Soil and Water Interventions and Strategic Programming for Food Security in the Western Sahel: The Case of Burkina Faso

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Soil and Water Interventions and Strategic Programming for Food Security in the Western Sahel: The Case of Burkina Faso

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Preface

We must mobilize all knowledge and insights to lift the biophysically poorly endowed Sahelian region with booming population, rapid urbanization and changing climate out of poverty and hunger. Decades of development cooperation with billions of dollars invested have been unable to push the region into a green revolution to meet its food needs. While the carrying capacity of the region has increased over the past three decades due to increasing rainfall, it is collapsing more heavily due to soil degradation and increasing temperature. The prospects are indeed discouraging, and resolution calls for changes in the fundamental carrying capacity of the region and the strategic alignment of large implementation programs with complementary activities.

In this report, we aim to lay the foundation for the need for interventions in soil and water management to increase agricultural productivity in West Sahelian countries, with special emphasis on Burkina Faso. Arriving at a strategic allocation of activities and alignment of program to raise impact may be promising and must be put into practice, given that business as usual will be detrimental to the region. Current approaches in R&D and in implementing programs appear unable to reach farm practices and have limited or no impact. Novel approaches that combine R&D and the implementation program must be devised to realize impact and improve farm livelihood. Moreover, the national government may have to orchestrate the contributions of foreign aid to support national development priorities.

This study is executed by IFDC, ISRIC, eLEAF and EMSA to demonstrate their knowledge and expertise in supporting decision making for strategic soil and water interventions and programming to attain food and nutrition security (FNS) at scale in the Western Sahel, specifically Burkina Faso. Each chapter in this report has been prepared by specific authors and institutions, with the overall drafting by Prem Bindraban.

We would like to thank Nico Heerink and Christy van Beek for their reflections. We also thank the Netherlands Ministries of Agriculture, Nature and Food Quality and of International Affairs for their financial support and intellectual deliberations to set the scope for this work.

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Steven Wonink, Managing Director, eLEAF
Michiel Hillen, Director, EMSA

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Abbreviations

AETI	Actual EvapoTranspiration and Interception
AfSIS	Africa Soil Information Service
AfSP	Africa Soil Profiles database
AGRF	Above-Ground Fraction
ANPP	Annual Net Primary Production
AY	Actual Yield (attained by farmers)
BD	Bulk Density
CA	Concentration Agriculture
CEC	Cation Exchange Capacity
CF	Coarse Fragments
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CORAF	West and Central African Council for Agricultural Research for Development
CWD	Crop Water Demand
ECOWAS	Economic Community of West African States
ET	EvapoTranspiration
FAO	Food and Agriculture Organization of the United Nations
FMNR	Farmer-Managed Natural Regreening
FNS	Food and Nutrition Security
FSRP	Food System Resilience Program
GAP	Good Agricultural Practice
GAFSP	Global Agriculture and Food Security Program
GE	Grain Equivalent
HI	Harvest Index
IFAD	International Fund for Agricultural Development
ISFM	Integrated Soil Fertility Management
MoU	Memorandum of Understanding
NEPAD	New Partnership for Africa's Development
OECD	Organisation for Economic Co-operation and Development
OM	Organic Matter
PCP	Precipitation
PNSR	National Rural Sector Program
PPP	Public-Private Partnership
PR	Phosphate Rock
PY	Potential Yield (plant nutrient and water demand satisfied and plants protected)
R&D	Research and Development
RET	Reference EvapoTranspiration
RZD	Root Zone Depth (soil rootable depth)
RZL_RWS	Root Zone Limited Relative Water Sufficiency
RZL_WA	Root Zone Limited Water Availability
RZ-PAWHC	Root Zone Plant Available Water-Holding Capacity
SDFA	Development Strategy Agricultural Sectors
SME	Small and Medium Entrepreneurs
SMI	Small and Medium Entrepreneurs
SWC	Soil and Water Conservation
T	Transpiration
TBP	Total Biomass Production
ToC	Theory of Change
UCOBAM	Union des Cooperatives Agricoles et Maraîchères du Burkina

WA	Water Availability
WAAPP	West Africa Agricultural Production Program
WAFA	West African Fertilizer Association
WaPOR	Water Productivity Open-access Portal
WAEMU	West African Economic and Monetary Union
WL_ET	(Root Zone) Water-Limited Evapotranspiration
WL-T	(Root Zone) Water-Limited Transpiration
WL-TBP	(Root Zone) Water-Limited Total Biomass Production
WL-YLD	(Root Zone) Water-Limited Yield
WUE	Water Use Efficiency
WY	Water-Limited Potential Yield (plant nutrient demand met)
WoSIS	World Soil Information Service

Executive Summary

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Scope of this study

The Sahelian region faces immense challenges to safeguard the availability of sufficient food due to its poor biophysical conditions, exacerbated by population growth, urbanization and changing climate, which can all potentially destabilize the society.

The prospects for the Sahelian region are discouraging, and resolution calls for changes in the fundamental carrying capacity of the region, i.e., its potential ability to support plant growth. Soil improvement and the timely availability of water are the most pressing production factors essential to coping with the huge spatiotemporal variability of resource availability. Successful pilots have been reported in this regard but have not reached sufficient scale to demonstrate resolution of food insecurity.

Therefore, this study will (1) describe the challenges, (2) quantify the spatiotemporal variability and possibilities for enhancing the production base of the Sahel, (3) present a concise inventory of successful pilots and programs, and (4) identify strategic partnerships among major development donors, national governments, and agribusinesses to reach impact at scale. While building our insights around evidence from the Sahelian region, we will highlight Burkina Faso as a case country.

This study is executed by IFDC, ISRIC, eLEAF, and EMSA, organizations demonstrating their knowledge and expertise in supporting decision making for strategic soil and water interventions and programming to attain food and nutrition security (FNS) at scale in the Western Sahel, specifically Burkina Faso. Each chapter in this report has been prepared by specific authors and institutions, with the overall draft by the report editor. No references or detailed explanations have been provided in this summary as they are given in the various chapters.

Toward Sustainable Agricultural Practices

The natural ecological production potential of the Sahelian region is estimated at approximately 3.3 t ha^{-1} y^{-1} of above-ground biomass, with plant-available water and soil nutrients being the prime determinants. Hence, the maximum attainable (organic) yield levels can reach 1.0 to 1.5 t grains ha^{-1} depending on the harvestable proportion of the cultivation crop and provided that nutrient cycles are fully closed.

As nutrient cycles are not closed in agriculture, soils are being depleted at almost 50 kg NPK ha^{-1} y^{-1}, in Sub-Saharan Africa, further deteriorating the poor production base. Organic amendments (manure and compost) are hailed to increase yield and build up soil organic matter and are considered “sustainable practices” in many development programs. Agronomic trials, however, generate misleading information, as they are being conducted with excessively high application rates of manure or compost, ranging from 5 to 20 t ha^{-1} and do not reflect actual availability amounts. The potential supply of manure in Western African Sahel, i.e., when all manure was to be collected from roaming cattle and transported to arable lands, reaches a mere 2.5 kg N and 0.6 kg P ha^{-1} arable land, equivalent to 2 t ha^{-1} y^{-1}. Only a fraction of this amount can actually be utilized. While relevant to help sustain soil health, these organic amendments will be unable to counter even the soil nutrient losses, let alone maintain soil health and increase yields, and may in some instance actually immobilize nutrients for plant uptake.

The other foremost driver of crop performance is the availability of water. Farmer-Managed Natural Regreening (FMNR), i.e., agronomic practices that concentrate water and nutrients in small pits and increase crop yields (along with protecting trees), was reintroduced in the mid-1980s and has been cherished for regreening the Sahelian landscape. While pockets of successes have indeed been reported, these human interventions could be reintroduced successfully in the region because of the increasing availability of water. Natural changes in rainfall over the past decades have been the main driver for the overall regreening of the Sahelian region from the mid-1980s onward, following a dry period in the 1960s and 1970s. Location-specific rates of natural regreening depend strongly on the hydrological properties of the soils and landscape.

As organic amendments are internal to the system, they can elevate the agroecological productivity in small pockets only that concentrates the nutrients from adjacent fields that are mined for soil nutrients, and therefore unable to elevate the overall productivity of the region. This situation is comparable to the production systems up to the 18th century in the Netherlands for instance. The use of mineral fertilizers has the potential to raise this bar, but their effectivity is constrained under the poor soil and weather conditions. Yet, combined with organic amendments and water conservation methods, they create additive effects that increase the nutrient and water use efficiency, yield, and biomass. Then again, the role of organic or green manure may not be overstated (see section on Validation).

The higher in situ production of biomass from the use of mineral fertilizers must break the downward spiral of soil degradation and drive the upward trend of improving soil health, yield, and overall system productivity. Crop residues, when combined with mineral fertilizers, have been found to give comparable crop yield interactions, as do manure and compost, with a long-term sustained impact. Continuous mono-cropping deteriorates soil health, while inclusion of a leguminous crop tends to enhance the overall resilience of the system. Along with the ability of crop residues to restore soil organic carbon, judicious use of higher amounts of in situ–produced residues from mineral fertilizer use in rotational cropping opens an opportunity to sustainably increase crop yields and enhance resilience and overall productivity of the system through improved soil health.

Crop response to this Integrated Soil Fertility Management (ISFM), which combines organic and mineral fertilization in cropping systems, is still highly variable. This is in line with the location-specific differences in natural regeneration whereby soil type and depth, hydrological properties of soils and the landscape significantly modulate vegetation regrowth. These findings urge consideration of site-specific adaptation of ISFM to the huge variability in the region, geared toward the prevailing socio-economic conditions. Some of this variability could be reduced with water conservation practices.

To meet the increasing food demand of the growing population of Western Africa, crop yields should increase by up to 80% of the production potential under rainfed conditions, i.e., exceeding 4 t ha^{-1} for the small grains (sorghum and millet) and 7 t ha^{-1} for the major grains (rice and maize). This production potential is attained when crops are supplied with all desired nutrients and protected against pests, diseases and weeds under the prevailing rainfall that is captured on the field. Clearly, these production levels greatly exceed the natural production base of 1-1.5 t ha^{-1} and are far beyond the internal recycling of nutrients, calling for the judicious use of mineral fertilizers through ISFM practices.

The development of the fertilizer sector therefore becomes an essential building block to breaking out of the poverty trap. Several governments, including that of Burkina Faso, have reintroduced fertilizer subsidies following the food crises of 2008. Despite being landlocked, fertilizer prices in Burkina Faso do not come at a premium compared to prices in coastal countries. Subsidies may distort proper market functioning, but a pre-order voucher system, unrelated to a specific fertilizer formulation, could overcome this problem and allow farmers to access the products that best fit their cropping systems. The current fertilizer infrastructure and developing marketing approaches could be further fine-tuned to allow sustainable cultivation practices in Burkina Faso.

Production Potential and Variability

Theoretically, crop production in Burkina Faso on the potentially cultivable 11.5 million ha, of which 1.1 million ha is irrigable, can only provide the population with a moderate diet of up to 1.7 kg grain equivalents p^{-1} d^{-1} up to the year 2100 (compared to the current consumption of about 4.5 kg GE p^{-1} d^{-1} in Europe). Yields of the grain crops, however, should increase by 120 to 200 kg ha^{-1} y^{-1}. These rates have been attained during the green revolution in various regions in the world, but this is an unsurmountable challenge under business as usual in the Western Sahelian region, given the increase of 10 to 30 kg ha^{-1} y^{-1} over the past decades in Burkina Faso and comparable rates in neighboring countries. Increase in food production has already come at great expense to the natural habitat, as the estimated agricultural area of about 6 Mha in 2001 rose to about 11.5 Mha in 2014. Extrapolation of these past rates of yield increase, assuming business as usual, result in an unchanged diet at the current insufficient level of approximately 1.1 kg GE p^{-1} d^{-1} until 2050. As the neighboring Sahelian countries face similar resource constraints, food linkages with countries south of Burkina Faso may become increasingly important.

A major concern in agricultural productivity is the huge variability in the planted area and yield and, with that, the total annual production of crops. The erratic rainfall is a major driver of this variability (Figure ES1). Whereas yields of up to 4 to 7 t ha^{-1} can be attained with the total amount of rainfall in the growing season, conserving water to be available to the crop is a major challenge.

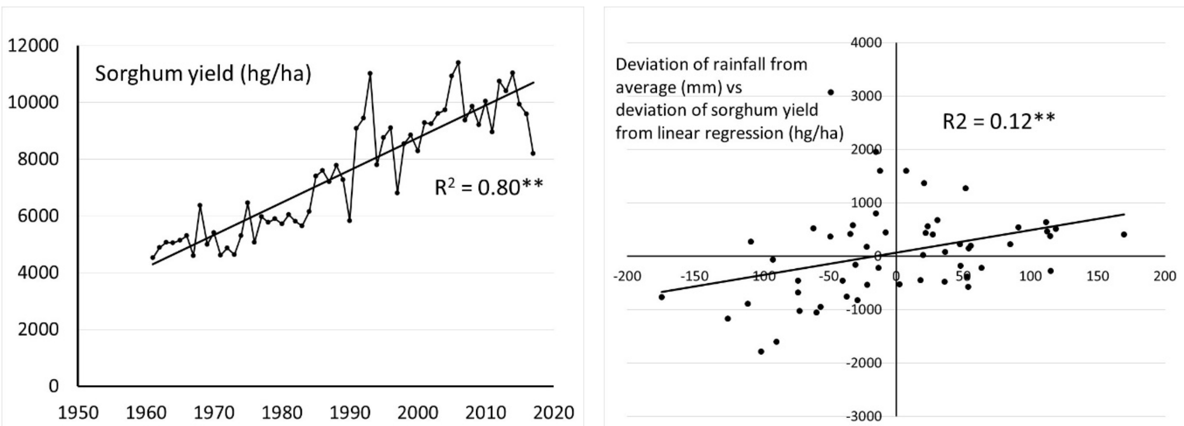

Figure ES1. Yield trend and variability in sorghum yield (left) with yield variability highly correlated with seasonal rainfall (right).

The quantitative spatiotemporal analysis of water and nutrient availability for growth of maize, sorghum, and millet illustrates how data sources can help to identify areas with relatively low and high sufficiency of water and/or nutrients, i.e., the availability of water/nutrients relative to crop demand, and how these vary over time. This allows identification of areas with the best prospects for investment in sustainable intensification – areas for combined water/nutrient interventions and areas where one may be prioritized over the other. A foremost driver of ultimate impact on growth is the depth of the soils, as it affects the availability of water and exploitable soil volumes through rooting by the crop (Figure ES2). The finding from this modeling exercise should be considered preliminary due to shortcomings from the exploratory nature of this study, which could be addressed in future endeavors.

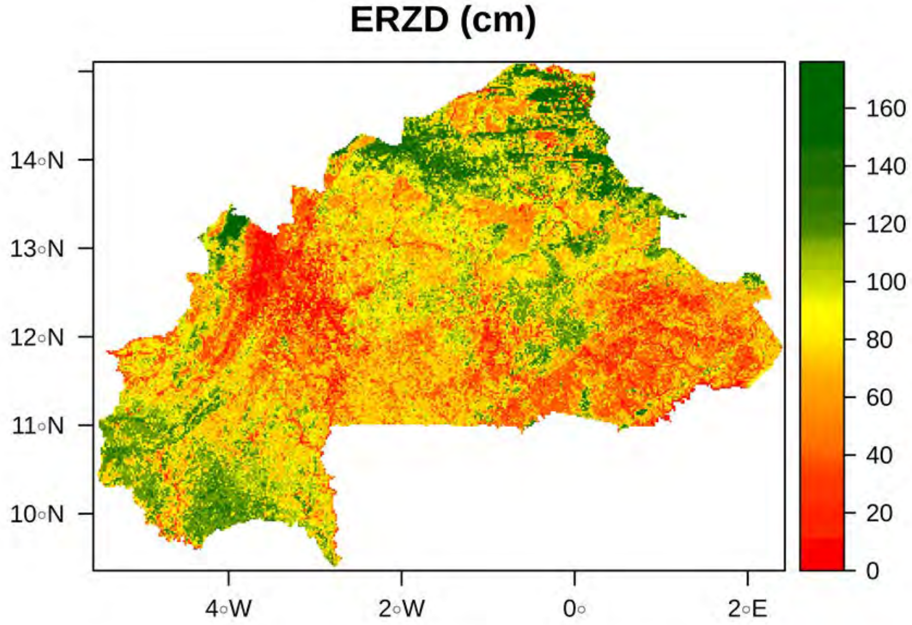

Figure ES2. Soil rootable depth (cm) in Burkina Faso.

Investment in water management in the South Sudan (southwest) may be less rewarding due to high water sufficiency. The semi-arid climate zone (North Sudan) reveals a variate picture largely related to the variation in rootable soil depth. The north/northeast arid area (Sahel) shows a consistent insufficiency of water for all study crops throughout the years, which suggests water management to be a necessity for increase crop productivity (Figure ES3).

The best prospect for use of mineral fertilizers is in regions where water sufficiency is adequate, such as in the South Sudan (Figure S3). When water sufficiency is inadequate, nutrient application may not pay off, which is mainly toward the north and on soils with shallow rootable depth. In these latter areas, promising investments include those in water management, such as irrigation, to enhance water sufficiency and crop potential, fertilizer nutrients to enhance crop production, and water productivity improvement.

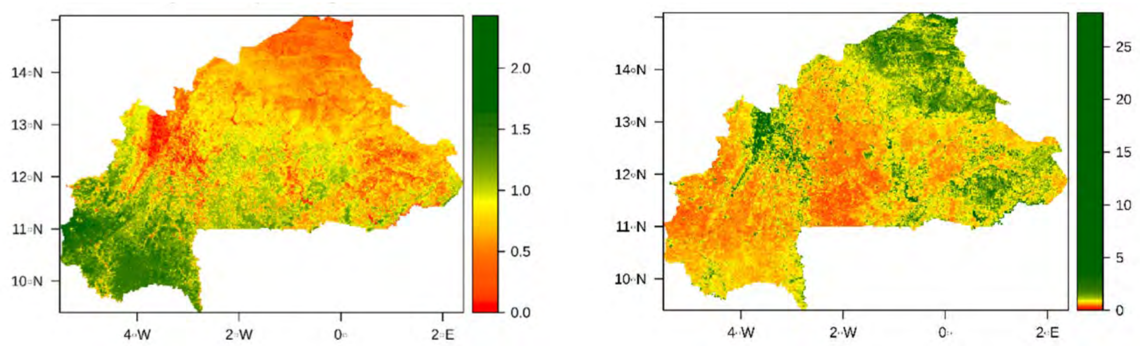

Figure ES3. Relative soil water sufficiency (left) and relative sufficiency of P (patterns are near similar for N and K) (right) for sorghum, averaged over 2009-2019. A value less than 1 indicates a shortage relative to demand.

The temporal dimension can be captured through the frequency in number of years out of 10 that the (water or nutrient) sufficiency is below a threshold, with a threshold defined at 1 when supply meets demand. The resulting maps represent the spatiotemporal frequency that an investment in fertilizers may be successful in terms of crop yield response (Figure ES4).

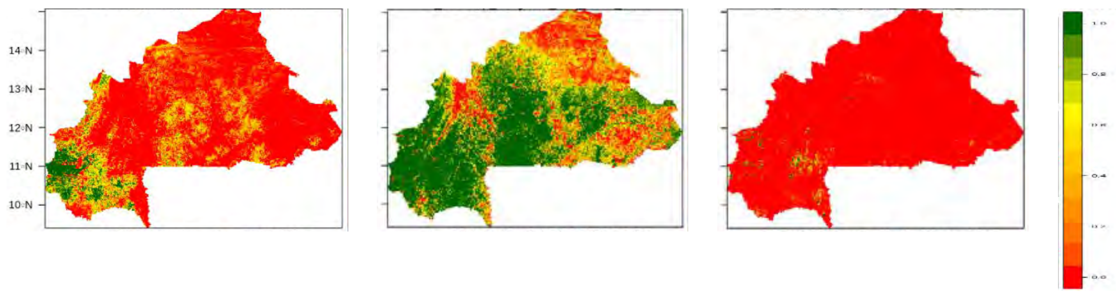

Figure ES 4. Frequency (y y^{-1}) of a likely crop response to fertilization for sorghum; left to right: N, P, and K (green = 1, yellow = 0.5 and red = 0).

Validation

Yield responses to ISFM turn out to be very crop and site specific. Some soils reveal modest responses to fertilization (either mineral or organic), while others may show synergistic effects between these two sources of nutrients, whereby the responses vary from crop to crop. Yet, the role of organic or green manure may not be overstated. In most instances, it is the total amount of nutrients added from both mineral and organic substances that determines the yield response, therefore not revealing synergism but merely an additive nutrient effect (Figure ES5).

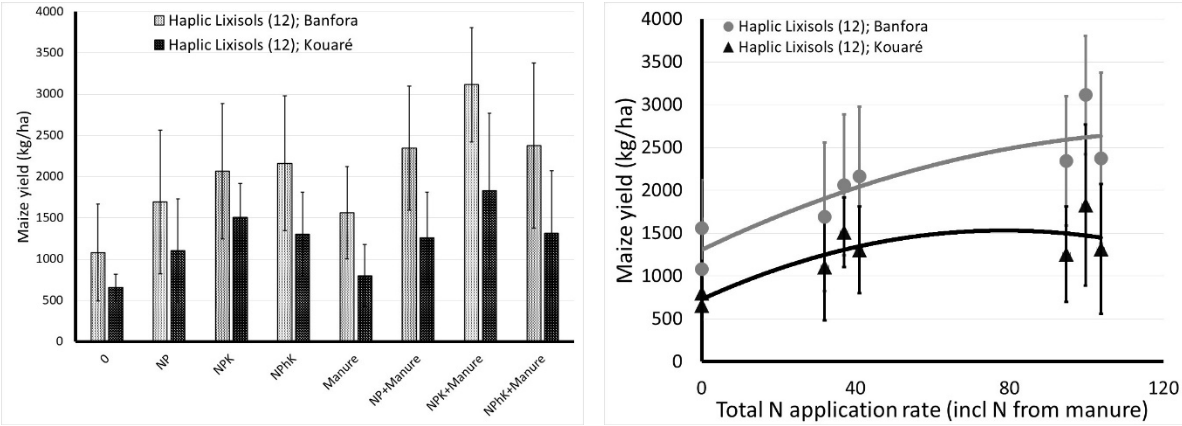

Figure ES5. Effect of organic and inorganic fertilization on maize yields (left), also plotted against total amounts of N applied from both mineral fertilizers and manure (right), revealing an additive effect from total N application rather than synergistic effects from manure.

Cropping systems have a significant impact on the production system. Continuous cultivation of sorghum results in allelopathic responses that suppress yield. Fallow sorghum rotations come with higher sorghum yields but a lower system yield due to the unproductive fallow. The inclusion of a leguminous crop tends to enhance the overall resilience of the production system.

Yields of over 2 and 4.5 t ha^{-1} for sorghum and maize, respectively, are generally recorded in trials. An important notion is that the use efficiency of water increases with increasing yield, along well-established relations (Figure ES6). This implies that yields can be further doubled or tripled given the amount of available (rain)water.

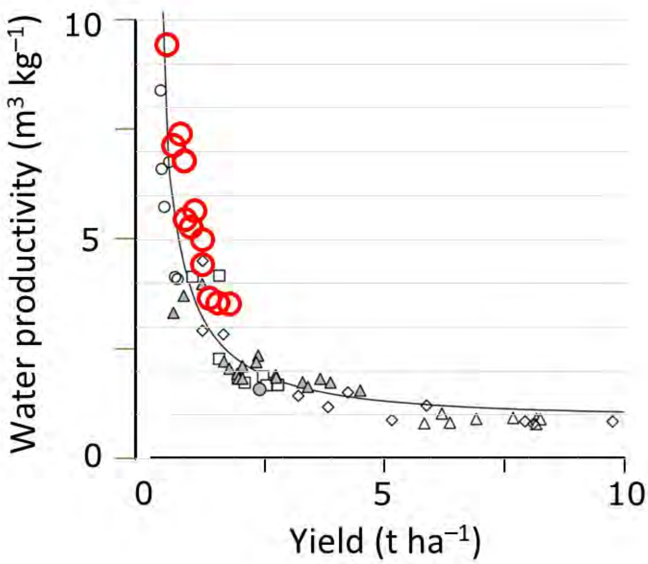

Figure ES6. Dynamics of green water productivity (m^3 kg^{-1} grain) and yield (t ha^{-1}) follow a well-established relationship for cereal crops in tropical countries. Red circles are the productivities as found in the various soil and water conservation (SWC) practices in the AGES program in Burkina Faso.

Reflections on Development Programs

To capture the essence of development programs, objective, reproduceable and verifiable reflections on and assessments of the impacts from research and development (R&D) or implementation programs on FNS call for an analytical framework.

The development discourse on FNS has evolved from a rather agro-technological emphasis on agricultural production up to the 1980s to then include socio-economic conditions with a strong focus on farm households, resource entitlements and social justice. Since the beginning of this century, the plea for comprehensive participatory approaches with public-private partnerships (PPPs) in development of food value chain has gained momentum with the active business-driven involvement of stakeholders and the need for creation of an enabling environment.

Past reflections and evaluation on the impact of R&D, however, have revealed little or no impact at all on development of agriculture or reduction of FNS. Recently, a review of over 100,000 journal articles confirmed that most of the agricultural research publications were unable to provide solutions to the challenges of smallholder farmers and families.

Nevertheless, the discourse highlights the need for a three-pronged approach, i.e., agro-technological, business development and institutional pathways, that should be simultaneously implemented to arrive at long-term sustained impact on development. Therefore, a recently proposed theory of change (ToC) for reflections on R&D projects was adjusted for the purpose of our reflections on country programs (Figure ES7).

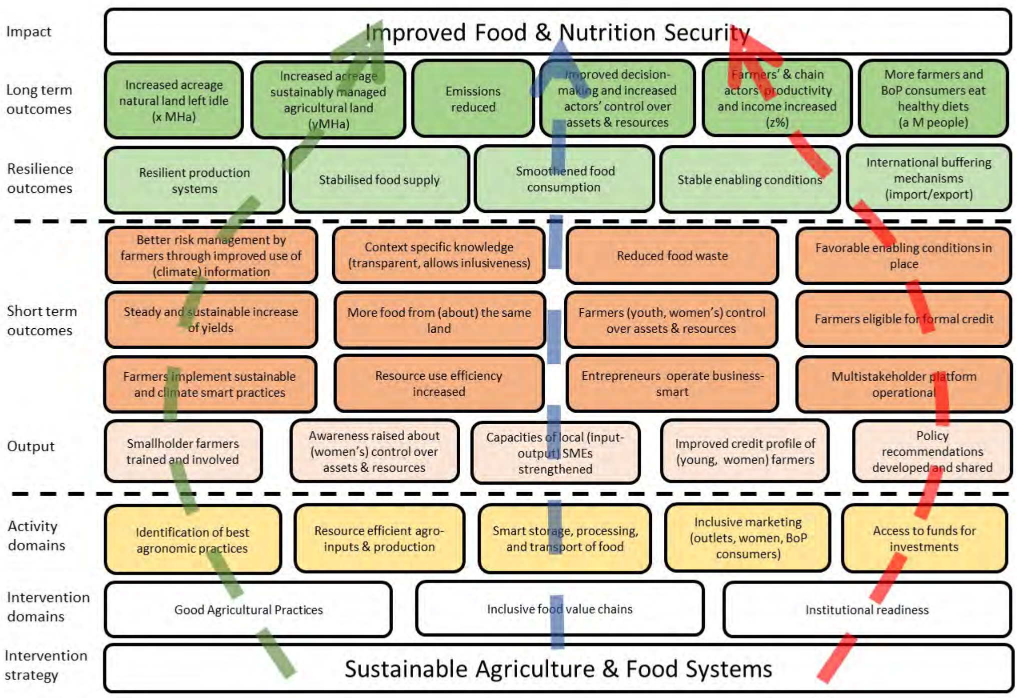

Figure ES7. Comprehensive ToC that encompasses agro-technological (green arrow), business development (blue arrow) and institutional (red arrow) pathways to be addressed simultaneously to reach impact at scale on FNS.

Most efforts of rural and agricultural development programs in Burkina Faso (and Western Sahelian countries) are geared toward agro-technological improvement of the production system, primarily through small-scale irrigation and SWC practices. These may be accompanied by "training" of directly involved stakeholders, such as (women) farmers, extension officers and irrigation managers. More recently, emphasis has been placed on improved storage hardware and capacity and on market access from an institutional perspective rather than actual business development efforts for the stakeholders in the value chain. There seem to be few linkages to policy recommendations or policy adjustments, based on the experiences and lessons gained from program implementation. Importantly, 80% of the investment financing of U.S. $300 million annually in rural and agricultural development in Burkina Faso comes from official development assistance and the remainder from the government, suggesting a major impact of the donor community on rural development in Burkina Faso. Major areas of intervention are resilience, food security, water management and value chain development.

Yet, the new West Africa Food System Resilience Program (FSRP) of the World Bank, a follow up of the West Africa Agricultural Production Program (WAAPP) that is currently under construction, seems to continue to pursue the agro-technological production pathway, with some soft activities on training, extension, and IT services, but still without a business development focus. As such, it seems to pursue business as usual in aiming to attain FNS. There is a need, however, to develop actions that promote inclusive value chain development as the engine to drive ISFM within a broader context of food systems.

IFDC, an international center for soil fertility and agricultural development, has had a presence in Burkina Faso since 1996. In all its endeavors, IFDC operates closely with local institutions and the private sector in line with government policies to attained highest impact. Apart from a prime focus on agro-technological improvements and policy support on regulatory measures for agricultural inputs, IFDC has also moved into business development in food value chains over the past two decades, primarily funded by OECD donor countries. At the request of development banks and national governments, IFDC also provides technical support to program implementation, thus expanding its reach. But these linkages need to be further exploited, while IFDC aims to incorporate its unique expertise on value chain business development into these development programs.

The Netherlands is involved primarily through development cooperation in Burkina Faso, yet with no specific attention to soil health or through an indirect reach only. Some small agribusiness linkages in fruits and vegetables aiming to also address soil issues are known to exist. Netherlands businesses are even involved in the development of the fertilizer value chain related to knowledge transfer, blending equipment and organic fertilizer exports.

Components for a Resilient Food System

Based on the findings in this report, we suggest that development of a resilient food system can be achieved only when a net of interdependencies is weaved among stakeholders by pursuing all three pathways – agro-technological, value chain development, and institutional.

Agro-technologically, ISFM practices with balanced use of in situ–produced organic matter from mineral fertilizers along with water conservation technologies in ecologically synergistic crop rotations can reduce production variability and create an upward spiral of soil health improvement and productivity increase. Systematically processed data, such as that presented in Chapters 3 and 4, could help to specify location-specific interventions and investments.

Stakeholders in the value chain and those creating the enabling conditions must be linked through business relationships, knowledge exchange and smooth flow of commodities from producers to consumers and revenues from consumers to producers to allow sustainable investment in agriculture and soils.

The agro-technological and value chain developments must be embraced by knowledge institutions, civil society, and policymakers to create the enabling conditions for widespread adoption. Buffering of food through stocks, processing, and trade should reduce food waste and complement production-enhancing mechanisms. Policy regulations to enhance the production capacity of the system, such as fertilizer subsidies through voucher systems, must reach the targeted farmers to be effective.

Overall Findings and Recommendations

- Impact from development programs
  - Promising agro-technological options are being revealed through development programs to boost agricultural productivity within the scope of the program area and time frame.
  - Little information could be gathered about the sustained long-term impact of development programs in Burkina Faso that so far have emphasized agro-technological approaches, sometimes combined with training and more recently with post-harvest actions, such as increasing storage facilities and marketing.
  - The widespread impact of development programs at large scale is unclear given the scant (publicly available) reporting.
  - The low increase in national crop yields (with a decrease for various crops in some West African Sahelian countries) and the unchanging variability in yield and area cultivated over time, suggest that that development programs so far have not resulted in widespread impact at scale, despite the annual investments of about U.S. $300 million in Burkina Faso alone.
  - Yet, crop productivity (yields) must increase, and variability decrease to meet food needs and prevent further encroachment of agriculture into natural lands, exacerbating climate change and loss of biodiversity.
- Agro-technological practices
  - Internal nutrient cycling is unable to increase the agroecological system productivity to levels needed to feed the population of Burkina Faso (and the West African Sahelian region).
  - The most viable and sustainable pathway to increase location-specific production, which may reduce production variability, should include ISFM with mineral fertilizers along with in situ–produced crop residues, combined with water conservation practices.
  - Soil data is a basic component that must be combined with information on water availability and with actual trials under field conditions to identify site-specific ISFM/SWC practices.
  - Even if the entire production potential of Burkina Faso is developed, it will provide the growing population with a moderate diet only.
- Inclusive food value chains
  - Development of food value chains is important to connect stakeholders in the food system to collectively enhance the production, trading, processing, and marketing of agricultural goods.
  - Yet, experience with developing enabling conditions for widespread adoption of the successful value chains through up or out scaling is limited but essential.

    - Moreover, the development of financially circular value chains may be essential to revert funds to farming for sustainable investments in ISFM/SWC.
    - Business linkages with coastal countries for the trade of agro-inputs and food will become increasingly important, and these south-north tracks must be expanded for the development of a resilient regional food system.
- Institutional readiness
    - Soft development skills, such as capacity building, training and awareness raising, are common components in R&D and development programs, but their impact remains elusive.
    - Few programs explicitly target only policy change for the creation of long-term and sustained enabling conditions for wide-spread adoption of sustainable productivity enhancing practices or the continued development of soft skills.
- The complexity of development and the need for comprehensive approaches to walk the agro-technological, business development and institutional pathways simultaneously call for consorted actions.
    - The dominant role of donors in the development of the agriculture and rural sectors of Burkina Faso (and in West African countries), each with their own priorities and approaches influenced by the political constituency in their home countries, appears unable to boost development.
    - Alignment of programs of various donors, each aiming to address specific aspects of development, by the national government is therefore deemed essential to reach impact.
    - The outputs and outcomes as well as the impacts, if attained, of development programs must be institutionalized to ensure long-term impact, calling for strategic dialogues between the donor communities and the receiving nation.

Growing insights on the lack of impact from R&D and implementation programs indicate that entirely novel approaches in combining the two must be devised to realize impact and improve farm livelihood. Pursuing current funding mechanisms for both tracks separately is ineffective and must be overhauled.

Given the complexity and comprehensiveness of agricultural development for FNS, the national government must orchestrate the contributions of foreign aid to support national development priorities and approaches, rather than accepting views, perceptions, and approaches, reflecting the sentiments of the donor's constituents, imposed upon them.

1. Introduction

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The Sahelian region faces immense challenges to safeguard the availability of sufficient food due to its poor biophysical conditions. Resource constraints under increasing population pressure further degrade the production base, causing severe human suffering. Climate change further deteriorates these conditions, with the upsurge of conflicts driving people to search for more fertile grounds for securing their livelihoods, mostly in the region, but also further afield. The West African Sahelian region will see an increased import of cereals and meat and a decline in export of some food crops, while others will even shift from exporting to importing, including fruits and vegetables (Wiebe, 2017). The prospects for the Sahelian region are discouraging, and resolution calls for changes in the fundamental carrying capacity of the region.

Soil improvement and the timely availability of water are the most pressing production factors and essential to cope with the huge spatiotemporal variability of resource availability. In general, successful pilots have been reported from research and development (R&D) on agricultural development but appear unable to reach impact at scale (e.g., Carneiro and Garbero, 2018; Faure et al., 2018; Sparrow and Traoré, 2018; Hounkonnou et al., 2018; Westermann et al., 2018). A recent review of over 100,000 journal articles confirmed these findings. By far, most of the agricultural research was unable to provide solutions to the challenges of smallholder farmers and families (Nature Editorial, 2020).

Successful pilots have also been reported on soil and water management but have not reached demonstrable scale in addressing food insecurity. Insight in the production potential for the region may shed some light on the potential reach of such successful pilots or whether complementary measured will be needed. Moreover, impact at scale calls for well-orchestrated investment activities of global donors, local governments, and actors (e.g., private businesses). While building our insights around evidence from the Sahelian region, we will quantify soil-water aspects and institutional linkages specifically for Burkina Faso.

Burkina Faso ranks 144 of 157 countries in the human capital index of the World Bank, with 40.1% of the population living below the national poverty line. The 20.3 million people in 2019 produced U.S. $16.7 billion, or a mere U.S. $820 per capita. It is a low-income Sahelian country with a largely agrarian economy that employs over 80% of the working population and contributes approximately 35% to GDP. It provides 61.5% of the monetary income of agricultural households. The African Development Bank (AfDB, 2017) had a positive economic outlook for the economy from 2017 to 2020 of about 7% growth per year, as drought along with some socio-political upheaval had caused a growth of about 4% only in 2014 and 2015. Indeed, a growth rate of 6-7% was attained during the past few years (World Bank, 2020a).

The country's economic growth obviously depends upon the performance of the agriculture sector, which itself is highly dependent on the variability of agricultural and climate conditions. Agricultural output is constrained by the low and poorly distributed rainfall, poor management of water resources, inaccessibility of inputs and equipment, and persistent land tenure insecurity (AfDB, 2017).

A recent scoping report (2SCALE, 2019a) reviews the current market situation and points to the relatively favorable food balances due to overall food production increase that exceeds demand for maize, for instance, with some export. Yet, half of the rice consumed is imported, calling for the need to enhance local production and post-harvest quality improvement. Production of various crops increase, such as a doubled yield of cowpea over a 10-year period. Horticultural products have been found to cover national demand during the dry period, while supply is very insufficient during the rainy season. Products are exported to neighboring countries and international markets in the Netherlands and France for fresh and dried tomatoes and onions. The review arrives at significant opportunities for agribusiness development for most staple, legume, and horticultural crops, as well as for animal-based products. These opportunities with vibrant value chain actors linked to smallholder farmers should indeed drive agricultural productivity increase and build resilient food systems.

While supply may meet "economic demand," it remains questionable whether that demand is sufficient to meet healthy dietary needs. Moreover, production increase may result primarily from expansion of agricultural area rather than yield increase. Therefore, FNS remains a major concern. The percentage of food inadequacy and malnutrition is declining, but the total number of people suffering from these deficiencies is increasing due to the rise in population at around 3% per year. The great majority of the population therefore remains highly vulnerable to food and nutrition insecurity. Belesova et al. (2017), for instance, found that low per capita household crop production is associated with poorer nutritional status of children in a rural farming population in Burkina Faso in a year with average farm productivity. They argue that the population would experience greater levels of acute child undernutrition in years of low agricultural productivity. The probability for low productive years is very high due to rainfall variability. Low rainfall may explain 80% or more of the losses in agricultural production.

Through their economic analysis, Zidouemba and Gerard (2018) found a decline in agricultural productivity to further plunge the urban and rural poor into a deeper food crisis, while positive agricultural productivity trends may help alleviate poverty and food insecurity. Interestingly, their results reveal greater positive impact for the urban population than for the rural population from agricultural productivity development. However, climate change will impact the urban population more fiercely, with an overall economic damage of almost 10% by 2050 due to a greater volatility in yields and international agricultural prices, a decrease in average yields, and an increase in food prices (Zidouemba, 2017). This economic reduction is much less than other estimates of up to 25%; Somé et al. (2012) based the sole focus on production that excludes market-based coping mechanism and adaptation strategies. Developing resilient agricultural and food production systems, therefore, will clearly reduce the devastating impact of climate change and variability.

This report will describe the biophysical and agro-technical challenges (Chapter 2) and quantify the spatiotemporal variability for enhancing the production base, specifically for Burkina Faso (Chapter 3). An evidence base for the proposed agro-technical interventions on soil and water management is built in Chapter 4, followed by continued evidence building from a review of major development programs (Chapter 5). To limit repetition, no concluding chapter is added, but the lessons drawn to arrive at agro-technological, institutional and agribusiness recommendations, and strategic program alignment to reach impact as scale have been presented in the Executive Summary.

2. Agriculture, Its Ecological Drivers, and Successful Interventions in Burkina Faso

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2.1 Primary Production

The large-scale variability in plant production or annual net primary production (ANPP) is explained by mean average temperature, soil nitrogen (N) that is likely more limiting in temperate regions, and soil phosphorus (P) that is more limiting in tropical areas (Cleveland et al., 2011). Ardö et al. (2018) report approximately 8 t ha^{-1} y^{-1} for the Sahelian region, of which about 3.3 t is above-ground biomass. Nutrient uptake, particularly of P, calcium (Ca), and magnesium (Mg), from soil depths between 1 and 4 meters was found to be an important driver for deep rooting in arid and semi-arid ecosystems, complementing the hypothesis about deep rooting for the uptake of relatively deep soil water (McCulley et al., 2004).

Provided that nutrient cycles are fully closed, a maximum 3 t ha^{-1} y^{-1} above-ground biomass in cereal production with a harvestable proportion (Harvest Index; HI) for small grains like millet and sorghum of 30% implies attainable yields of 1 t ha^{-1} y^{-1} and approximately 1.5 t ha^{-1} y^{-1} for improved maize varieties with a HI of 0.5. These yield levels are maximally attainable yields under natural conditions or under "organic agriculture."

For comparison, the ANPP for the Netherlands approximates 6.5 t biomass ha^{-1} y^{-1}, but with the highest rates around 21 t ha^{-1} y^{-1} during summer in closed canopies and approximately 0 during winter in January (Cruz, 2013). Highest values are found on clay rich soils in the northern parts, and lower rates on the sandy southern parts. This suggests maximum (organic) yield levels of around 2.5-3 t ha^{-1} y^{-1}, equivalent to the highest yield levels obtained in selected locations by the end of the 18th century.

However, as the agricultural produce is consumed by humans and animals, nutrients are dispersed far afield, breaking the nutrient cycle. The soil nutrient amounts of cultivated fields will dwindle over time, and yields continue to decrease when nutrients are not replenished. By far, the largest increase in food production is being achieved by increasing the acreage of the cultivated land, while yield increases have been modest with absolute levels remaining low. Indeed, vast tracks of land are being cleared in Sahelian countries for cultivation (e.g., Nébié and West, 2019), which leads to the dramatic decline in soil organic matter by 80-90% in just two to four years (Zingore et al., 2005). Exposure of the bare soil to wind between crops causes a high rate of erosion (Toure et al., 2018), while continuous cultivation without replenishment of nutrients removed by harvested produce further deteriorates the production capacity of the already poor soils, with declining yields over time (Bationo et al., 1998; Adams et al., 2016). Green and animal manures are insufficient to balance the nutrient cycle and sustain soil health, and continuous cropping leads to the depletion of over 50 kg ha^{-1} y^{-1} of N, P, and K combined in Sub-Saharan African countries (e.g., Lesschen et al., 2007; Cobo et al., 2010). Under natural conditions, crop production will therefore be nutrient limited, and additional mineral fertilizers must be applied to maintain and increase yields (Breman et al., 2001). This is more important for the cultivation of shallow-rooting crops or crops grown on P-fixing soils (Fageria and Oliveira, 2014).

Based on 30 m spatial resolution analysis, Knauer and colleagues (2017) estimated the agricultural area at about 6,044 Mha, or 22% of Burkina Faso's land surface, in 2001, to increase by about 90% to 11,499 Mha in 2014, covering 42% of the country area (Figure 1). This highlights the encroachment into natural areas detrimental to biodiversity, soil productivity, and resilience of the agroecosystem. The population increased from approximately 12 million in 2001 to more than 17 million in 2017 and is projected to rise to 27, 43, and 82 million in 2030, 2050, and 2100, respectively, in the medium scenario projection of the United Nations (2017). There has been an overall increase in agricultural area per person from 0.63 ha in 2001 to 0.88 ha in 2014, although some provinces that had been intensively cultivated in 2001 revealed a decline. Agricultural productivity per unit land and labor therefore must escalate to ensure food security for the increasing urban population. Yet, based on their future scenarios, Jahel et al. (2018) question whether the rate of intensification of agricultural systems, accompanied with some other measure like outmigration and demographic regulation, would be able to halt the threat to the natural vegetation.

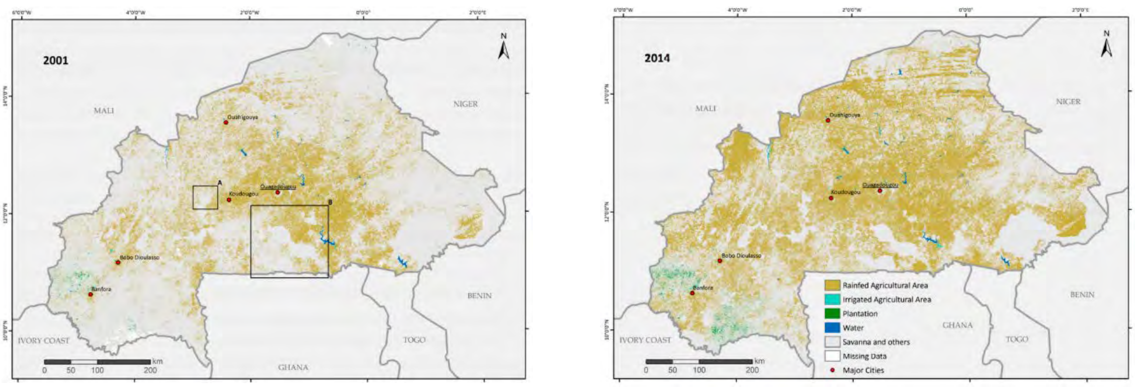

Figure 1. Increase in rainfed agricultural land from 2001 to 2014 in Burkina Faso (Knauer et al., 2017).

2.2 Natural or Human-Induced Regreening of the Sahel?

Because farmers often cannot afford agro-inputs, much effort has been made over the past three to four decades in search of farmer-managed natural regeneration (FMNR) approaches of the Sahelian agroecological zones, especially in densely populated regions. Growth pits and stone contour bunds create microclimates, reduce runoff, and should increase water infiltration and accumulation of organic matter to improve soil health. Rehabilitation of lands and improved soil health are indeed essential components for sustainable intensification and food production increase.

Box 1. Farmer-Managed Natural Regeneration (FMNR) and Concentration Agriculture (CA)

Re-greening initiatives in Burkina Faso (Yatenga Province); FMNR+CA

- Farmers reintroduce the zaï technique in the 1980s in densely populated area.
- Zaï functions best with between 300-800 mm rainfall.
- Growth pits create a microclimate and concentrate water and nutrients.
- Farmers disseminate zaï through farmers' markets and zaï schools, with over 20 schools and 1,000 members in 2001.
- In the late-1970s and early-1980s farmers started building stone contour bunds following contour lines to harvest rainwater.
- Reduced runoff rate, increased water infiltration and well recharge, along with trapped sediments and organic matter improved the soil.
- Rehabilitated plots have 126 larger and more diverse species of trees per hectare compared to 103 on control plots.
- These practices have resulted in crop diversification, increased livestock density, and intensified agriculture.
- External inputs were needed from development programs, e.g., to supply and transport stones.

Impact of CA in Burkina Faso

- Stone bunds and zaï, sometimes combined, increased cereal yields by 40% to more than 100%.
- A study on 17 sites found cereal yields of almost 800 kg ha^{-1} with stone bunds, compared to 450 kg ha^{-1} on control plots.
- Yields could increase to 1,000 to 1,250 kg ha^{-1} with the application of at least 5 t manure ha^{-1}.
- It is estimated that the approximately 400 kg more grains per hectare allowed farmers to produce 80 kt more cereals on the 200 kha of rehabilitated land, enough to feed about 500,000 people.
- FMNR is estimated to produce an additional 500 kt of cereals, which can supplement the requirements of 2.5 million people in 2009.
- Additional socioeconomic benefits include less migration for work by men, improved supply of fuelwood reducing the time women spend on collection, increased income including that of women, and better nutrition.

Source: Reij et al., 2019. WRI report.

The rate at which FMNR+CA occurs, and the low attainable productivity level of the soil-water system appear insufficient to keep pace with the growing food demand. Moreover, it is important to verify the claimed increase in FMNR with background drivers of regreening of the Sahelian countries (Figure 2). The Sahelian regions experienced extreme drought during the 1970s and 1980s; rainfall, temperature, and humidity were the drivers of the widespread reduction in vegetative growth, with a modest impact of anthropogenic pressure (Rishmawi and Prince, 2016).

Following this prolonged dry period, the Sahel started to regreen as a result of increasing rainfall, which led to increases in both herbaceous and tree cover (Abdi et al., 2017). Plant-available water in the soil and vapor pressure deficit together were found to control the primary productivity of Sahelian vegetation for 90% through their impact on the greening and browning phases (Abdi et al., 2017). The regreening trends observed over pastoral Gourma in the southeastern part of Burkina Faso, for instance, were found highly significant over the entire period from 1984 to 2011 (Dardel et al., 2014). This implies a significant resilience of Sahelian ecosystems to extreme climatic events. Soil type and soil depth were found to significantly modulate the vegetation trends observed. Indeed, positive vegetation trends were found over the widespread deep sandy soils, while non-significant trends in vegetation cover were observed over shallow soils. Also, elongation of the growing season favors growth, and rivers and lakes have refilled (Rishmawi and Prince, 2016; Dardel et al., 2014; Ndehedehe et al., 2016, 2018; Zhang et al., 2018; Tamagnone et al., 2019; Vivekananda et al., 2019).

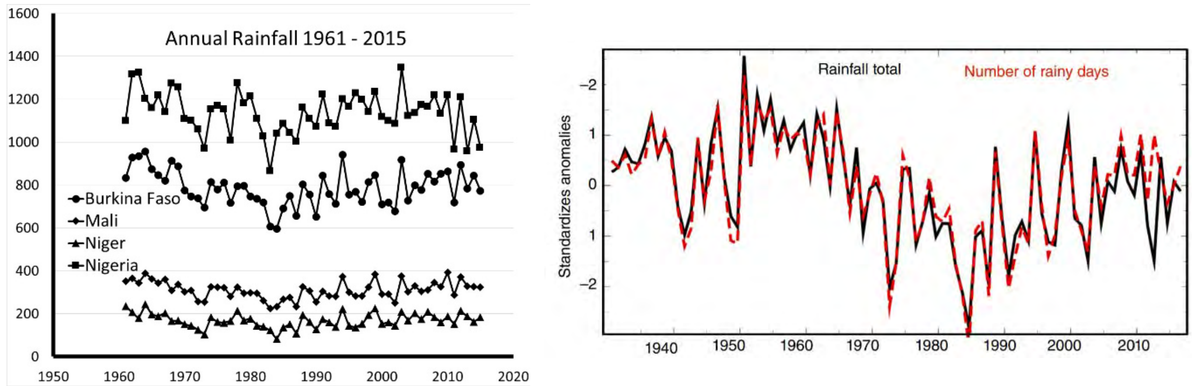

Figure 2. ***Changes in annual rainfall in selected Sahelian countries (left; see also Figure 3 for more details on Burkina Faso; data from FAOSTAT [2020] and World Bank [2020a]) and (right) summer-mean (July to September) standardized anomalies in rainfall totals (black solid line) and number of rainy days (red dashed line) averaged over the region 10°N–20°N and 20°W–30°E (from Biasutti, 2019).***

Zhang et al. (2018), found that the growing season vegetation in the semi-arid zone of 300-700 mm yr^{-1} to be significantly impacted by rainfall patterns, especially by the number of rainy days and timing of onset and cessation of the wet season. Ndehedehe et al. (2016) found the Terrestrial Water Storage (i.e., the total amount of surface waters, soil moisture, canopy storage, and groundwater) over West Africa to show an increase of 6.85 ± 1.67 mm y^{-1} from 2002 to 2014, attributed to a water surplus from wetter seasons and lower evapotranspiration rates. The increased streamflow since 1990 in the Sirba River, a major tributary to the Niger river in Burkina Faso and Niger, is mainly explained by the increasing surface runoff in the whole area, associated with the annual rainfall recovery of the past decades and the reduction of the infiltration capacity of the soil (Tamagnone et al., 2019). Yet, the maximum streamflow in recent years has led to flood disasters as well as to an increase in the number of people affected by flooding events.

Important for understanding of the natural or human-induced causes for regreening is the distinction between herbaceous and woody species. Woody and herbaceous vegetation provide different, but complementary, ecological and socio-economic benefits. Woody plants provide energy (fuelwood and charcoal), food (fruit, nuts, vegetables, etc., for human consumption; browse for animals), traditional medicines, and long-term carbon storage in woody biomass; herbaceous vegetation, by contrast, is a primary grazing resource for livestock and wildlife and ecosystem services such as erosion control. Zida et al. (2019) show that rainfall alone is not enough to explain the dynamics of agrosystems' woody plant cover in a small area in northern Burkina Faso. However, they did not advance rainfall into subsequent processes, such as Terrestrial Water Storage (see Ndehedehe et al., 2016) for more precise assessments. They pursue the argument to relate the woody plant cover to agricultural practices, such as bunding, fallow, grass strips, half moon, mulching, stone dyke barriers, stone row, and zaï and note these practices to be key for establishment of woody species. Yet, Anchang et al. (2019) conclude that long-term regreening trends across the West African Sudano-Sahelian region are dominated by increase in woody vegetation, suggesting a steady recovery of woody populations in the aftermath of the 1970s and 1980s drought.

Coincidently, soil and water conservation (SWC) methods have been gaining momentum starting from the mid-1980s as well, and regreening has been claimed to result from human interventions (Reij et al., 2009). Some local communities indeed indicate to have improved their livelihoods through SWC practices like zaï and pruning of trees on their lands (Nébié and West, 2019), while state officials contend that SWC has only local impacts rather than regional (West et al., 2017). Wildemeersch et al. (2015) found the zaï method with manure application to mitigate both dry spells and soil-water drought, as this induces an important increase of soil-water storage, resulting in higher grain yields.

Various spots have been identified where human intervention may have been the prime driver of improvement, while natural regreening is found to be the dominant factor (Ugbaje et al., 2017). Notably, Zida et al. (2019) found that rainfall alone is not enough to explain the dynamics of agrosystems' woody plant cover, attributing it to farm practices.

This review suggests that human interventions may accelerate naturally occurring regeneration and that the human interventions could be reintroduced in the region successfully because of the increasing availability of water. Concentration agriculture (CA), such as zaï, combined with agroforestry practices, fertilizer microdosing, and water harvesting have given promising results in various pockets in the region. The findings, however, urge consideration of location-specific biophysical and socio-economic conditions to adapt these technologies to the huge variability in the region. It allows little generalization and urges site-specific management in any effort to attain impact at scale, rather than blueprint approaches.

2.3 Regreening, Variability, and Agricultural Productivity

The combined effects of rainfall patterns and soil characteristics to hold water for plant growth have proven to be the major drivers for biological productivity in the Sahelian region. They determine the variability in greenness and in crop production. The temporal changes of Terrestrial Water Storage along with rainfall explain a significant proportion of variation in cashew nut, potatoes, and cowpea yields, allowing simulation of crop yield with a high predictive potential (Ndehedehe et al., 2018). In situ soil moisture content at 25 cm depth or below during the reproductive and grain filling period correlates strongly with in situ millet yield in Niger from 2006 to 2012 (Gibon et al., 2018). Satellite-based soil moisture variation from 1998 to 2014 in the Sahel was found to explain the aggregated FAO national-level millet yield data of Niger, Mali, Senegal, and Burkina Faso.

Figure 3 demonstrates the increasing trend and variability of cultivated acreage, yield, and production of sorghum in Burkina Faso from 1961 to 2017 and the seasonal rainfall over the same period. While all variables increase over time, there is considerable variation between years, with changes in annual production between years of up to 35%.

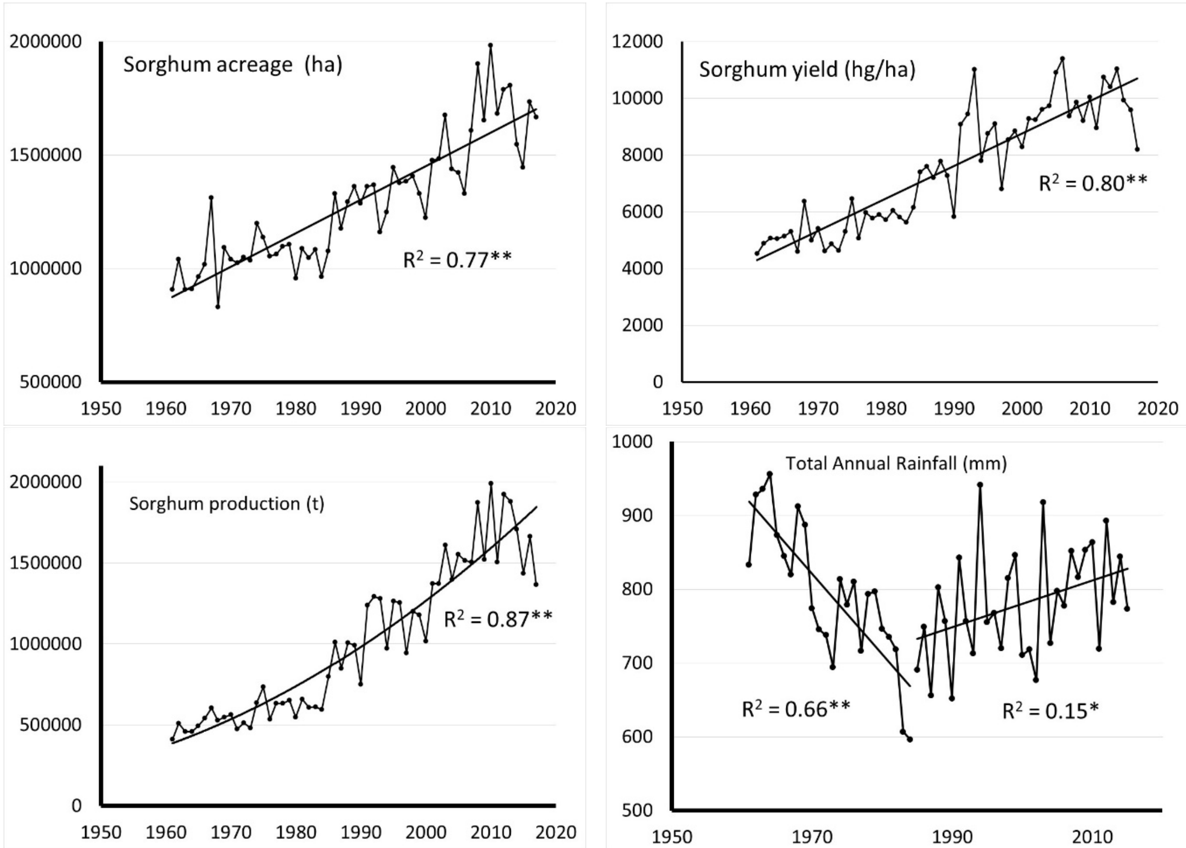

Figure 3. Trends in cultivated acreage, yield, and production of sorghum and in seasonal rainfall in Burkina Faso from 1961 to 2017. Data from FAOSTAT (2020).

The regression variables, as shown in Figure 3, are presented in Table 1 for the prime staple crops of four Sahelian countries in Western Africa. The area for cultivation of major staple cereals increased strongly, especially for sorghum and millet, in all countries except Nigeria. Here, maize and rice acreage increased fastest over the past decades but fluctuated heavily in the last 10 years with no clear continuation in increase. Yield increase is modest for sorghum and millet at less than 10 kg ha^{-1} y^{-1} or even negative, starting from low initial levels yields reaching maximum levels of 0.7 to 1.6 t ha^{-1} across the countries. Annual yield gains have been higher for rice and maize with yields reaching up to 3 t ha^{-1}.

Table 1. ***Change in acreage, yield, and production per year (slope) and strength of the relation from 1916 to 20017 (R^2).***

Slope (R^2)	Burkina Faso Acreage (1,000 ha)	Burkina Faso Yield (kg ha^{-1} y^{-1})	Burkina Faso Production (1,000 t)	Mali Acreage (1,000 ha)	Mali Yield (kg ha^{-1} y^{-1})	Mali Production (1,000 tons)	Niger Acreage (1,000 ha)	Niger Yield (kg ha^{-1} y^{-1})	Niger Production (1,000 t)	Nigeria Acreage (1,000 ha)	Nigeria Yield (kg ha^{-1} y^{-1})	Nigeria Production (1,000 t)
Maize	12.40 (0.68)	25.21 (0.80)	24.30 (0.73)	12.71 (0.62)	28.24 (0.59)	30.70 (0.58)	0.22 (0.23)	9.59 (0.28)	0.34 (0.28)	98.05 (0.69)	16.92 (0.68)	176.49 (0.83)
Sorghum	14.75 (0.77)	11.41 (0.80)	26.06 (0.86)	17.50 (0.69)	4.85 (0.21)	18.93 (0.75)	60.50 (0.93)	-3.77 (0.17)	21.19 (0.60)	37.01 (0.19)	9.24 (0.37)	92.96 (0.61)
Millet	12.53 (0.72)	9.34 (0.79)	17.08 (0.81)	25.54 (0.78)	3.15 (0.13)	23.56 (0.78)	110.79 (0.96)	0.37 (0.01)[a]	52.81 (0.83)	-14.96 (0.04)[a]	9.55 (0.20)	37.19 (0.11)[a]
Rice	1.54 (0.41)	30.30 (0.74)	4.59 (0.61)	9.60 (0.74)	45.44 (0.82)	36.24 (0.70)	0.19 (0.27)	50.10 (0.69)	1.38 (0.78)	67.00 (0.83)	7.27 (0.13)	120.56 (0.76)

[a] Not significant. All other values statistically significant. Negative values indicate a declining trend. (Based on data from FAOSTAT, 2020.)

The annual rainfall in Figure 3 suggests a possible relation with acreage and yield, which is indeed found to be significant, as depicted in Figure 4 for sorghum in Burkina Faso. The deviation in seasonal rainfall for each year relative to the average seasonal rainfall over the period 1961 to 2015 is depicted on the x-axis. A regression of yield, acreage cultivated, and total production over time revealed the trend during this period (Figure 3). The deviation of the annual value of these variables relative to the trend value is depicted on the y-axis. As both acreage and yield are significantly determined by rainfall, the total natural production is destined to vary vastly. Table 2 reveals this strong correlation between seasonal rainfall with the acreage cultivated and the yields obtained to be valid across the board for the four crops and four countries analyzed. Together, they significantly affect the ultimately annual production volumes.

The changes in total cereal (maize, sorghum, millet, and rice) from one year to the other range from increases of 22% to reductions of over 60% in Burkina Faso. Increases are 25%, 57%, and 38% and decreases are 74%, 30%, and 42% for Mali, Niger, and Nigeria, respectively (own calculations). The total changes of all four countries together range from 27% down to 25%. The magnitude of these relative changes remains stable over the entire period. The lack of a decrease in annual fluctuation over time suggests that relative vulnerability has not decreased over time and that absolute vulnerability has become even larger, i.e., growing fluctuations in total volumes over time. These huge fluctuations in production significantly affect food availability and jeopardize food security at national and even Sahelian scale.

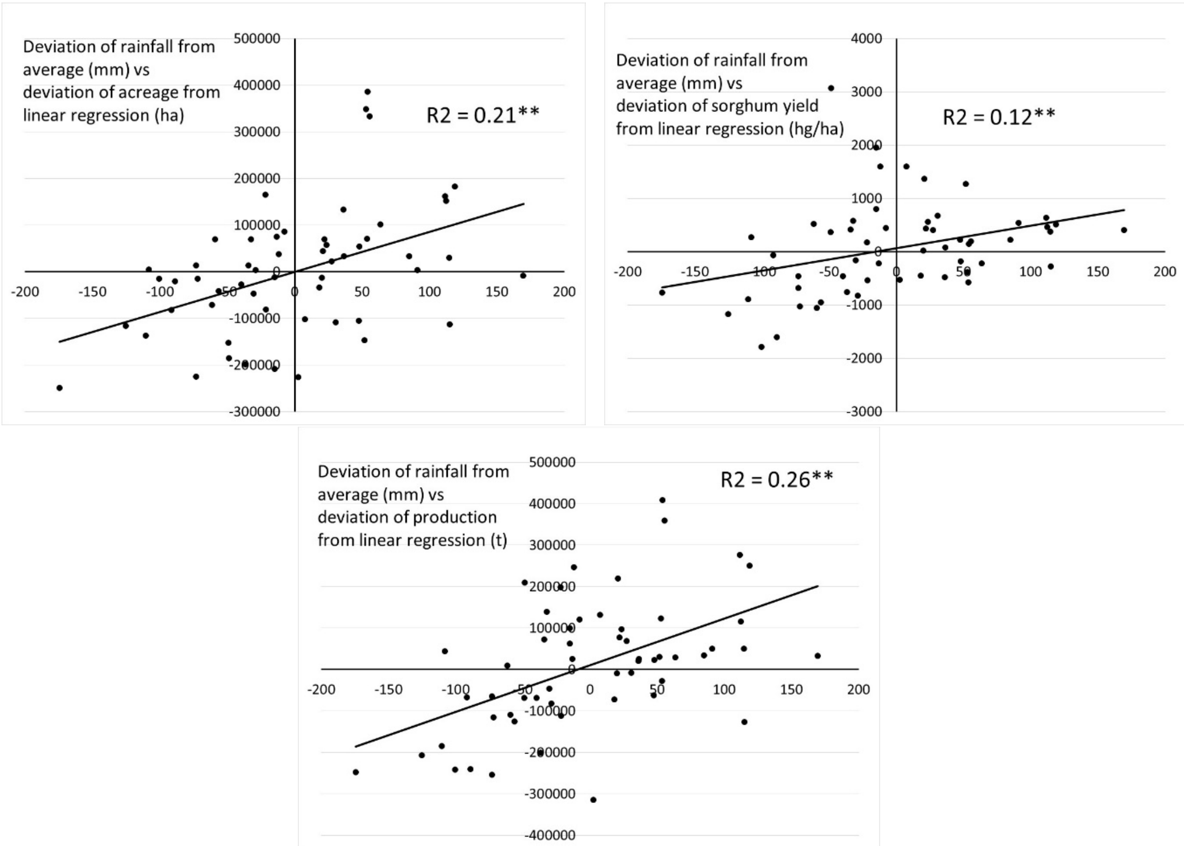

Figure 4. ***Deviation of acreage, yield, and annual production from linear regressions of sorghum in Burkina Faso (y-axis) versus the deviation from average seasonal rainfall during 1961-2015 (x-axis). Data from FAOSTAT (2020) and World Bank (2020a).***

Table 2. ***Correlation (R^2) between deviation in acreage and yield from linear regression and deviation in production from polynomial regression versus deviation in rainfall from average rainfall during the cropping season.***

	Burkina Faso			Mali			Niger			Nigeria		
	Acreage	Yield	Production	Acreage	Yield	Production	Acreage	Yield	Production	Acreage	Yield	Production
Maize	0.30	0.05	0.18	0.14	0.07	0.11	0.00	0.07	0.00	0.00	0.14	0.02
Sorghum	0.20	0.12	0.26	0.09	0.01	0.15	0.06	0.32	0.19	0.23	0.01	0.25
Millet	0.07	0.24	0.18	0.06	0.10	0.22	0.18	0.36	0.30	0.19	0.00	0.14
Rice	0.14	0.01	0.09	0.24	0.28	0.16	0.20	0.00	0.18	0.16	0.19	0.01

Significant values in red.

2.4 Agricultural Production Potential

Most emphasis to increase food production in development programs is placed on the development of irrigated systems, but the largest production gains can be achieved by closing the yield gap of maize, millet, and sorghum on existing lands. Water-harvesting techniques would be more appropriate in this regard. For these, rainfed yields of respectively 7, 4, and 3 t ha^{-1} can be obtained, up from the current 1.7, 1.0, and 0.9 t ha^{-1}. Legumes may also contribute significantly to FNS. This implies, theoretically, that crop production in Burkina Faso under rainfed cultivation can provide the population only with a moderate diet of up to 1.7 kg grain equivalents (GE)[1] per person per day up to 2,100 (Table 3), provided that yields increase by 120 to 220 kg ha^{-1} y^{-1}. Yield gains, however, have been only between 10 and 30 kg ha^{-1} y^{-1} over the past decades, suggesting an insurmountable challenge under business as usual. Extrapolation of these past rates of yield increase, assuming business as usual, results in an unchanged diet of current insufficient levels of approximately 1.1 kg GE p^{-1} d^{-1} until 2050. As the neighboring Sahelian countries face similar resource constraints (e.g., MER, 2017), food linkages with countries south of Burkina Faso may become increasingly important.

Table 3. Actual (2018) and potential production estimates for Burkina Faso.

Crop	Area (Mha)	Yield (t ha^{-1})	Production (Mt y^{-1})	Potential Rainfed area (Mha)	Potential Water-Limited Yield (t ha^{-1})	Rainfed Production (Mt y^{-1})	Potential Irrigated Area (10%) (Mha)	Potential Yield Irrigated (t ha^{-1})	Irrigated Production (Mt y^{-1})	Total Production (Mt y^{-1})	Yield 2050 BAU[d] (k ha^{-1})	Production BAU (Mt y^{-1})
Maize	1.0	1.7	1.7	14.5	7	10.2	0.23	10	2.3	12.5	2.4	4.1
Sorghum	1.9	1.0	1.9	2.7	4	10.9		6		10.9	1.4	3.7
Millet	1.4	0.9	1.2	2.0	3	6.0		5		6.0	1.1	2.2
Rice	0.2	1.5	0.3		4		0.69	11	7.6	7.6	2.4	1.7
Legumes	2.2	0.6	1.2	3.1	2	6.2	0.23	3	0.7	6.9	0.9	2.9
Cotton	0.5	1.1	0.5	0.7								
Other	0.3			0.4								
Total	7.4		7.6[a]	10.4[b]		39.4	1.15[b,c]		11.3[a]	50.7		17.4[a]

[a] Legumes double counted to arrive at "grain equivalents."
[b] Total cultivable area (11.5 Mha) from Knauer et al. (2017).
[c] Max 7.5% irrigable. (AfDB, 2017): Potentially irrigable 230 kha, 500 kha of bottomlands; 1,200 water bodies (dams, lakes, ponds) that can harness up to $5*10^9$ m^3 y^{-1}, able to irrigate 300-500 kha.)
[d] BAU = Business as Usual.
[e] Additional data from FAOSTAT, Bado (2002), and Youl et al. (2013)

[1] Grain equivalent represents an aggregate measure for food products and diets consumed (WRR, 1995). For comparison, European consumption is approximately 4.5 kg GE p^{-1} day^{-1}.

3. Spatiotemporal Sufficiency of Soil Water and Nutrients for Major Crops in Burkina Faso

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3.1 Introduction

Sustainable intensification of agriculture in Burkina Faso is needed to keep up with the growing demand for agricultural products while reducing the agricultural pressure on its natural resources. Cropland expansion into pastoral and marginal lands and shortening of fallow periods have contributed to agricultural growth, although at the expense of aggravated soil degradation with the limits of this extensive agricultural system being exceeded.

Agricultural productivity in Burkina Faso is biophysically limited by the availability of water and nutrients. Both can be improved with investments in inputs and management, while the primary land users have limited investment capacity and face large risks of no return on these investments. Information on the availability of soil water and soil nutrients relative to their requirement for agricultural intensification may facilitate investment decision making.

Water available from rainfall is generally sufficient for moderate yield levels, but erratic rainfall patterns create overwhelming risks at farm and even national level. The actual availability of water to plants depends on the water-holding capacity of the soil as well. Yet, the very low inherent soil fertility of the Sahelian region further hampers plant growth.

The objective in this chapter is to identify high potential intervention areas for agricultural intensification. To this aim, the latest developments in satellite earth observation and meteorology and soil information will be used to demonstrate and guide investments in sustainable agricultural intensification and regreening for the Western Sahelian region, specifically applied to Burkina Faso. This activity will deliver maps as components of a decision support system. The methodology can be fine-tuned and the products turned into an operational decision support system for investment options.

This study focuses on three main crops cultivated in Burkina Faso: maize, sorghum, and millet. The envisaged information generated provides actionable information on spatiotemporal variations in the (in)sufficiency of (soil) water and nutrients to meet specific crop requirements. This pilot focusses on environmental conditions and does not consider economic data.

Results are presented in the form of maps at a spatial resolution of 250 m, produced using data from the FAO-WaPOR database and the ISRIC soil data hub, and are available together with a full description of the methodology as a technical report (Leenaars et al., 2020). As sorghum is the main crop covering the country from north to south, we have chosen selected results on sorghum to demonstrate the various components of the envisaged information.

3.2 The Modeling Rationale

The core of the approach is to estimate the sufficiency of water and nutrients, i.e., the amounts available from the soil (supply) relative to the amounts required by the crop (demand). The approach is based on spatially detailed maps (over 4 million grid or raster cells) over an 11-year time series (2009-2019) for maize, sorghum, and millet and considers water, nitrogen (N), phosphorus (P) and potassium (K). In total, the estimation is produced from approximately 600 million data points to show the spatial and temporal variation of the sufficiency.

The innovative aspect of the study is twofold. First, it combines both water and nutrients into an integrated measure to evaluate the options for intensification, where other approaches generally focus on either water or nutrients. Second, this integration of data products from various disciplines is done in a spatially and temporally exhaustive manner, showing a comprehensive spatiotemporal picture.

Here we refer to existing data to illustrate the relevance of the concept for assessing the potential that can be reached by agricultural intensification in terms of productivity and production together with the inputs required.

Multi-year average sorghum yield and production per agroecological zone in Burkina Faso are given in Table 4 for potential yield (PY), water-limited potential yield (WY), and actual yield (AY) (GYGA, 2020). An increase in nutrient availability, e.g., through fertilization, would increase yield from the actual 1 t ha^{-1} (AY) to 5.3 t ha^{-1} (WY). Irrigation or water conservation to meet crop water need would increase yields to 6.7 t ha^{-1} (PY). Total annual production on the current area of nearly 2 Mha cropped with sorghum through optimized nutrient availability would be about 10.6 Mt on average for the whole of Burkina Faso (WP) and over 13 Mt through both optimized water and nutrient availability (PP). The presented values, specifically for sorghum, are of the same magnitude as in Table 3, confirming the overall estimates. The high variation in yield over time under the actual and water-limited production levels can be controlled only through water management.

Table 4. Yield (Y) and production (P) of sorghum per agroecological zone at three production ecological levels (P: potential, W: water-limited potential, A: actual), including coefficient of variance of yield over time.

Agroecological Zone	Area (kha)	Production Ecological Yield Levels (t ha^{-1})			Production (Mt)			Coefficient of Variance of Yield over Time		
		PY	WY	AY	PP	WP	AP	CV_PY	CV_WY	CV_AY
Arid	1,227	5.9	3.9	0.8	7.3	4.8	1.0	5.6	41.9	30.7
Semi-arid	585	6.4	5.6	1.2	3.7	3.2	0.7	2.4	9.5	16.5
Sub-humid	188	8.0	7.9	1.0	1.5	1.5	0.2	4.5	4.8	7.9
Country	2,000	6.7	5.3	1.0	13.3	10.6	2.0	2.9	17.0	17.6

Box 2. LANDMARC

LANDMARC is a €7 billion Horizon2020 research project looking at the land-climate-development nexus and aiming to better understand the impacts of land use-based mitigation technologies or negative emission solutions. Funded by the European Commission, 19 consortium partners will be working to estimate the climate impact of land-based negative emission solutions, assess the potential for regional and global upscaling, and map their potential environmental, economic, and social co-benefits and trade-offs.

Through one of its case studies, LANDMARC connects with the Burkina Faso Forest Investment Project (FIP), where it will assess the project's impact on carbon sequestration in vegetation using satellite earth observation and models. eLEAF will use satellite-based data on Net Primary Production (NPP) to monitor and evaluate the project interventions impact on carbon uptake in vegetation.

3.3 Data Sources

The following datasets (maps) were used in the analysis for 2009-2019 (see Annex 1 for details):

- Seasonal soil water availability was calculated based on the length of the crop growing season, CHIRPS precipitation, runoff (hydrological groups, land cover, slope), and soil rootable depth.
- Seasonal crop water demand was calculated based on the length of the crop growing season, reference evapotranspiration, and crop factors.
- Seasonal soil water sufficiency was derived from soil water availability relative to crop water demand.
- Seasonal soil nutrient supply was calculated based on soil nutrient concentrations (N, P, K), pH, bulk density, and coarse fragments content.
- Seasonal crop nutrient demand was calculated based on crop nutrient parameters and potential yield, solely limited by water availability, whereby potential yield was derived from potential biomass production, which was estimated from potential transpiration and evapotranspiration, calculated from above, and actual biomass production, transpiration, and evapotranspiration, as downloaded from the FAO-WaPOR database.
- Seasonal soil nutrient sufficiency was derived from soil nutrient supply relative to crop nutrient demand.

Crop calendars, as obtained from the Global Yield Gap Atlas (GYGA, 2020), provide the start and end dates of the growing season across agroecological zones (see Annex 2 for the zonation). Together with crop factors (Table 5), these lengths of seasons were used to calculate seasonal water availability and crop water demand.

Table 5. Start and end dates of the crop growing season per agroecological zone and values of the crop factor (Kc) across the different growth stages for sorghum.

Zonation		Crop Growing Season			Crop Development Stages							
Climate	Agroecology	Start	End	Length (days)	Initial (Kc/days)		Vegetative (Kc/days)		Flowering (Kc/days)		Generative (Kc/days)	
Arid	Sahel (N)	01/07	31/10	122	0.35	20	0.75	31	1.1	41	0.65	30
Semi-arid	N Sudan (NW, C, E)	01/06	31/10	153	0.35	24	0.75	41	1.1	53	0.65	35
Sub-humid	S Sudan (SW)	01/06	31/10	153	0.35	24	0.75	41	1.1	53	0.65	35

Daily rainfall and reference evapotranspiration were downloaded from the FAO-WaPOR database (www.fao.wapor) for above defined seasons for 2009-2019 along with the annual sums of the actual evapotranspiration, transpiration, and biomass production.

Soil profile data for Burkina Faso were originally compiled in the Africa Soil Profiles (AfSP) database (Leenaars et al., 2014), including data from AfSIS (2020) and are also available from the WoSIS database. Summary statistics of selected soil properties are given in Table 6. The soil maps produced from these soil profile data can be obtained from the ISRIC datahub (data.isric.org), the Africa SoilGrids (Hengl et al., 2015), Africa SoilGrids nutrients (Hengl et al., 2017), and Africa SoilGrids GYGA (Leenaars et al., 2018a).

Table 6. Summary statistics of selected soil data for Burkina Faso as compiled in the AfSP and WoSIS databases.

Property	Unit	Profiles	Layers	Min	Max	Avg	StdDev
Profiles	-	911	3307				
Year	-	834	-	1966	2002	1984	13
Root depth	cm	221	-	0	220	69	46
Gravel	v%	750	2616	0	100	16	27
Clay	w%	710	2497	0	97	27	16
Bulk density	kg/dm^3	92	284	1.00	2.26	1.75	0.20
pH H2O	-	523	1784	4.5	9.4	6.6	0.9
Exchangeable bases	cmolc/kg	499	1699	0.2	142.1	80.5	10.0
CEC	cmolc/kg	495	1684	0	100	10	9.3
Base saturation	%	495	1682	5.0	100	75.3	20.4
Organic C	g/kg	547	1787	0.0	40.1	4.9	4.5
Total N	g/kg	528	1666	0.0	2.8	0.4	0.3
Total P	mg/kg	398	1202	10	5219	132	247
Moisture at pF 2.5	v%	64	201	1.4	45.8	17.6	9.2
Moisture at pF4.2	v%	209	705	0.8	31.6	9.0	5.7

3.4 Spatiotemporal Variation of Soil Water Availability and Sufficiency

Soil water sufficiency is assessed by comparing the seasonal soil water availability (supply) with the seasonal crop water demand and expressed as a relative measure.

Soil Water Availability

Soil water availability is defined as the amount of water that is potentially available for crop growth. It is derived from daily rainfall, daily runoff, length of the crop growing season, and the depth of soil that holds the water. Daily rainfall data from 2009-2019 were downloaded from the FAO-WaPOR database. Daily water availability was calculated by subtracting the estimated daily runoff from the daily rainfall. The estimation of runoff was based on the approach suggested by the USDA Natural Resources Conservation Service (SCS, 1972). Seasonal water availability (WA) was then calculated by summing the daily water availabilities over the length of the growing seasons.

The actual water availability in Burkina Faso is seriously limited by the nature of its soils, which are often gravelly and with an iron pan at shallow depth, seriously reducing the root zone plant-available water-holding capacity. Much of the seemingly available water is therewith not stored in the soil and not available for crop growth. As the above calculation of daily and seasonal water availability did not include this rootable soil depth, a map of soil rootable depth (Leenaars et al., 2018a), together with a soil depth specific reduction factor (0-100%), was used to estimate the seasonal soil water availability from the seasonal water availability. The factor is derived from an estimate of Guilpart et al. (2017), who simulated the overall effect of the soil rootable depth on water-limited yield potentials.

Seasonal water availability, and root zone limited soil water availability, ranges from near 0 to almost 1,100 mm across the country and over the years. Maps of the root zone limited soil water availability are given for sorghum in Figure 5, including the long-term average (mm) and the yearly (seasonal) deviation (in %) from the long-term average. These maps show that the seasonal soil water availability was particularly low in 2011, 2013, and 2017 due to below average rainfall in most of the country. They also show that the water availability is on average low in the Sahel (north), where the defined length of season was only 122 days, as well as in North Sudan (east and northwest), where the soil rootable depth seems the main limiting factor. The standard deviations from the multiyear average are more or less similar throughout the country in relative terms (approximately 10-15%).

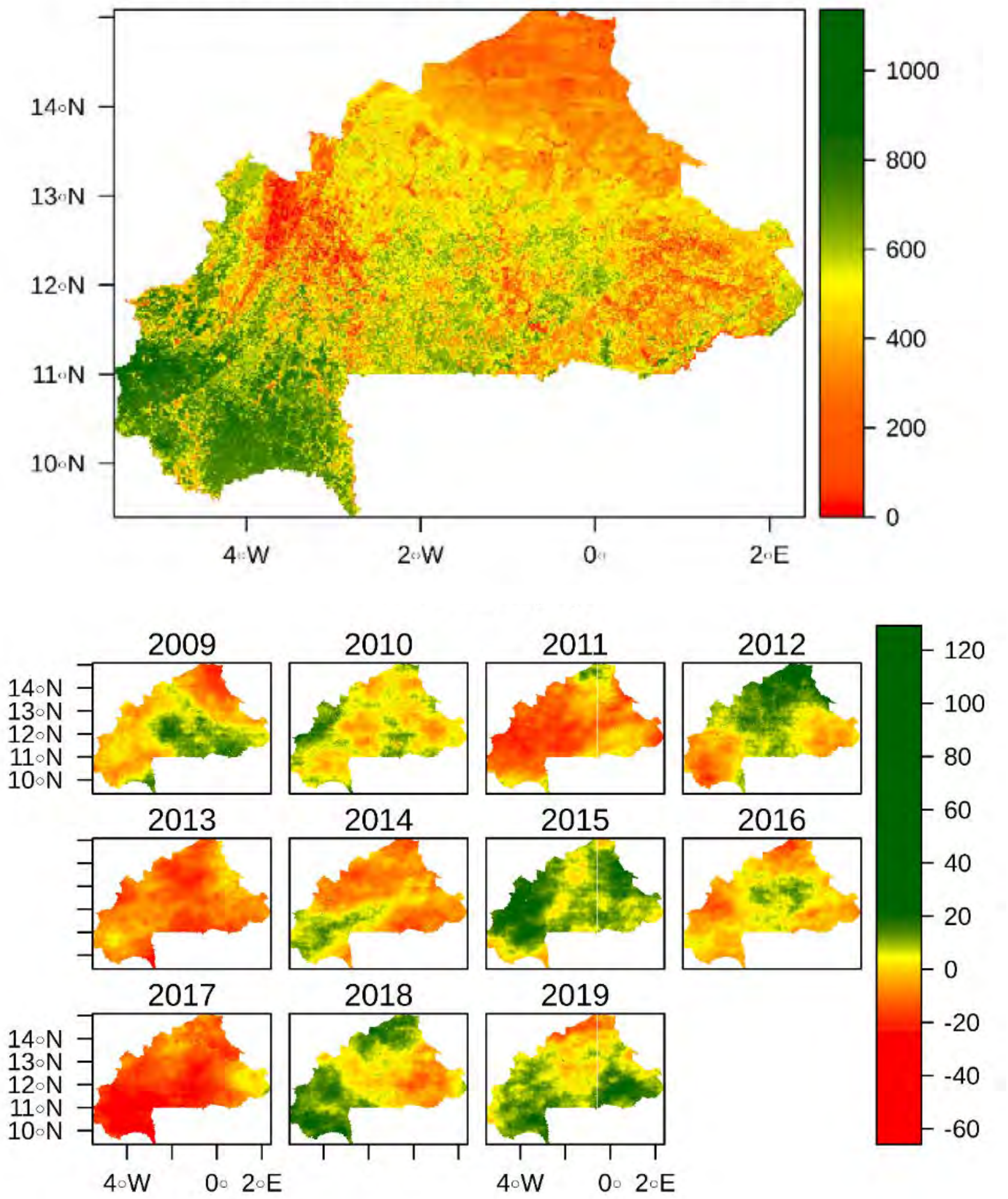

Figure 5. Long-term average (top, mm) and yearly deviation (bottom, %) from the long-term average of the root zone limited soil water availability for sorghum.

Crop Water Demand

Crop water demand is defined as the amount of water needed for a crop to grow optimally (achieve its potential), assuming no water limitation, and includes both soil evaporation and crop transpiration. It is estimated from the reference evapotranspiration, which represents the atmospheric demand for water, in combination with a crop factor (which is climate, crop, and crop development stage specific and increases from the start of season until flowering, after which it decreases again until maturity; see Table 5). The methodology used to assess water demand is from Brouwer and Heibloem (1986), which in turn is based on Doorenbos et al.

(1979). Daily data on reference evapotranspiration were downloaded from the FAO-WaPOR database.

Calculated crop water demands vary between 400 and 900 mm. The resulting maps show unexpected patterns and artifacts that proved due to the starts and lengths of growing seasons defined for each crop across the agroecological zones, which can be resolved in a follow up by using more gradual start and end dates. Note that the maps also show a sudden increase of crop water demand from 2014 onward, which may be the result of inconsistencies in meteorological time series used in the input data.

Soil Water Sufficiency

The root zone limited relative soil water sufficiency (RZL-RWS) is calculated for each season as the soil water availability relative to crop water demand: *RZL-RWS = RZL-WA / CWD, where RZL-WA = root zone limited soil water availability and CWD = crop water demand.*

Maps of the relative soil water sufficiency for sorghum are given in Figure 6. The water sufficiency is on average adequate for sorghum in the South Sudan zone (southwest) and the central part of the North Sudan zone where the sufficiency exceeds 1 (soil water availability exceeds crop water demand). This is also the case for maize. The pattern for millet is fairly similar though with a sufficiency that is generally lower, probably due to the late start of season. The years with below average rainfall (2011, 2013, and 2017) show a below average sufficiency, as expected. Two years with near average water availability (2014, 2016) also show important below average sufficiency, and apparently, reference evapotranspiration was well below average in those years.

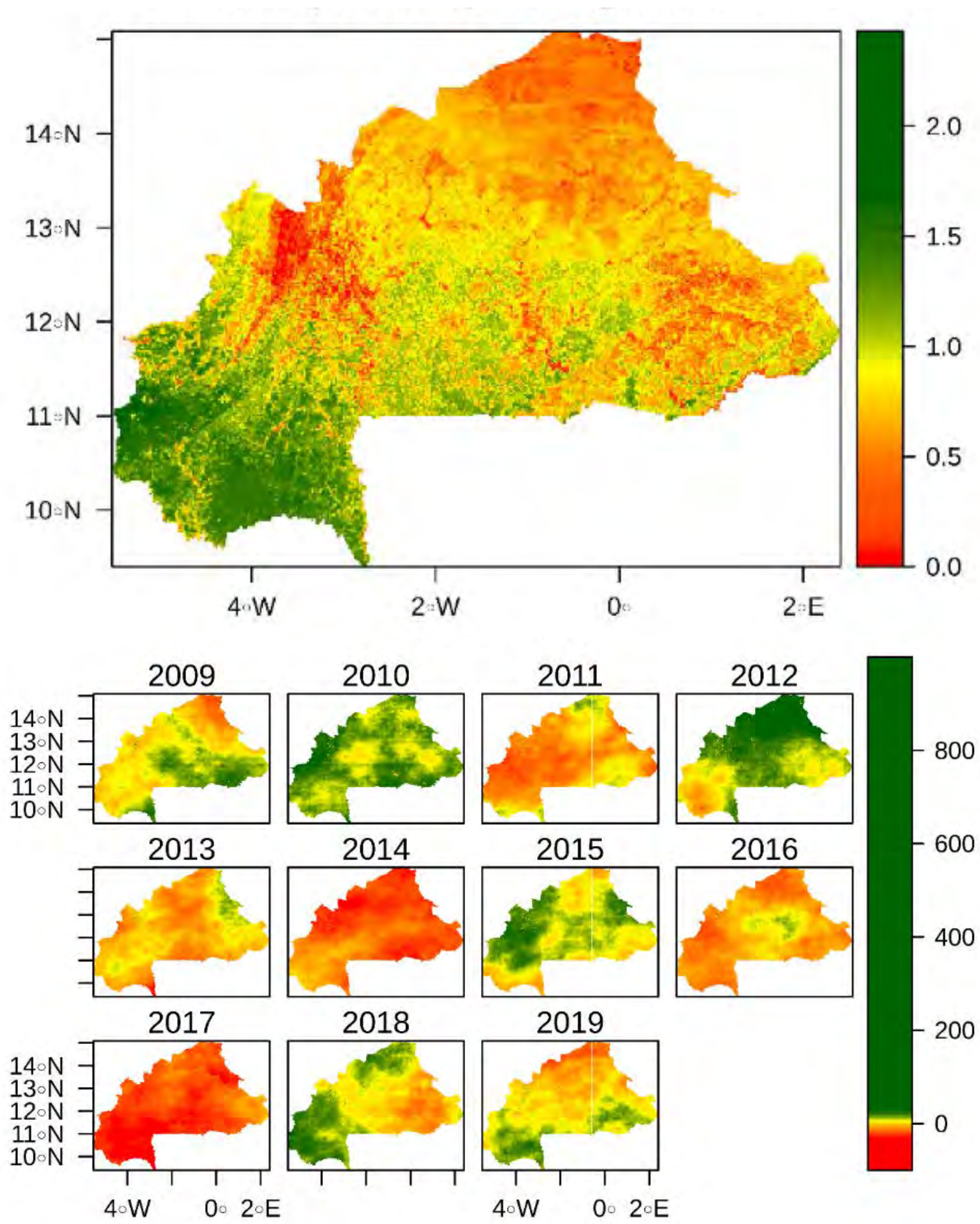

Figure 6. ***Long-term average (top, mm/mm) and the yearly deviation (bottom, %) from the long-term average of the relative soil water sufficiency for sorghum. A sufficiency less than 1 mm/mm indicates a shortage relative to demand.***

The maps of the yearly standard deviation from the multi-year average show that the sufficiency is occasionally eight times (800%) the average sufficiency, which indicates that the temporal variability is very high indeed.

Note that seasonal soil water sufficiency does not necessarily reflect actual sufficiency because seasonal variability, e.g., droughts at crucial crop stages, is not considered.

3.5 Spatiotemporal Variation of Soil Nutrient Availability and Sufficiency

Soil nutrient sufficiency of N, P, and K is defined as the amount of N, P, or K supplied by the soil relative to the amount of nutrients demanded by the crop. It is reported here as a relative measure.

Soil Nutrient Availability

Soil nutrient contents (N, P, and K) are mapped from soil profile data as the weight of nutrient relative to that of soil (mg kg^{-1}) in the 0-30 cm depth interval. The soil profile data were collected about 37 years ago (1984), and we assume that 0.5% of the nutrient contents has been lost every year due to unsustainable soil nutrient mining farming practices, implying a decline of 16%. Declining soil fertility implies a declining nutrient sufficiency, which results in increasing fertilizer requirements to meet crop nutrient demand. To sustain the productive capacity of the soil these soil nutrient stocks need to be restored.

To give an idea of the absolute amounts of soil N, P, and K in the 0-30 cm depth interval, we calculate the absolute nutrient content by : *Nut_abs (kg* ha^{-1}*) = Nut_rel x BD x 3 x 1 x (100 – CF) / 100, whereby 1 = 100* dm^2 *x 10,000* m^2 */1000.000 mg, with Nut_rel = relative nutrient content (mg* kg^{-1}*), BD = bulk density (dm/*kg^3*) and CF = coarse fragments content (v%).* Note that these contents refer to N, P, and K as measured (total N, available P, and exchangeable K).

From the soil fertility maps, the soil nutrient supply is calculated using Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS; Janssen et al., 1990; Sattari et al., 2014). The soil nutrient supplies (kg ha^{-1}) are a fraction of the absolute soil nutrient contents (kg ha^{-1}) and represent the amount of soil nutrients that become available in the soil water solution for crop uptake. The effective soil nutrient supply that is effectively available for crop uptake is assumed to be only 90% of the supply calculated by QUEFTS, assuming that a fixed and arbitrary part of the nutrients in solution is lost, for example, due to leaching.

Maps of the absolute N, P, and K contents in the soil (0-30 cm), as well as maps of the effective availabilities (supplies) of soil N, P, and K, are given in Figure 7. The maps suggest that the measured contents are approximately 5-50 times as high as the yearly availabilities. They also suggest that the N and, to a lesser extent, available P contents are highest where clayey soils dominate and exchangeable K contents in areas with sandy soils, which is due to differences in geology. The availability of P is least directly related to its corresponding soil content because this availability is also a function of other soil properties, such as pH.

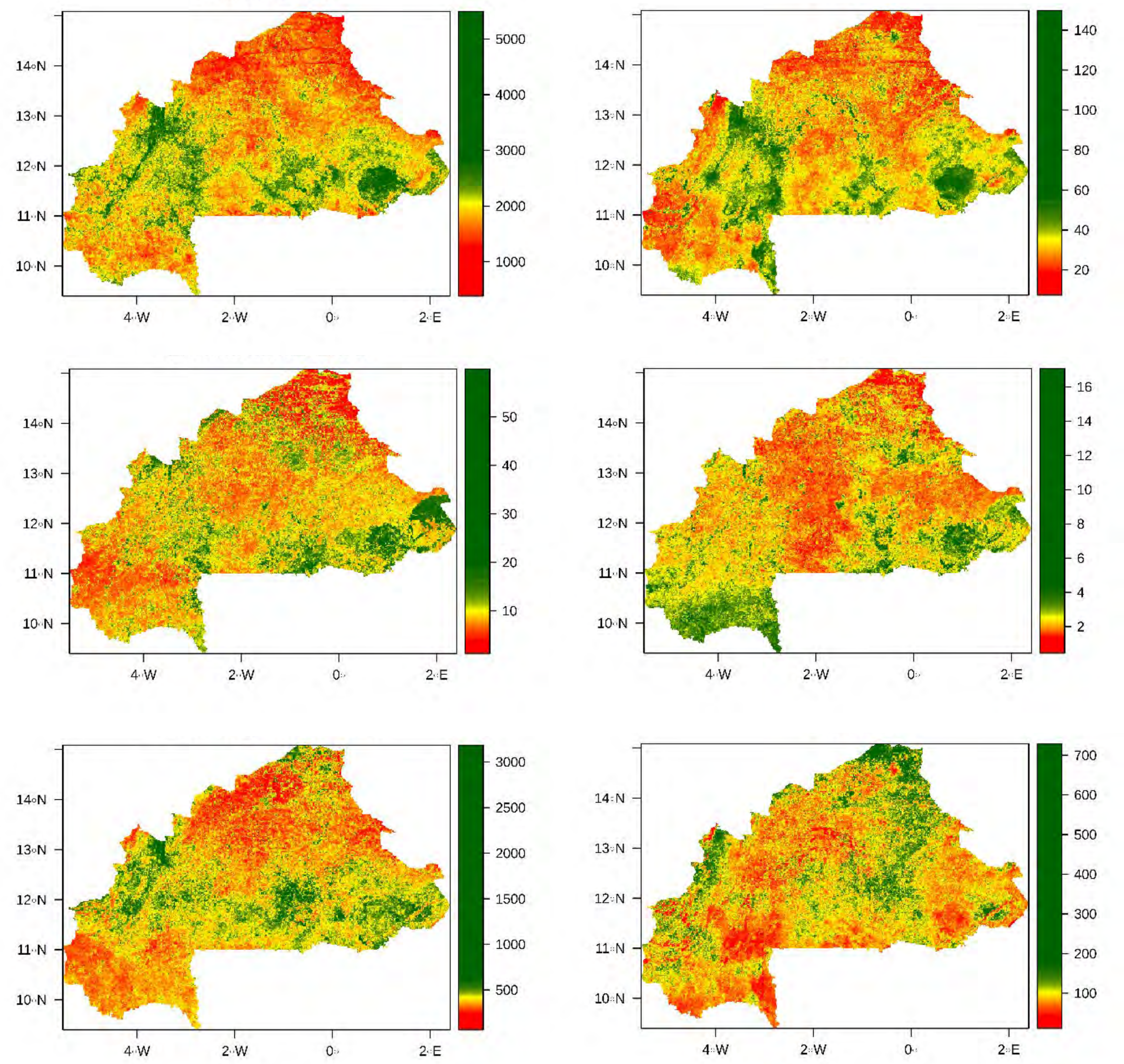

Figure 7. ***Soil nutrient contents (left; kg ha^{-1}); soil nutrient availabilities (right; kg ha^{-1}). Top to bottom: N, P, and K.***

Crop Nutrient Demand

The crop nutrient demand is determined from the soil water-limited crop yield potential, which is estimated from the soil water-limited biomass production potential (WL-TBP). Total biomass production (TBP) is in moderate climates a linear function of transpiration (T) and governed by a crop-specific transpiration efficiency. In dry areas, like Burkina Faso, the Reference Evapotranspiration (RET or E0) also plays a role (de Wit, 1958): *TBP = m x T / RET, with m = crop-specific transpiration efficiency (kg kg^{-1})*. For water-limited conditions this implies that *WL-TBP = m x WL-T / RET, with WL-T = water-limited transpiration potential.*

The transpiration efficiency *m = TBP x RET / T* which is equal to *m = WL-TBP x RET / WL-T*. This implies that *WL-TBP = TBP x WL-T / T*. The water-limited transpiration potential (WL-T) is easily deducted from the water-limited evapotranspiration (WL-ET) and the ratio of T over ET. WL-ET is simply equal to the soil water availability but maximally crop water demand and already calculated on a seasonal basis. T and ET, as well as TBP, were downloaded from the FAO-WaPOR database on an annual basis. Herewith, we deducted the water-limited potential of the seasonal crop biomass production from the actual biomass production (TBP) as *Seasonal WL-TBP = annual TBP x seasonal WL-T / annual T.*

It should be noted that TBP from the FAO-WaPOR database reflects biomass and not necessarily crop biomass production and represents the outcome of actual stresses, such as soil moisture stress, but also other, possibly unknown stresses, such as nutrient deficiencies or pests and diseases. It includes both below- and above-ground biomass and ranges from below 1 to occasionally above 15 t ha^{-1} across the country and years but is on average well below 10 t ha^{-1}, as expected. Further note that the use of annual (full year) data combined with seasonal data does not play a major role in the above equation but it is nevertheless strongly recommended for any follow up study to process all data according to a similar representation of time (similar season lengths).

The soil water-limited crop yield potential (WL-YLD) is calculated per crop and per season to estimate the crop nutrient demands. The calculation of WL-YLD is very simple: *WL-YLD (kg* ha^{-1}*) = WL-TBP x AGRF x HI, with WL-TBP = water-limited total crop biomass production, AGRF = above-ground fraction and HI = harvest index.*

The AGRF is set at 0.8, which seems a reasonable estimate for cereals derived from root:shoot ratios reported in literature. This fraction is substantially higher than the default fraction of 0.65 previously used in the calculation of above-ground biomass production in the FAO-WaPOR database v1. The harvest index (yield over above-ground biomass) varies over the years and across geographies. We used fixed values reported by Leenaars et al. (2018b) of 0.38, 0.25, and 0.20 for maize, sorghum, and millet, respectively. These are near similar to those compiled by van Duivenbooden (1992) for West Africa suggesting 0.41, 0.20, and 0.22, respectively.

Note that the resulting estimates of WL-YLD are far too low compared to other studies (FAO, IIASA, 2012.; GYGA, 2020; Van Loo et al., 1990; Sivakumar et al., 1991; van Noordwijk et al., 1994; Driessen et al., 1997) and are near to actual yield levels (Prudencio, 1983; Dugué, 1989; Pieri, 1989; Leenaars et al., 1992). These low estimates are the direct result of low estimates of WL-TBP, near equal to actual TBP levels, which may be due to the data used in the equations, but which also requires revisiting the estimation procedure itself. It is likely more effective to apply transpiration efficiencies from literature. The low estimates of WL-YLD will imply low estimates of crop nutrient demand.

The crop nutrient demand is calculated per crop, per season, and per nutrient (N, P, and K). These demands are calculated from the soil water-limited crop yield potentials (WL-YLD) calculated above and represent the amounts of nutrients that need to be taken up by the crop, including its full biomass, to reach that water-limited yield potential.

QUEFTS parameterizes yield-uptake efficiencies, and these parameters are valid for given crops in given regions with given climate and management conditions. These efficiencies vary considerably, and that variation is represented by parameters *d* and *a*, representing the efficiency (*d*) at diluted and (*a*) accumulated nutrient concentration. The *a* and *d* parameters for maize are copied from Leenaars et al. (2018b) and for sorghum and millet from van Duivenbooden (1992) and are given in Table 7. The differences in yield-uptake efficiencies have large impact on the nutrient demands of each crop. Crop nutrient demand is calculated for each nutrient as the ratio of water-limited yield over the average of the *a* and *d* efficiency.

Table 7. QUEFTS crop parameters for estimating crop nutrient demand at water-limited crop yield potential.

Crop	dN	dP	dK	aN	aP	aK	HI
Millet	45	350	22	15	108	9	0.20
Sorghum	80	500	42	19	124	15	0.25
Maize	64	386	83	25	46	25	0.38

The resulting estimates of nutrient demands are somewhat on the low side compared to other studies (GYGA; Leenaars et al., 2018a), which is directly due to the low estimates for the water-limited crop yield potentials. Although the absolute values are too low, we think that the spatial and temporal variations are well reflected.

Nutrient Sufficiency

Nutrient sufficiency is the capacity of the soil to supply the amount of nutrients relative to the amount of nutrients demanded by the crop at its water-limited potential. (Note that this definition deviates from the more common definition relative to a soil test-based threshold of a more arbitrary nature). The nutrient sufficiency is calculated and mapped per crop, season, and nutrient (N, P, and K) as the soil nutrient availability (supply) divided by the crop nutrient demand.

Low nutrient sufficiency is manageable to a certain extent by the provisioning of fertilizer nutrients. However, the sufficiency is highly variable in space and time, as shown in this section, which implies that fertilizer nutrient requirements also vary in space and time or across geographies and years. That spatiotemporal variation poses a serious risk of investment in fertilizers, which is particularly relevant for smallholder farmers who cannot afford taking high risks.

Maps of the relative nutrient sufficiency (kg kg^{-1}) of phosphorus for sorghum are given in Figure 8. The patterns are near similar for the other nutrients and are apparently determined by the variation in crop nutrient demand, as governed by water availability, more than by the variation in soil nutrient supply. The degree of sufficiency varies though between the nutrients. The availability of P seems on average insufficient relative to demand in much of the country (yellow) and highly insufficient in the southwest and central part (red). The availability is more than sufficient (green) where the demand for P is low in the north and on shallow soils and/or the availability is high on clayey soils.

Note that the estimates of the N, P, and K sufficiency are on the high side, especially for nitrogen, suggesting that soil fertility is adequate; however, this is false and directly due to the low estimates for nutrient demand as a result of the low estimates for water-limited crop yield potentials.

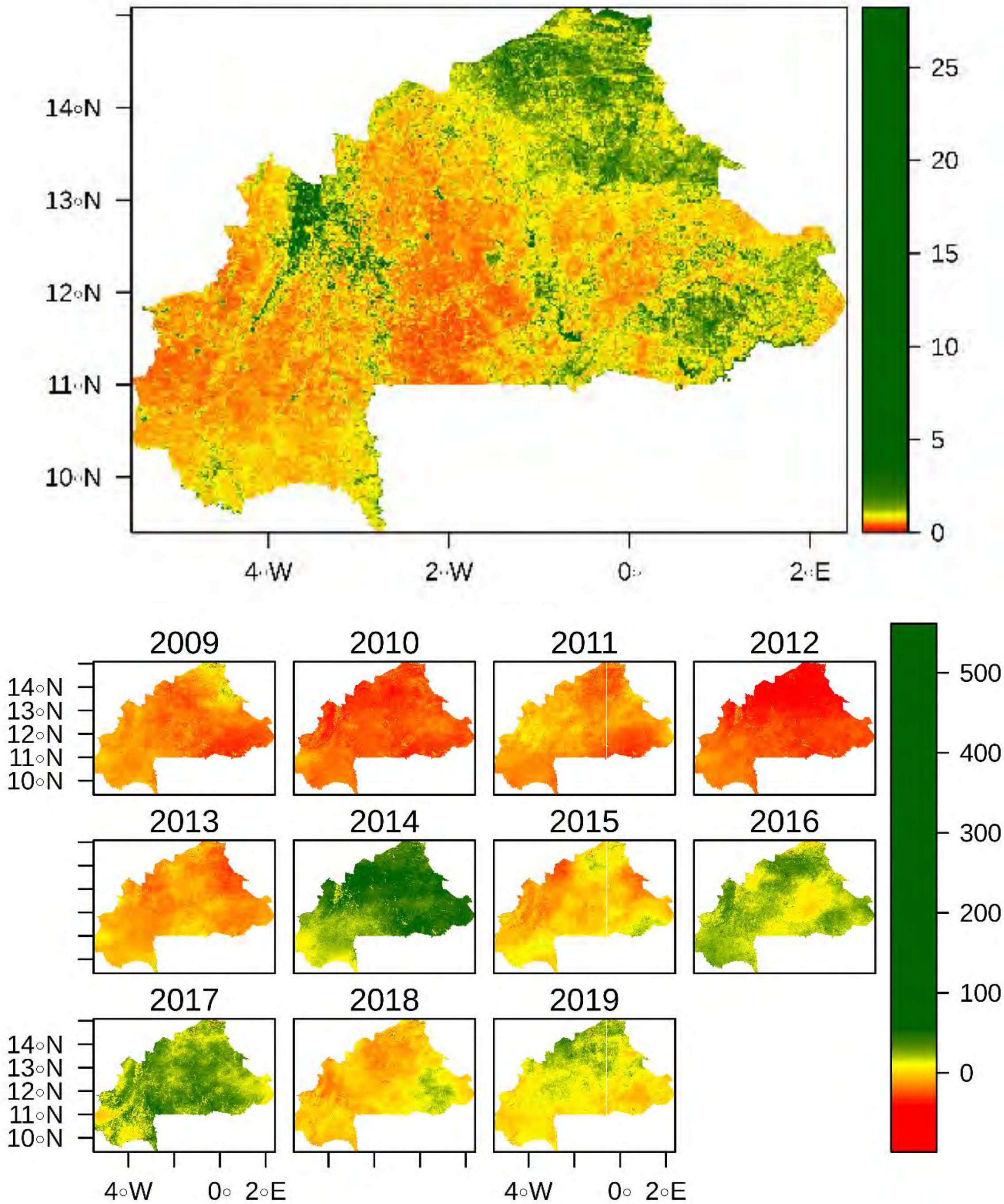

Figure 8. ***Long-term average (top, kg kg^{-1}) and the yearly deviation (bottom, %) from the long-term average of the relative sufficiency of P for sorghum (patterns are near similar for N and K). A sufficiency less than 1 kg kg^{-1} indicates a shortage relative to demand.***

The maps of the yearly deviations from the multi-year average show a variation of nutrient sufficiency between mainly -100 and +100%. The occasional deviation of +500% occurred in a very dry year. The maps suggest below average sufficiency until 2013 and above average from 2014 onward. Obviously, this discontinuity is an artifact and directly due to the discontinuity in the TBP data, as downloaded from the FAO-WaPOR database.

Besides the spatiotemporal variation in nutrient (in)sufficiency and the associated fertilizer requirements is the variation in crop response to a fixed rate of fertilizer application, for example, which we evaluated and mapped comparable to those done by Leenaars (1992, 1998) as the frequency (year/year) that the sufficiency is below a threshold (or the required fertilizer rate above a threshold). It is safe for an investor, given the threshold, to invest in the defined amount of fertilizers if the frequency = 1, indicating a likely crop response to the fertilizer nutrients in 10 out of 10 years. The higher the threshold, the lower this frequency will be. We show here the results with the threshold defined at a sufficiency of 1 (where supply meets demand). The resulting maps represent the spatiotemporal frequency (or the contrary of risk) that an investment in a microdose of fertilizers in a given year will be successful in terms of crop yield response. Note that the threshold is a very marginal one (evaluating where supply < demand) due to the nature of the estimates, suggesting only marginal nutrient insufficiencies.

Maps of the frequency of a likely crop response to fertilizers (or of the frequency where sufficiency < 1) are given per nutrient in Figure 9. This frequency is near 10/10 years (green) for nitrogen in the far southwest and for phosphorus in most of the country where the average sufficiency is below 1. Fertilization with potassium seems near never worthwhile (red). (Note, though, that these outcomes are proof of concept only.)

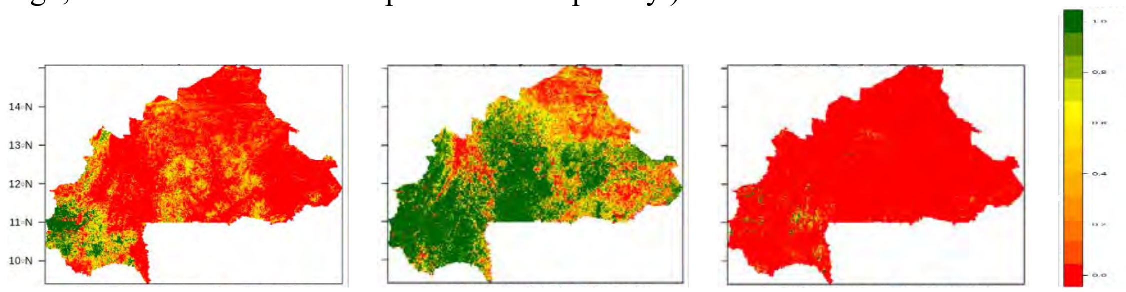

Figure 9. Frequency (year/year) of a likely crop response to a microdose of fertilizer nutrients for sorghum. Left to right: N, P, and K (green = 1, yellow = 0.5, and red = 0).

3.6 Discussion

The proof of concept estimates the spatiotemporal variability of each of the water and nutrient components and their combination, illustrating how the data sources can support the identification of areas where the sufficiency of water and/or nutrients is relatively low or high and varies over time to determine areas with best prospects for investment in sustainable intensification (of maize, sorghum, or millet cultivation), i.e., areas with high and low yearly variability in water sufficiency (manageable by irrigation and/or water harvesting) or nutrient sufficiency (manageable by fertilization).

First, we focused on identifying areas with the best prospects for investment in sustainable intensification by means of water management. Water sufficiency is adequate for each of the three rainfed crops and each of the 11 years, except for millet in 2017, in the southwestern part of the country with a sub-humid climate (South Sudan). Prospects to invest in water management are minimal in this zone except when crops with larger crop water demand are being cultivated, including varieties with a longer growing cycle. The entire zone between the southwest and the far north/northeast area, corresponding with the semi-arid climate zone (North Sudan), shows a highly variable picture of water sufficiency largely related with the variation in rootable soil depth. It requires additional more detailed investigation to identify areas with good prospects for investments in water management in support to the crops considered here. The north/northeast area, corresponding with an arid climate (Sahel), shows a consistent water insufficiency for each of the crops and throughout the years. This area offers good prospects for investments in water management to increase crop production. Alternatively, this area requires crops with lower water demand than defined, including varieties of shorter duration, to ensure successful cultivation. Note that the analysis was a proof of concept and that the definition of the length, and start, of the cropping seasons only permits preliminary conclusions about water availability and sufficiency and is a point of attention for any follow-up study.

Second, we focused on identifying areas with the best prospects for investment in sustainable intensification by means of fertilization. For this purpose, we estimated the spatiotemporal variability of the gap between the amount of nutrients demanded by the crop (of the three major crops) and the amount of nutrients available (supplied) from the soil. This gap defines the (manageable) nutrient insufficiency (or deficiency) and indicates the room for investment in fertilizer nutrient application. We translated the nutrient gap to a relative nutrient sufficiency being the ratio of supply relative to demand. The yearly variability of the nutrient sufficiency is translated into a frequency (years per year) when the sufficiency is below a given threshold. That frequency indicates the likeliness that the crop will respond favorably to a given amount of fertilizer nutrients. A frequency of 0.8, for example, indicates a likeliness of favorable response in 8 out of 10 years. Best prospects to invest in fertilizer nutrients is in those areas where the relative nutrient sufficiency is low which is for each of the three crops mainly towards the south and on deep rootable soils where water sufficiency is adequate. The relative nutrient sufficiency is adequate where water sufficiency is inadequate (resulting in water-limited crop yield potentials that are relatively low with associated low demand for nutrients), which is mainly toward the north and on soils with shallow rootable depth. The best prospects to invest in the latter areas are in the domain of water management, such as irrigation, to enhance water sufficiency and crop potential, combined with investments in fertilizer nutrients to enhance crop production (and also improving water productivity). Note that the analysis was a proof of concept and that the water-limited yield potential, defining crop nutrient demand, was generally underestimated because of the estimates for water availability and demand and the data for total biomass production.

Generally, the nutrient gaps are somewhat smaller in size than expected from literature, which is mainly due to water-limited crop yield potentials that are well below potentials reported in literature and rather in line with actual, nutrient-limited yield levels (Fischer et al., 2012; GYGA, 2020; Pieri, 1989), which for sorghum are approximately 7 and 1 t ha^{-1}, respectively.

The low yield potentials seem to be the result of low values calculated for crop water demand and for actual total biomass (TBP), as downloaded from the FAO-WaPOR database. In time, the relative nutrient sufficiency suddenly increased drastically from 2014 onward. This is not due to a sudden improvement of crop management, including fertilizer application, but due to the maps of total biomass (TBP), which show a sudden decrease from 2014 onward. The latter is unexplained because the timeline of precipitation does not show a similar change and this observation has been reported to the FAO-WaPOR database. The analysis itself deserves attention as well, though, because it takes TBP into account, which reflects actual biomass of standing vegetation (of C3 nature) and not necessarily of crop. Concerning soil, the impact of soil rootable depth on the water sufficiency is evident in both space and time and is possibly somewhat overestimated due to the simplified approach applied. The impact of soil rootable depth on the nutrient sufficiency also appeared to be very prominent both in space and time and was larger than the impact of soil fertility. This implies that the spatiotemporal nutrient sufficiency and the size of the nutrient gaps seems more determined by water availability than by nutrient availability.

Concluding, whereas certain variables have been underestimated and would need additional attention in any follow-up study, the spatiotemporal variation of the variables has been adequately depicted.

This study proved that spatiotemporal data on soil (nutrients, depth), meteorology, water, and crops can be combined as components of a possible decision support system to estimate the spatiotemporal variation in soil water and soil nutrient sufficiency. This information is key for strategic planning, risk assessment, and decision making on investments for sustainable intensification of agriculture in Burkina Faso as well as the Western Sahel. The resulting maps, showing the spatiotemporal variation of water and nutrient sufficiency, provide the first guidelines on where to invest in what and how much, but definite, applicable results always require additional investigation and verification on the ground. The data and procedures to produce the maps are adequate, but a number of shortcomings, which were due to the exploratory nature of this pilot study, were also identified. Also, a complete decision support system should consider socio-economic components besides the environmental components captured in this study.

Particular attention is needed for a number of points, based upon which we expect to produce results with enhanced accuracy and applicability, knowing that the following steps should be taken:

- Integrate the various data components (weather, soil, and crop [and biomass], and crop management) into an analysis at a higher temporal, within season, resolution with time steps of 1 day, for example. This will permit consideration of within-season periods of drought. Integrate the soil rootable depth map into the daily water balance calculations to assess the seasonal water availability and sufficiency.
- Avoid analyses combining seasonal and annual (full year) data. This seems quicker but results in unnecessary uncertainties.
- Fine-tune the definition of the (year and crop-specific) start dates and lengths of the growing seasons as well as the agroecological zonation and corresponding crop varieties. We defined lengths of growing season of 122, 153, and 153 days for the arid, semi-arid, and sub-humid zones, respectively, whereas a gradual definition from 90 to 120 and 150 days is more appropriate and preferable.
- Verify the FAO-WaPOR maps of Total Biomass Production (TBP). They seem to contain an error, with a sudden drop from 2014 onward, which has been reported to FAO-WaPOR. Also note that TBP is for an average C3 plant, whereas the evaluated cereals are of a C4 nature.
- Evaluate the applied procedure to estimate the water-limited potential of total biomass production. The suggested alternative is to apply crop-specific transpiration efficiencies, derived from literature or estimated from the WaPOR data at an appropriate temporal resolution, to assess the water-limited potentials based on water availability.
- Improve the map of soil rootable depth, detangling the depth to groundwater.
- Possibly assess soil nutrient availability, as a fraction of soil nutrient contents, in a way other than using the QUEFTS algorithm. Nutrient uptake can be estimated from actual crop (or biomass) production as a proxy for soil nutrient availability.
- Estimate actual levels of crop biomass production, (evapo)transpiration, and nutrient uptake, as well as both the nutrient-limited and water-limited potentials, to create a fully coherent overview of the opportunities to invest in.

Box 3. Development of Smart Innovation through Research in Agriculture (DeSIRA)

Under DeSIRA, ISRIC is preparing the project "Land, Soil and Crop Information Services to support Climate Smart Agriculture (LSC-IS)."

The four year project (2021-2024) will develop sustainable land, soil, and crop information hubs in national agricultural research organizations that facilitate the exchange of knowledge and information between farmers, knowledge organizations, the private sector, and policymakers; enhance the effectiveness of national Agricultural Knowledge and Innovation Systems (AKIS 2.0); and contribute to rural transformation and climate-smart agriculture in East Africa.

World Soil Information (ISRIC) will work together with the Dutch Ministry of Foreign Affairs, Wageningen University & Research, and ILRI/CCAFS. The national agricultural research centers in the countries (Ethiopian Institute for Agricultural Research [EIAR], Kenya Agricultural and Livestock Research Organization [KALRO], and Rwanda Agricultural Board [RAB]) are principal national implementing partners; they will be co-developers of the LSC-hubs as well as beneficiaries, as their capacity is being built and strengthened through this action. In addition, a number of (knowledge) institutions will be involved to provide specific input in the process including ASARECA, ICRAF, IUCN, Agro-Cares, and DLR.

4. Verification of outcomes

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4.1 ISFM, SWC, and Productivity

The finding in Chapter 2 about the impact of rainfall and soil variability on natural and human-induced regeneration of the Sahelian region, and the quantification of the attainable yield levels in Chapter 3, suggests that Integrated Soil Fertility Management (ISFM) is key to breaking the upper yield limits. To increase productivity and resilience of the system, ISFM practices targeted to location specific conditions should be deployed, integrating organic inputs, soil amendments like lime and rock phosphate, use of mineral fertilizer, improved germplasm, agroforestry, water harvesting, rotations or intercropping with legumes, and crop-livestock systems.

Application of organic amendments, in situ or available in the vicinity, is an important source to replenish soil nutrients and improve soil health, but with the availability of about 10% of the organic amendments needed to sustain productivity levels, yield will decline over time (Bationo et al., 2020). Supplemented with mineral fertilizers, yields can even increase over time (Bationo et al., 1998). However, these dynamics will differ strongly depending on the interplay between multiple production factors, such as soil type, amount of organic matter available, amounts of supplemental mineral fertilizers, and rainfall. Fertilizer microdosing at rates of 10-20 kg ha^{-1} can increase cereal yields by 0 to 100% at yield levels below 1 t ha^{-1} (Bielders and Gérard, 2015; Aune et al., 2017; Bationo et al., 2020), but is unable to sustain those yield levels ,which decline over longer periods of time (Adams et al., 2016). These authors find higher yields at recommended rates of around 40-50 kg fertilizers ha^{-1} decline over time as well for the sandy soils in Sadore, Niger, and organic amendments unable to increase soil organic matter due to high rates of decomposition and lack of nutrients. It should be noted that the fertilizers applied may not have covered the spectrum of required nutrients to sustain organic matter and yield. Carbon sequestration, which is essential to improving soil health, will be feasible only with appropriate fertilization, given that every 200 kg of stable soil organic matter (100 kg C) sequestered also sequesters 10 kg N, 1 kg P, and 1 kg S. Nitrogen fixation by legumes, for instance, will remain low because of unavailability of phosphorus and other nutrients.

These and a vast number of other findings between 1960 and 2020 (Breman et al., 2019) suggest natural processes alone to be inadequate to sustain soil productivity given the growing need for food.

The site specificity of ISFM has been demonstrated by research conducted by IFDC (Youl et al., 2013). Around 10 sorghum trials were conducted in Kouare, Banfora, and Saria with low rates of fertilizer application treatments aimed to identify most limiting N, P, and K nutrients with and without manure, and in some instance with the addition of dolomite, during 2012-2013. Also, a double dose of P was applied on these P-limited soils (Tables 8 and 9).

Table 8. Soil characteristics in experimental locations.

Village	Soil Type	Soil OC ($g\ kg^{-1}$)	Soil TN ($g\ kg^{-1}$)	Soil AvP ($mg\ kg^{-1}$)	Soil ExK ($Mmol\ kg^{-1}$)	Soil pH_H_2O	Crop
Critical level			0.4-1.5	11-31	0.4-1.9	< 5.5	
Kouaré	Haplic Lixisols	4.23[a]	0.33	2.7	6.8	5.6	Sorghum
Banfora	Haplic Lixisols	5.50	0.39	3.4	2	5.7	Sorghum
Saria	Pisoplinthic Plinthosols	3.34	0.26	2.2	NA	4.5	Sorghum
Kouaré	Haplic Lixisols	2.75	0.22	6.3	5.7	4.9	Maize
Banfora	Haplic Lixisols	5.50	0.39	3.4	2	5.7	Maize

[a.] Values in red indicate levels below critical levels for adequate crop growth.

Table 9. Trial treatments for sorghum and maize.

Treatment	N_m ($kg\ ha^{-1}$)	P_m ($kg\ ha^{-1}$)	K_m ($kg\ ha^{-1}$)	Manure ($t\ ha^{-1}$)[a]
0	0	0	0	0
NP	32	10	0	0
NPK	37	10	12	0
NP_hK	41	20	0	0
Manure	0	0	0	5
NP+Manure	32	10	0	5
NPK+Manure	37	10	12	5
NP_hK+Manure	41	20	0	5

[a] 5 t ha^{-1} manure is equivalent to 62.8 kg N, 15.6 kg P, and 116.0 kg K (see Figure 15).

The yield responses for both sorghum and maize reveal comparable patterns with a seemingly synergistic effect between mineral fertilizer and organic manure (Figures 10 and 11). Application of a double doses P did not result in yield benefits, likely due to the P-fixing nature of the soils and the likely inadequate supply of the other nutrients. Yet, the high soil acidity (low pH) together with low soil C and N in Saria suppressed the expression of mineral and manure addition on crop performance resulting in low responses. The soils in Kouaré only showed an overall response from the control with no further increases to mineral fertilizer nor manure. The soils in Banfora were most responsive, with strong synergistic effects between mineral fertilizers and manure in sorghum and to lesser extent in maize. Maximum yields of over 2 t ha^{-1} for sorghum and over 3.5 t ha^{-1} for maize were recorded.

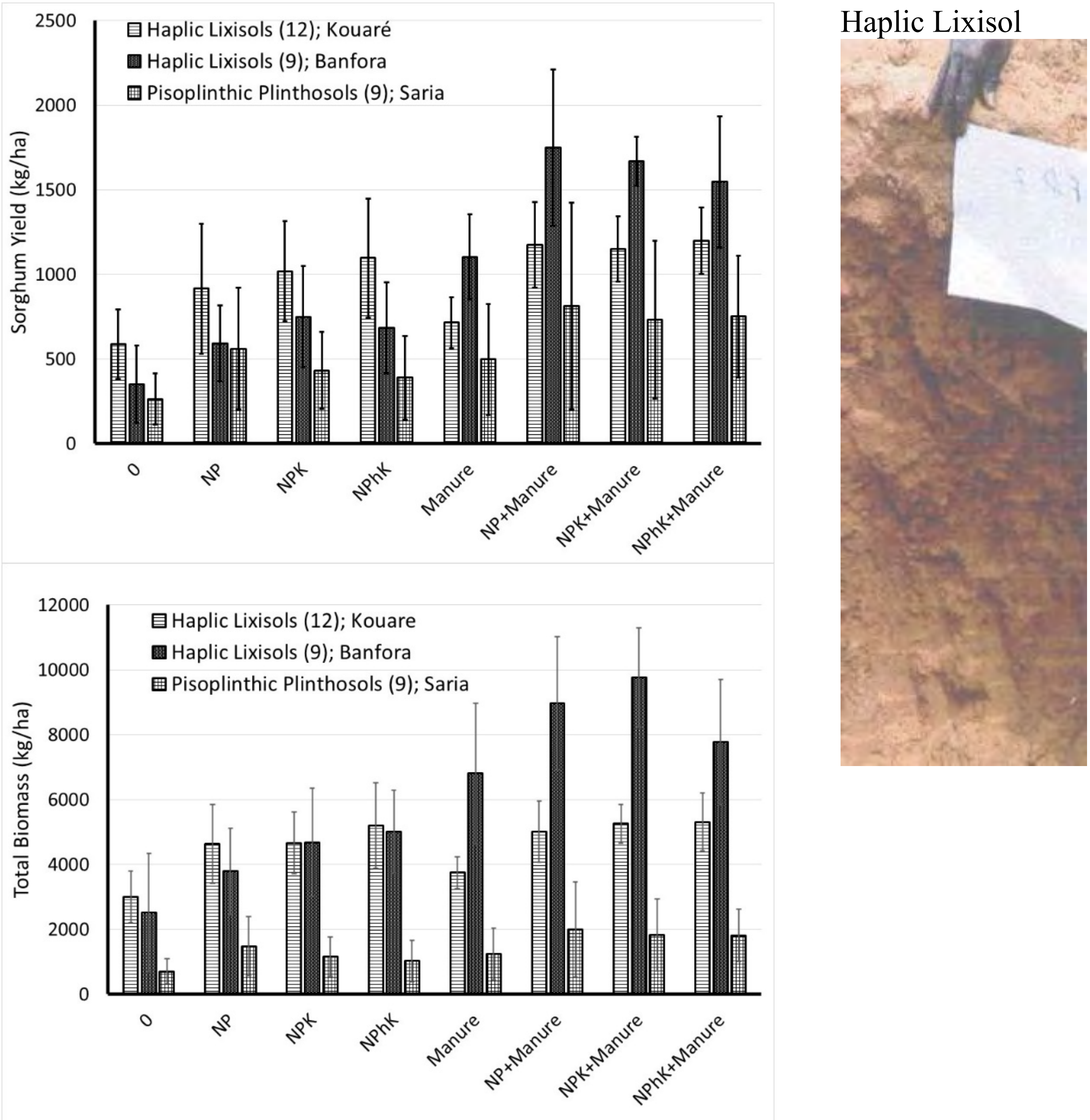
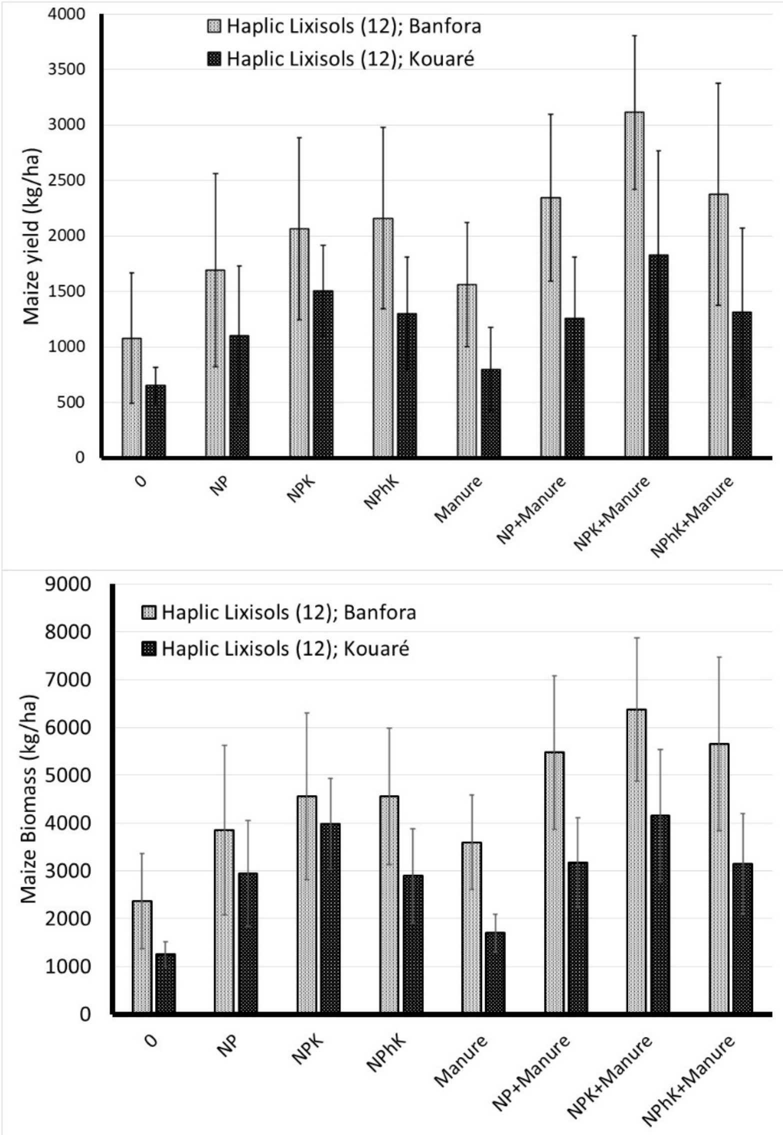


Figure 10. ***Effects of organic and inorganic fertilization on sorghum yields (top) and biomass (bottom) in 21 trials in Haplic Lixisols near the towns of Kouare and Banfora and 9 trials in a Pisoplinthic Plinthosol in Saria in 2012. Bars indicate standard deviation (data from Youl et al., 2013). (Soil profile courtesy of J. Leenaars).***



Pisoplinthic Plinthosols

Figure 11. ***Synergistic effect of organic and inorganic fertilization on maize yields (top) and biomass (bottom) in Haplic Lixisols on 12 trials in Kouare and 12 trials in Banfora in 2012. Bars indicate standard deviation (data from Youl et al., 2013). (Soil profile courtesy of J. Leenaars).***

Yet, the role of organic or green manure may not be overstated. Figure 12 presents the same data as in Figure 10 and 11 but plotted against the total amount of nitrogen applied to the crop, including the nitrogen from the 5 t ha^{-1} of manure. Except for the Haplic Lixisols in Banfora, there seems to be no synergistic effects, but rather cumulative, simply from the higher application rates of N. In some instance, organic amendments may even immobilize nutrients for plant uptake.

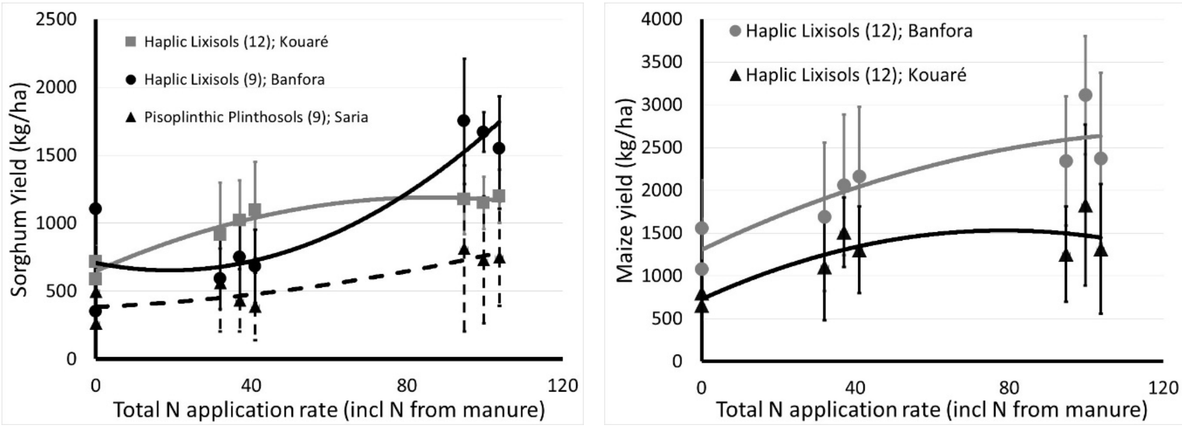


Figure 12. ***Sorghum and maize yield response against total N applied from both mineral fertilizers and manure. Bars indicate standard deviation (data from Youl et al., 2013).***

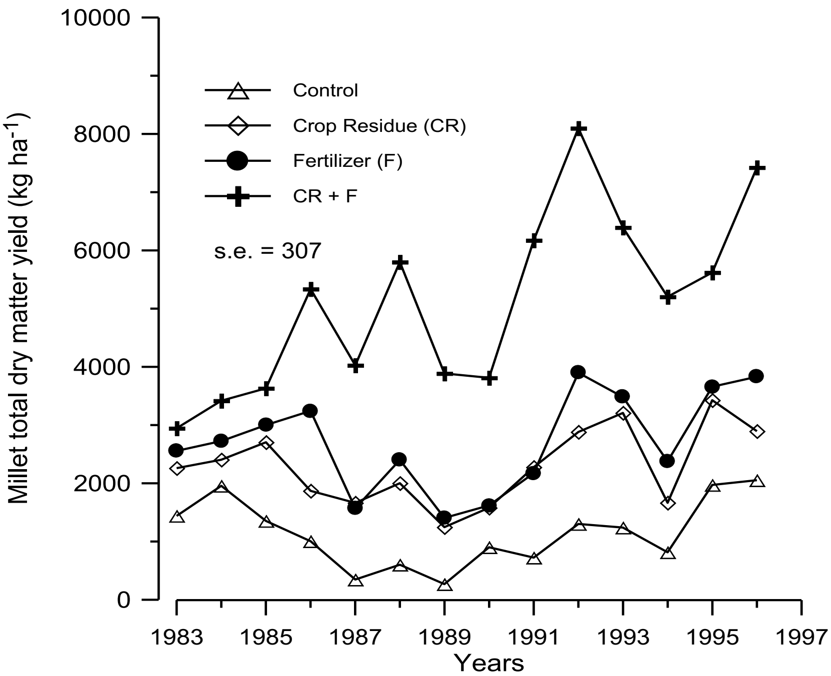


Figure 13. ***Pearl millet total dry matter yield as affected by different management practices over years (from Bationo et al., 1998).***

These combined effects have long been well known to exist, with Figure 13 illustrating the temporal dimension. Here, crop residues at 2 t ha^{-1} and the annual application of 13 kg P ha^{-1} plus 30 kg N ha^{-1} led to large additive effects (Figure 13). Notably, the levels of soil organic carbon were lowest at 1.7 g kg^{-1} at 0.1 m soil depth in unmulched control plots and highest at 3.3 g kg^{-1} with the combined application of residues and mineral fertilizers (Figure 14).

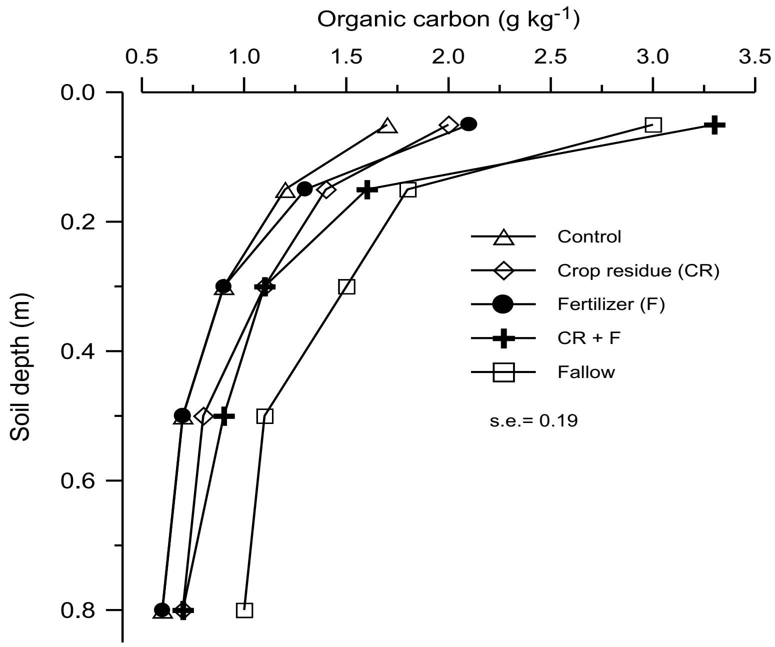


Figure 14. Soil organic carbon as affected by soil depth and management practices, Sadoré, Niger, rainy season, 1996 (from Bationo et al., 1998).

Also note that conversion of natural lands into cultivation areas leads to an overall decline in organic carbon, irrespective of the management practice, with the highest amounts found in adjacent fallow fields, especially in deeper soil layers (Figure 14).

Residue Management and Organic Amendments

Organic amendments are cherished to increase yield and enhance use efficiency of mineral fertilizers, as shown with the trials, and can potentially build up soil organic matter (e.g., Padwick, 1983). Yet, these effects are attained only at application rates in the range of 4 to 20 t ha^{-1} or more. Application of these massive amounts is not likely to be feasible for most farmers. Apart from use of green and animal manure for other functions, such as fuel, the costs and logistics of moving around these massive volumes and their handling in the field preclude widespread adoption.

De Leeuw et al. (1995) estimated that the collection of all available manure in the Western African Sahel suffices to supply annually a mere 2.5 kg N and 0.6 kg P ha^{-1} arable land, equivalent to about 2 t manure ha^{-1}. These rates are estimated to produce an additional 1.2 million t of grains. Manure rates in most of the on-station experiments, however, are between 5 to 20 t ha^{-1}, generating misleading information as quantities used by farmers may range from 1 to 4 t ha^{-1}, whereby only islands of higher application amounts exist for certain farmers with more than 50 cows (De Leeuw et al., 1995; Williams et al., 1995). Moreover, it takes between 10-40 ha of dry season grazing land and 3-10 ha of rangeland of wet season grazing to maintain yields on 1 ha of cropland using animal manure (Fernandez et al., 1995). Figure 15 presents the nutrient concentrations in samples of manure.

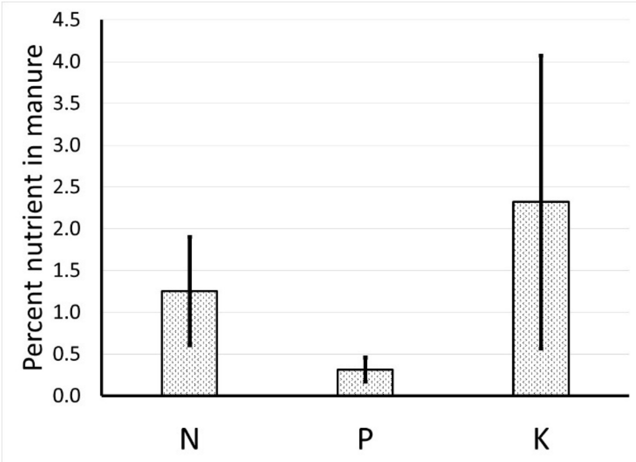


Figure 15. Percentage of N, P, and K in manure. Standard deviation indicates large variation in values. (Youl et al., 2013; data from Youl through personal communication).

In situ cultivation of green manure and crop rotations then become realistic options to maintain or improve soil health. Figure 14 also presents the changes in biomass production due to the fertilization treatments. Soil nutrients are being depleted in the zero-fertilization treatment, deteriorating soil health and productivity, and the inadequate availability of manure limits the reach of this unsustainable option. This is where the use of relatively low amounts of mineral fertilizers can change the downward spiral of degradation into an upward trend of steady increase in soil fertility and health, whereby sufficient biomass may remain, even after use by cattle, to cover the soil.

Interestingly, Bado (2002) demonstrates the higher resilience of cropping systems in a long-term trial (Figures 16 and 17). All crops have been fertilized. Mineral NPKSB complex fertilizer, manure, dolomite, triple superphosphate, and chloride of potassium were applied to the seedling. The mineral complex was applied basally at about 14, 10, 11, 6, and 1 kg N, P, K, S, and B ha^{-1}, respectively, while sorghum and cotton received an additional topdressing of urea totaling 40 kg N ha^{-1}. The manure was obtained from cattle in the stables of the Farakô-Ba and Kouaré research stations, and the compost produced at research stations from sorghum stalks. Manure and compost were applied at sowing at 3 and 5 t ha^{-1}, respectively. Residues were the straw or the tops of the previous crop that have been reincorporated every year in the ground. Dolomite was applied at 3 t ha^{-1}. The precise combination of these amendments depended on the treatments.

The fertilization treatments, including manure and compost, indicate that the yields obtained have been dependent on the input of nutrients collected outside the production field and "concentrated" on that field. This is a zero-sum game unable to drive sustainable agricultural intensification.

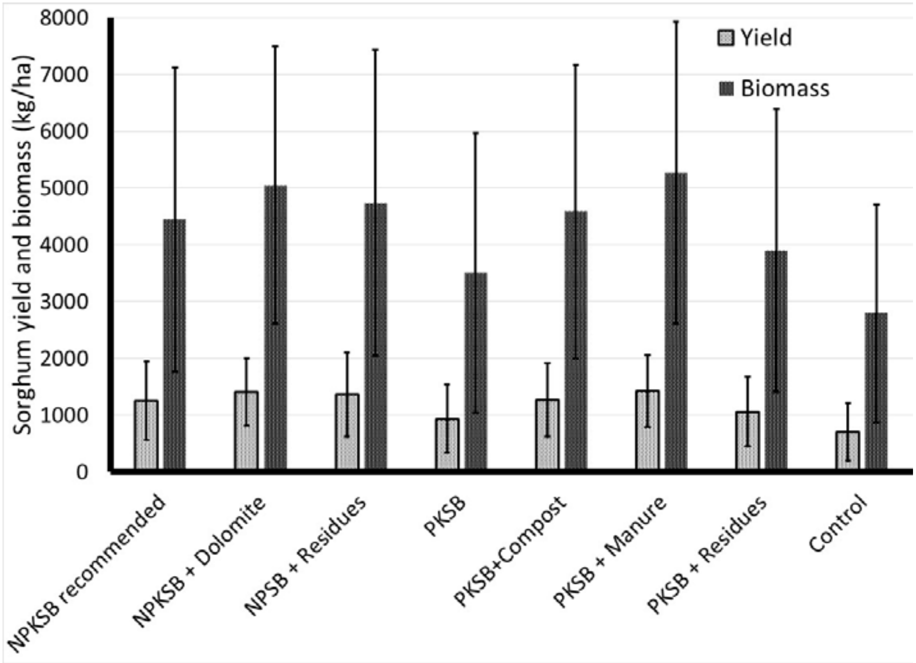


Figure 16. ***Impact of various organic and inorganic fertilization strategies on sorghum yield and biomass, averaged over nine seasons (for yield, biomass observed in seven years) in Farakô-Ba (data from Bado, 2002).***

All fertilization treatments out-yielded the control to a varying degree, with mineral NPK fertilizers and their combination with residues or dolomite being equal to or outperforming treatments that include manure or compost. Most interesting is the associated production of biomass that increases from around 3 to over 5 t ha^{-1}, generating the opportunity to cover the soil. Along with the ability of crop residues to restore soil organic carbon, judicious use of in situ–produced residues opens an opportunity to increase the overall productivity of the system and enhance its resilience through improved soil health.

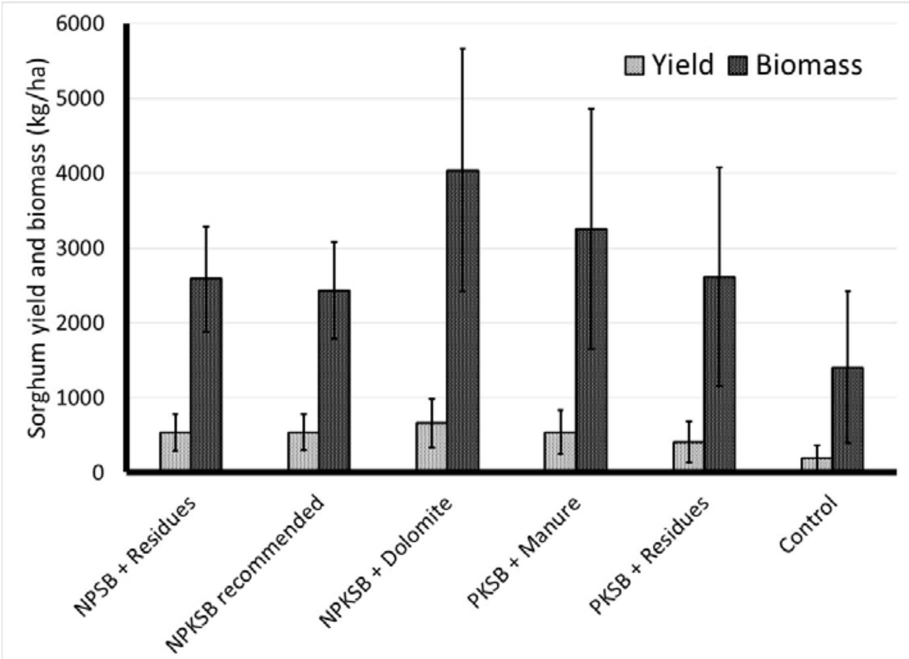


Figure 17. Impact of various organic and inorganic fertilization strategies on sorghum yield and biomass, averaged over nine seasons (for yield, biomass observed in seven years) in Kouaré (data from Bado, 2002).

Bado (2002) also researched the impact of crop rotation in sorghum yield (Figure 18). The author does not provide any argument for the decrease and subsequent increase in yield over time, except that the yields in the first year were considered to be very high. The trend does not relate to the rainfall pattern either and remains unresolved. Yet, the pattern remains the same for all cropping systems, suggesting no interactions with rainfall of fertilization. Continuous cultivation of sorghum results in allelopathic responses that suppress yield, i.e., the release of biochemical products by one plant that inhibit growth of another. While the fallow-sorghum rotation comes with higher yields it does reduce overall production due to the inclusion of a fallow. The inclusion of a leguminous crop tends to enhance the overall resilience of the production system.

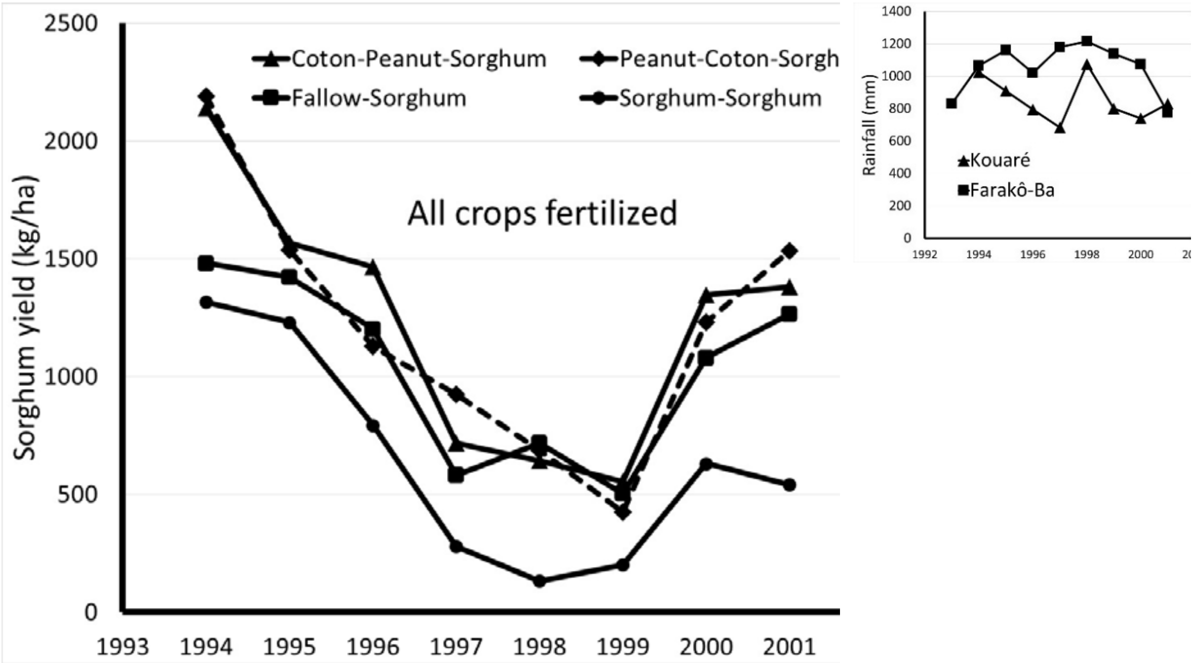


Figure 18. Impact of cropping patterns on sorghum yield in Farakô-Ba, Burkina Faso (left; derived from Bado, 2002); annual rainfall for Farakô-Ba and Kouaré over the same period (right).

4.2 Fertilizer Value Chain Burkina Faso

The total consumption of fertilizer increased steadily from 160 kt in 2000 to 265 kt in 2018 in Burkina Faso, yet the amounts of mineral fertilizer nutrients NPK supplies per hectare remained unchanged due to increasing acreage (Table 10). With 143 kt of NPK 15-15-15 and 72 kt of urea in 2018 (EnGRAIS, 2019), these products make up about 60% and 30% of the fertilizers in the country (Statistiques Burkina Faso, 2020). This stagnant supply also holds for the major cereals (maize, rice, millet, and sorghum) at rates that do not compensate for the nutrients extracted with the harvest of N and P, leading to soil nutrient depletion (Table 11; Figure 19). Obviously, this “average” figure is indicative only, as some farmers may use sufficient fertilizers that prevent soil nutrient mining, while others may use none, depleting their soils at a high rate.

Table 10. Application rate per hectare of the major nutrient in Burkina Faso.

Year	N	P	K
	kg ha^{-1}		
2010	11.2	1.3	2.4
2011	8.3	1.8	3.8
2012	12.1	2.0	3.8
2013	12.3	2.6	4.7
2014	13.6	2.7	6.3
2015	13.5	3.0	6.0
2016	15.9	3.5	7.2
2017	13.9	3.1	5.9
2018	13.8	2.7	5.8

Table 11. Crop specific actual fertilizer application rates in Burkina Faso in 2018.

	Nutrients from Fertilizers* (kg ha^{-1})			Amount in Yield (kg)			Yield (t ha^{-1})
	N	P	K	N	P	K	
Maize	17.1	3.3	7.2	20.4	4.6	6.3	1.7
Sorghum	11.4	2.2	4.8	18.7	3.2	4.1	1.1
Millet	7.9	1.5	3.3	13.6	1.9	2.9	0.8
Rice	18.8	3.7	7.9	16.5	1.7	1.4	1.5
Burkina Faso Average	13.8	2.7	5.8	-	-	-	-

* Fertilizer types: N-P-K 15-15-15, urea, DAP, MOP, other.

Note: Orange boxes indicate potential depletion of soil nutrients.

Source: Statistiques Burkina Faso, 2020; WAFA Factsheet, 2020.

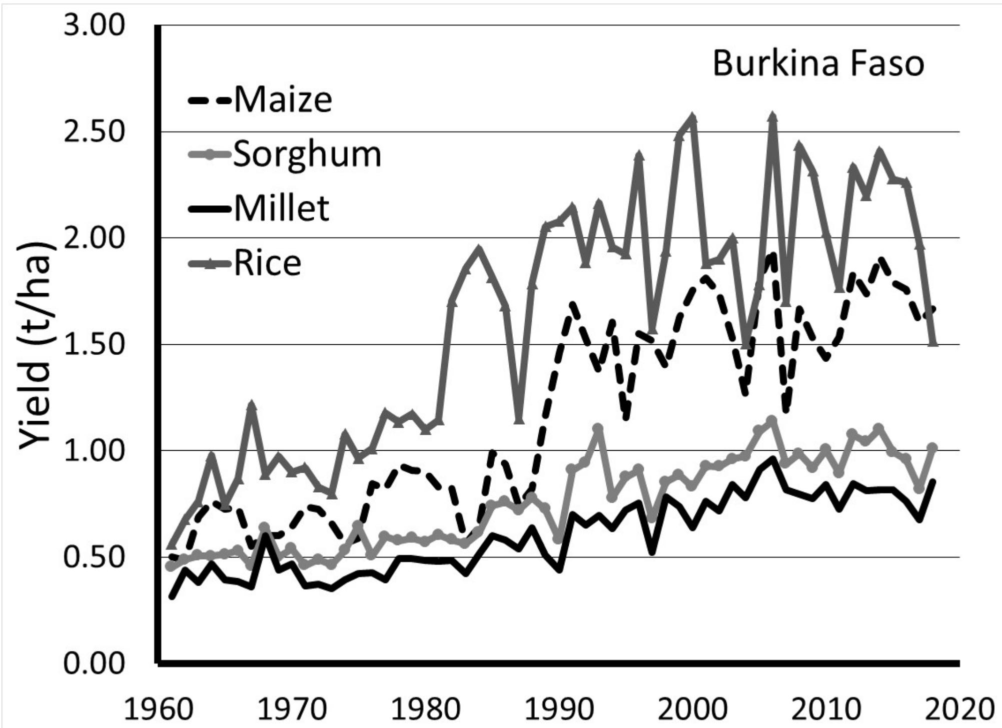


Figure 19. Yield trends of major cereals in Burkina Faso (data from FAOSTAT, 2020).

While fertilizers are being imported, a rock phosphate mine has been operational in eastern Burkina Faso since 2012. The PR is being grinded to make phosphate available in 50 kg bags for local consumption and is used as a soil improver. The nominal capacity of 2.5 t h^{-1} and can produce 6000 t y^{-1} of phosphate. The volumes produced increased from 1,320 tons in 2018 to 1,800 tons in 2019. Installation of a fertilizer blending unit with capacity of 120,000 t y^{-1} with start-up expected in 2021.

The production of organic fertilizers is mainly carried out by three actors with the production volumes increasing from 1,000 tons in 2018 to 3,100 tons in 2019.

Fertilizer costs in West African production zones depend mainly on the global fertilizer costs, which can vary by +/- U.S. \$50 t^{-1} in the space of a few months. With such strong competition in the West African market, all stakeholders in the fertilizer value chain are already working toward optimizing their logistics (Figure 20). The FOB reference price for urea and NPK 15-15-15 is U.S. \$275 t^{-1}, while the farm gate retail price reaches \$479 and \$496, respectively, in Burkina Faso, an increase due to handling, storage, and transport of 70-80% (EnGRAIS, 2019). These additional costs for Burkina Faso are not different from costs in importing countries like Ghana, Côte d'Ivoire, Senegal, and Togo, suggesting that being landlocked may not necessarily come at a premium. Prices in Mali, however, are 100% higher than FOB prices. Despite the rather efficient logistics, the EnGRAIS program (2019) still has identify various options that could reduce the inland costs.

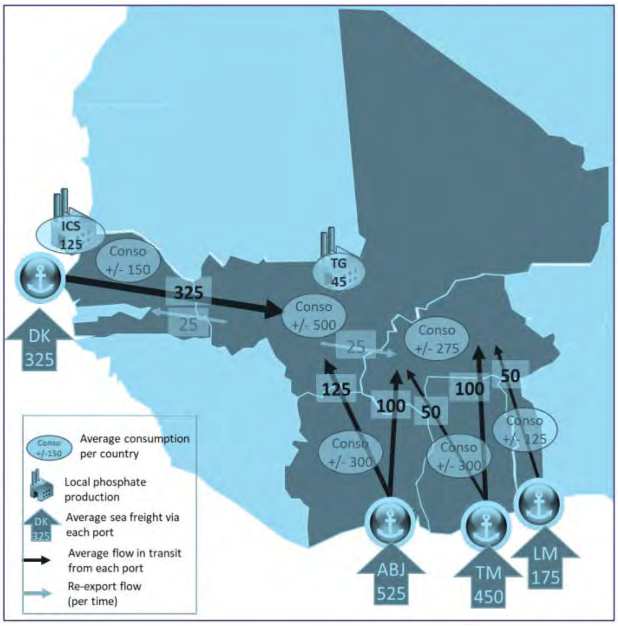


Figure 20. ***Fertilizer imports, flows, production, and consumption in the six countries unlocking the landlocked Mali and Burkina Faso. Figures are averages over 2015-2018 in thousands of tons. (from EnGRAIS, 2019)***

A significant challenge in the region is proper management of fertilizer subsidies. Following the financial and food crisis in 2008, and to overcome the low use of fertilizers, the Government of Burkina Faso implemented an input subsidy program, as have various other West African countries. Subsidies do stimulate increased use of fertilizers, but the operational efficiency to reach target farmers is hampered and they distort effective operations of the market (e.g., Coulibaly and Savadogo, 2019; Odionye et al., 2020).

Fertilizer subsidies could be much more effective through a pre-order voucher system, unrelated to a specific fertilizer formulation. This would allow importers and dealers to optimize their logistics according to their market share, distribution network, and investment strategy, as they could better anticipate demand. Farmers could obtain the fertilizer products best fit for their cropping system on time (EnGRAIS, 2019).

Challenges in the fertilizer value chain could be best addressed through dialogues between stakeholders. In Ghana, Aremu et al. (2020) found that interviewed stakeholders responded positively to the idea of establishing a multi-stakeholder fertilizer platform. At the regional level, the West African Fertilizer Association (WAFA) was installed by the fertilizer sector players, now comprising 28 companies from nine countries, with the aim of sharing common opportunities and difficulties and finding sustainable solutions to promote sustainable agriculture. With the overall increasing volumes of the fertilizers market, the value chain may further evolve, yet the rate of increase is insufficient to increase the application rates per hectare or to prevent expansion of agricultural land into pristine ecosystems that comes with loss of biodiversity and emissions of greenhouse gases.

As presented, the combined use of in situ–produced organic matter with mineral fertilizers through an ISFM and water management approach will be essential to break the downward trend of soil degradation and agricultural expansion. An initial infrastructure and marketing approach are already present that would need to be further developed.

Box 4. Narrow Focus on Cotton is One of the Causes for Burkina Faso's Poor Soils

Cotton has always been the dominating cash crop that comes with challenges, primarily related to vulnerability to weather and price fluctuations. Agronomically, this dominance has caused negative effects on soil fertility and fertilization practices for other crops. Cotton is the currency earner par excellence and, as such, the main target market for fertilizers. Fertilizer formulations, blending capacity, and distribution infrastructure are all practically geared toward serving the cotton sector.

Farmers in sectors other than cotton experience difficulties in accessing proper fertilizer products, with devastating effects on their crop performance and soil health. The problem is even more pronounced, since many farmers combine cotton cultivation with other crops; growing cotton is the main (if not the only) way to gain access to fertilizers through contract farming arrangements with the cotton companies. Farmers that do not intercrop with cotton are also affected by this "one-size-fits-all" approach to soil care and fertilization.

Altering this situation to support non-cotton farmers is a major challenge due to existing infrastructure and organizational structures. The commercial relevance of other sectors was simply considered too low to invest in, while the total capitalization of agro-export sectors, such as cashew, oil seeds and mango, is too limited to drive change.

Fortunately, initiatives are being supported to transform the fertilizer value chain. IFDC has implemented large programs to improve the sustainability and inclusiveness of cotton with the private sector embracing those changes. IFDC also supported the development of the national strategy and action plan on ISFM from 1996 to 1998 and supports the government in the implementation of its ISFM strategy. Other national and international initiatives and public-private endeavors are gearing up to drive change.

The international fertilizer market is dominated by a dozen large multinationals. Major international players are also currently taking initiatives to develop the fertilizer market in Burkina Faso. While one of the largest international fertilizer producers has been the best-known fertilizer manufacturer in the region for years, another major player has recently launched a campaign to become the leading supplier in the West African sub-region. To this end, it is investing heavily in capacity, marketing, and distribution but also in improved and more tailored solutions for farmers and in technical assistance and knowledge transfer. The company has launched three initiatives in Burkina Faso aiming to improve soil conditions and crop performance:

- A program, among others, to provide training on proper fertilizer use and ensure, in collaboration with local distributers, the supply of proper fertilizer and other inputs.

- Agronomic trials and on-farm demonstration plots to test new fertilizer solutions on the main crops.
- A mobile laboratory to reach farmers in remote areas to raise awareness on soil testing, soil fertility management, and good agricultural practices and to provide fertilizer recommendations for smallholder farmers. To date, some 15,000 farmers have been impacted.

There is even some Netherlands involvement in the fertilizer value chain development in Burkina Faso related to knowledge transfer, blending equipment, and organic fertilizer exports (see Section 5.4).

While the challenges in the development of the fertilizer sector are significant and could be supported, the sector is under construction in Burkina Faso.

5. Strategizing Agricultural Development

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5.1 Development Programs and Impact

There is an urgent need for the development community to provide evidence of the impact from aid investments in addressing global challenges, instigated by dwindling public support for development assistance. Achieving FNS sustainably and in an inclusive manner, i.e., with significant participation of youth and women and reaching base-of-the-pyramid (BoP) consumers, is among the most notorious development challenges. While numerous success stories of pilot programs can be given, the biggest challenge is how to reach a large number of farmers and consumers.

The development discourse on attaining food security has advanced over the past decades from a rather agro-technological emphasis on agricultural production increase through the 1980s to then include socio-economic conditions with a strong focus on farm households and social justice and equity as the foundation. Development interventions were considered public activities, with governmental bodies, non-governmental organizations (NGOs), and research entities dominating the scene. Some institutions argued against the involvement of the profit-making private sector, which was seen to skew the power balance even more toward disfavoring resource-poor farm households. Since the beginning of this century, however, the plea for comprehensive participatory approaches with public-private partnerships (PPPs) in development of the food value chain has gained momentum with the active business-driven involvement of stakeholders and the need for creation of an enabling environment.

These dimensions of the development discourse were used by Van Wesenbeeck and colleagues (2020) as a foundation to develop an analytical framework for review of R&D projects conducted under the auspices of the Netherlands Science Foundation (NWO) following policy priorities from the Netherlands Ministry of Foreign Affairs Directorate-General for International Cooperation (DGIS) to improve FNS. They developed a theory of change (ToC) that presumes IF the good agricultural practices, inclusive value chains, and enabling conditions are put into place through the identified activity domains, THEN actors' capabilities and power relations will be enhanced, allowing them to make informed decisions about their actions toward sustainable practices that will augment the resilience of the food system and improve FNS. They argue that all three intervention domains must be addressed simultaneously for impact at scale.

Van Wesenbeeck and colleagues (2020) found that the research projects reached an output level only, while the outcomes, let alone the impacts, were beyond the project scope due to the limited reach from the financially small and short-term approach. The lessons learned reveal that change processes should involve multiple actors and simultaneous intervention in various domains and at various scales over a longer duration, adjusted to local specific conditions. It therefore remains questionable whether lessons learned from financially small and short-term projects with unverified outcomes are relevant to long-term processes aiming at real transformation.

Here we will use this ToC to disentangle the pathways pursued in larger national, bilateral, and multilateral programs (Figure 21).

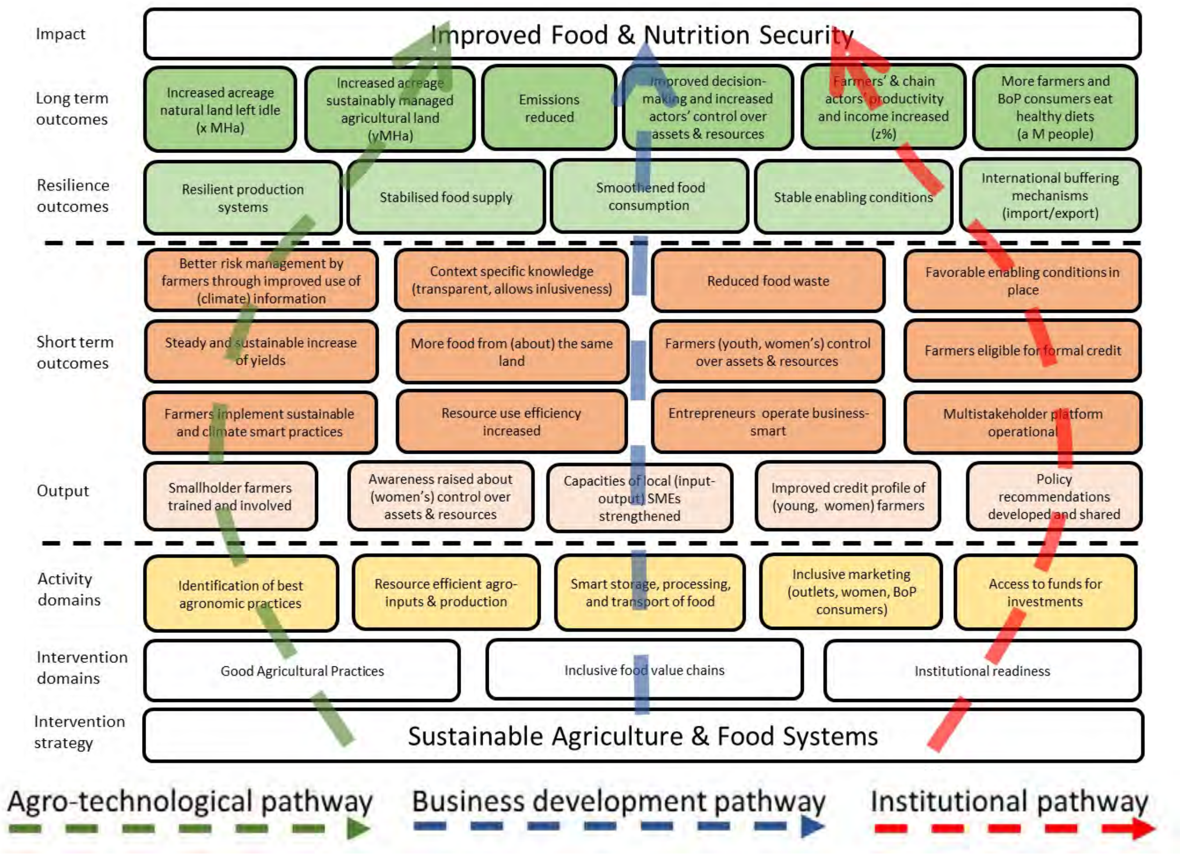

Figure 21. A comprehensive ToC encompassing three pathways to be addressed simultaneously to reach impact at scale on FNS (modified from Van Wesenbeeck et al. [2020]).

5.2 Development Programs

In 2012, Burkina Faso adopted its National Rural Sector Program (PNSR) for 2011-2015 to be consistent with the sub-regional policies (WAEMU, NEPAD, ECOWAS) and the country's commitments (country declaration, Maputo Declaration, Millennium Development Goals). Its general objective was to "contribute to strengthening the foundations for sustainable rural development that generates robust and sustained rural sector growth to combat poverty and food insecurity." The PNSR is based on the principles of (1) good governance, (2) human capital development, (3) gender mainstreaming, (4) reduction of regional disparities, (5) mutual responsibility, and (6) strengthening of partnership.

The Development Strategy for Agricultural Sectors (SDFA) of the Ministry of Agriculture and Hydraulic Facilities (SDFA, 2018) for the period 2019-2028 recognizes soils of Burkina Faso to be fragile and degrading and will require proven techniques for conserving soil fertility and enhancing use of surface water. Yet, no explicit activities or budgets have been allocated to address these fundamental challenges. The vision of the SDFA is geared toward institutional strengthening for organized and structured performance to contribute to sustainably to food security, reducing poverty, and strengthening an inclusive growth of the national economy.

Annexes 1, 2, and 3 contain more detailed information about national, bilateral, and multilateral projects and programs. Based on their descriptions, the pathway pursued along the lines of the ToC (Figure 21) were assessed, and an overview is presented in Table 12.

Table 12. Recent and ongoing programs in agriculture, food, and rural development in Burkina Faso.

Program	Pathway	Remark	Period
National Projects and Programs			
1. National hydraulic development program, phase 1 (PNAH1)	Agro-technological		2017-2022
2. Agricultural production intensification program (PIPA)	Agro-technological	Some capacity building	2016-2020
3. Development of small-scale village irrigation (PPIV)	Agro-technological		2015-2020
4. Restructuring and valorization program of the managed plain of Niofila/Douna (PRMV/ND)	Agro-technological	Some capacity building	2013-2021
5. Project to strengthen the resilience of rural populations to climate change through the improvement of agricultural productivity (PRAPA)	Agro-technological	Some capacity building	2017-2020
6. Improving water management in rainfed agriculture systems to ensure food security in Burkina Faso: research and technological development (AGES)			2013-2015
Bilateral Projects And Programs			
7. Project of localized irrigation and agricultural resilience in Burkina Faso (PIRA-BF)	Agro-technological	Professionalizing women farmers' skills	2019-2022
8. Irrigation program in the big west (PIGO)	Agro-technological	Training	2016-2020
9. Project to improve agricultural productivity through water and soil conservation (PACES)	Agro-technological	Maintenance fund established for post-program activities	2017-2019/ 2020-2024
10. Small dams agricultural valuation project (PROVALAB)	Agro-technological	Value chain approach (not business development)	2017-2020
11. Resilience and food security project - central plateau (RESA - central plateau)	Agro-technological (+ institutional)	Financial mechanisms and processing capacity	2017-2020
12. Drip irrigation promotion project (PPIG)	Agro-technological (+ institutional)	Enabling conditions for marketing	2015-2019
Multilateral Projects and Programs			
13. Burkina Faso agricultural resilience and competitiveness project (PReCA)	Agro-technological + Business development	Helping value chain stakeholders to develop and finance their investments	2020-2025
14. Support project for agricultural sectors in the south-west, hauts-bassins, cascades and Boucle du Mouhoun regions (PAFA-4R)	Agro-technological (+ institutional)	Promotion and marketing	2020-2025
15. Project 1 of the program to strengthen resilience against food and nutrition insecurity in the Sahel (P1-P2RS)	Agro-technological	Storage and marketing facilities	2015-2020
16. Reclamation project of water in the north (PVEN) stage development	Agro-technological	Producers associations, training	2013-2021
17. Pensa and Liptougou agricultural development project (PDAPL)	Agro-technological	Institutional capacity	2016-2021
18. Agricultural development project in the soum zone (PDA-SOUM)	Agro-technological + institutional	Capacity building, organization of producers	2017-2021
19. Support project for the promotion of agricultural sectors (PAPFA)	Agro-technological (+ institutional)	Promotion of marketing	2018-2024
20. Regional support project for the initiative for irrigation in the Sahel-Burkina Faso (PARIIS-BF)	Institutional		2018-2024
21. Agricultural Productivity Program in West Africa (WAAPP)			2011 - 2016

The overview reveals that, by far, most of the program efforts are geared toward agro-technological improvement of the production system, primarily through small-scale irrigation and SWC, often accompanied by "training" of directly involved stakeholders – farmers, women farmers, extension officers, and irrigation managers. More recently, emphasis has been placed on improved storage hardware and capacity and on market access from an institutional perspective rather than through actual business development efforts for the stakeholders in the value chain. There seem to be few linkages to policy recommendations or policy adjustments based on the experiences and lessons gained to the program implementation.

An important feature in rural and agricultural development is that investment financing comes mainly from official development assistance that contributes about U.S. $250 million per year, with the central government providing around U.S. $55 million per year to the sector. Major donors in 2015 include USAID (41%), World Bank (16%), Germany (12%), Switzerland (5%), AfDB, European Union, and France. The areas of intervention are resilience, food security, water management, and value chain development. This dominating proportion of the donor contribution may have an overwhelming impact on the development of this sector in Burkina Faso.

The African Development Bank's strategy in Burkina Faso for 2017-2021, for instance, focused on two pillars: the promotion of access to energy and support to agriculture sector development to ensure inclusive growth. The agricultural development component focuses on improving water management to ensure food self-sufficiency, generate agricultural surpluses for processing, and develop agribusiness and employability in the rural sector. No mention is made in the plan about soil productivity enhancement.

Development projects or programs are executed, either:

- By the public administration, including local authorities, state companies, private companies, and governmental companies, or
- By an agency on the basis of a contract between the government and the execution agency, mostly NGOs, as well as private companies through the PPP or the technical and financial partners of the State acting as executing agencies.

5.3 Reflections on Development Programs

The PAPSA Program

The Agricultural Productivity and Food Security Program (PAPSA) was executed from 2012 to 2018, primarily funded by the World Bank and the Global Agriculture and Food Security Program, totaling U.S. $116 million. In Burkina Faso, rice yields in the lowlands of the program implementation area increased relative to the average rice yield in the nation (Figure 22, left). The acreage of rice impacted by the program increased in the program period to 9 kha, which, combined with the yield increase over that period, contributed an additional rice production of 10-15 kt, depending on the annual variation (arrow in Figure 22; right). The program impacted a total of about 13 kha, including millet, sorghum, maize, and cowpea, with yields on formerly degraded lands of 0.95, 1.25, 2.5, and 1.2 t ha^{-1}. The yield increases are presumed to have resulted from the use of higher yielding variety, combined fertilization with mineral and organic fertilizer, enhanced water availability, and weed and pest control.

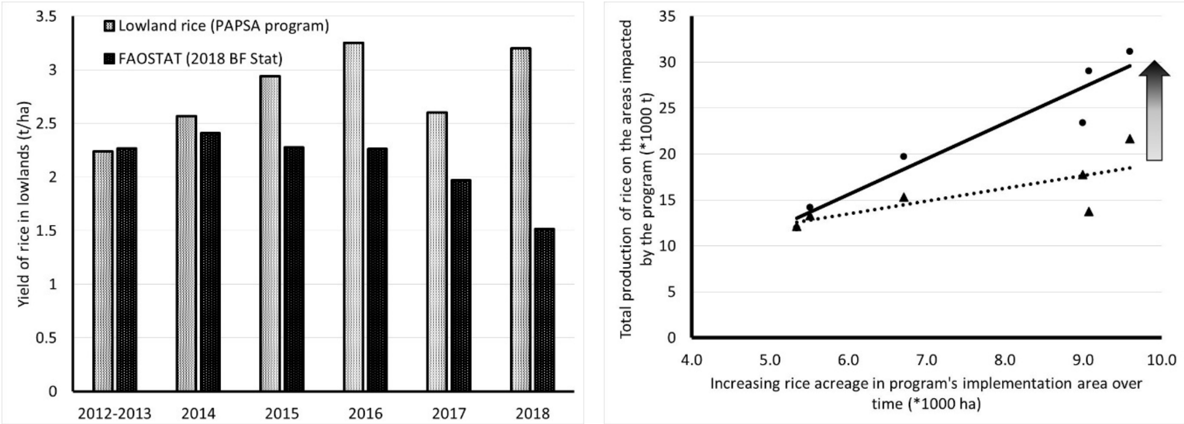

Figure 22. ***Impact of the World Bank's PAPSA program on rice yields relative to national average yield (left) and total production on the impacted rice acreage (right; straight line) as compared to national yield levels (right; dotted line).***

World Bank's West Africa Programs WAAPP and FSRP

The World Bank has shifted since 2008 from a country-level to a regional approach of financing agricultural research in Africa for productivity increase by facilitating regional cooperation to generate and disseminate differentiated, but regionally more appropriate technologies through the establishment of national centers of excellence. Through this mechanism in its West Africa Agricultural Productivity Program (WAAPP) of close to U.S. $500 million over a 10-year period starting in 2008, the World Bank aimed to contribute to agricultural productivity increase by generating and disseminating improved technologies in 13 participating countries, including Burkina Faso. The program made a significant contribution to regionally oriented research and trained over 1,000 scientists (30% female), establishing nine centers of excellence, and upgrading research infrastructure. Yet, due to its focus on prioritized commodity, important "orphan crops," such as yam and cowpea, that are highly important for the region were omitted. Moreover, the technology transfer by bringing researchers, extension services, cooperatives, and other civil society organizations to work together needed attention to reach scale (Stads and Beintma, 2017).

WAAPP-Burkina Faso was conducted from July 2011 to June 2016 for U.S. $21 million, targeting fruits and vegetables, particularly mango, onion, and tomato. The approach pursued centered around the integration and harmonization of national agricultural policies and linking research, extension, producers and private operators for development and adoption of improved technologies. It aimed to increase productivity by 15% on 100 kha, benefiting 200,000 people, of whom 40% were women.

Through 2016, the program directly benefited over 6 million farmers, processors, and small businesses across the region, of whom 45% were women. WAAPP is estimated to have increased food production in West Africa by more than 3 million tons and raised beneficiary incomes by an average of 34%. It delivered around 160 climate-smart crop varieties, technologies, and techniques to approximately 5.7 million farmers, covering 3.6 million hectares. These technologies have boosted productivity by up to 150% (World Bank, 2020b).

Despite the achievements of WAAPP and of other initiatives, agricultural productivity continues to be low and highly variable. Reaching scale appears to be a significant challenge. Building on the results from WAAPP, the World Bank is transforming the program into the

West Africa Food System Resilience Program (FSRP) to be executed through regional coordinating bodies ECOWAS, CORAF, and AGRYMET. The program contains components on digital services, food systems productivity, and market integration. CORAF coordinates the component "Resilience and Sustainability of Food System's Productive Base," with a total budget of U.S. $450 million. The program is under development but continues to strengthen research and extension for adapting and adopting innovations and technologies for resilient food systems (U.S. $100 million) and, by introduction of sustainable practices in targeted areas, to strengthen food security (U.S. $350 million). The latter contains a component on land and watershed management for improvement of soils' fertility and water retention capacity, floodplains restoration and water mobilization, and irrigation development. While this provides an opportunity for linkages with third programs to enhance soil health and water management, the program again emphasizes the agro-technological production pathway, with some soft activities on training and extension, but lacks a business development focus. With that, it seems to pursue business as usual in aiming to attain FNS. There is a need, however, to develop actions that promote inclusive value chain development as the engine to drive ISFM within a broader context of food systems.

The PACES Project

The PACES project, funded by German aid, evaluates the combination of stone rows built on contour lines with water harvesting technology (zaï pit) and fertilizer use on sorghum grain yields (Table 13).

Table 13. Effect of SWC technologies on sorghum grain yields.

Treatment	Sorghum Grain Yield (kg ha^{-1}) 2018	2019
Stone rows + Farmers' Practice[1]	793.6[c]	535.2[d]
Stone rows + Zaï	841.2[c]	715.0[c]
Stone rows + Zaï + Urea	1,063.1[b]	870.9[b]
Stone rows + Zaï + NPK + Urea	1,428.7[a]	1,158.4[a]

[1] Farmers' practice: building stone rows on the contour lines with no application of mineral fertilizer.
[a, b, c, d] Indicate significant different values

The AGES Project

The AGES program aimed to improve water management in rainfed agriculture systems to ensure food security in Burkina Faso. Several SWC methods have been tested, including:

- Stone rows: rows of stones fixed on contour lines with rows spacing 30-50 m, depending on slope.
- Zaï pits: micro-basins of 30-40 cm diameter for 10-15 cm depth, dug in quincunx on lines with 80 cm spacing. The earth from the pit is disposed in the form of a crescent toward the upstream in order to capture the runoff water.
- Grass strips: biological barriers composed of herbaceous (*Andropogon gayanus* or other grass), set in the fields following the contour lines. The strips have 30-50 m spacing, depending on the slope.
- Earth bunds of 80 cm wide, 30 cm height, and 33 m spacing are built on contour lines.
- Half-moon: micro-catchments made as semicircular earth bunds of 30 cm high. They are 15 cm deep with 4 m diameter and 4 m spacing between half-moons on the same line, 8 m spacing between lines passing at the center of the half-moons.

- Three levels of fertilization:
  - Organic Matter (OM): 5 t ha^{-1} per year (organic mixture of cow dunk and crop residues)
  - OM + urea 50 kg ha^{-1} (equivalent to 23 kg N)
  - OM + NPK (14-23-14) 100 kg ha^{-1} + urea 50 kg ha^{-1} (equivalent to 37, 10, 12 kg N, P, K)

Sorghum responses to their treatments are given in Figure 23. Farm practice includes building of stone rows on the contour lines with no application of mineral fertilizer. Synergistic or additive effects between OM and mineral fertilizer are confirmed and might be somewhat more pronounced with water conservation practices. Yet, OM application rates of 5 t ha^{-1} again rejects the notion of insufficient availability to implement these practices at large scale. Importantly, the additional straw from the fertilizers could set an upward trend in soil health improving in motion.

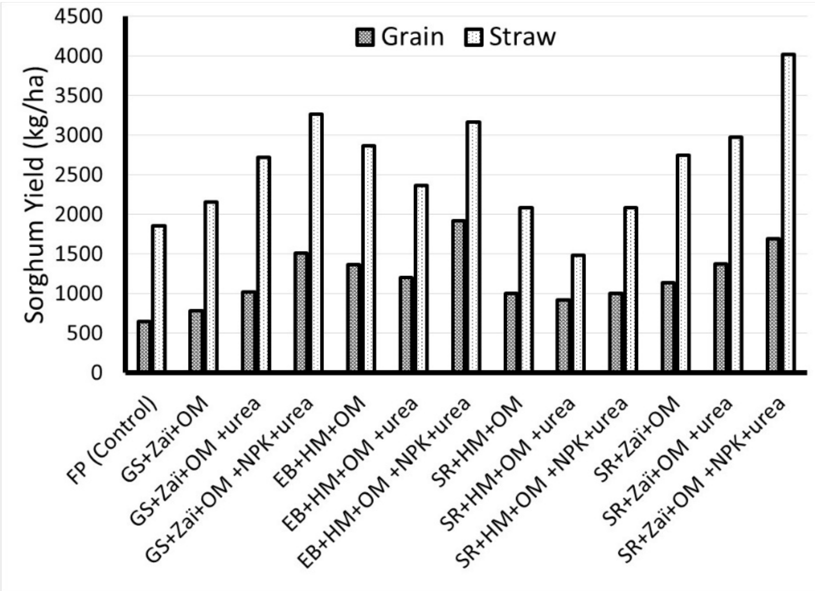

Figure 23. ***Grain yield and straw of sorghum under a range of SWC practices in Burkina Faso. FP = Farmers' Practice; GS = Grass Strips; OM = Organic Matter; SR = Stone Rows; EB = Earth Bunds; HM = Half-Moon.***

An important concept of ISFM is the increased efficiency of water use (Figure 24). The theoretical lower limit is around 600 liters of water per kilogram of grains, with 1,000 liters being a value of more practical use. The water use efficiency (WUE) increases under increasing controlled cultivation with higher yield levels (e.g., Rockström, 2003; Molden et al., 2010). The WUE observed under the various SWC practices seamlessly follows the standard curve (Figure 25), confirming the accuracy of the trial observations. Note that the highest WUE, i.e., the lowest amount of water needed per kg of grains, is obtained with fertilization.

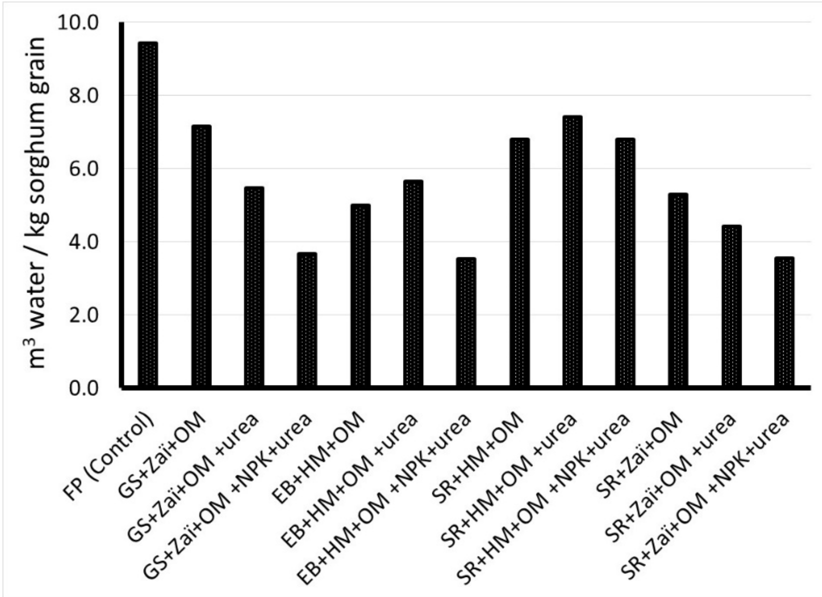

Figure 24. (In)efficiency of water use under different SWC practices.

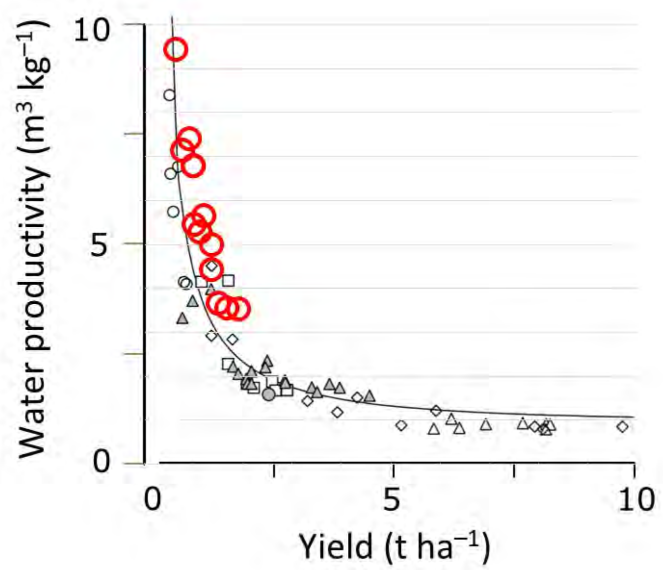

Figure 25. Dynamics of green water productivity (m3 kg^{-1} grain) and yield (t ha^{-1}). Data originate from evapotranspiration and yield observations for different tropical grains (from Rockström, 2003). Red circles are the WUE, as found in the various SWC practices of the AGES program from Figure 24.

Maize yields have been found to respond modestly to water conservation practices without mineral fertilization at the Péni site. This synergistic effect is also prominent in Houndé; water conservation does give an initial yield benefit. Yields with the use of fertilization (OM and mineral) can boost maize yields up to 4.5 t ha^{-1} (Figure 26).

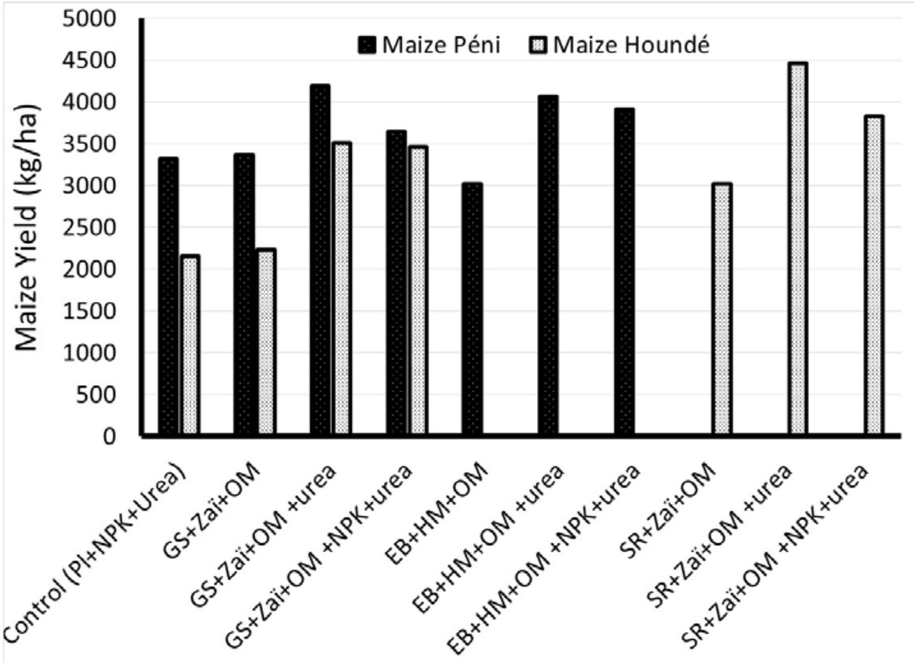

Figure 26. ***Grain yield of maize under a range of SWC practices in Burkina Faso. Pl = Plowing; GS = Grass Strips; OM = Organic Matter; SR = Stone Rows; EB = Earth Bunds; HM = Half-moon.***

The AGES Project: SWC Adoption and Impact

A detailed survey was conducted to identify the rate of adoption of SWC practices by farmers at the district (departement) level (Figure 27, left). Actual yield levels attained at the provincial level in Burkina Faso reveal an increasing trend from north to south associated with rainfall (Figure 27, right). Figure 28 indicates widespread use of manure, yet while some farmers with cattle may apply up to 5 t ha^{-1}, the overall quantities applied (of manure or compost; quantities not registered in the survey; personal communication K. Quattara) are unlikely to be anywhere near 5 t ha^{-1}, even at which rate yield increases are modest only (Table 13; Figures 23 and 24). While no firm conclusions can be drawn from this visual comparison, no apparent relation seems to emerge between water conservation technologies and crop yield levels. While adoption may be considered "high" and yields may have been higher on specific intervention spots, the overall impact on yield levels at the provincial scale seems limited. Also, these practices collectively seem not to have reduced yield variability over the past decades. This could suggest that these practices must be complemented with the use of mineral fertilizers to unlock the benefits of water conservation.

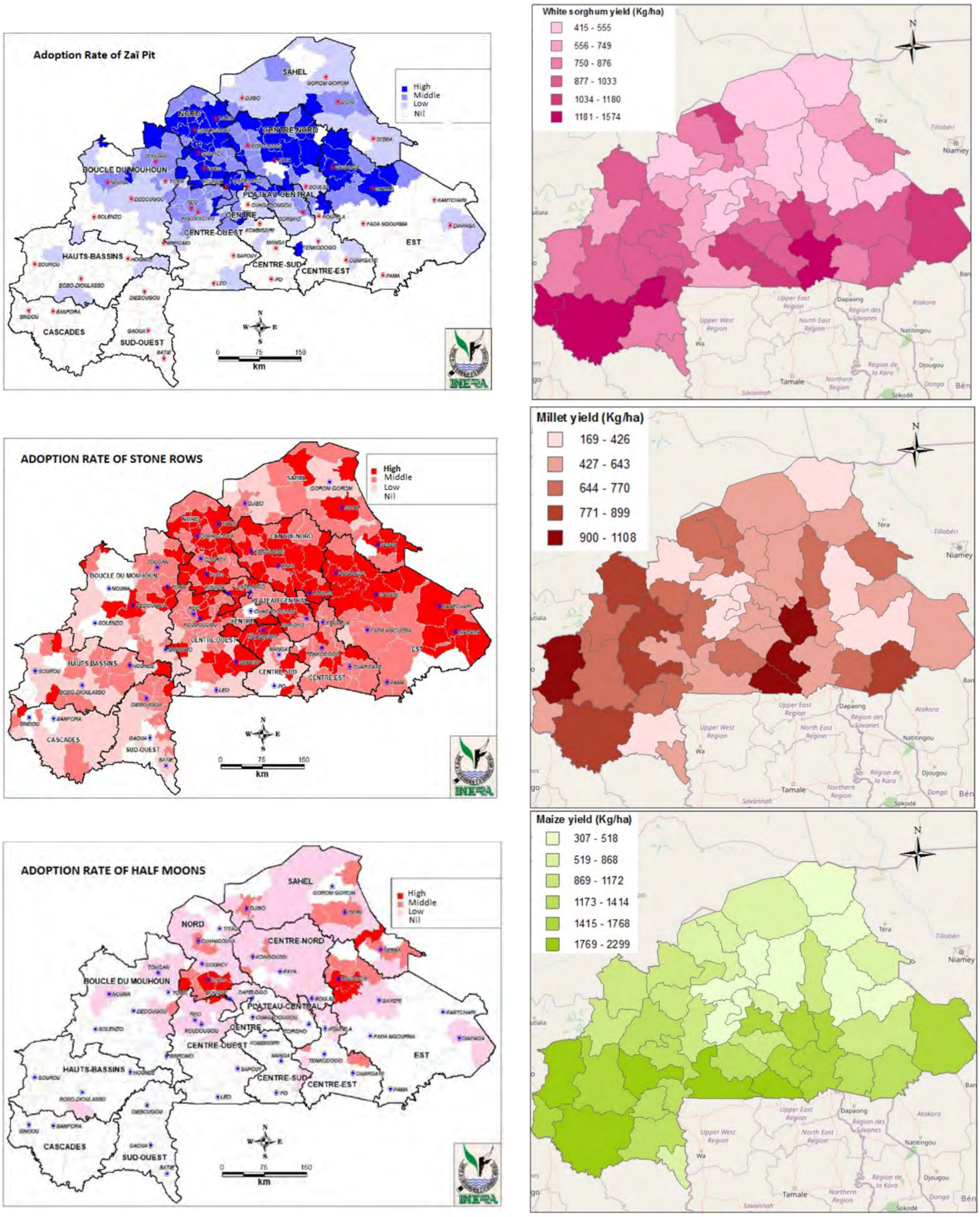

Figure 27. Adoption of water conservation measures in Burkina Faso (left; from INERA) and yield levels of sorghum, millet, and maize in 2018 at provincial levels (right; from EAtlas, 2020). High: >60%; Middle: 40-60%; Low: <40%; Nil: 0% of famers adopted the practice.

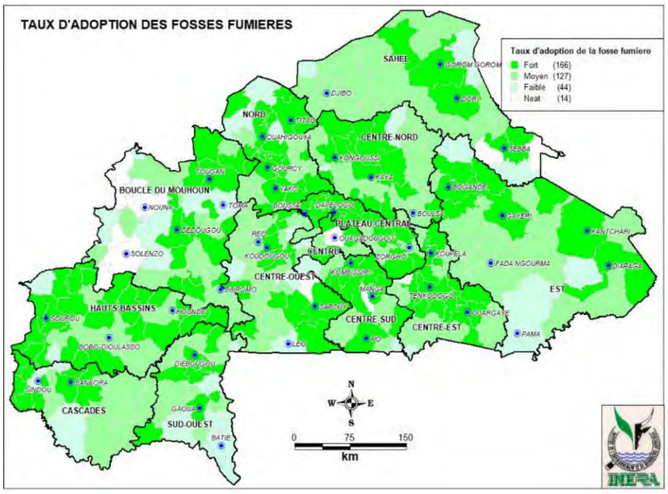

Figure 28. *Use of manure by farmers. High: >60%; Middle: 40-60%; Low: <40%; Nil: 0% of famers using manure. The number indicates the number of districts in the category.*

Synthesis Development Programs

Most of the program activities and achievements could be synthesized as depicted in Figure 29. Most efforts of rural and agricultural development programs are geared toward agro-technological improvement of the production system. Emphasis is placed on small-scale irrigation and SWC that may be accompanied by "training" of directly involved stakeholders – farmers, women farmers, extension officers, and irrigation managers. More recently, emphasis has been placed on improved storage hardware and capacity and on market access from an institutional perspective. Yet, actual business development efforts for the stakeholders in the value chain are no part of the programs. Hence, the most direct impact is obtained by increasing agricultural productivity in the program target areas. Little is reported about the widespread adoption of these successes.

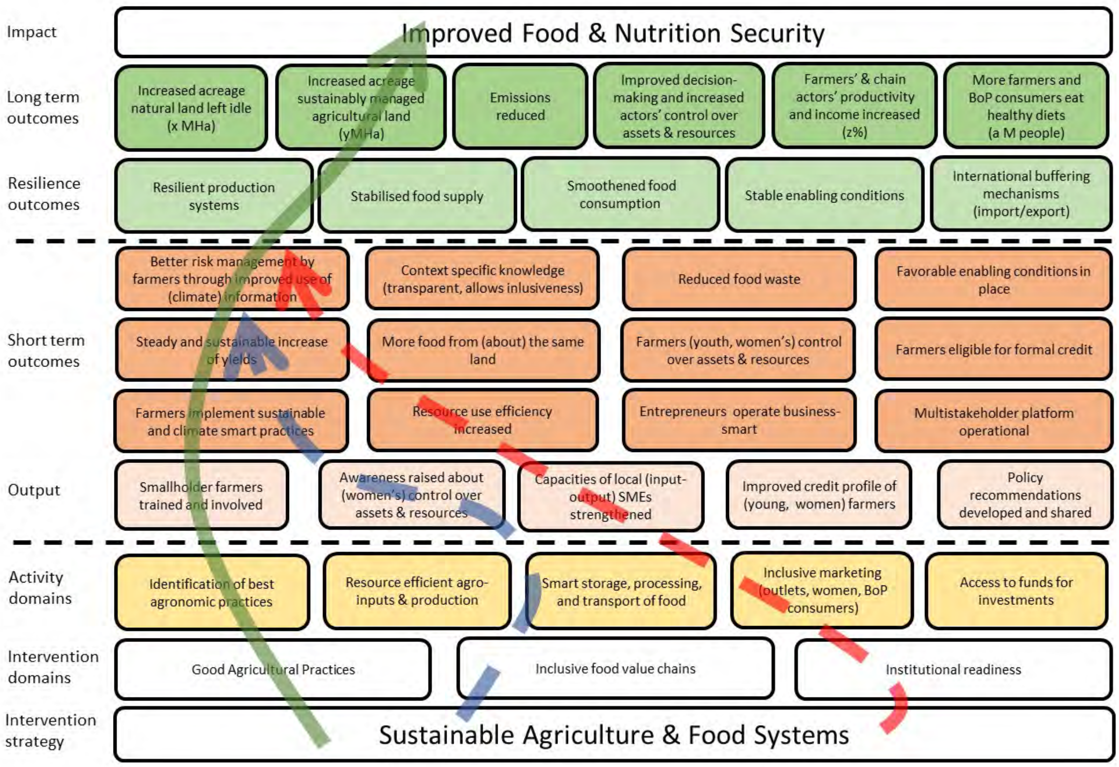

Figure 29. ***Schematic presentation of the avenues pursued by development programs in Burkina Faso. Solid line indicates tangible outputs and outcomes, while dotted lines indicate supporting activities geared toward supporting the agro-technological pathway.***

IFDC, as a non-governmental, nonprofit organization, has had a presence in Burkina Faso since 1996 to support research and development in agriculture and permanently opened its representation through a Memorandum of Understanding (MoU) with the Government of Burkina Faso in 2003 (Annex 6). In all its endeavors, IFDC operates closely with local institutions and the private sector in line with government policies to attain the greatest impact. Initially, many programs emphasized productivity-enhancing activities, supported by policy recommendations and policy development. Increasingly, IFDC's programs, including those in Burkina Faso, have been designed to support actors to create a favorable environment for the development of input-output markets, targeted to specific socially disadvantaged groups. Hence, apart from a prime focus on agro-technological improvements and policy support on regulatory measures for agricultural inputs, IFDC has transitioned over the past one to two decades into development of the food value chains as well.

While IFDC is able to attain its program objectives, long-lasting efforts and alignment with a larger program might further enhance its impact. The Government of Burkina Faso (through the Ministry of Agriculture, Water Resources and Fisheries) the African Development Bank group, and the International Fund for Agricultural Development (IFAD) have requested and are requesting IFDC to provide technical support for (1) development and dissemination of technological options for ISFM and agricultural intensification in the project area and (2) organization of actors to facilitate producers' access to agricultural inputs, markets, and various services, including finance, and capacity building of actors. These linkages need to be further exploited, while IFDC may aim to suggest incorporation of its unique expertise on value chain business development into these development programs to walk simultaneously along the agro-technological, business development, and institutional pathways.

5.4 Selected Netherlands Programs

The Netherlands is supporting farmers in the areas of food security, reforestation, water, climate, and energy, with specific attention on improving soil quality (Netherlands Ministry of Foreign Affairs, 2019). This section is not intended to be complete but to only reflect a few appealing programs and private initiatives related to agribusiness and soil health in exploration of the proposed pathways of the ToC (Figure 21). The Netherlands programs do address the agro-technological production pathway but are exploring novel approaches, primarily in local and international value chain business development.

The Dryland Development Program (DryDev)

With total funding of over €50 million from the Ministry of International Affairs, through DGIS, over the period from 2013 to 2019, the Dryland Development Program (DryDev) aimed to transform subsistence farming and emergency aid in dryland areas into sustainable rural development by reaching over 227,000 farmers, half of which women, across five countries, including Burkina Faso. A mid-term evaluation (Van Gerwen et al., 2018a) reveals that the program experienced a myriad of organizational problems, even confusion as to whether it was a research or an implementation program. The review (Van Gerwen et al., 2018b) revealed little connectedness with local policymakers and fragile linkages with communities in Burkina Faso, as well as unbalanced nutrient management practices with too little manure and organic matter for composting, while efforts around value chain development were in their initial stages. The final report of the program (DryDev, 2020) indicates that a total of 123,000 ha of previously degraded communal land were rehabilitated, over 90,000 hectares of farmland were put under improved soil and water conservation practices and climate smart practices applied on 53,000 ha. Application of SWC and climate smart practices was found to contribute to diversification and increase in crop yields, but increases were too localized to result in significant impact at scale. The impact assessment found no significant change in gross cash value of crops harvested at the program and country level (Figure 30). The report is indeed modest in its conclusions that “good results were delivered” with “many successful farmer stories” and the most important lessons to be the need for participatory action research from the start of the program.

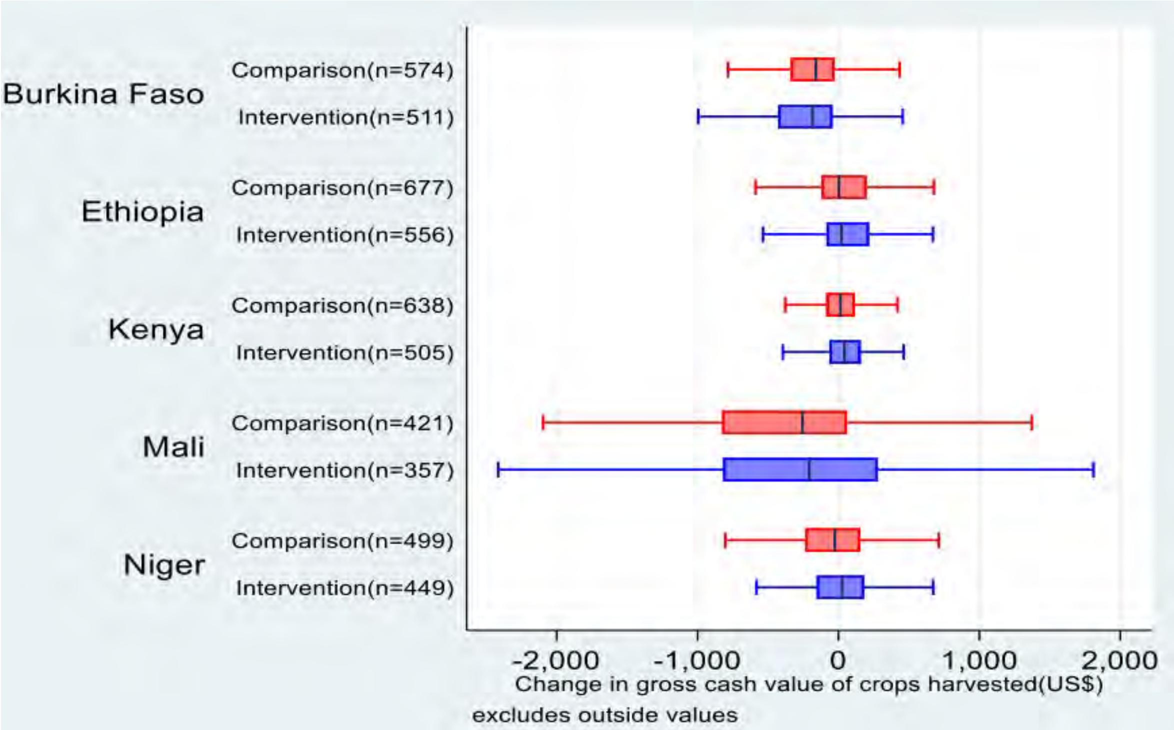

Figure 30. Change in gross cash value of harvested crops between DryDev sites and comparison sites (population not enrolled in the program).

The 2SCALE Program

The 2SCALE program is an incubator and accelerator program that manages a portfolio of PPPs for inclusive business in agri-food sectors and industries for small and medium enterprises (SMEs). With financial support from the Dutch government of over €50 million, the program developed 58 national and internationally linked PPPs from 2012 to 2018 during its first phase, increasing the opportunity to over 627,000 smallholder farmers (of whom 36% are women) to participate on fair terms in agribusinesses, agri-food chain, or food markets and to improve productivity, income, and FNS. It strengthened the capacity of 4,426 SMEs (32% female-led), of which 2,535 were producers' organizations, to improve sales and provide jobs while sustainably supplying food to regional, national, and local markets. Over 40% of the partnerships solely or specifically supplied products geared to reach BoP markets. Hence, the program reached all of its outputs and almost all of its outcomes (Oomes et al., 2018; 2SCALE, 2019b). Research is currently ongoing to assess the durability of the PPPs of this first phase, with specific emphasis on the inclusiveness component, i.e., reaching resource-poor farmers, disadvantaged groups like women and youth, and BoP consumers.

Key lessons drawn from the most successful partnership included (1) the need for a committed lead partner (champion), (2) business cases that were based on regional comparative advantages, (3) a focus on local networks to engagement and empowerment of local actors, (4) a facilitated and inclusive process to identify and co-develop opportunities, and (5) a strong entrepreneurial "learning-by-doing" spirit (2SCALE, 2019c).

The 2SCALE program has been extended with the aim to develop another 60 PPPs by the end of 2023 in six West African and three East African countries The second phase will continue to incubate inclusive agribusinesses, as in the first phase and, in addition, will also replicate their agribusiness through (business-to-business) cross-learning and construction of networks for sharing and adoption with the assistance of the leading PPPs. Moreover, it will facilitate (sub)sector system changes beyond the individual PPPs. This approach should scale the impact and allow PPP development for inclusive agribusinesses beyond the direct sphere of the program (2Scale, 2020).

The overall synthesis along the analytical ToC (Figure 31) would suggest a strong emphasis on business actions for value chain development with linkages to farm production to secure sourcing and creation of access to credit facilities to secure investment needs. The lines are straight, suggesting tangible outputs, outcomes, and impact long these paths. The program does not address widespread support to improve overall farm productivity or policy development or widespread adoption of institutional conditions, which would be well beyond its mandate and abilities. The agro-technological and institutional pathways, therefore, are servicing the development of the value chain rather than pursuing their path straight up for widespread impact.

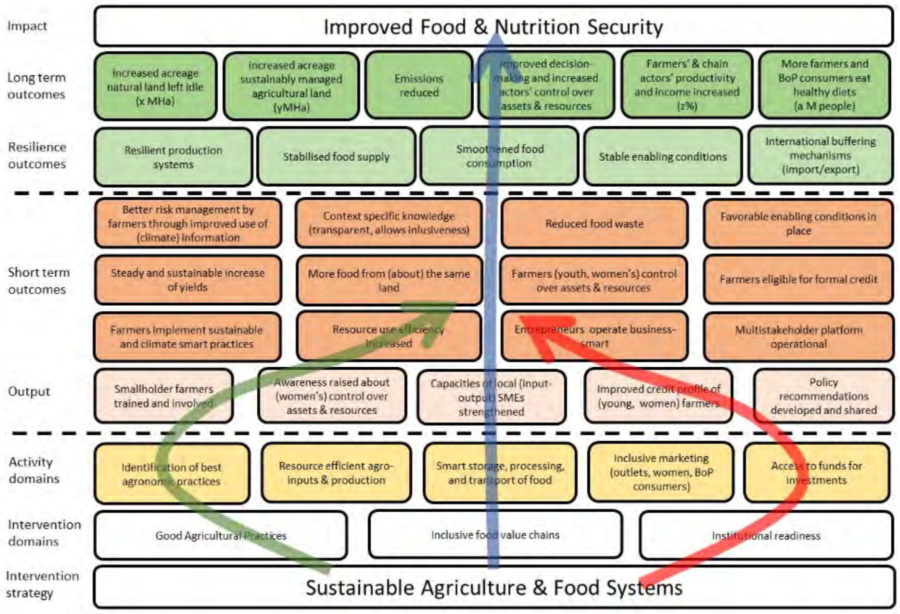

Figure 31. ***Synthesized development pathways pursued by the 2SCALE program (see text for explanation).***

Netherlands Agro-Business and Soil Health

The Netherlands agribusiness has developed various initiatives with agribusiness in Burkina Faso on demand. A large cooperative of leading producers of fruits and vegetables in Burkina Faso, united in the Union des Cooperatives Agricoles et Maraîchères du Burkina (UCOBAM), took the initiative to develop and implement an investment and technical assistance project to combat low productivity and post-harvest losses among its members. The project comprises investments in irrigation, mechanization, and storage to be supplied and co-funded from the Netherlands. UCOBAM is discussing with a Netherlands supplier to invest in the Zobam drip irrigation system that uses solar-powered pumps. Several smaller scale initiatives have demonstrated the feasibility of this agro-technological innovation.

The Nature & More program of the Dutch international distributor of fresh organic and fair fruits and vegetables from overseas developed an outgrowers scheme with about 400 farmers in Burkina Faso to grow mangos, intercropped with cereals and groundnuts, among others.

Farmers in the southwest of the country cultivate on average about 3 hectares of mango that is certified as organic and for fair trade. The local sourcing partner was established in 2005 by Netherlands NGOs ICCO and AfroFair. The trading business partners in both countries run a soil improvement program for their farmers, comprising awareness raising, technical assistance, and supply of inputs. This has resulted in significant improvements of soil conditions and a sharp increase of yields. In addition, there are social programs for drinking water supply and community gardens. The Dutch distributor is the first SME that carried out an income assessment for living expenses that resulted in an improved pricing scheme.

In Kaya, central Burkina Faso, some 100 kilometers north of Ouagadougou, the company Burkina Fresh was originally set up by the Dutch fruit importer in 2005. The company established drip irrigation infrastructure, provided inputs, and trained farmers on agronomy and soil management. Initially, the company exported green beans and mango to Europe for distribution in some major supermarket chains. Pressure by interest groups to reduce airfreight exports forced the company to shift from exports to Europe toward exports in the sub-region. The company is now supplying retailers in large urban areas, such as Abidjan and Accra.

The Government of Burkina Faso, through the National Development Project Bagré Pôle (growth pole of Bagré) in the southeastern Municipality of Bagré, aims to contribute to increased economic activity through an increase in private investment, employment generation, and agricultural production. Interventions include investment in irrigation canals to serve 15 kha of farmland and promotion of agricultural development by developing critical services and direct support to smallholders and SMEs, including partial financing of technical assistance and capacity building. Dutch suppliers of mechanization equipment and irrigation systems are exploring options for partnership.

Interventions by Dutch NGOs unfortunately mainly target Sustainable Development Goals other than the ones linked to soil fertility. A rare example of a project that has links is the She Sells Shea project by ICCO, co-funded by the Dutch government under the Facility for Sustainable Entrepreneurship and Food Security (FDOV) program and implemented in collaboration with private sector actors and local NGOs. It targets the value chain of shea butter and, to a lesser extent, other oil seeds.

Netherlands Involvement in the Fertilizer Value Chain of Burkina Faso

Agro-input suppliers and service providers are increasingly aware of the catalytic role they can play in countering soil issues in Burkina Faso's agriculture. Moreover, they realize that there are good business opportunities for them. Helping farmers improve their soil conditions will lead to increased yields and quality products and as a consequence to purchasing power.

Several local input suppliers and agro-dealers are developing plans to diversify their fertilization portfolio to arrive at more tailored plant nutrition solutions, addressing specific needs of farmers based on soil properties, water accessibility, and microclimates. One of the avenues is to invest in a fertilizer blending plant. A main blending facility may be developed by the Association of Wholesalers and Retailers of Agricultural Inputs (AGRODIA), which is working on a design with the Dutch supplier of fertilizer blending technology. Others fertilizer importers and distributors are working on investment plans for fine-tuning fertilizers to location-specific needs. Also, suppliers from Côte d'Ivoire, supported by Dutch technology, and Ghana are targeting Burkina Faso.

To utilize animal manure more effectively, there are several leading manufacturers of "organic fertilizers." Chicken manure, due to its high dry matter content, is known to be a highly useful raw material. Due to its abundant availability in the Netherlands from the highly concentrated intensive poultry industry, the Netherlands exports around 300 kt of organic fertilizer per year at a growth rate of around 15% annually, of which some 10% goes to Africa. The Netherlands has a handful of leading exporters, one of which has a growing track record in Burkina Faso and reports good results with blended application of mineral and organic fertilizers. Attempts to industrialize local production have failed, due to the lack of capacity and lack of concentration of the poultry industry in Burkina Faso.

5.5 Overall Reflection on the Impact of R&D and Implementation Programs

Our assessment on the limited impact of implementation programs (Section 5.3, Figure 29) is corroborated by Alpha & Fouilleux (2018), who found food security policies in Burkina Faso (and in other African countries; Schouten et al., 2018) to focus on agricultural production, rather than pursuing an inter-sectoral approach. They argue that this policy perception arises from (1) dependency arising from the way food insecurity has historically been framed around cereal deficits, (2) measurement and assessment of food security not to be neutral and directly shaping both policy debates and decision making, and (3) fragmented power relations between actors with different views on FNS due to the institutional configuration. Yet, they do argue that new concepts such as "nutrition-sensitive agriculture" combined with more open forums may have the potential to lead to more inter-sectoral food security policies.

R&D on agricultural development also appears unable to reach impact at scale (Chapter 1 for references). These findings were confirmed in a recent review that showed by far most of the agricultural research appeared unable to provide solutions to the challenges of smallholder farmers and families (Nature Editorial, 2020). The lessons from the 2% published agricultural and agronomic research with relevance to solutions for small-scale producers include adoption of climate-resilient crops due to increasing uncertainty, the need to address water demand, and membership to farm organizations that may positively effect yield and income (Nature Plants Editorial, 2020). The availability and effectiveness of extension services and outreach, education levels, farmers' access to inputs (especially seeds and fertilizers), and socio-economic status of farming families determined the adoption of climate-resilient crops. Half of the studies found social differences to influence adoption, whereas 30% did not report any effect of social difference (Acevedo et al., 2020). Liverpool-Tasie et al. (2020) found non-contractual market linkages of smallholder farmers with SMEs to be as effective as formal contracts between large producers and large enterprises. SMEs tend to provide complementary services, such as input provision, credit, information, and logistics.

These insights indicate that entirely novel approaches in R&D and in implementation programs must be developed to realize impact and improve farm livelihood. Pursuing current funding mechanisms for both tracks separately turns out to be ineffective and must be overhauled.

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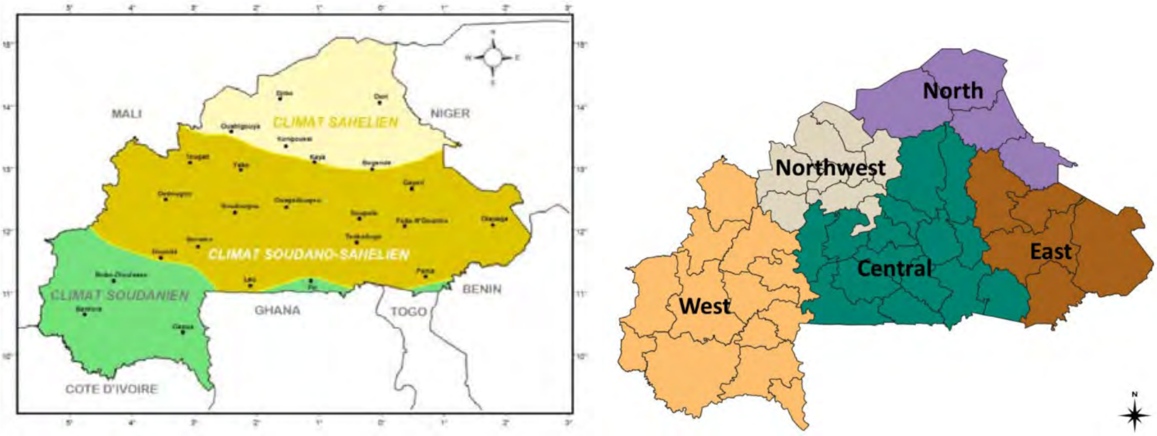
7. Annexes

Annex 1. Summary Overview of Input Data Sources Used for the Analysis

Output Dataset	Source Dataset	Spatial And Temporal Resolution	Unit	Remarks
Soil water availability (supply)	Daily rainfall (PCP), CHIRPS precipitation from FAO-WaPOR DB	5km spatial resolution, resampled to 250m resolution; daily temporal resolution, 2009-2019	mm/day	From FAO-Wapor: Data link (PCP) (Ref.: Funk et al., 2015)
	Hydrological soil groups - HYSOGs250 m dataset Slope – SRTM Yearly land cover (LCC 250m), from FAO-WaPOR DB	250m spatial resolution 250m spatial resolution 250m spatial resolution, annual (full year) temporal resolution, 2015	mm/day % -	Input data to calculate daily runoff SRTM From FAO-Wapor: Data link (LCC) (Ref.: Copernicus GLC)
	Soil rootable depth (RZD) Soil root zone plant-available water holding capacity (RZ-PAWHC)	250m spatial resolution resampled from 1km resolution	Cm mm	From ISRIC datahub: Data link (RZD) Data link (RZ-PAWHC) (Ref.: Leenaars et al., 2018)
Crop water demand	Daily reference evapo-transpiration (RET), from FAO-WaPOR DB	20km spatial resolution, resampled to 250m resolution; daily temporal resolution, 2009-2019	mm/day	From FAO-Wapor: Data link (RET)
	Crop coefficients (Kc)	-	-	FAO crop coefficients for 3 major crops
Relative water sufficiency	Soil water supply Crop water demand	-	-	Calculated.
Soil nutrient availability (supply)	Soil sample data on relative nutrient contents (CNPK) and pH, BD and CF (AfSP/WoSIS)	-	g/kg (C, N) mg/kg (P, Ptot) cmolc/kg (K) - (pHH2O) kg/dm3 (BD) m3/100m3 (CF)	From ISRIC datahub: Data link (AfSP)
	Soil maps on relative nutrient contents and pH, BD and CF (Africa SoilGrids)	250m spatial resolution		From ISRIC datahub: Data link (maps)
Crop nutrient demand	Yearly actual biomass production (TBP) Yearly actual evapotranspiration (AETI) Yearly actual transpiration (T)	250m spatial resolution, annual (full year) temporal resolution, 2009-2019	kg/ha/year mm/year mm/year	From FAO-Wapor: Data link (TBP) Data link (AETI) Data link (T)
	Root zone water-limited evapotranspiration (RZ WL-ET), biomass (RZ WL-TBP) & yield potential (RZ WL-Y)	250m spatial resolution, seasonal temporal resolution 2009-2019	mm/season kg/ha/season kg/ha/season	For 3 major crops Calculated.
	Crop nutrient parameters (QUEFTS), harvest index & above ground fraction		kg/kg	For 3 major crops & nutrients. Obtained from literature and regional trial data (ref.: Leenaars et al., 2017)
Nutrient sufficiency	Soil nutrient supply Crop nutrient demand	250m spatial resolution, seasonal temporal resolution 2009-2019	Absolute: kg/ha Relative: kg/kg	For 3 major crops & nutrients. Calculated.

Annex 2. Agroecological Zonation



Agroecological zones of Burkina Faso represented according to (a) climate and (b) provincial groupings

Annex 3. National Projects and Programs

3A. NATIONAL HYDRAULIC DEVELOPMENT PROGRAM, PHASE 1 (PNAH I)

Specific objectives	• Develop and enhance ±3,500 ha of irrigated perimeters around water bodies. • Ensure rehabilitation and enhancement of 500 ha of surrounding irrigated perimeters. • Develop supplemental irrigation on ±2,100 ha and on all developed areas.		
Expected results	• 3,500 ha of new irrigated areas are developed. • 500 ha of old irrigated perimeters are rehabilitated. • 2,100 ha and over 4,000 ha of developed and rehabilitated perimeters are covered by supplementary irrigation. • Technical capacities of agents and producers for irrigated crops, water management, and irrigated areas are strengthened. • 9,488 tons of cereals, 1,500 tons of tubers, and 23,375 tons of vegetable crops in additional production are produced.		
Duration	Start 2017	End 2022	
Cost	Donors / sources of funding	Nature of financing	Amount in U.S. $
	State	Subsidies	123,459,300
	Beneficiary	Contribution	3,818,300
	TOTAL		**127,277,600**

3B. AGRICULTURAL PRODUCTION INTENSIFICATION PROGRAM (PIPA)

Global Objective	Contribute to the achievement of self-sufficiency and food security through the intensification of family farms.		
Specific objectives	• Provide annually to farms improved seeds, fertilizers, phosphate, and pesticides. • Strengthen the technical capacities of stakeholders (agents, seed producers, and farmers). • Popularize and implement regulations on inputs (seeds and fertilizers). • Ensure the monitoring and evaluation of activities in the field.		
Expected results	• Seeds of improved varieties, chemical fertilizers, phosphate, and pesticides are provided annually for five (5) years to farms. • Technical capacities of stakeholders are strengthened. • Regulations on inputs (seeds, fertilizers) are popularized and implemented. • Monitoring and evaluation of activities in the field is ensured.		
Duration	Start 2016	End 2020	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Subsidies	59,268,100
	TOTAL		**59,268,100**

3C. DEVELOPMENT OF VILLAGE SMALL SCALE IRRIGATION PROGRAMME (PPIV)

<table>
<tr><td>Global Objective</td><td colspan="3">Contribute to the achievement of food and nutrition security and poverty reduction.</td></tr>
<tr><td>Specific objectives</td><td colspan="3">• Promote the mobilization and efficient use of water resources.
• Increase the developed agricultural and hydro-agricultural areas.
• Promote the sustainable management of agricultural land.
• Build the capacities of producers and their organizations.
• Coordinate, monitor, and evaluate activities in the field of irrigation and sustainable management of agricultural land.</td></tr>
<tr><td>Expected results</td><td colspan="3">• Mobilization and efficient use of water resources for agricultural purposes is ensured.
• Developed areas are increased.
• Sustainable management of agricultural land is ensured.
• Capacities of producers and their organizations are strengthened.
• Effectiveness and efficiency of irrigation and sustainable land management interventions are improved.</td></tr>
<tr><td>Duration</td><td>Start Jan 2015</td><td colspan="2">End Dec 2020</td></tr>
<tr><td rowspan="3">Cost</td><td>Donors / sources of funding</td><td>Nature of funding</td><td>Amount in U.S. $</td></tr>
<tr><td>State</td><td>Subsidies</td><td>113,813,200</td></tr>
<tr><td colspan="2">TOTAL</td><td>113,813,200</td></tr>
</table>

3D. RESTRUCTURING AND VALORIZATION PROGRAM OF THE MANAGED PLAIN OF NIOFILA/DOUNA (PRMV/ND)

<table>
<tr><td>Implementation Zone</td><td colspan="3">Region of Cascades (Léraba Province)</td></tr>
<tr><td>Global Objective</td><td colspan="3">Contribute to improving food security and reducing poverty in the Léraba area by developing irrigated areas and intensifying/diversifying agricultural production.</td></tr>
<tr><td>Specific objectives</td><td colspan="3">• Increase agricultural yields (reach at least 75% of the maximum yields of varieties grown on the site by 2017).
• Increase in agricultural production (at least 30% per year from 2013 to 2017).
• Increase farmers’ incomes (at least 18% per year from 2013 to 2017).</td></tr>
<tr><td>Expected results</td><td colspan="3">• 410 ha of old irrigated areas are rehabilitated and operational.
• 1000 ha of new irrigated perimeters are developed and enhanced.
• The increase in agricultural production in the plain is effective.
• Capacities of professional agricultural organizations and supervisory staff are strengthened.</td></tr>
<tr><td>Duration</td><td>Start 2013</td><td colspan="2">End 2021</td></tr>
<tr><td rowspan="3">Cost</td><td>Donors / sources of funding</td><td>Nature of funding</td><td>Amount in U.S. $</td></tr>
<tr><td>State</td><td></td><td>48,021,000</td></tr>
<tr><td colspan="2">TOTAL</td><td>48,021,000</td></tr>
</table>

3E. PROJECT TO STRENGTHEN THE RESILIENCE OF RURAL POPULATIONS TO THE EFFECTS OF CLIMATE CHANGE THROUGH THE IMPROVEMENTOF AGRICULTURAL PRODUCTIVITY (PRAPA)

<table>
<tr><td>Global Objective</td><td colspan="3">Contribute in a sustainable manner to food security and the reduction of poverty in rural areas, by reducing the vulnerability of agricultural production to climate change.</td></tr>
<tr><td>Specific objectives</td><td colspan="3">• Increase the area of agricultural land developed by supporting the construction of mechanical and biological works for the conservation of water and soil.
• Increase areas of exploitable land by supporting recovery of degraded land.
• Acquire equipment for the restoration and recovery of degraded lands.
• Secure and increase agricultural production by mobilizing runoff water at small scale.
• Improve soil fertility by monitoring and implementing integrated soil fertility management techniques.
• Strengthen capacities of actors through training, equipping small SWC materials.
• Capitalize on and set up national standards (technical sheets, guide, manual, etc.) in SWC.
• Set up a geographic information system (GIS) to manage agroecological zones and SWC designs.</td></tr>
<tr><td>Expected results</td><td colspan="3">• 15,000 ha of vegetated anti-erosion installations are carried out.
• 3,000 ha of degraded land are reclaimed by a combination of degraded land reclamation techniques.
• 2,000 ha of lowlands are developed and enhanced.
• 4 Vallerani tractors and accessories are acquired to support the implementation of soil recovery arrangements.
• 40 small-scale runoff water spreading and/or storage structures are carried out (spreading thresholds, micro-dams/artificial pond [boulis]).
• 500 stormwater collection basins are created.
• 300,000 tons of organic manure are produced and used.
• Spreading thresholds carried out and the banks of water bodies are protected.
• Vegetated strips are put in place.
• A GIS to manage agroecological zones and SWC sites set up.</td></tr>
<tr><td>Duration</td><td>Start Jan 2015</td><td colspan="2">End Dec 2020</td></tr>
<tr><td rowspan="3">Cost</td><td>Donors / sources of funding</td><td>Nature of funding</td><td>Amount in U.S. $</td></tr>
<tr><td>State</td><td>Subsidies</td><td align="right">35,923,900</td></tr>
<tr><td colspan="2">TOTAL</td><td align="right">35,923,900</td></tr>
</table>

3F. IMPROVING WATER MANAGEMENT IN RAINFED AGRICULTURE SYSTEMS TO ENSURE FOOD SECURITY IN BURKINA FASO: RESEARCH AND TECHNOLOGICAL DEVELOPMENT (AGES)

Global Objective	Contribute to food security and poverty reduction in Burkina Faso.		
Specific objectives	• Identify, improve, and contribute to the dissemination of efficient rainwater management technologies suitable for the agroecological zones of Burkina Faso for sustainable agricultural production. • More specifically, it involves (1) carrying out a diagnosis and targeting of efficient rainwater management technologies, (2) conducting research on improving the targeted technologies, (3) determining the socio-economic conditions and environment linked to the adoption of improved technologies, and (4) disseminating improved targeted technologies.		
Expected results	• Rainwater management technologies are identified and assessed. • The best technologies are targeted and research for their improvement to take into account global changes is carried out. • Socio-economic and environmental conditions related to the adoption of targeted and improved technologies are determined. • Dissemination of targeted and improved technologies is ensured by the project stakeholders. • Institutional and technical capacities of the actors involved are strengthened.		
Duration	Start Jan 2013	End Dec 2015	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Subsidies	113,636,600
	TOTAL		**113,636,600**

Annex 4. Bilateral Projects and Programs

4A. PROJECT OF LOCALIZED IRRIGATION AND AGRICULTURAL RESILIENCE IN BURKINA FASO (PIRA-BF)

Implementation zone	• Boucle du Mouhoun: Balés , Banwa, Kossi, Mouhoun, Nayala, and Sourou • Center-West: Sanguié • Hauts-Bassins: Houet • North: Lorum , Passoré, Yatenga, and Zandoma		
Global objective	Contribute to the achievement of food security and the reduction of the incidence of poverty, focusing on the progression of the socio-economic empowerment of women in the intervention area.		
Specific objectives	Improve the access of women farmers and processors to productive resources, professional skills, and employment and income opportunities to improve the productivity of irrigated crops and the production linkage to market.		
Expected results	• Irrigated cultivation is developed on a sustainable basis thanks to better access by women to efficient and resilient irrigation methods/systems. • The professional skills of women farmers in irrigation and resilient agriculture as well as their access to remunerative markets are improved.		
Duration	Start Dec 2019	End Nov 2022	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	392 000
	Austria Cooperation	Subsidies	2 385 300
	TOTAL		**2 777 300**

4B. IRRIGATION PROGRAMME IN THE BIG WEST (PIGO)

Intervention zone	• Cacades region (Comoé) • Hauts Bassins region (Houet, Tuy) • Southwest region (Bougouriba, Ioba , Noumbiel, Poni) • Central Ust region (Sissili)
Global objective	Contribute to improving food security and increasing the agricultural income of the populations in the project intervention area.
Specific objectives	The populations around the developed lowlands and small irrigated areas have better sources of income in the production, processing and marketing of agricultural products and improve their food security.
Expected results	• 2000 ha of rice-growing lowlands are developed and enhanced. • 40 ha of market gardening areas are developed and developed. • 80 warehouses for the storage and preservation of agricultural products have been built and equipped. • 5 processing units for agricultural products are built and upgraded. • 40 threshing and drying areas/tarpaulins produced and upgraded. • Crossing structures are being built to open sheltering developed lowlands. • At least 10,000 sector actors are trained on various themes (management of facilities, production techniques, financing action, etc.).

Duration	Start 2016	End 2020	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	1,848,600
	KFW	Grant	25,045,600
	Beneficiaries	Contribution	2,094,300
		TOTAL	**28,988,500**

4C. PROJECT TO IMPROVE AGRICULTURAL PRODUCTIVITY THROUGH WATER AND SOIL CONSERVATION (PACES)

Intervention zone	Regions of Central Plateau and Center-North		
Global Objective	Contribute to strengthening household food security in the Central Plateau and Center-North regions.		
Specific objectives	Contribute to improving the production and productivity of rainfed agriculture on rehabilitated land in order to strengthen the resilience of producers to the effects of climate change.		
Expected results	• Land degraded or threatened by degradation in the intervention area is managed using soil and water conservation measures (SWC). • An additional 13,000 ha of degraded land is developed using SWC measures. • Producers in the intervention area practice additional soil fertilization measures. The additional measures targeted concern the promotion of improved agricultural practices, in particular the production of organic manure, targeted plantations, the use of quality seeds, and any other measure improving the availability and infiltration of water and promoting the fertility of the crops. • The PACES implementation mechanism is operational and a strategy for the sustainability of the achievements and the post-project maintenance of the facilities has been drawn up (Maintenance fund).		
Achievement period	Start	End	
	Initial phase: Jan 2017	Dec 2019	
	Second phase: Jan 2020	Dec 2024	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	1,347,700
	Beneficiaries	Contribution	2,576,100
	KFW	Don	11,330,200
	TOTAL		**15,254,000**

4D. SMALL DAMS AGRICULTURAL VALUATION PROJECT (ProValAB)

Intervention zone	Regions of Center, Center-North, Center-West, East, and Plateau Central		
Global Objective	Households sustainably improve their food/nutritional security and increase their income by upgrading water from small dams through the development of promising value chains.		
Specific objectives	• Users put in place good governance for the sustainable management of infrastructure, water resources, and developed land. • Farmers quantitatively and qualitatively increase their ASP-H productions. • The producers/facilitators and other actors of the value chains to improve their economic and social performance.		
Expected results	• Infrastructure, water resources, and developed land are managed in a sustainable manner. • The volume of products sold has increased. • Product competitiveness is improved.		
Duration	Start Jan 2017	End Dec 2020	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	1,044,492
	ASDI	Grant	10,062,524
	TOTAL		**11,107,016**

4E. RESILIENCE AND FOOD SECURITY PROJECT - CENTRAL PLATEAU (RESA - CENTRAL PLATEAU)

Intervention zone	Central Plateau region		
Global objective	Contribute to improving food security and self-sufficiency as well as the income of the populations of the Central Plateau.		
Specific objectives	Strengthen the resilience of the populations of the Central Plateau by improving their technical and financial capacity for production (animal and agricultural) and processing (rice, soybean).		
Expected results	• The level of equipment of the populations of the fragile zones of the Central Plateau is improved. • The populations are provided with inputs and improved seeds for agricultural production and supported with fodder seeds, feed for livestock, and poultry and veterinary products for animal production. • Women, young people, and vulnerable people are supported in their income-generating activities (IGA) by grants to finance equipment and infrastructure for processing agro-pastoral products. • The sustainability of agro-pastoral production is ensured through the activities of Water and Soil Conservation, Soil Defense and Restoration and the fight against silting up and siltation of water collection basins. • Technical capacities of the beneficiaries of the subsidies are strengthened.		
Duration	Start Dec 2017		End Dec 2020
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	176,945
	Austria	Grant	1,192,649
	TOTAL		**1,369,594**

4F. DRIP IRRIGATION PROMOTION PROJECT (PPIG)

Intervention zone	• Boucle du Mouhoun: Balés , Banwa, Kossi, Mouhoun, Nayala, Sourou, • Center-West: Sanguié and Boulkiemdé • Hauts-Bassins: Houet • North: Yatenga		
Global Objective	Contribute to achieving food security and increasing the income of farmers by promoting innovative irrigation technologies.		
Specific objectives	Sustainably increase agricultural productivity and marketing capacities for irrigation products in the project area through the drip irrigation system.		
Expected results	• Drip irrigation system are adopted by the irrigators in the project area • Actors' technical, managerial, and organizational capacities are strengthened. • Markets for irrigation products are structured and functional. • Project coordination, management and monitoring-evaluation are ensured.		
Duration	Start Dec 2015		End Oct 2019
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	426,841
	Austrian Cooperation	Grant	4,237,685
	Total		**4,664,527**

Annex 5. Multilateral Projects and Programs

5A. BURKINA FASO AGRICULTURAL RESILIENCE AND COMPETITIVENESS PROJECT (PRECA)

<table>
<tr><td>Intervention zone</td><td colspan="3">Regions of the Boucle du Mouhoun, Cascades, Hauts-Bassins, and North</td></tr>
<tr><td>Global objective</td><td colspan="3">Increase agricultural productivity and market access for small producers and small and medium agro-industrial entrepreneurs (SMEs/SMIs) for selected value chains in the intervention areas</td></tr>
<tr><td>Specific objectives</td><td colspan="3">• Eliminate constraints to agricultural productivity, mainly in irrigated production systems.
• Improve competitiveness and promote access to markets through three sub-components aimed at (1) strengthening the capacities of central department of the MAAH in terms of sanitary and phytosanitary control, development of norms and quality standards, and support for market knowledge, (2) providing marketing facilities, and (3) building or rehabilitating rural road infrastructure.
• Enable the country's private agriculture and agro-processing sector to become more competitive in domestic and external markets by helping producers, processors, buyers, and traders to develop and finance their investment initiatives.
• Support project coordination and institutional strengthening and create a CERC at MAAH.</td></tr>
<tr><td>Expected results</td><td colspan="3">• Development of 5,497 ha of perimeters, including 4,497 ha with total control of water and 1,000 ha for fruit trees.
• Increase in yield of rice (>40%), Mango (30%), tomato (40%), and onion (50%).
• Construction/rehabilitation of 14 purchasing counters, 90 warehouses/ stores; increase in sales volumes of targeted products.
• Funding of 2,445 sub-projects.
• Development of 344 km of rural roads in agricultural production basins.</td></tr>
<tr><td>Duration</td><td>Start 2020</td><td colspan="2">End 2025</td></tr>
<tr><td rowspan="6">Cost</td><td>Donors / sources of funding</td><td>Nature of funding</td><td>Amount in U.S. $</td></tr>
<tr><td>State</td><td>Counterpart</td><td>13,909,090</td></tr>
<tr><td colspan="2">IDA</td><td>181,818,182</td></tr>
<tr><td colspan="2">Partner Financial Institutions</td><td>15,636,363</td></tr>
<tr><td>Beneficiaries</td><td>Contribution</td><td>26,727,272</td></tr>
<tr><td colspan="2">TOTAL</td><td>238,090,909</td></tr>
</table>

5B. SUPPORT PROJECT FOR AGRICULTURAL SECTORS IN THE SOUTH-WEST, HAUTS-BASSINS, CASCADES AND BOUCLE DU MOUHOUN REGIONS (PAFA-4R)

Intervention zone	Regions of the South-West, Boucle du Mouhoun, Cascades, and Hauts-Bassins
Global objective	Sustainably improve food security and the income of farmers involved in the production and development of products in the rice, market gardening, sesame, and cowpea sectors
Specific objectives	• Improve productivity and agricultural production. • Support the promotion and marketing of agricultural products.

Expected results	• Accessibility to inputs, equipment, and support/advice is promoted. • 3 000 ha of lowlands are built or rehabilitated. • 500 ha of small market gardening perimeters are developed. • 300 ha of market gardening with water-saving irrigation technologies carried out. • 100 km of tracks for access to the sites are made.		
Duration	Start 2020	End 2025	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	8,349,090
	IFAD	Loan	71,086,545
	IFAD	Don	1,073,454
	Beneficiaries	Contribution	9,303,272
	TOTAL		**89,812,363**

5C. PROJECT 1 OF THE PROGRAM TO STRENGTHEN RESILIENCE AGAINST FOOD AND NUTRITION INSECURITY IN THE SAHEL (P1-P2RS)

Intervention zone	Center, Center-Ouest, Center-Sud, Central Plateau, Sahel, and Boucle du Mouhoun regions		
Global Objective	Contribute to improving food and nutrition security and reducing poverty in Burkina Faso by strengthening the resilience of rural communities against food and nutrition insecurity.		
Specific objectives	• Develop rural infrastructure in the hydro-agricultural, forestry, pastoral, fisheries, and nutritional fields. • Improve productivity and increase agro- sylvo- pastoral, and fishery production on a sustainable basis. • Promote the economy of post-harvest sectors and access to markets. • Improve the nutritional quality of foods and facilitate their accessibility to the vulnerable.		
Expected results	• 3 new micro-dams are built, and 4 dams are rehabilitated. • 2,125 ha managed (irrigated perimeters, lowlands, and market garden perimeters). • 500 ha of SWC are developed. • 500 runoff water basins and 06 micro-dams are developed. • 58 stores for storage, Warrantage and animal feed are built and equipped. • 3 commercial houses (Sesame, Fonio, Yam) are built. • 3 cattle markets are built, and 25 vaccination parks are built.		
Duration	Start Sept 2015	End 2020	
Cost	Donors / sources of funding	Nature of financing	Amount in U.S. $
	State	Counterpart	5,020,301
	ADB	Loan	17,263,534
		Grant	17,263,712
	Beneficiaries	Contribution	1,073,640
	Total		**40,621,189**

5D. RECLAMATION PROJECT OF WATER IN THE NORTH (PVEN) STAGE DEVELOPMENT

<table>
<tr><td>Intervention zone</td><td colspan="3">Andékanda (Province of Lorum), Pensa (Province of Sanmatenga), Liptougou (Province of Gnagna)</td></tr>
<tr><td>Global objective</td><td colspan="3">• Contribute to the reduction of poverty in rural areas by increasing agricultural income and creating rural jobs.
• Contributing to the achievement of food security in the regions covered by the project.</td></tr>
<tr><td>Specific objectives</td><td colspan="3">• Develop and increase food and market garden production around the three dams by providing additional production of 2,120 tons of paddy rice and 10,000 tons of market garden products (onion, tomato, potato, cabbage, okra, and chili).
• Preserve productive capital by enhancing the value of water and soil resources through the development of 680 ha of irrigated areas and the implementation of environmental and social safeguard measures for the immediate watersheds of the development.
• Train farmers so that they can manage and use developed lands and reduce their dependence on climatic hazards.</td></tr>
<tr><td>Expected results</td><td colspan="3">• 530 ha of irrigated perimeters developed for rice cultivation and maize in wintering and market gardening in the dry season.
• 150 ha of market garden areas are drip-fed and double cropped.
• 06 storage and drying area stores, 6 hullers, 9 threshers, 3 parboiling centers, and 140 manure pits are built at the level of said facilities.
• 9 equipped boreholes, 18 access corridors to dams for livestock, 2 vaccination parks, and 30 bio-digesters are carried out at the irrigated perimeters.
• At least 12 groups or associations of producers are operational and put in business relations with traders and microfinance institutions and the capacities of their members are strengthened.
• 3,260 beneficiary producers are trained in cultivation techniques.
• 450 ha are treated by biological measures (planting, defenses/assisted natural regeneration, hedgerows, windbreaks) for dam closure.
• 05 km of mechanical treatments (earth bunds, stone bunds, treatment of gullies) are carried out at the level of the watersheds of the developments.</td></tr>
<tr><td>Duration</td><td>Start July 2013</td><td colspan="2">End Dec 2021</td></tr>
<tr><td rowspan="6">Cost</td><td>Donors / sources of funding</td><td>Nature of funding</td><td>Amount in U.S. $</td></tr>
<tr><td>State</td><td>Grant</td><td>5,450,909</td></tr>
<tr><td>BOAD</td><td>Loan</td><td>16,363,636</td></tr>
<tr><td>MFI</td><td>Grant</td><td>1,138,181</td></tr>
<tr><td>Beneficiaries</td><td>Contribution</td><td>263,636</td></tr>
<tr><td colspan="2">TOTAL</td><td>23,216,363</td></tr>
</table>

5E. PENSA AND LIPTOUGOU AGRICULTURAL DEVELOPMENT PROJECT (PDAPL)

Intervention zone	Pensa (Province of Sanmatenga), Liptougou (Province of Gnagna)		
Global Objective	Contribute to reducing poverty and food insecurity of rural households by improving agricultural production, productivity, and marketing in the regions of Pensa and Liptougou.		
Specific objectives	• Develop agricultural land and irrigation infrastructure managed by the community. • Improve agricultural production and productivity in the regions of Pensa and Liptougou. • Strengthen the institutional capacities of the rural world and farmers, in particular access to microfinance and to markets.		
Expected results	• Agricultural land and irrigation infrastructure managed by the community are developed. • Agricultural production and productivity in the regions of Pensa and Liptougou are improved. • The institutional capacities of the rural world and of farmers, in particular access to microfinance and to markets, are strengthened.		
Duration	Start Dec 2016	End Dec 2021	
Cost	Donors / sources of funding	Nature of financing	Amount in U.S. $
	State	Counterpart	2,054,545
	IDB	Loan	20,394,909
	TOTAL		**22,449,454**

5F. AGRICULTURAL DEVELOPMENT PROJECT IN THE SOUM ZONE(PDA-SOUM)

Intervention zone	• Nanoro, province of Boulkiemdé • Soaw, province of Boulkiemdé • Pilimpikou, Passoré province • Samba, Passoré province • Kordié, province of Sanguié	
Global objective	Contribute to strengthening food security and reducing poverty in the project area.	
Specific objectives	• Increase pastoral, fishery, and agricultural production, particularly that of rice, corn, and market garden products. • Contribute to the creation of wealth in the intervention area by increasing farmers' incomes, creating new jobs, and improving the general socio-economic environment. • Ensure the sustainability of developments and the enhancement of production through capacity building and organization of producers.	
Expected results	• Pastoral, fishery, and agricultural production, particularly that of rice, corn, and market garden products, has increased. • The project contributes to the creation of wealth in the intervention area by increasing farmers' incomes, creating new jobs, and improving the general socio-economic environment. • The sustainability of the facilities and the enhancement of production through capacity building and the organization of producers is ensured.	
Duration	Start 2017	End 2021

Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterparty	12,072,727
	RCPB	(non-disbursable)	1,363
	IDB	Loan	30,927,272
	BOAD	Loan	11,818,181
	Total		**56,181,818**

5G. SUPPORT PROJECT FOR THE PROMOTION OF AGRICULTURAL SECTORS (PAPFA)

Intervention zone	Regions of Boucle du Mouhoun, Cascades and Hauts-Bassins		
Global Objective	Sustainably improve food security and the income of farmers involved in the production and development of products in the rice, market gardening, sesame, and cowpea sectors.		
Specific objectives	• Improve productivity and agricultural production. • Support the promotion and marketing of agricultural products.		
Expected results	• Accessibility to inputs, equipment and support/advice is promoted. • 3 000 ha of lowlands are built or rehabilitated. • 500 ha of small market gardening perimeters are developed. • 300 ha of market gardening with water- saving irrigation technologies are carried out. • 100 km of tracks for access to the sites are made.		
Duration	Start 2018	End 2024	
Cost	Donors / sources of funding	Nature of financing	Amount in U.S. $
	State	Counterpart	8,311,533
	IFAD	Grant	20,246,042
		Loan	20,246,042
	OFID	Loan	21,311,623
	Green Fund	To research	20,246,042
	Beneficiaries	Contribution	16,729,624
	TOTAL		**107,090,909**

5H. REGIONAL SUPPORT PROJECT FOR THE INITIATIVE FOR IRRIGATION IN THE SAHEL-BURKINA FASO (PARIIS-BF)

<table>
<tr><td>Intervention zone</td><td colspan="3">Regions of Boucle du Mouhoun, Center, Center-Ouest, Nord and Hauts-Bassins</td></tr>
<tr><td>Global objective</td><td colspan="3">Improve the capacity of stakeholders to develop and manage irrigation and increase irrigated areas by following a regional approach based on “solutions” in participating countries of the Sahel.</td></tr>
<tr><td>Specific objectives</td><td colspan="3">• Improve the institutional framework of irrigated agriculture by strengthening concerted planning in the planning of investments.
• Increase the areas exploited and improve their management (revitalization, new developments).
• Manage and share the knowledge acquired in the implementation of the project.</td></tr>
<tr><td>Expected results</td><td colspan="3">• The process of access to land and water on irrigated areas is improved on transparent and equitable bases with a view to securing producers.
• The investment planning and implementation process is concerted and is based on reliable data analyzes and targeted studies on natural resources, potential market production systems, and the needs of stakeholders in the Project Intervention Zones.
• The institutional and organizational capacities of the main stakeholders in the development and management of irrigation are strengthened.
• Bankable investments carried by the project obtain financing.
• Solutions for revitalizing and/or modernizing existing systems and developing new systems are available and implemented in selected areas.
• Associated infrastructures and quality services to producers and field operators (support services for irrigators including training, agricultural advice, ICT tools financial products) are established or improved and accessible in selected areas.
• Information and knowledge on irrigation are produced, shared and accessible to the various stakeholders in the irrigation sub-sector.</td></tr>
<tr><td>Duration</td><td>Start Nov 2018</td><td colspan="2">End Mar 2024</td></tr>
<tr><td rowspan="7">Cost</td><td>Donors / sources of funding</td><td>Nature of funding</td><td>Amount in U.S. $</td></tr>
<tr><td>State</td><td>Counterpart</td><td align="right">3,113,045</td></tr>
<tr><td rowspan="2">IDA</td><td>Grant</td><td align="right">6,306,818</td></tr>
<tr><td>Loan</td><td align="right">18,920,454</td></tr>
<tr><td>GPOBA</td><td>Grant</td><td align="right">5,903,181</td></tr>
<tr><td>Beneficiaries</td><td>Contribution</td><td align="right">222,000</td></tr>
<tr><td colspan="2">TOTAL</td><td align="right">36,463,500</td></tr>
</table>

5I. AGRICULTURAL PRODUCTIVITY PROGRAM IN WEST AFRICA (WAAPP)

Intervention zone	Country		
Global objective	To generate and disseminate improved technologies for the sustainable intensification of agricultural production.		
Specific objectives			
Expected results	• Three (03) improved technologies developed by the National Center of Specialization in Fruits and Vegetables (CNS-FL). • 15% increase in productivity in the field by improved technology developed. • 100,000 ha covered by technologies disseminated under the Program. • 200,000 beneficiaries, 40% of whom are women. • 1/3 of the beneficiaries of the Program have adopted the new varieties developed. • Demonstration of technologies developed by the CNS in at least two other countries participating in the Program.		
Duration	July 2011	June 2016	
Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	
	World Bank	Loan	
	TOTAL		**20,909,090**

5J. AGRICULTURAL PRODUCTIVITY AND FOOD SECURITY IMPROVEMENT PROJECT (PAPSA)

Intervention zone	Country	
Global objective	To improve the capacity of small-scale farmers to increase food production and ensure greater availability of these products on the market throughout the year.	
Specific objectives	• Improve the transfer of agricultural technologies and their extension to improve productivity and increase food production. • Strengthen the capacities of actors to manage the variability of different food products at the local and national levels through greater storage and access to credit under the warrantage system. • Increase the efficiency of public and private service providers involved in the implementation of the project.	
Expected results	• At least 800,000 direct beneficiaries affected by the project, including 40% women and 10% youth. • At least 540 tons of fish produced in the targeted areas. • At least 5,786,921 tons of food produced in the project area including: 1,475,432 tons of maize, 347,088 tons of rice, 2,172,302 tons of sorghum, 1,109,036 tons of millet, 649,563 tons cowpea, 12,500 tons of onion, and 21,000 tons of tomato. • At least 14,000 tons of agricultural products are stored by producers in the warrantage system. • At least 5,000,000 liters of milk are collected.	
Duration	July 2010	Nov 2019

Cost	Donors / sources of funding	Nature of funding	Amount in U.S. $
	State	Counterpart	6,238,872
	IDA, World Bank	Loan	68,334,727
	GAFSP		32,243,272
	Beneficiaries		9,767,527
	TOTAL		**116,584,399**

Annex 6. IFDC's Program in Burkina Faso

IFDC is a non-governmental, nonprofit organization present in the Burkina Faso since 1996 to support R&D in agriculture and permanently opened its representation through an MoU with the government there in 2003. IFDC-Burkina Faso has implemented around 20 projects with a national or regional scope. Only selected number of programs are described here.

In all its endeavors, IFDC operates closely with local institutions in line with government policies to attain the highest impact. Apart from its initial focus on agro-technological improvements and policy support for regulatory measures on agricultural inputs, IFDC has moved over the past decade into development of the food value chains as well.

IFDC has supported the Government of Burkina Faso in the development of the national strategy and action plan on ISFM from 1996 to 1998. These documents served as a basis for the formulation and implementation of major development projects and programs financed by the International Fund for Agricultural Development (IFAD), including the Sustainable Rural Development Program (PDRD, 2006-2013) in the North Center and the Community Investment Program in Agricultural Fertility (PICOFA, 2006-2013) in the East region and other agricultural development projects with other donors (FAO, AfDB, USAID, DGIS).

The project *Socio-Economic and Favorable Political Environments for the Improvement of Soil Fertility (FASEPE)*, financed by the Directorate-General for International Cooperation (DGIS) of the Netherlands at €3.1 million between 2000 and 2005, worked with policymakers of the national public sector, sub-reginal, regional, and international organizations, farmers or agricultural research and training institutes, and the private sector. It aimed to create favorable conditions for the adoption and start of the effective implementation of policy reforms and new soil fertility management strategies, empower farmers and their organizations and the private sector. At the government's request, IFDC provided support on needs and legislation about seeds and fertilizers and on legislative and regulatory controls of the quality of these inputs.

The *Professionalization of Distribution of Agricultural Inputs in Burkina Faso Program (PRODIB)*, funded by AGRA, supported input dealers in organizational development and formation of 1,137 distributors by setting up a guarantee fund to facilitate their access to credit. This enabled the increased number of members of the Association of Wholesalers and Retailers of Agricultural Inputs (AGRODIA) from 227 to 717, with program support, to reach more than 390 producers.

The *Agro-pastoral Family Farm Modernization Component Inputs Program (PAMEFA-Vi)*, funded by the Swiss Agency for Development and Cooperation (SDC) worked with implementing partners the Cooperative for Marketing of Agricultural Inputs and Materials (COCIMA) and AGRODIA to enhance access to agricultural inputs for 315,000 farmers and sustainably increase their income and productivity through proper quality inputs with the support of the agricultural extension service.

The Government of Burkina Faso (through the Ministry of Agriculture, Water Resources and Fisheries), the African Development Bank (AfDB) group, and IFAD have requested and are requesting IFDC to provide technical support for (1) development and dissemination of technological options for ISFM and agricultural intensification in their project area and (2) organization of actors to facilitate producers' access to agricultural inputs, markets and various services, including financial, and capacity building of actors. IFDC provided its expertise for the programs:

- *Participatory Rural Development and Decentralized provinces Bazèga and Kadiogo (PDRD / BK).*
- *Support for Local Development of Provinces of Comoé, Léraba, and Kénédougou (PADL / CLK).*
- *Sahel Livestock Development Program Phase II.*
- *South West Rural Development Program (PDRSO).*
- *Community Investment Program in Agricultural Fertility (PICOFA) provinces (Kompienga, Tapoa, Gourma, Komondjari, Gnagna)*
- *Sustainable Rural Development Program (PDRD), provinces (Lorum, Yatenga, Passoré, Bam, Zondoma)*

IFDC has implemented three large programs on the cotton sector in the C-4 countries (the four cotton-producing countries of Benin, Burkina Faso, Mali, and Chad), funded by USAID, the CFC, and the European Union. The programs were implemented when the C-4 countries were going through an unprecedented crisis. IFDC was able to significantly increase yields by at least 39% for cotton and 25% and 5% for maize and cowpea, respectively. Improved fiber quality, cost savings, and mitigation of risks to human health and the environment prompted several cotton companies to spontaneously adopt the practices without further assistance. Numerous theoretical and practical trainings on good agricultural practices (GAPs) through 571 cotton demonstration fields, 547 for maize and 542 for groundnut, reached over 42,000 men and 10,000 women and over 10,000 members of the Cotton Producers Board. Craftsmen using cotton, including 246 members of the Union of Textile and Clothing Professionals of the Center, were trained to design, produce, and market almost 100 new products in domestic, regional, and international markets. IFDC developed important gender-sensitive training modules on GAPs and post-harvest conservation/storage and food processing. It also developed advocacy tools for better integration of women producers by facilitating access to extension services, land, credit, and innovative technologies. It contributed to the development of the African Cotton Quality Charter.

Increasingly, programs such as *Produce More Rice with Less Fertilizers*, *2SCALE*, *Accelerating Agribusiness in Africa (AAA-Bridge)*, *From Thousands to Millions*, *Strengthening the Agricultural Inputs Access Capabilities and Regional Market Inputs*, executed or in progress, have been designed to support actors to create a favorable environment for the development of input-output markets, targeted to specific socially disadvantaged groups.

Currently, IFDC-Burkina Faso is implementing three programs. The *2SCALE* program in Burkina Faso was described in the introduction of the main document.

Technologies for African Agricultural Transformation (TAAT), based on the African Development Bank's agricultural development strategy, aims to radically transform African subsistence-based agriculture to agriculture as entrepreneurship and business. IFDC is involved in the Soil Fertility Enabler with the aims to (1) facilitate a responsive private sector-led input delivery system to support the scaling up of agricultural input-based technologies, (2) establish regional technology delivery infrastructure, and (3) deploy transformative agro-input technologies.

The *Smallholder Agricultural Productivity Enhancement Program (SAPEP)*, funded by the Islamic Development Bank from 2015 to 2021, is designed to overcome poor soil health, limited seed production, poor access to markets and finance, and weak research-extension-farmer linkages. The program seeks to increase the use of ISFM technologies by smallholder farmers, enhance access to improved crop varieties, and improve access to financial services and output markets for smallholders and other producers along the agricultural value chain.

Since its presence, IFDC has established and maintained partnerships with public actors (Ministries of Agriculture, Higher Education, Research, universities, and other ministries) at national and provincial levels, private actors (PO, umbrella organizations), financing services (Caisses, banks), regional organizations, and NGOs. IFDC maintains communication with these partners by representation and attendance at meetings.