (local and global product markets). Socio-ecological resilience can be increased when tree resources are protected, restored and regenerating at levels that historically existed and that in the past provided numerous environmental services and were part of traditional drought-management strategies. Reij et al (2009) summarise the origins and results of farmer-managed natural regeneration in Burkina Faso and Niger, from its beginnings when Tony Rinaudo of Serving in Mission helped local farmers develop it as a low-cost option for reproducing trees and shrubs, to its utility in efforts to ‘re-green the Sahel’. Along with other conservation agriculture techniques they summarise results in increased supplies of fodder, firewood, fruit and medicinal products and apparent increased groundwater recharge.

4.4.3 Household-level impact of NTFPs and micro-enterprises

The production, sale and use of NTFPs has the potential to significantly increase the income and food security of households in the Sahel region. Trees provide a variety of products – food, medicine, building materials, firewood (coppicing) – that can be used domestically or commercially. Typical tree species in the region used for NTFPs and micro-enterprise are: *Acacia Senegal*, *Adansonia digitata*, *Balanites aegyptiaca*, *Hyphaene thebaica*, *Lannea microcarpa*, *Sclerocarya birea*, *Ziziphus mauritiana*.

In some communities NTFPs are already a significant source of income. Heubach et al (2011) calculated that NTFPs contributed about €0.6/day to household incomes in northern Benin, raising incomes to €2.0/day, 30% above the national average (€1.40/day).

With international marketing mechanisms like ‘green’ and ‘fair trade’ the commercialisation of NTFPs (eg shea, baobab) has the potential for smallholders to participate in a bigger trade, which could improve income and employment opportunities, especially for poor and otherwise disadvantaged people. NTFP trade can be their only source of cash, and can come at key times of the year (Belcher et al 2007). However commercialising and expanding NTFP markets is potentially very complex and challenging, and it is essential to take a comprehensive view of the whole value chain in production and market planning if the new markets are to be sustainable (Belcher et al 2007).

4.4.4 Impact of integrating trees into farm production systems

Numerous studies have been conducted into the impact of integrating trees into farm production systems. Bayala et
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al (2012) found variable impact on yields of cereals, but on sites with an annual rainfall of less than 600mm both parkland and coppice agroforestry would increase cereal yields more often than not, whilst also providing fodder for livestock and alternative sources of income (NTFPs). *Faidherbia albida* and *Guiera senegalensis* produce the most positive crop responses in parkland systems when comparing the yield of grain and straws in the Sahel (Bayala et al 2014).

Anthofer et al (1997) investigated the impact of nine agroforestry mulches on wheat in Ethiopia and found that some outperformed standard (20 kg P + 30 kg N per ha) fertiliser applications. In Malawi, Garrity et al (2010) recorded increases in yield of 100-400% for maize grown under *Faidherbia albida*.

However results also show that care has to be taken when introducing and promoting new species for use in agroforestry systems, particularly as ‘fertiliser trees’, as they do not always have equal or beneficial effects on different crops (Anthofer et al 1997, Kamara et al 1999, Garrity et al 2010). Bayala et al (2014) looked in more detail at the interactions between crops and trees in agroforestry systems, and found that the crop plant type (C3 or C4 plant) and tree species had a distinct effect on whether the tree-crop relationship increased yields or decreased yields; but conclude that a more comprehensive analysis is needed to fully understand the interactions. It is still open to discussion whether trees increase soil fertility, or whether they just maintain, or make more readily accessible, the nutrients already in the soil (Bayala et al 2014).

### 4.4.5 Contribution to food security and micronutrient enhancement at household level

Due to their morphology, longer annual reproductive cycle and deep root systems, trees are generally less susceptible to drought than annual field crops, making them a valuable source of food in the drought-prone Sahel region.

Schrekenberg et al (2006) examined the role of indigenous fruit trees in poverty reduction and found that indigenous fruit trees provide an essential source of food during the ‘hunger season’ and can be a staple of traditional diets, making a significant contribution to a family’s nutritional needs. Garrity et al (2010) found that the use of fertiliser trees increased household food security by generating an extra 57-114 ‘person days of maize consumption’ per household.

Spreading the use of agroforestry techniques and commercialising NTFPs has the potential to address food security issues faced by subsistence farmers in the Sahel. However Belcher et al (2007) caution there is a real risk that the gains of increased commercialisation will not be captured by the intended beneficiaries if the issues of land tenure, access rights, market knowledge and skills gaps are not also addressed.

### 4.4.6 Contribution to ecosystem services

Scattered trees, like those found in agroforestry systems, provide a range of ecosystem functions that are disproportionately large compared to the area they occupy (Manning et al 2006). The ecosystem services provided by agroforestry at a local scale include increased carbon sequestration, increased soil nutrients, plant biodiversity conservation, and habitat for animals. At a landscape scale agroforestry contributes to improved air and water quality, increased tree cover, and increased genetic connectivity for trees (Manning et al 2006, Jose 2009).

While the adoption of agroforestry has the potential to increase the amount of trees in the landscape, Belcher et al (2007) point out that although there are clear ecological implications to NTFP commercialisation, particularly in the use of ‘wild’ species, yet more baseline assessments are needed for West African parklands to properly assess the impacts and sustainability. West African parklands have lower diversity than undisturbed savannah, but have significantly more diversity and offer more services than a monoculture field.

### 4.4.7 Relative rates of return on different tree planting methods

The rates of return on different planting methods are influenced by environmental and climatic uncertainties and the potential for economic return. Direct planting or active revegetation is expensive because of the time, labour and material costs required to grow and establish a tree and depending on the desired product it can be several years before farmers see any economic return. In contrast, farmer-assisted tree regeneration can have zero material costs and very low time and labour costs.

Dorrough et al (2008) found that active revegetation was less costly than passive revegetation (natural regeneration of trees) in high-productivity situations, however at low productivity passive revegetation was less costly than active revegetation. This suggests that different methods may be more suitable for some tree species than others depending on their economic value to the community.
4.4.8 Modifying tree species via grafting for increased drought tolerance and production capacity

For as long as farmers have been collecting products from trees, either ‘domesticated trees’ in agroforestry systems or collecting NTFPs from ‘wild’ trees, they have been selecting and promoting trees with desired genetic traits. Schrekenberg et al (2006) found that the domestication of indigenous fruit trees has resulted in fruit that is 40-66% larger than the ‘wild’ varieties for some species.

The process of selection for desired traits has the benefit of being free and technologically accessible to everyone, however it can also be a very slow process. Other methods of improving the genetic stock of selected tree species can be faster and more productive but also more expensive (Mng’omba et al 2008). The decision process for propagating tree species needs to consider the potential economic return, the time it will take to realise that return, and the cost and technology required.

Direct tree-crop interactions are highly variable and yet to be fully researched in the Sahel in relation both to positive effects – shade, water retention, water quality, soil nutrients – and potentially negative effects – uptake of water or ‘storage’ of water in trees (which reduces liquid water for growing crops, but can be potentially beneficial where trees provide livestock fodder). However, declining tree and shrub cover is always likely to be followed by soil degradation and accentuated extremes of temperature and water stress. Willemen et al (2013) emphasise that tree-based ecosystem approaches (TBEA) are not well-represented in peer-reviewed literature beyond hydrological/ecomystem impacts, lacking data on income benefits for farmers, and about impacts on agricultural production and resilience. Much more data gathering and analysis is needed in the Sahel.

4.4.9 Decision-making for uptake of tree-based approaches

Willemen et al (2013)’s review of TBEA emphasises that tree-based approaches provide ecosystem benefits only when practised at scale (by spatial extent and practice). They reviewed 111 sites in 53 locations (more than half in Africa), identifying practices that utilise trees in croplands, trees in grasslands, forest-based systems, complex multi-strata agroforestry and home gardens. TBEA practices ranged from trees in conservation agriculture systems providing improved fallows and fodder banks (see section 4.5 for a description of tree- and fodder-banks) to use as fertiliser trees, live fencing, hedgerows and woodlots. The Sahelian sites they reviewed were in Niger, at seven sites using trees in parkland agroforestry systems and under natural regeneration.

The most commonly reported drivers (across the entire study) were soil/degradation/quality issues, desire to increase income, and the need to produce food and fodder for subsistence. In Zambia for example, the initiatives to integrate trees into conservation agriculture were reported to be influenced by reduced access to fertiliser, increasing land degradation and rising input costs. Increasing yields, traditional practice and increased knowledge and technology were also recorded. Seven drivers were sometimes reported as singular reasons for TBEA: improving soil quality, income generation, food and fibre, household nutrition, nature conservation and climate change adaptation. Shade provision and incentives were only reported as secondary to other reasons (Willemen et al 2013).

4.5 INTEGRATIVE LAND USE PLANNING

Within the project target area, or other areas in the Sahel which need support with resilience planning, there are several factors that necessitate integrative land use planning for productivity and viable livelihood options in a water-stressed region. As discussed in section 4.2, assessing the demands for agricultural water usage requires wider water basin analysis (bluewater and greenwater). The permanent vegetation and soil resources across the region play a vital role that transcends land tenure and borders at various governance levels.

Over most of the project target area tree canopy cover is 1% or less (light green/pale yellow in figure 13). There are very few areas where the level of tree cover warrants classification as forest in conventional terms, but this sparse population of trees nevertheless plays a vital role in supporting local livelihoods.

FAO (2012) provide an overview of a ‘landscape approach’ – the need for integrative planning and governance considerations and trade-offs or synergies amongst different land uses – in their publication Mainstreaming climate-smart agriculture into a broader landscape approach. Besides citing examples of holistic approaches to sustainably managing farmland, rangelands and forests, they refer to the resources available on Sustainable Land Management (SLM) from WOCAT (World Overview of Conservation Approaches and Technologies). WOCAT’s global network of soil and water conservation specialists dedicated to sustainable land management brings together expertise in knowledge management...
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and decision support for up-scaling SLM among all stakeholders including national governmental and non-governmental institutions and international and regional organisations and programmes (www.wocat.net 2014). The WOCAT online databases provide information on SLM approaches and technologies and SLM mapping.

Wani et al (2009) note that linking the demand side of users of diverse watershed services to the supply side (water/soil resources and associated technological innovations) is the conceptual foundation of the ICRISAT Integrated Community Watershed Model. This is a model that has been through trial experiments in India (multiple sites), China, Thailand and Vietnam with positive outcomes. Typical activities within an Integrated Community Watershed Model include: the application of cost-effective RWH structures, conservation agriculture and agronomic technologies; crop diversification with inclusion of high value crops; pest management; restoration of degraded lands via forestry and soil/water management practices; establishing micro-enterprises based on agricultural products and services (eg value-added processing of feeds and quality compost, poultry and fodder farms, biodiesel plantations, etc); development of ‘self-help groups’ to establish seed banks; credit/loan associations; provision of technical information and training from scientific agencies, NGOs and researchers; and community-led land use and intervention planning (Wani et al 2009).

ICRAF is developing a decision support tool called ‘Polyscape’ to map ecosystem services from rural areas in order to improve landscape management that includes trees, agriculture and other land uses. It develops a framework exploring land management impacts on multiple ecosystem services. It supports decisions from sub-field scale to approximately 1000km², reduces data deficiency and incorporates local knowledge, prioritises existing preservation, and identifies opportunities for change and increased synergies in (ecosystem) service provision (Jackson et al 2013).

‘Waterworld’, a mapping decision support tool developed by Kings College London and AmbioTEK, was used for the map data and climate scenario maps presented in section 3 of this document. The model can run land use or climate change scenarios and incorporate land management interventions (or other data available for upload) to understand impacts relative to baselines (www.policysupport.org/waterworld, 2014).

Clear benefits are derived by planning and integrating on-farm with off-farm activities, and where the by-products of one system/value chain can provision another. An example would be post-harvest plant residues, which should effectively be increased by improved water/soil management, and can provide animal fodder during times of water scarcity or for fattening animals to obtain higher prices, and manure which can be used as fertiliser or as biogas. Various authors affiliated with the ICRISAT Integrated Community Watershed Model have presented data on crop yields, soil nutrient loads, water productivity and groundwater recharge, economic returns, etc.

4.5.1 Integrating off-farm livestock and pastoralist needs

Moving amongst and between the various water resources and vegetation types, across borders and land tenure systems, are off-farm livestock herders and nomadic pastoralists, and the wildlife species that both function within and support the function of the resources (eg pollinators). Climate model predictions suggest that the length of the growing season for vegetation in the north would not necessarily increase, rather that the sites and incidents of plant productivity in the north of the project zone may vary with a less marked season.

Integrative planning which considers the human responses to climate variation – changes in vegetation demands, movement of livestock and people – would anticipate potential conflict areas. The cross-border scale of the project area is a demonstrable example of the need for integrative planning, with multilevel stakeholder outreach. Regardless of net predictions on rainfall in the climate models, a UNEP analysis of climate change, migration and conflict in the Sahel (UNEP 2011) summarises the immediate effects of higher temperatures. The drying of water bodies, the concentrated use by people and animals at water points and the disease potential are compounded with changes in the viability of traditional grazing grounds. The migration and movement of people and livestock is not only ancestral but can be driven by traditional and non-traditional livelihoods becoming less viable (UNEP 2011).

The five core challenges threatening the resilience of pastoral systems are summarised by Little and McPeak (2014) in a conference paper of the International Food Policy Research Institute. They posit that: (1) loss of land is the primary challenge through encroachment of neighbouring agriculturists, development of irrigation, tourism, conservation and land ‘grab’ investments;
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(2) endemic violence and conflict disrupt markets and increase vulnerability during droughts; (3) whilst increasing population and settlement can offer supplemental feed and crop residues, there is the risk of overgrazing, such as in the Sahel where settlement is resulting in more intensive grazing and night grazing; (4) wealth disparity amongst different herd (size) owners, such that the poorest of pastoralists try to diversify into (high risk) rain-fed farming and charcoal-making to supplement their livelihoods; and (5) climate variation (Little and McPeak 2014). Decision-making to respond appropriately will require flexibility. How and when pastoralists will move for grazing access and resources is pivotal to successful integrative planning and resource allocations in the project target area.

These problems will likely only get worse both within villages and amongst transhumance practitioners, despite studies showing mobile livestock husbandry being arguably a climate-adapted livelihood strategy for the rural poor (cited by Turner et al 2014 as Amanor 1995; Niamir-Fuller 1999; Thébaud and Batterbury 2001; McCarthy and Di Gregorio 2007; Adriansen 2008; Pedersen and Benjaminsen 2008). In livestock production, practices could include stocking different animal species to spread risks, promoting fodder varieties that are less climate-sensitive, and providing alternatives to more destructive, desperate options (e.g., fuelwood harvesting and charcoal production). However, efforts to secure mobility for herders to enable ongoing access to water, grasses, and fodder are invariably needed, such as establishing livestock corridors and delineating grazing lands, including across borders.

Turner et al (2014) cite several studies about herding and benefits and costs of moving livestock, but call for more multi-site studies related to climate variability. They studied four villages in Niger and 28 in Mali between 2007-09, to characterise the decision-making amongst rural livestock owners behind the variation in their livestock mobility practices. They confirm that ‘herders’ and ‘farmers’ are not exclusive categories since groups practice both some farming and herding. Nonetheless they conclude that “true herders” own more cattle, and that social identities persist and still form the basis of conflict. They summarise three general characteristics of livestock management in the region: village-based livestock with a small percentage of people keeping small stock at home (i.e., for fattening or in order to tend

Figure 14. Headcount of wildland grazers (head/km²) (Data source Mulligan, M. (2014) SimTerra: A consistent global gridded database of environmental properties for spatial modelling. http://www.policysupport.org/simterra [based on Wint, G.R.W. and T.P. Robinson. (2007). Gridded livestock of the world 2007. FAO, Rome, 131 pp.]). Grazing density is highest in the central south of the region, but even though most of the project area shows a low or absent grazing headcount, it supports low intensity grazing with varying degrees of livestock mobility within the project area itself and across its boundaries.
wounded animals) and others letting animals disperse at the edges of village land; proximate encampment-moving livestock within 40 km of village territory; and distant encampment for longer-distance (>40 km) seasonal movements (usually of cattle not smaller livestock). The latter category is also known as ‘transhumance’, which in the region is generally (although not entirely) where herders move animals north in the rainy season for higher quality forage and south in the dry season.

There are myriad decisions and challenges behind herding movements. Movement away from villages in the rainy season may be motivated by the promise of better pasture from newly sprouted grass, local pasture shortages and the need to reduce risks of damage to standing crops near settlements. In the dry season gaining access to better pasture and water ranks highly in choices. However, moving farther afield creates risk from such factors as lack of pasture along routes, conflicts or cost associated with animal damage to crops (where crops encroach on livestock movement corridors), wild animals, disease or high concentrations of livestock, government or customary authority harassment, farmer/herder conflicts and others (Turner et al 2014).

4.5.2 Establishing or increasing buffers for periods of stress or scarcity

The study by Turner et al (2014) demonstrated that herders are concerned about various issues such as “too much selling of hay”, thievery, rainfall decline, a loss of palatable forage and of certain trees and bushes. For herders to invest time to herd, or spend the resources to entrust others to herd their animals, they require relevant information to be delivered (presence of livestock disease, size and quality of pasture, density of vegetation) by sources they deem as reliable and specific (witnessed by themselves, by a kinsman, a telephone contact or trusted local informant) rather than by word of mouth at markets or delivered via radio meteorological information.

In a detailed analysis of changes since 2005 in policies and programmes in the Sahel, the issues for supporting pastoralism are outlined, including a summary of the work of the NGO JEMED (Youth Mission for Assistance and Development) in northern Niger which promoted grain banks for people (at affordable prices) and fodder banks for livestock pasture (Gubbels 2011).

Figure 15. Herb cover (%) for 2010 according to the MODIS Vegetation Continuous Fields Product Mulligan, M. (2014) SimTerra: A consistent global gridded database of environmental properties for spatial modelling. http://www.policysupport.org/simterra [based on Hansen, M., R. DeFries, J.R. Townshend, M. Carroll, C. Dimiceli, and R. Sohlberg (2006), Vegetation Continuous Fields MOD44B, 2001 Percent Tree Cover, Collection 4, University of Maryland, College Park, Maryland, 2001.] compatibility: water_mask. Central areas carry 20-50% herbaceous cover (lighter greens), thinning out to zero in some northern areas. Only toward the south and west does the % cover rise above 50% (darker greens).
For both on-farm (smallholders) and off-farm resource users (off-farm livestock, NTFP producers, pastoralists), the establishment of resource ‘banks’ for critical resources such as cereals, fodder and trees will prove important to protect existing resources and allow for a form of social protection based on natural resources, complementing other forms of social protection (crop insurance schemes, cash for work programmes on infrastructure and farm labour). Such reserves, devised through an integrative planning process, can provide critical buffers in the event of a crisis, preventing conflicts during the actual period of environmental stress.

**TREE BANKS**

Tree-banking is a concept developed by TREE AID. It is a stock of tree resources specifically identified, governed and managed by dryland communities with the aim of building up household and community resilience to environmental and economic shocks.

Under tree-banking plans, communities build up tree resources and then regulate their use to ensure they are available to the community in the event of a climate event or disaster. Communities establish thresholds for when the stocks might be used by local people, for what purpose and at what level of intensity. As well as plans for intensive use of the resource in times of extreme hardship, tree-bank agreements may include ongoing, low level draw-down of the resource. They are distinct from fodder banks (planting of trees and shrubs particularly useful for livestock) in that people have the ability to derive household foods and income directly from non-timber forest products.

In some cases, there may be implementation of mechanisms for generating investment revenue from tree-banks. The regulation and fee generation from cut and carry fodder, sale of non-timber forest products and limited pollarding for fuelwood can enhance local livelihoods through micro-enterprises. This in turn can generate funds for monitoring and regulating the resource. Mechanisms for investment can also include adopting schemes that produce carbon credit payments for stocks held eg voluntary carbon schemes such as Plan Vivo or potential Payments for Environmental Services (PES) from third parties such as water authorities.

Tree-banking increases the visibility of benefits local communities derive from trees. It also increases local roles in protecting and managing tree resources for longer term sustainability. This helps to discourage and reduce overuse and depletion of the resource through, for example, unregulated timber and charcoal extraction or unregulated livestock grazing.
INDEPENDENT OF THE TECHNOLOGIES and approaches employed at household or community levels there is a strong case (as presented in section 4.5) for integrative planning. This is the best option in the face of increasing uncertainty and frequent scarcity of resources and to accommodate the mobility of people and livestock which is integral to traditional climate adaptation strategies. The context of the climatic challenges and the diversification of livelihoods in the Sahel naturally call for a scaled-up approach within the geographical setting of the project target area (ie in relation to the distances, variable governance boundaries, land use classes and climate variability). Landscape scale interventions, including agroforestry and agricultural water management, can deliver returns of environmental services (notably groundwater re-charge), whilst reducing risk and promoting the diversification of livelihood options.

Singh et al (2012), in a detailed analysis of a single watershed programme in the Bundelkhand region of central India, found that it took roughly four years from project inception for participants to experience a positive benefit-cost ratio. There are few quantified studies in the Sahel from which to extrapolate costs and benefits for integrative strategies, either at community or farmer level. Nonetheless, Reij et al (2009) identified six key lessons from Burkina Faso and Niger on effective partnerships for agricultural development that can enhance food security for poor farmers faced with the uncertainties of climate change:

1. Encourage innovation by local people.
2. Undertake multiple innovations which can trigger or enhance each other (impacts on soil, water, vegetative regeneration).
3. A single menu of technical options can achieve scale but farmers will need to test, adapt and choose their selections locally.
4. Communities working collectively will achieve sustainable benefits.
5. Farmers will adopt resource conservation innovations if one or more component provides significant benefits in the first or second year.
6. Long-term, multi-scale collaborations are important but successful projects demonstrated that farmer-designed solutions and charismatic leaders stimulated change and engendered some risk tolerance.

Scaling up can be achieved by inclusive planning, carefully brokered agreements on the rights of access, management and monitoring of resources supported by trustworthy information sources for all parties, and an understanding of the drivers behind decision-making and likelihood of uptake.

5.1 LOCAL EMPOWERMENT: ADDRESSING DIFFERENTIAL VULNERABILITY

Differences in gender and other roles, culture, and ethnicity all influence power, access to and control over resources. Some groups or individuals are enabled to participate in decision-making processes and take action to protect their livelihoods from climate risks, while others are hindered from doing so. Therefore, with a particular focus on gender-based disparities, decisions about resource and labour choices need to raise awareness and promote and identify context-appropriate, mutually supportive and gender-equitable actions that build resilience of individuals, families and communities.

Opportunities to empower women in decisions on climate-resilient agroforestry and crop production must address the barriers, opportunities and interests of women in relevant technologies and approaches. This requires:

• Use of participatory risk, vulnerability and capacity analyses (such as the Climate Vulnerability and Capacity Analysis model developed by CARE International) to capture women’s perspectives and priorities.
• Recognition that it is not just men who should be making use of climate information and market intelligence to inform decisions on the family farm.
• Support for women to group together, as they will often work best in groups to overcome barriers (eg building a stronger collective voice and leading by example against persistent labour and time burdens), seize opportunities to apply new technologies and approaches and gain income and elevated status in the household.
• External support to address inequities in access to natural resources. Women may struggle to change the status quo without external engagement which encourages local and religious authorities and traditional natural resource governance structures to facilitate access to land and other resources.
• Support for business literacy. Illiterate women can master business literacy and where they do their opportunities for profiting from new technologies and approaches will be much enhanced.

Assessing studies and cited best practice on the adoption of new strategies for resilient thinking under climate change suggests that some of the key drivers are:
• Necessity (prohibitive access to agricultural inputs, need for food, fibre, nutrition, income/coping mechanisms).
• Improved access to knowledge (new conservation agriculture techniques or inclusion of crop cultivars delivered by a convincing local innovator).
• At least some short-term return on the time, cost and labour input but in combination with longer term returns to buffer against risk.
• Communal planning that protects resources for the future but with the potential for short-term gains (tree and fodder banks, income from NTFPs); this can also provide short-term security over land tenure and land management agreements.
• Trusted information sources (such as decisions about where to herd animals, how to avoid conflict, investments in major assets or livelihood transitions).

5.2 CONCLUSIONS

Important choices must be made at farm level in choice of cultivars/varieties between optimising potential yield versus yield stability/plasticity. These choices must also take into account the fit with traditional farming practices or the need to overcome barriers to adopting alternatives to traditional practices. There is a spectrum of technologies available, varying in cost and accessibility (notably supplementary inputs such as mulch, irrigation and fertiliser). The approaches are possible by informing farm-level choices on cultivars, mostly through diverse varieties for plant phenotypic plasticity and genetic heterogeneity to stabilise yields under variable conditions.

The returns on investment and the allocation of human (and specifically women’s) labour or its re-direction to adopt different techniques need to be considered to build resilience, but no single technique will be transformative for rain-fed, smallholder farming. Household food security could be increased however, and the proportion of income spent on food could be consistently reduced. The result would be that people would have to spend less of their household income (or liquidised household assets) to purchase food when under climate stress and would be able to invest in diversifying their resource use, their productivity strategies and alternative livelihoods.

Individual resilience strategies combined with collective buy-in to landscape-scale interventions and land-use planning is a general pre-condition for realising significant on-farm and off-farm returns. Collective planning about buffers to natural resources when needed (such as tree- and fodder-banking) and building collective buying power to create local markets for bringing fertiliser inputs into a region and enabling them to be sold in affordable amounts are examples of the power of building community resilience with direct benefits to individuals. Integrating livestock herders with participatory methods at the larger scale of the project target area also ties in with a coordinated approach to land use and decision-making about mobility that is based upon security, trustworthy information-brokering and conflict prevention.

By also facilitating community level agreements, a resilience programme’s successful design facilitates the sustainable management of micro-catchments and tree resources, nested within broader agreements at commune, ‘Cercle’ and cross-border levels to regulate the use of soils, water, tree and fodder resources within major boundaries of a water basin.

The results of the climate projections beyond the current state of a water-stressed system underscore that agricultural and pastoral production strategies and commodities must be developed in a coordinated fashion.
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GLOSSARY

AGRHYMET – Regional Centre of the Permanent Interstate Committee for Drought Control in the Sahel. Informs and trains on Sahelian food security, desertification control and water control and management.

Agro-ecological zone – Defined by the FAO as zones on the basis of combinations of soil, landform and climatic characteristics and their utility for crop production.

Agroforestry – The cultivation of trees and/or shrubs in conjunction with crop- or livestock-raising systems.

Agrosilviculture – Combining the growth of trees or woody shrubs and annual crops in combinations or stages that do not hinder the growth of either and ideally so that each has a beneficial effect on the other (see also Agroforestry).

Agro-silvo-pastoral – The practice of combining the production of tree products and crops with that of graze and browse for domestic animal production in a mutually beneficial way (see also Agroforestry).

AmbioTEK – A Community Interest Company that functions as a provider of the WaterWorld mapping software and products in conjunction with Kings College London.

BRACED – Building Resilience and Adaptation to Climate Extremes and Disasters, funding programme in 2014 from UK Aid (DFID).

BRWB – Building Resilience Without Borders in the Sahel, a project developed by CARE International, RBM, SNV and TREE AID for consideration under the BRACED programme funded by the UK Department for International Development (DFID).

Climate-smart agriculture (CSA) – A wide array of farming strategies that increases agrobiodiversity, water retention, and carbon sequestration to improve income flows and reduce susceptibility of single crop failure (after Willemen et al 2013).

Conservation agriculture (CA) – Agriculture system characterised by: (i) continuous minimum mechanical soil disturbance (ie no tilling and direct planting of crop seeds); (ii) permanent organic soil cover with residues and cover cropping; and (iii) diversification of crop species grown in sequence and associations (FAO 2013).

Coppice – Regeneration of woody vegetation growing from the cut stumps of trees or shrubs from shoots above ground or suckers below ground.

Cultivar – Cultivated varieties of plants derived from selective breeding.

DFID – United Kingdom Department for International Development.

Drip irrigation – Method for watering crops in which water is delivered in small amounts directly to the plants’ roots. Saves water by reducing runoff and evaporation, and prevents soil erosion and loss of soil nutrients.

DRR – Disaster Risk Reduction.

Evapotranspiration – The loss of water to the atmosphere by the combined processes of evaporation from surface water and plant transpiration.

FAO – Food and Agriculture Organisation of the United Nations.

FMNR – Farmer-managed natural regeneration.

Fodder – Plants given to livestock as feed.

Fodder-banking – Planting of or setting aside of trees and shrubs for livestock consumption or for cut-and-carry to confined livestock.

Groundwater recharge – Water penetrating between soil particles, cracks in rocks to a subterranean ‘saturated’ zone (groundwater) and underground aquifers resulting in water storage.

Hedgerow – A row of shrubs and/or trees that form a boundary or an area, typically a term used in agricultural systems bordering a field or road.

ICRAF – World Agroforestry Centre.


Intercropping – Planting species adjacent to each other that have beneficial effects such as fertiliser, pest protection, shade, or differing soil nutrient usage (after Willemen et al 2013).

IWM – Integrated watershed management.

MDG – Millennium Development Goals.

Microdosing – Applying small amounts of inorganic fertiliser to each seed/seedling planted. A means of improving soil fertility and increasing crop yields.

NDVI – Normalised difference vegetative index. The productivity of vegetation.

NTFP – Non-timber forest product.

Parklands – The deliberate retention of trees on cultivated or recently fallowed land, where trees are an integral part of the system, providing food, fuel, fodder, medicinal products, building materials and saleable commodities, as well as contributing to the maintenance of soil fertility, water conservation and environmental protection.

Pollarding – Cutting back the top branches of a tree to stimulate dense growth of new shoots.

RBM – Réseau Billital Maroobe, the network of pastoralist associations in Niger.

Resilience – The ability of a system to absorb disturbance and still retain its basic function and structure (Walker and Salt 2006).

RNNDVI – Inter-year rainfall variability. ‘Rain Normalised’ Productivity or Rain Normalised NDVI (Normalised Difference Vegetation Index), which is a measurement used from Remote Sensing Imagery.

RWH – Rain Water Harvesting.
Shelter belt – Narrow strips of trees and shrubs planted to protect annual crops or pasture from excessive wind, rain and sun (after Willemen et al 2013).

Seasonality – The extent to which rainfall is concentrated in a rainy season.

SLM – Sustainable Land Management.

SNV – Netherlands Development Organisation.

Stover – Refuse from a field crop, such as stalks and leaves, remaining after the crop is harvested.

Stone bund – Low wall built of stones to control rainwater runoff and soil erosion.

TBEA – Tree-based ecosystem approaches.

Transhumance – Distant, seasonal encampment by people tending livestock (usually cattle) for longer-distances (>40 km) (after Turner et al 2014).

Tree-banks – A stock of tree resources specifically identified, governed and managed by dryland communities to increase household and community resilience to environmental and economic shocks, distinct from fodder in that people have the ability to derive household foods and income directly from non-timber forest products. The concept was developed by TREE AID.


VCR – Value-Cost Ratio, most used in agricultural terminology as a benefit-cost measure calculated as the value of a crop yield increase resulting from a treatment eg fertiliser application, divided by the cost of the treatment.

Warrantage system – The practice of farmers storing surplus crops during times of crop over-production and low prices, waiting to sell until the crop becomes more scarce and prices rise. Also known as inventory credit system.

WOCAT – World Overview of Conservation Approaches and Technologies.

Zai – Farming technique of Sahelian West Africa in which seeds are planted in pits dug into the soil in which organic waste is placed. The method captures rainwater and nutrients, facilitating growth of crops.
LITERATURE CITED


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